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# Towards a Sustainable Systems Framework: The Assessment of Silvoarable Agroforestry as an Innovative Cropping Practice

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TOWARDS A SUSTAINABLE SYSTEMS FRAMEWORK : THE ASSESSMENT OF SILVOARABLE AGROFORESTRY AS AN INNOVATIVE CROPPING PRACTICE

CONTENTS

## ABSTRACT

Questions are continually being asked about the direction in which land based production in the UK is evolving. Present systems are criticised as being damaging to the wider environment and rural communities. Of equal concern is the reliance upon non-renewable resources within agricultural systems and the effect "modern farming" is having on agroecosystem processes.

This thesis uses an integrative research approach to investigate the sustainability of land based production. It is argued that the view of what constitutes a sustainable system is constantly changing suggesting that increasingly sustainable systems are those which evolve along pathways which keep future options open. It is recognised that to do this links have to be made between the concept of sustainability in physical and social systems and the policy and decision makers who play a major part in the change process.

A series of interfaces are explored using a variety of research activities which demonstrate one approach for linking the concept of sustainability to the provision of policy relevant information. Silvoarable agroforestry is used as a research medium or case study which enables the application of the research approach to an innovative cropping practice which could possibly increase the degree of sustainability of land based production.

The contribution of the thesis is interpreted at three levels.

1. The application of a integrative research approach to synthesis information from both physical and social systems in a manner which enables the concept of sustainability to be linked to human managed production systems which interact with the natural environment,

2. The use and linking of several research activities, some of which provide a contribution to methods of working within individual disciplines, to provide a methodology for the assessment of the potential of innovative cropping practices,

3. The assessment of silvoarable agroforestry as an innovative cropping practice. Information is provided on the effects of these systems on agroecosystem processes, the economic and financial implications of their uptake, the technical issues as perceived by the farmers and finally the likelihood of uptake of these systems.

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The Soil Survey and Land Resource Centre at Silsoe for the provision of data.

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Concerns are increasingly voiced amongst scientists, (Lowrance 1990, MacRae et al 1990, Vogtmann 1991, Giampietro et al 1992), politicians (Body 1982,1984,1990), public, (Farmers Weekly, 15th Feb 1992, "Public view of farming") and the farmers themselves, (see interviews in chapter 7), that farming is reliant on high levels of inputs, many of which are either non-renewable or derived from non-renewable resources. In some cases these inputs are seen to be adversely affecting the soil, water and the wider environment which has meant that many view farming in an unfavourable light, (Harper 1989). Although the rural fabric which provides a backcloth for the industry is inevitably in a continual process of change, (Lemon 1992), there are increasing doubts concerning the direction of change, (Clunies-Ross & Hilyard 1992).

## 1.3 THE SUCCESS OF THE AGRICULTURAL INDUSTRY IN THE UK,

There are approximately 18 million hectares of land under some form of agriculture within the UK, (MAFF 1989), approximately 75% of the total land area. Of this approximately 7 million hectares is under tillage, (Nix 1992), the remainder being split into permanent pasture, (5 million hectares), and rough grazing, (6 million hectares), providing an estimated gross output of nearly £14 billion in 1990, (Nix 1992). Although the regular full-time work force has been falling in line with increased mechanization, numerous people are still employed in the allied and service industries which means that in some rural areas agriculture is still a major employer. Average farm size has been increasing rapidly since the last World War and is presently about 72 ha, (Burrell et al 1990), this being much larger than our European partners. (Eurostat Agriculture 1990 gives the average size of the UK farm in 1987 as 64.4 ha whilst the average of the 12 European Community nations is 13.4 ha).

The gradual increase in farm size, increased mechanization, market support, and improved plant varieties, knowledge and availability of growth inputs such as fertilizers and pesticides have enabled farmers to increase productivity dramatically over the last 40 years. This is reflected in figures on the self-sufficiency of the UK in several products since 1970. For instance in cereals the UK's self sufficiency rose from 61% in 1971 to 108% in 1985, (Annual Review of Agriculture 1987). This increase in self-sufficiency is reflected in the increased yields of wheat per hectare, demonstrating a growth in output per unit area, see Figure 1.1.

Thirtle and Bottomley (1991) have investigated total factor productivity in UK agriculture from 1967-1990 and suggest this has risen at an average rate of 1.9% per annum over this time. This they attribute to increases in output and the use of less inputs. At the same time the hygienic standard of food produced has improved, the aim being to produce a higher quality product. This on the whole has been successful, i.e. extensive campaigns to eliminate Bruccelosis, improve the hygienic quality of milk and the imposition of strict standards regarding the contamination of milk with antibiotics.

# CHAPTER 1: RESEARCH BACKGROUND AND THEORETICAL FRAMEWORK,

*"....knowledge of what is does not open the door directly to what* **should** *be. One can have the clearest and most complete knowledge of what is, and yet not be able to deduce from that what* **should be** *the goal of our human aspirations." (Albert Einstein)*

## 1.1 INTRODUCTION AND SUMMARY

This thesis focuses on the future of land based production in UK, using agroforestry as a cropping innovation, to investigate assessment criteria and the process of change to increasingly sustainable farming systems. The agricultural industry in the UK is seen by some as the best and most progressive in the world, whilst others see it as an ill-directed economic burden and a environmental disaster. These characteristics are expanded to provide a research background, considering both the success of the UK farming industry and the "costs" associated with this success.

The concept of sustainability is introduced and defined in general terms as the need to be aware of the impact of farming activities today on the ability of future generations to produce food. This is expanded and underpins the research framework which argues the need for long-term ecological assessment of change in tandem with shorter term economic and financial aspects of the process of change. The chapter concludes with a summary of the research process and information about the structure of the thesis.

## 1.2 AGRICULTURE IN THE UK: RESEARCH BACKGROUND,

Within the UK a position has been reached where not all of the agricultural land is needed for the production of food, and since 1988 set-aside options have been available to encourage farmers to take their land out of production, (MAFF 1990). It has been estimated that by the year 2000, 1.5 million hectares of land could be surplus to requirements, (Carter 1990). Set-aside regulations have become increasingly complex under the 1992 Common Agricultural Policy,(CAP), reforms, (MAFF 1992, UKASTA 1992), and farmers are being encouraged to set 15% of their land aside if they are to claim area payments, (Farmer's Weekly, 28th August 1992, pp13,14). The need for the reforms is in part an indicator of the remarkable productivity that European, but in particular, UK farming systems have achieved. Since the Second World War farmers have been encouraged to increase production through a myriad of policies which have helped to revolutionize agricultural practice.

*"In the quarter century between 1950 and 1975, we experienced a technical revolution, based on petrochemicals, in methods of agricultural production. Nitrogenous fertilizers relaxed the nutrient constrains on crop production. A succession of new crop protection chemicals and herbicides improved the reliability of farming, while mechanization improved labour productivity," (O'Callaghan 1992)*

Figure 1.1 Increase in wheat production per hectare since 1950,

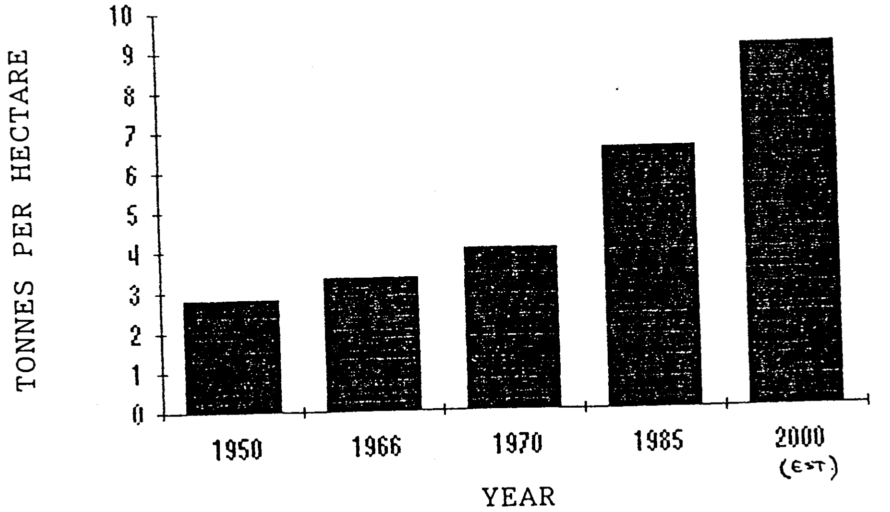



Figure 1.2: Agricultural support in the UK since 1977

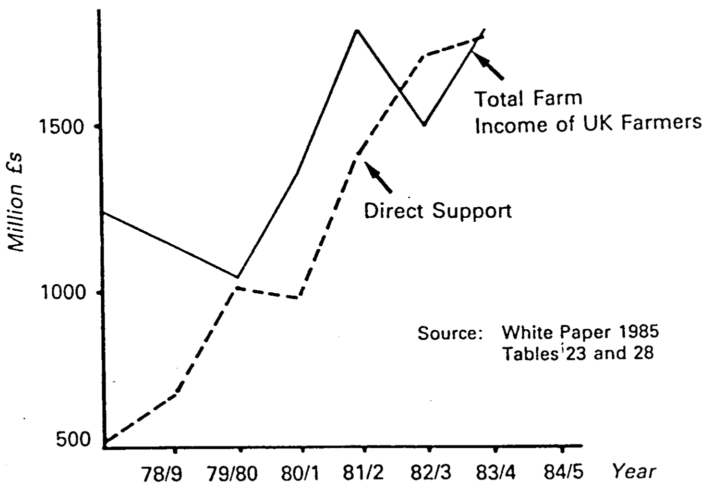
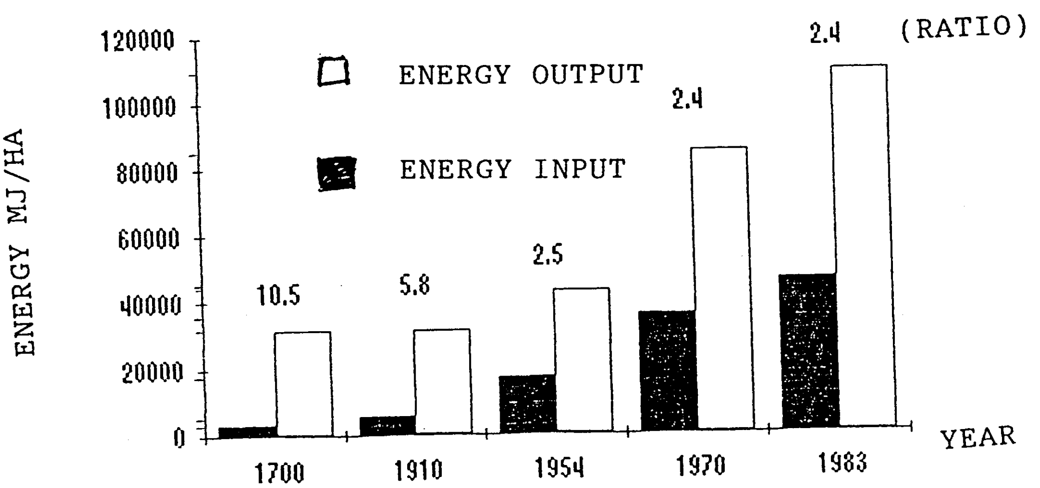



Figure 1.3 : Support energy use, yield and ratio in agriculture since 1700, (after Hall et al 1986)



## 1.4 THE ECONOMIC, SOCIAL AND ENVIRONMENTAL COST OF SUCCESS,

Despite the skills and innovative ability of the farmers themselves, increases in productivity have been achieved in part because of the generous amounts of financial support received by the agricultural industry, particularly since our belated entry into the European Community in 1971. The Treaty of Rome (1957) provided the framework through which support has been provided to countries throughout the European Community. Figure 1.2 illustrates the support farmers have received compared to their total income.

An article in the Economist, (12th December 1992), suggested that had a family within the European Community saved its contributions to the communities farmers during the 1980's, it could have brought several acres of British farmland- enough for a subsistence farm. Thus the cost of Common Agricultural Policy is being seriously questioned. Over production of many commodities throughout the EC has led to either wastage, massive storage costs or disposal onto the world markets, the cost and social implications of which are difficult to justify. The protectionist European Community market and its policies of dumping onto the world markets have caused problems in many parts of the world, (Marsh et al 1992, The Economist, 12th December 1992), and have been a major stumbling block within the GATT talks, (Sturgess 1991). This has forced the European Community to seek ways of cutting production, with reforms of the Common Agricultural Policy, (Ackerill 1992), and the so called MacSharry proposals, (Farmer's Weekly 20th March 1992 pp62). These have lead to the setting aside of approximately 750,000 hectares of land in the UK alone during 1992/93 in an attempt to curb over production, (MAFF 1993 personal communication).

Concern of the general public regarding the cost of agricultural support has been reinforced by the nature of certain agricultural practices and their impact on the environment. With regard to the countryside, Shoard (1980) declared,

*"... the English landscape is under a sentence of death. Indeed the sentence is already being carried out".*

Whereas many critics cite policy as the major influence on the countryside, Shoard goes on to say,

*" The executioner is not the industrialist or the property speculator, whose activities have touched only the fringes of our countryside. Instead it is the figure traditionally viewed as the custodian of the rural scene :- the farmer."*

Although an extreme view, this provides an example of the tide of feeling that has risen against modern farming. Official bodies such as the Nature Conservancy Council (1984) are often careful not to blame the farmers themselves,

*"...recent economic forces and government policy for agriculture have lead to practices highly inimical to the conservation of nature."*

Increased interest in the countryside is reflected in the number of people belonging to "countryside organizations", i.e. National Trust membership increased from 23,000 in 1950 to 1.6 million in 1986, (Britton 1990). These organizations have published a plethora of documents relating to the countryside, ( Countryside Commission 1984- Agricultural Landscapes, World Wildlife Fund 1983-Investing in rural harmony, Report for the Council for the Protection of Rural England- How to help farmers and keep England beautiful.)

Farming has been highlighted as a general polluter of the environment with increasing publicity being given to incidents of contamination from slurry and silage storage, but perhaps more significantly the pollution of drinking water, and the links with the application of nitrogen based fertilizers, *(see Addiscott et al 1991 for a good review)*. Farming has been further criticised because of the impact it has on habitats such as hedges, copses and wetlands, (Council For The Protection Of Rural England 1986, CAP reform and the environment, Nature Conservancy in Great Britain 1984). From an ecological point of view the concern for the loss of habitats is reflected in awareness of loss of species of both plants and animals, in which modern farming methods are implicated.

Demand for farm labour has decreased along with the increase in farm size and amalgamation of individual farms, with the consequence that many rural communities have become dominated by commuters, (Lemon 1992). Since 1975 the numbers employed on farms has fallen from 550,000 to 440,000, a fall of 20%, (Eurostat Agriculture 1992: Commission for European Communities). Additionally, changes in land tenure have lead to a situation where the generational continuity in the countryside is reduced. Concern for the general environment has focused interest on the farms themselves with increased awareness over animal welfare, (Gregory 1991). Recent issues concerning BSE in cattle, (Bovine Spongiform Encephalopathy or mad cow disease), and salmonella in eggs, (see Farmer's Weekly 19/6/92), have focused often ill informed public and media attention on farming practice, in some cases leading to controversial restrictions.

## 1.5 THE RESOURCE COST,

From the scientific viewpoint there has been growing realization that increases in productivity have partly been at the expense of energy intensive inputs such as cultivation and nitrogen, which are presently derived from or are reliant on non renewable fossil fuels. This is demonstrated in Figure 1.3 which illustrates energy use, yield and ratio in American agriculture. The graph illustrates that both input and output of energy from US agriculture has increased, particularly over the last 40 years. However, the ratio of input to output is nearly constant over this period showing that the efficiency of energy use is neither increasing or declining. This suggests that increases in output are being achieved by increased input and not by improved efficiency as is sometimes claimed.

Soil erosion has become a problem in many parts of the world, including Europe, (Pimentel et al 1987). In the UK soil erosion is not usually regarded as a problem although a recent review, "Soil erosion in Britain", (Hodges and Arden-Clarke 1986), suggests that erosion has been increasing substantially over the last 15-20 years and that as much as 44% of our arable soils maybe at risk to some degree. In tandem, increasing attention is being paid to the concepts of soil quality and soil protection, (Howard and Hornung 1989). Others have suggested the need for soil quality objectives, (Haberern 1992, Thomson 1992).

The effects of "modern farming" on the soil were investigated by an Agricultural Advisory Council, the findings being published in the Strutt report (1970). This report was commissioned because of worries about the inherent fertility of the soil being eroded and the fundamental structure of the soil being damaged beyond repair. The report found,

*"...no great fertility problem resulting from modern farming methods".* However they go on to comment, *"Soil structure is another matter. On unstable soils the influence of organic matter is all important..... Some soils are now suffering from dangerously low levels and cannot be expected to sustain the farming methods imposed upon them."*

The benefits of organic matter in the soil were highlighted in discussions with a mixed arable/ dairy farmer, (see chapter 7),

*"The muck from the dairy unit has reduced cultivation cost because the ground is kinder, with increased aeration. In dry years the surrounding arable units suffer whereas our crops keep on growing". (16)*

The question of loss of soil quality is receiving increased attention in the popular press, (see Peter Bullock's comments, Farmer's Weekly, 8th January 1993), although the effect of current farming on the soil system is difficult to quantify. A recent review, "Changes in soil organic matter content following change in land use," (Howard and Howard 1991), studies the organic matter question in greater detail.

## 1.6 QUESTIONING THE SUSTAINABILITY OF AGRICULTURE

Despite over-production being at the centre of considerable debate, there is little doubt that land based production systems in the future are going to have to remain highly productive to deal with demands for both food and possibly energy. Although change is inevitable, there is a need for change, in terms of our farming systems, to occur in a desirable direction or pathway. At the moment a "window of opportunity", (Address given to the Royal Agricultural Society of England by Prince Charles 1991), exists for the western world to design future farming systems combining the knowledge and experience from both the recent and distant past with the technologies, science and social understanding of the present. At its broadest level this thesis questions the nature of future farming systems and the process of change along desirable pathways, adhering closely to the philosophy put forward by Spedding (1991) in a recent note, "Thinking about the future." He suggests three realistic aims,

*"1. The projection of possibilities - that one should be aware of,*

*2. The description of scenarios - amongst which one can choose,*

*3. The identification of the determinants of change."*

One of the key threads running through this thesis is concerned with how the process of change is viewed and how, given alternative pathways for change, desirable options can be identified and encouraged. Our concepts of what farming systems in the future will be like and what will be demanded of them is a continually changing phenomena and farming systems need to be responsive to this. In subsequent chapters emphasis will be placed on the need for pathways of change to become increasing conserving of the soil, nutrients and biodiversity, but maintaining high productivity. It is from this conceptual base that this research has been designed. Figure 1.4 provides a diagrammatic representation of these pathways of change.

It is suggested that future farming systems will need to continue to intercept large quantities of sunlight, and through the process of photosynthesis, convert this into a useful product, either directly or indirectly. From this perspective the earth's land area may be viewed as a huge solar panel, the energy intercepted being fundamental to life processes. This concept associated with sunlight interception provides one of the corner stones in this thesis. Our incomplete understanding of how best to manage farming systems combined with a need, certainly in the recent past, to produce copious amounts of food has lead to a situation where high levels of non-solar energy, in a multitude of forms, has been used to produce food. Taylor et al (1993) provide an energy balance for a mixed English farm, (Table 1.1),

Table 1.1: Energy balance of a traditional English farm, (adapted from Taylor et al 1993).

| Input | Energy equivalent(GJ) | Output | Energy equivalent(GJ) |
|---|---|---|---|
| Labour | 725 | Biscuit wheat | 3221 |
| Machinery | 629 | Milling wheat | 6054 |
| Electricity | 144 | Winter Barley | 3150 |
| Fuel | 1728 | Beans | 940 |
| NPK | 5418 | Cattle | 741 |
| Corn seed | 325 | Sheep | 170 |
| Pesticides | 735 | Milk | 2239 |
| | | Straw | 4676 |
| Total | 13338 | Total | 21191 |
| Input :output ratio | 1 | : | 1.59 |

Table 1.1 illustrates that the energy embodied in the range of products leaving the farm is nearly balanced by that embodied in the

Figure 1.4: A diagrammatical representation of pathways of future change

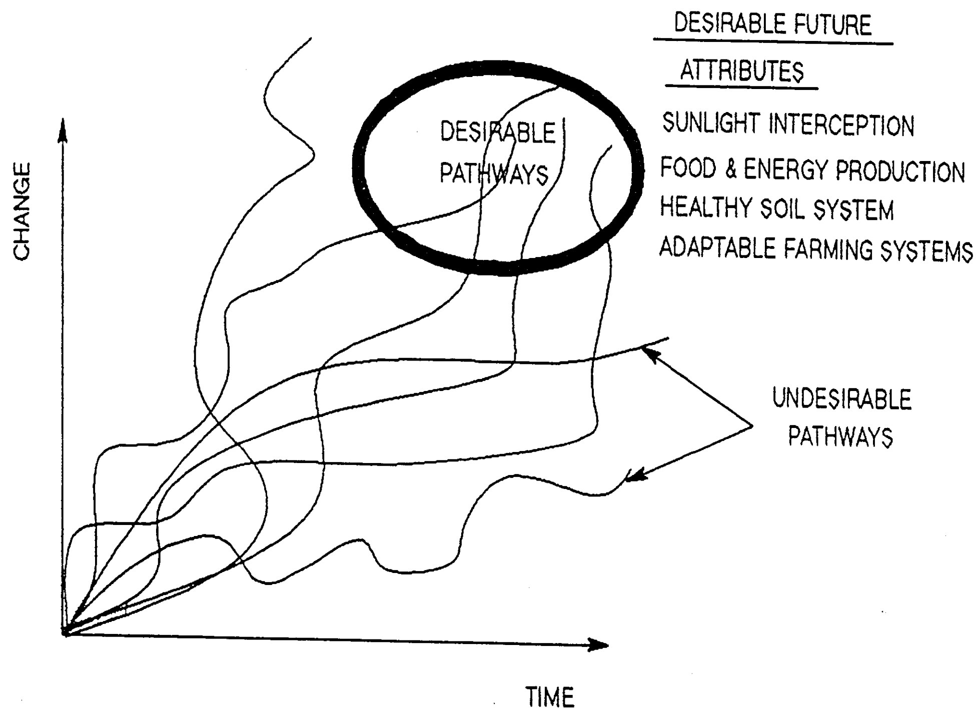
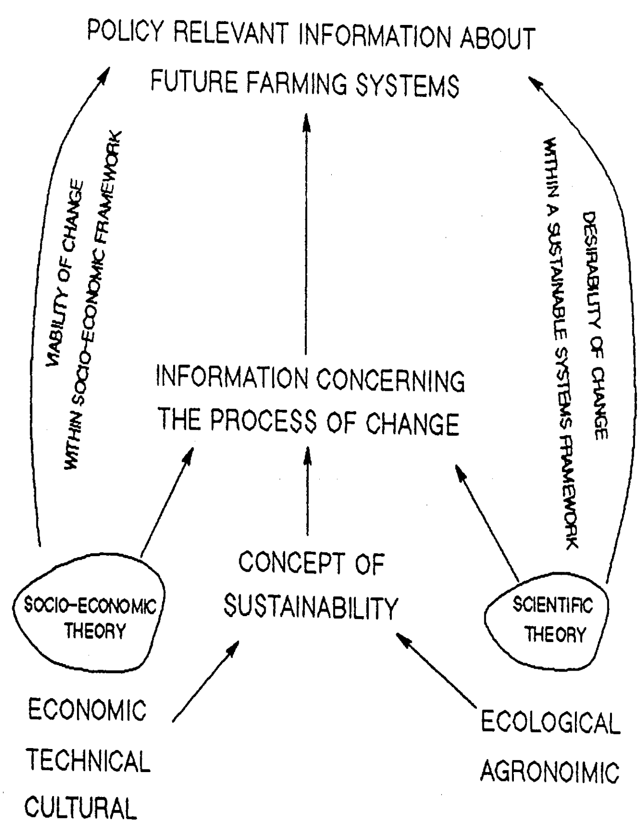



Figure 1.5 Conceptual model



inputs used on the farm in production, (Note the high levels of input in fuel and fertilizer). Future farming systems will need to intercept as much, if not a greater amount of the sun's energy per unit area than our present systems, but using up an ever decreasing amount of external energy. There are many advocates of "extensive systems" but generally these systems do not yield as highly as "conventional" systems. Perhaps more importantly they do not intercept as much sunlight per unit area when compared to more conventional farming systems. The process of change from the highly open farming systems of today, based on mainly annual cropping, poor nutrient cycling and reduced biodiversity, to systems increasingly diverse in nature with closer cycling of nutrients and less reliance on the human intervention to maintain the natural processes, will not nor cannot evolve overnight. This is referred to in the thesis as the process of change to increasingly sustainable systems. The concept of agricultural sustainability is in its crudest sense the realization that the farming systems used today will have some impact on the ability of our forebears and future generations to produce food. This thesis develops what is referred to as a sustainable systems framework to investigate the introduction of an innovative cropping practice, namely agroforestry.

Agroforestry is a form of spatially mixed cropping, examples of which have been used throughout history in the UK. Until quite recently in the UK poplar-arable combinations could be found, (Beaton 1987). With the advent of modern farming methods these systems are now rare in the UK, although they are receiving increased research interest, particular the more spatially defined intercropping systems. Agroforestry is a particular form of intercropping in which a woody perennial crop is grown in close association with a non-woody crop. Reasons for the increased interest in these systems is summarized by Carruthers 1988,

*1. Present and anticipated demand for forestry products,*

*2. High proportion of the UK that is farmland and farm surplus's,*

*3. Agroforestry may be socially, organisationally and financially more acceptable to farmers than plantation forestry,*

*4. Environmental benefits including attractive landscapes, habitat diversity and prevention of soil erosion,*

Chapter 6 describes the many different forms of agroforestry systems found throughout the world and discusses why it has been chosen as a medium of assessment. This thesis considers one derivation:- silvoarable agroforestry which is the growing of trees, in this case poplar, in widely spaced rows across the field, allowing arable cultivation to continue in the "alleys" in between.

## 1.7 A CONCEPTUAL FRAMEWORK

The assessment of the effects of proposed changes in cropping practice often involves some form of economic analysis. It is argued that the usefulness of these assessments carried out in isolation is limited because they take no account of the longer-term ecological consequences of change. These relationships between ecological and economic attributes need to be explored more fully, (Adams et al 1992). Unfortunately assessments of proposed changes in cropping practice rely on relatively short-term indicators and often ignore the longer term implication of change. For instance, Giampietro and Pimentel (1990) suggest that one of the short-comings of economic analysis is that it often overlooks the work of self-organization of the biosphere machine in terms of direct cost, (the amount of energy required to maintain the flow of matter in the cycles), and of the indirect cost, (the value of the biosphere capital, represented by the huge amount of embodied energy that has been spent for millions of years to produce and store information in the actual structure and function of the biosphere).

Lowerance (1990) recognises 4 objectives of agroecosystems management in the context of sustainability,: agronomic, ecological, micro and macro-economic. These are used by Blaschke et al (1992) in studying ecosystem processes and sustainable land use in the New Zealand steeplands. They struggle to quantitatively assess the ecological sustainability of the systems they are investigating, stating that the ecological sustainability objective is particularly difficult to assess.

The conclusions they reach are limited, stating that the natural disturbance regime in the area under study has been overtaken by the cultural one. Their research highlights the complexity of assessing changes in practice within the context of increasing ecological sustainability. At a national level it is important that decisions are taken to support changes in practice that are not only financially viable, but that are increasing the degree of ecological sustainability of land based production. Despite the problems involved indicators are needed to assess the impacts of change in the longer term if desirable pathways of change are to be followed. Further, the process of change to these desirable pathways needs to be understood. The underlying framework within this thesis is one which recognises the need to consider the long-term implications of change, but recognises the process of change is driven by social, economic and technical factors. This is illustrated by the conceptual model in Figure 1.5. This thesis argues that within a sustainable systems framework it is not appropriate to interpret scientific or socio-economic information in isolation, thus leading to questions about how information from these two bodies of knowledge can be combined in a manner which is both accessible and relevant to policy makers. This inevitably leads to consideration of the interfaces between individual disciplines and policy. This is referred to in this thesis as an integrative research process.

## 1.8 AN INTEGRATIVE DIMENSION TO THE RESEARCH

In a book entitled the "Evolution of the Biosphere", Budyko (1986), considers that the ever increasing volume of information in every field of science promotes specialization within specific branches of science. This limits the possibility of developing a synthesis of data from many lines of research. However, policy formulated within a sustainable systems framework will require the synthesis of data from a host of disciplines.

The term multidisciplinary is often a bedfellow in discussions involving sustainable agriculture, (Gliessman 1987, Macrae et al 1990). Whilst no attempt is made within this thesis to debate what is or is not multidisciplinary research, attempts are made to integrate information from a range of disciplines. A recent paper by Lockeretz (1991) focuses on "Multidisciplinary Research and Sustainable Agriculture", in which he analyses the degree to which component disciplines interact. Of his definitions, (additive, integrated, nondisciplinary and synthetic), it is the integrated approach which best describes the processes of research undertaken in this thesis,

*".....dividing the topic into disciplinary components, but gives special attention to the linkages among them and to the questions that either overlap or fall between different disciplinary domains."*

This can be achieved by either a team of people from several disciplines who have the ability to communicate and to step outside their own discipline or it may be undertaken by the individual, depending on the nature of the issue or problem. Lockeretz draws on an older piece of work to highlight the latter issue citing the work of Howard (1943), who suggested,

*"the net woven by a team may be full of holes,"* and instead recommended, *"one investigator with a real knowledge of farming combined with a wide training in science."*

However, there are many good examples of teams of researchers from various disciplines working together in problem solving. For instance Rhoades et al (1985) describe work done on the storage of potatoes in Peru where the combination of technologists and anthropologists was able to highlight issues which may have been overlooked within disciplinary research. In his conclusions Lockeretz again alludes to the value of the individual even when working within a seemingly disciplinary field, and suggests it is the ability to tackle previously unknown phenomena and to extend modes of thinking accordingly which is of importance. (We have the general theory of relativity not because the team that developed it was multidisciplinary, but because the "team" consisted of Albert Einstein). It has been recognised from the onset that the concept of sustainability is extremely complicated and this has shaped the research investigation, necessitating the inquiry into a range of disciplines, which although diverse in nature, form part of the research process. From a basis of agricultural science this research extends into the closely related disciplines of ecology, soil science and applied biology and those not so closely related such as rural sociology, information technology, technology assessment and policy studies. This research approach enables information from several disciplines to be integrated and used to develop one series of "*interfaces*" between the concept of sustainability and policy.

## 1.9 A SUMMARY OF THE RESEARCH PROCESS

It is the process of change to "increasingly sustainable systems" which provides the underlying motivation for this research and the core around which the research has been designed. A considerable amount of debate surrounds the concept of sustainability and the term itself is one which is used ever more frequently by politicians, informed members of the public and the media. Yet it is a concept which is poorly understood and often used without sufficient thought to what it means or how it relates to wider societal issues. This thesis recognizes that within complex evolving systems the design of research work embedded within a sustainable systems framework is in itself extremely problematic. It raises questions about the methods of undertaking research and the way in which policy, social and science research can be integrated to inform the decision making process about issues relating to the concept of sustainability.

It is argued that the view of what constitutes a sustainable system constantly changes, making the progression toward a endstate solution a fruitless task. Perhaps the best that can be achieved is for society today to avoid limiting the options available to future generations from which to choose. In the context of land based production systems this is argued to mean that the impacts of farming on the agroecosystem, and particularly the soil, should not compromise the ability of that land area to intercept sunlight in the procurement of food, energy and fibre. The interception and conversion of this sunlight is interpreted as a fundamental process to life and one which underpins the ecological sustainability of society.

However, to preserve or even increase the options available into the future there is a need to be able to measure and monitor the effects of change on these ecological processes in a manner which is meaningful, and, if necessary that can be reacted upon. This led to the investigation within the thesis of ecological processes associated with sunlight interception, biodiversity and nutrient cycling in an attempt to isolate appropriate measures within the agroecosystem. Organic carbon structure provides a useful indicator because it is related to many fundamental agroecosystem processes and because it is responsive to change over long-time periods. Its continued depletion can lead to soil systems which are vulnerable to inappropriate cropping systems. This linking of the concept of ecological sustainability to soil process and particularly measures associated with the volume of organic structure is the first interface explored within the thesis.

However, change in the carbon structure within established agroecosystems is generally slow, and although it may provide a useful background indicator of the state of a system the time-lag often associated with significant recordable changes is too great. The problem of its sole use is exasperated because of the mis-match in the rates of political and natural cycles. Thus whilst this mis-match exists, measures which record the responsiveness of agroecosystem processes to changes in cropping practice need to be quicker, i.e to fit in with these political cycles. This has led to the exploration of possible measures which can detect changes in agroecosystem processes more rapidly. Invertebrate measures are used within the thesis as a proxy measure of agroecosystem well being because they reflect the health of the detritus community which is in itself responsive to energy fluxes, nutrient cycling and theoretically can be used as an indicator of the biodiversity within that system as a whole.

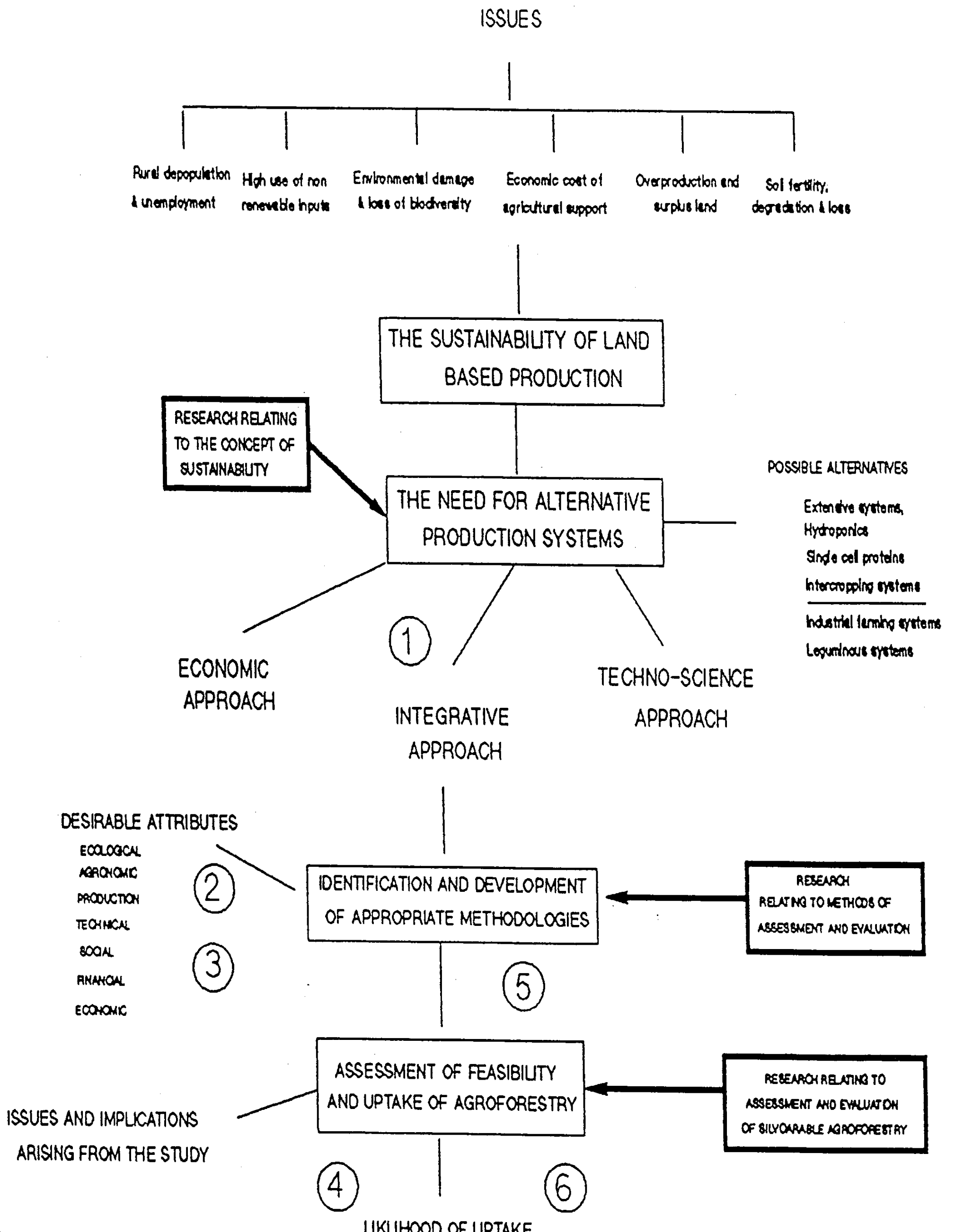
Thus a second interface within the research process links the concept of [ecological] sustainability, the volume of organic structure and the responsiveness of invertebrate populations to the cropping practices adopted by the farmer. These two simple measures aid the identification of changes in cropping practice which could increase the ecological sustainability of a given farming system.

However it is recognised that this science based approach is too simplistic. Firstly changes usually need to be economically viable or in the national interest in the shorter term before they will receive serious consideration. Secondly even if the above criteria are met the introduction of changes in cropping is in itself a complex process. Consequently a policy incentive or change often does not have the desired effect. Thus simply identifying the types of change that are desirable is only part of the problem associated with change within a sustainable systems framework. The investigation of the process of change, i.e linking policy or decision making to what the farmer actually does is seen as the third interface within the thesis. This interface is explored via two phases of interviews with farmers, and aided by a financial model. This part of the research recognises that despite a change in cropping being ecologically and economically sound it can remain unused simply because farmers do not adopt it.

Adoption will depend upon the current state of the system, the financial viability of the change on individual farms and the farmer's attitude and perceptions about the change. This latter piece of the research thus gives some impression of the ease with which a specific change in cropping could be introduced, and also the mechanisms, financial or otherwise, that could be used to encourage it. Within the thesis silvoarable agroforestry is used as a research medium or case study to explore the process of change to increasingly sustainable farming systems. Conclusions are drawn not only about the effects of agroforestry on the wider agroecosystem but about the possibility and likelihood of its uptake on farms. In doing this the thesis makes a contribution to the method of working using an integrative research approach to explore one set of research techniques. Conclusions are drawn within each chapter about the individual research techniques used which are thought to provide contributions within individual disciplines.

The last chapter draws wider conclusions about the adoption of innovative cropping practices such as agroforestry. It also discusses the issues associated with carrying out research within a sustainable systems framework, the concept of pathways of change, the use of an integrative research approach and comments on the wider debate

Figure 1.6 Conceptualization of the research process from issues to implications




RESEARCH ACTIVITIES

1 THE DEVELOPMENT OF AN AGROECOSYSTEM PERSPECTIVE WITHIN A SUSTAINABLE SYSTEMS FRAMEWORK

2 MODELLING THE EFFECTS OF AGRICULTURAL ACTIVITY ON CARBON/ORGANIC MATTER FLOWS AND STRUCTURE AS AN INDICATOR OF CHANGE WITHIN AGROECOSYSTEMS

3 THE INVESTIGATION AND USE OF SIMPLE INVERTEBRATE BODYSIZE ANALYSIS AS A REPRESENTATIVE MEASURE OF AGROECOSYSTEM WELL-BEING

4 ASSESSING THE IMPACT OF SILVOARABLE AGROFORESTRY SYSTEMS ON AGROECOSYSTEM PROCESSES

5 GAINING A REALISTIC INTERPRETATION OF THE CURRENT FARMING AGENDA AS SEEN FROM THE FARMER'S PERSPECTIVE

6 THE ECONOMIC, SOCIAL AND TECHNICAL EVALUATION OF ISSUES SURROUNDING THE UPTAKE OF AGROFORESTRY ON UK FARMS

surrounding the science/policy agenda. Thus conclusions are offered at three levels with respect to the research approach, the techniques used and the possibility of introducing innovative cropping practices such as silvoarable agroforestry in the UK.

## 1.10 MAPPING THE RESEARCH ACTIVITIES AND THE THESIS STRUCTURE

A period of time at the start of the research process was spent in isolating appropriate measures that were generalisable and understandable to a wider audience, and were not purely interpretable at a techno-science level. Therefore, the initial research activities were in fact running in parallel with forward research design, with the implication that not all of the research activities were formalised at the same time. Although a brief outline of the research activities is discussed in this chapter, the importance of each research activity and the reasons why a particular research activity was undertaken is discussed in greater detail within each of the appropriate chapters. Figure 1.6 locates these activities on a research map which links the issues associated with present farming methods to the assessment of increasingly sustainable land based production. The specific research activities that have been undertaken are:

1. The development of an (agro)ecosystems perspective within a sustainable systems framework aided by the use of a GIS,

2. Modelling the effects of agricultural activity on carbon/organic matter flows and structure as an indicator of change within the agroecosystem,

3. The investigation and use of simple invertebrate bodysize analysis as a representative measure of agroecosystem well being,

4. Assessing the impact of silvoarable agroforestry systems on agroecosystem processes,

5. Gaining a realistic interpretation of the current farming agenda as seen from the farmers perspective,

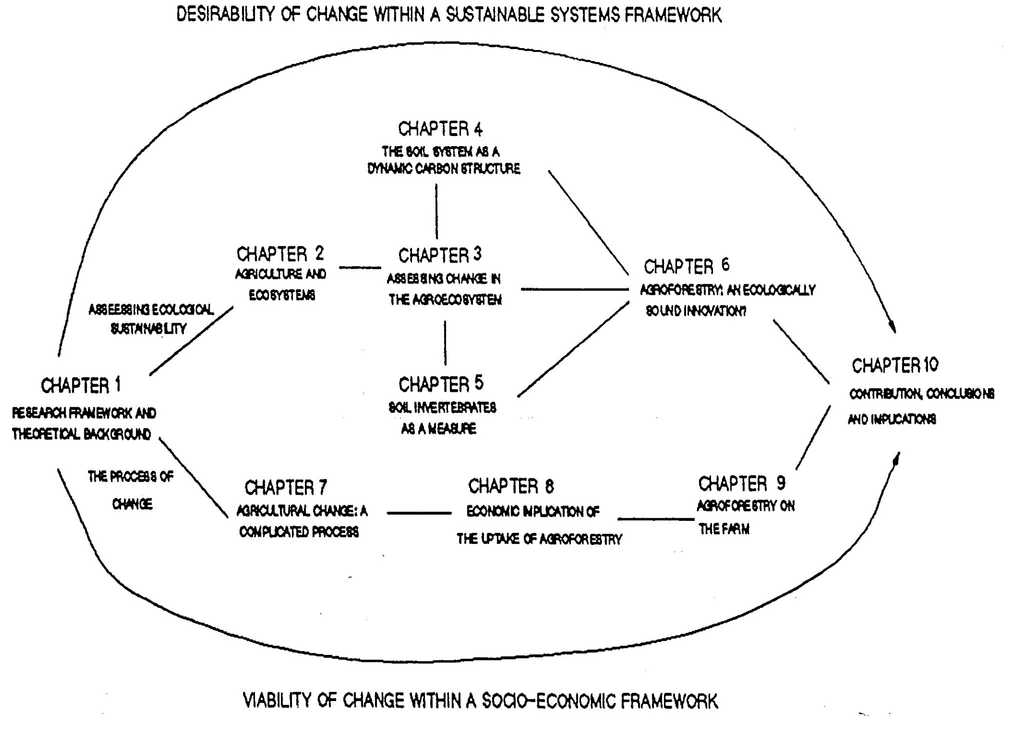
6. The economic, social and technical evaluation of issues surrounding the uptake of agroforestry on UK farms.

The first part of this research project focuses on the identification of ecosystem attributes that can be utilized in the assessment of the process of change toward increasingly sustainable systems. The need to be able to assess the effects of changes in farming practice on the (agro)ecosystem are pursued, concentrating on the biological components within the soil as possible indicators of change.

Agroforestry on arable farmland has been selected for investigation because it is a cropping practice that may provide the first step in the process of change toward increasingly sustainable farming systems. Ecological theory (Wood 1990), and broad economic analysis, (Thomas 1991) suggests that these cropping systems are worthy of further consideration. Additionally the growing of trees on arable land that is presently being set-aside is receiving increased attention. Access was negotiated to a local poplar silvoarable trial near Milton Keynes. Following the exploration of soil organic matter as an indicator of change and soil analysis at Rothamsted, the Wolverton site was sampled to discover if the establishment of the agroforestry system was having any impact on soil processes.

The second part of the research project considers the possibility of introducing cropping innovations into the existing farming infrastructure. A series of interviews with farmers in the East Midlands was undertaken to elicit the farming agenda and the framework into which a cropping system such as agroforestry needs to be introduced. A further series of interviews were undertaken to discuss the issues and problems associated with the uptake of silvoarable agroforestry on farms and to highlight mechanisms which could possibly be used to encourage the uptake of these systems on arable farms. Figure 1.7 provides a diagrammatic representation of the chapter layout.

Figure 1.7 Thesis design and chapter layout



# CHAPTER 2: SUSTAINABILITY, AGRICULTURE AND ECOSYSTEMS: IMPACTS, ALTERNATIVES AND THE PROCESS OF CHANGE,

*"... creativity is only a product of whole connected structures, ......investigations should return to the plascity and fluidity of natural things and processes."*
(Smuts 1926)

## 2.1 INTRODUCTION AND SUMMARY,

In the first chapter pathways of change were introduced and discussed with regard to the concept of sustainability, highlighting the desirable attributes of future farming systems and the pathways of change to such systems. This chapter investigates the concept of sustainability in greater detail, with specific reference to agricultural systems. The importance of photosynthesis in agricultural systems is used to introduce discussion on ecological energetics, the holistic nature of ecosystems and to highlight system structure, flows and cycles. This introduces the first interface explored within the thesis which links the concept of sustainability to fundamental ecosystem processes. The discussion is used to develop the attributes of ecosystems which ensure their functional development as a structure through time.

The impact of farming activity on the natural system is discussed and the concept of the agroecosystem is introduced. The differences between the natural system and the agroecosystem are debated, focusing particularly on the effect of agriculture on nutrient cycles, flows of energy and biodiversity. Some farming systems are associated with a spatial and temporal loss of the volume of agroecosystem structure. The loss of structural diversity affects the system's resilience, and the loss of functional diversity impinges on the adaptability of the system. Both of these attributes are associated with the underlying sustainability of that system.

A simple data analysis of soil carbon is used to highlight areas of England and Wales that could be vulnerable to inappropriate farming activities as measured by a loss of agroecosystem structure. It is concluded that some farming systems are not only unsustainable because of the amount of non-renewables they use, but because the level of intervention in ecosystem processes is so great as to question the future productive potential of those systems.

## 2.2 AGRICULTURAL SUSTAINABILITY,

The problem of trying to define sustainability has been tackled by many researchers. (O'Riordan 1985, Brown et al 1987, Liverman et al 1988, Pearce et al 1990, Robinson et al 1990).

O'Riordan (1985) states that the notion of sustainability is extremely hard to define and describes its definition as a,

*"exploration into a tangled conceptual jungle where watchful eyes lurk at every bend."*

Temporal and spatial scales complicate the definition of sustainability, (see Fresco and Kroonenburg 1992), and no attempt is made within this thesis to define sustainable endstates. However, it is assumed that the concept of sustainability is generally human centred, long-term and concerns interactions with natural systems.

Since the adoption of sedentary lifestyles and the development of agriculture some 10,000 years ago, (Conway 1987), human intervention has changed the evolutionary patterns of ecosystems, and continues to do so. The sustainability of agriculture is inexorably linked with this process of change and is closely associated with the dynamics of ecological and socio-economic change. Harwood (1989) takes account of this continual change and defines sustainable agriculture as a system that....

*"can evolve indefinitely toward greater human utility, greater efficiency of resource use and a balance with the environment which is favourable to humans and most other species"*

Human utility in itself is a very subjective view based on the systems and surroundings in which we live today. In reality, although quite accurate speculation may be undertaken with regard to what humans may find useful in a years time, these predictions may be extremely inaccurate over longer timeframes. This is exemplified if the change over the last 100 years is considered.

From past experience and present knowledge Chapter 1 highlighted concerns that farming methods today are having an impact on our ability to farm and produce food in the future, reducing the options available for following generations to utilize the land for productive purposes. This does not necessarily mean that they will not be able to produce food at any given point in time, only that their options for selecting different futures at a given instant may be reduced. Thus the adaptability of farming systems is being diminished. Sustainability in this context can be viewed as a maintenance of the adaptive capacity of farming systems. This adaptability is alluded to by Pearce et al (1990) who suggest that sustainable development within a given "vector" should allow development characteristics, (which are open to ethical debate), to be non-decreasing over-time.

If agriculture is the vector in this definition and the development characteristics are the options available in the future then this reflection on sustainable agricultural development may seem to be a useful progression. However, development to many implies growth, which in western society infers economic growth. Continued economic growth on a finite world resource base is unlikely to be sustainable, (Daly and Cobb 1989).

This highlights an interesting debate which says that change must be economically viable if it is to be successful. Although change may well be economically viable in the shorter term it may not be over the longer periods of time because it impinges on the ecological or natural functioning of the agroecosystem. Economic assessment often ignores any long-term benefits or those on which it is difficult to place a monetary value. Giampietro et al (1992) note that production systems optimized through economic indicators ignore the fact that human managed systems may be degrading environmental resources. i.e by consuming non-renewable resources and reducing the capacity of some parts of the natural systems to renew or recycle. Economic assessment of new technology should not be ignored, but used in combination with information indicative of the longer-term effects of change. This is recognised by Adams et al (1992) who highlight the need for the recognition of linkages between economic and ecological indicators of change in land use. In this sense increasingly sustainable land based production may be achieved by the identification and discouragement of innovations which are economically viable in the short-term but lead to the decreasing sustainability of agriculture in the long-term. For instance, investigating sustainability within the Great Lakes Basin, Slocombe (1990) states,

*"Monitoring of progress toward sustainability depends on identification of system characteristics that either support or decrease sustainability."*

Whether or not change is deemed to be increasingly sustainable will depend to a large degree on the current state of the system. The adoption of a certain cropping innovation in one situation, (with prevailing climate, soil type, and socio-economic conditions etc), may be deemed as increasingly sustainable, whereas in another situation it may well be decreasing the degree of sustainability of that system. This suggests that a cropping innovation can only be identified as increasingly sustainable when the present state of the system into which it is to be introduced is known. This reduces considerably the generalizations that can be made from one site/region to another.

## 2.3 THE NATURE OF FUTURE FARMING SYSTEMS?

The need to maintain high levels of productivity from land, either as food or energy products has been discussed. This is based on the premise that the sun's energy is a fundamental driver of biogeochemical processes, (Cox and Atkins 1979). Secondly, the sun is the only source of external energy to the planet, (Jackson 1991). In a paper on integrated agro-industrial ecosystems, Tiezzi et al (1991) consider any form of production will be limited by the density of solar flows, land quality, temperature etc and by inherent limits in the system. They suggest that these limits must be identified and observed to avoid upsetting the stability of the system. The optimization of the use of solar radiation through the understanding of (agro)ecosystem processes and interactions with the wider environment should provide a research focus. This has been described as an ecotechnological perspective that utilizes ecological principles, the self design capabilities of natural ecosystems and the sustainability of solar based ecosystems, (Mitsch 1991).

Within the UK there has been considerable muddled debate of the terms extensive and intensive farming systems. In the words of the Royal

Agricultural Society of England's report on the State of Agriculture in the UK,

*"The terms extensive and intensive applied to farming systems are confusing and should be dropped." (RASE 1991).*

The former tends to be associated with agro-industrial type systems, (Clunies-Ross and Hildyard 1992), using high amounts of fertilizer and pesticide. The latter are associated with low input/ output systems, (Pimentel 1984), and with increased environmental awareness.

In reality pathways to increased agricultural sustainability follow neither an intensive or extensive doctrine as defined above, but one in which relatively high levels of solar radiation are intercepted per unit of land and per unit of resource input. Some agricultural systems are clearly unsustainable, however the identification of, and rate of change to, increasingly sustainable systems is less clear. Research is progressing in several areas to improve photosynthetic processes, with increasing interest in the adaption of plants that have C4 photosynthetic pathways for growth in temperate climates, (Barden et al 1987). Similarly biotechnological developments are exploring the possibilities of increasing the range of crops that are capable of fixing nitrogen, (Wittwer 1980).

Other innovations use existing knowledge and technology in differing combinations to produce systems which increase light use efficiency or are conserving of nutrients, (Wittwer 1980). Research into alternative landuse has intensified with the advent of set-aside, and the need to do something, rather than nothing with the land. There has been a re-examination of mixed farming systems where by-products of one enterprise supplies the principle input for another. Research interest has been focused on the use of legumes as a supply of nitrogen to the agroecosystem and fuel crops to provide energy either on or off farm, (Newman and Wainwright 1988, Ford-Robertson et al 1992, RASE/WEDG 1993).

Non-pastoral UK farming systems rely almost exclusively on annual cropping which is temporally disjunctive in terms of sunlight interception, with relatively long time periods in which the soil remains bare or poorly covered with photosynthetic material, (Cox and Atkin 1979). The annual nature of the majority of farming systems adopted on arable land in the UK is contrary to the mixed annual & perennial combinations found in many "productive" natural ecosystems. Cox and Atkin (1979) view the planted crop as one which replaces the pioneer community of ecological succession, and subsequent successional stages are never allowed to develop.

## 2.4 SOLAR RADIATION AND ECOSYSTEM DYNAMICS

Life is only possible because of the sunlight incident on the earths surface. The energy flow into the atmosphere is responsible for the geophysical cycles that are so often taken for granted, and all living things are either directly or indirectly dependent on this solar radiation to provide an environment in which to live and appropriate food, (Hall et al 1986)

From a wider perspective, the earth as a system can be viewed as closed with respect to the flow of matter, but open to energy, (Jackson 1991). Upon the surface of the earth there is a continuous flow of energy and cycling of matter through living systems. Agricultural and natural systems intercept the sun's energy which powers global water and nutrient cycles, fundamental to the continual turnover and replenishment of the living system, (Hall et al 1986). Morowitz (1968) has shown that the flow of energy through a system will lead to cycling within that system. In the natural system this energy can be viewed in the context of providing for and replenishing the biological structures and flows associated with the continued interception of energy and the system functioning. In an agricultural context some of this energy is used in "technical activities which stabilize societal structure and function", (Giampietro and Pimentel 1990).

The maximum power principle, (Lotka 1922) suggests that an increase in the complexity of a natural community will be coupled with an increase in its ability to use solar energy. This theory is extended by HT Odum (1971,1983) to suggest that biological and social systems evolve toward higher levels of energy dissipation per unit area, although the actual energy dissipation per unit weight of standing biomass is likely to be reduced. As systems become increasingly complex a larger amount of energy may be dissipated per unit area to maintain the structure, although each kilogram of standing biomass will dissipate less energy. This dissipated energy per unit area provides linkages between ecosystem components. Tiezzi et al (1991) consider that the stability of a natural ecosystem is based on its capacity to create a network of links.

The total amount of solar radiation that is fixed by a biological system is often referred to as the Gross Primary Production, (GPP), and it is a measure of the energy needed to maintain the photosynthesising structure plus any additional energy that can be used to increase structure. The latter is referred to as Net Primary Production, (NPP). Several researchers have used these parameters to investigate the partitioning of solar energy in ecosystems, (Mitchell 1984, Vitousek et al 1986). This partitioning of solar radiation is fundamental to an elegant paper by Giampietro et al (1992) who introduce and define the concept of Biophysical Capital as the ability of an ecosystem to use solar energy for generating biophysical processes that stabilize the biosphere structure/function. This concept highlights two important functions of sunlight interception. It not only provides the plant with an energy source to increase or maintain its structure so that it can go on photosynthesising, but through the biomass it affects biophysical processes thus stabilizing the biosphere structure.

The linkages between ecosystem structure and energy dissipation has established a close tie between ecological theory and thermodynamics.

Jackson (1991) stresses that ecosystems do not consume energy, (first law of thermodynamics), but states,

*"What an ecosystem consumes, as revealed by the second thermodynamic law, is not energy but order".*

The ordered ecosystem structure thus formed can be interpreted as a three dimensional volume consisting of a structure of photosynthetic material and necessary support above the ground and an associated structure beneath the ground which is responsible for nutrient and water replenishment, (see Figure 2.1). Living in association with the plant communities, both above and below ground are a wide range of animal species.

Schneider (1988) recognises that these natural systems in a highly ordered state are far from thermodynamic equilibrium, and a constant flow of (the sun's) energy is needed to maintain this state. In asking the question, " What is death?" he considers it to be the point when the ability to maintain order out of disorder is lost, the flow of energy stops within the living system and it decays toward its thermodynamic equilibrium. In thermodynamic terms the ecosystem represents a highly ordered system, ( a low entropy state) indicated by the maintenance of the structure itself and cycling of materials within it. These general theories, although seemingly robust have proved difficult to operationalize and test at the ecosystem level as shall be discussed in the next section.

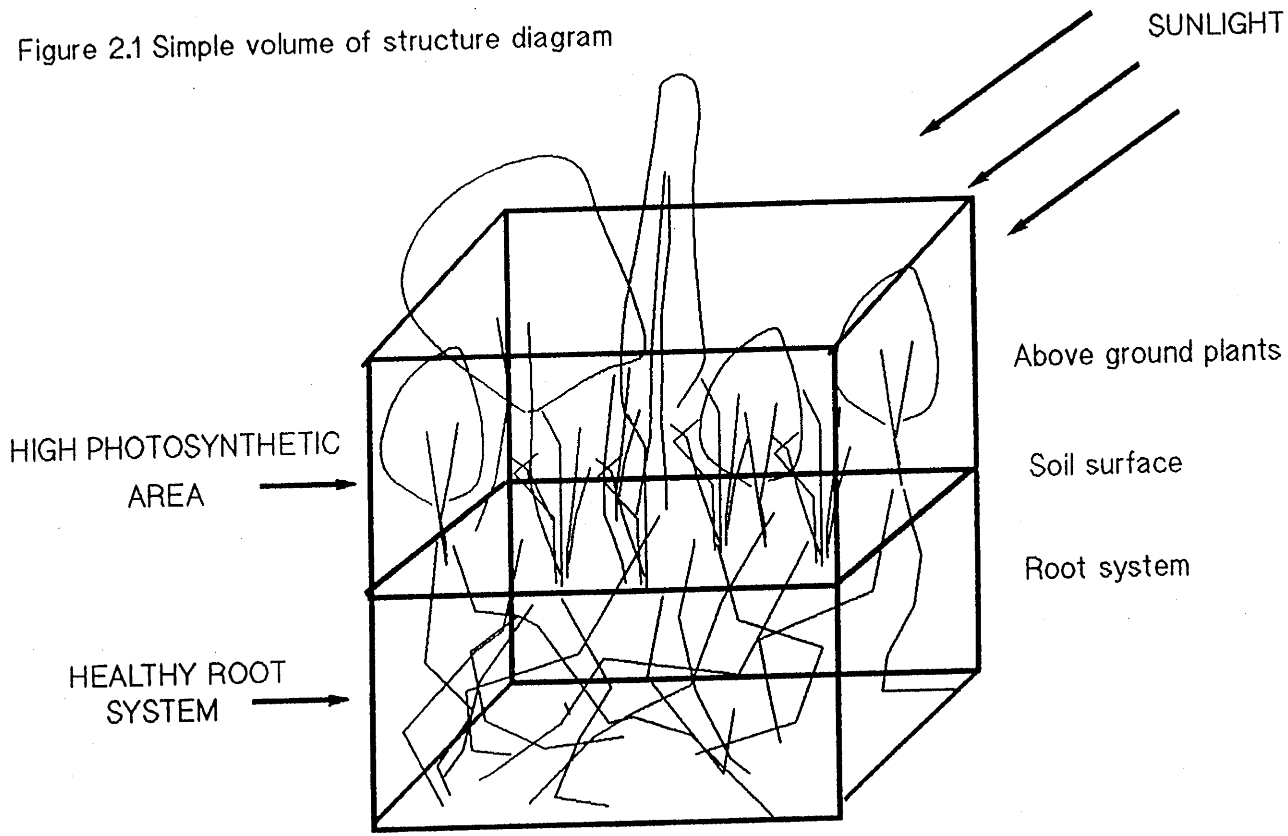
## 2.5 ENERGY FLOWS AND ECOSYSTEMS,

The observations of Charles Elton at Spilzbergen in 1921, allowed him to develop an explanation of structure within ecological communities, based on the recognition that large animals eat smaller ones, creating food-chains, Elton (1927). *(Referred to as food webs in present day ecology)*

He observed that creatures need energy to exist and this could be obtained by eating plants that derived energy from sunlight or eating other material that had ultimately been derived from plants. This laid the groundwork for the study of trophic dynamics in the ensuing years. Evelyn Hutchinson, inspired by Elton's "Animal Ecology", went on to study in greater detail the flow of energy through the ecosystem and the cycling of materials within it, (see Hagen 1991). Although only one of many successful ecologists of the era, Hutchinson was recognised, (and often criticised), for his development and support of controversial hypothesis. One of the most fundamental ecological papers by his protege, Raymond Lindeman, nearly went unpublished because of its bold development of limited experimental evidence, (Lindeman 1942).

However, research on energy flows in ecosystems progressed rapidly following the publication of "The trophic-dynamic aspect of ecology", (Lindeman 1942) and his theorizing about trophic levels. This work was extended greatly in the ensuing years both theoretically and through experimental research being undertaken on the energy flows in

Figure 2.1 Simple volume of structure diagram



nature, (Odum EP 1969,1971,1984, Margalef 1963,1968,1969, Schneider 1988). Lindeman's paper provided a conceptualization of a system through which energy flowed from intercepting plants, to herbivore and into predators, each being allocated a trophic level.

i.e level 1 plants
level 2 herbivores
level 3 carnivore 1
level 4 carnivore 2

Lindeman's theses was widely applied in the International Biological Programme, (IBP), and it wasn't until the programmes culmination in 1974 that the limitations of the trophic level approach became more apparent. Some larger animals fed at several levels, whilst others ate both plant and animals. Thus the discrete movement of energy from one level to the next did not always occur. However, energy flows have continued to remain a focus of ecological research, (Cousins 1980, 1985, Odum EP 1984, Odum HT 1984), and this lead to the redevelopment of some of Charles Elton's work on size structures in communities, (see Chapter 4). Elton's pyramid of numbers is seen as a thermodynamic description of communities in which some energy is embodied in large animals which is in an "unlikely" and highly ordered state.

## 2.6 ENERGY FLOWS, RESILIENCE AND STABILITY,

Resilience, like the concept of sustainability discussed earlier, is a complicated concept. The size of the disturbance and the time period or rate of recovery determine a system's resilience, as will the question of what needs to be re-established, i.e. is it the function or structure that needs to be resilient? For example a system maybe disturbed, loosing several species and its ability to photosynthesise at a given rate. It may recover the photosynthetic potential, (the function), quickly, but may never recover the same species, (the structure). Thus the resilience of system is measured in terms of the return time to a state defined by the observer in relation to initial conditions. This has a number of methodological consequences.

DeAngelis (1980) has demonstrated mathematically that the resilience of a system is determined by two parameters,

1. Energy flow through the system per unit of standing crop

2. A recycling index that measures the mean number of cycles a unit of matter makes in the system before leaving it.

He went on to develop the concept of transit time, which indicates the amount of time a unit of energy or matter stay in a system. Longer transit times will prolong the period of recovery following disturbance. For instance, the rainforests are extremely diverse, complex systems intercepting high levels of incident radiation with close cycling of matter. Whilst the majority of the structure remains in place they can withstand disturbance as the continued interception of high levels of incident sunlight ensures the rapid renewal of damage. However, if whole areas are cleared the recovery period is extremely slow if it occurs at all. The plant material necessary to photosynthesis and pump energy through the system no longer exists and thus the ability to recover is diminished. In the tropics the soil itself is often damaged and subsequently eroded. Nutrients left in the soil are quickly washed out by the high rainfall. The rainforest may well be resilient to continual natural disturbance which is part of the biospherical environment in which they have evolved, but they have little resilience to the type and scale of disturbance that can be caused by large-scale human intervention.

Attempts to manage fire in some ecosystems have led to similar larger scale effects. Often natural forests are "disturbed" by periodic small fires in which these ecosystems have evolved. This clears the dead wood out of the system and provides nutrients for new growth, (McGlade and Perez-Trejo 1991). Attempts were made to stop these fires as it was seen as a loss of timber and in some cases a danger to human life. As a consequence dead wood builds up in large tracts of forest, which eventually, by accident or because of circumstance, catches fire. These fires, stoked by vast quantities of dry wood built up over long periods, are more intense and burn over larger areas. The subsequent rate of recovery following these large fires is much slower. These particular ecosystems evolved with fire as periodic disturbance, increasing the internal flexibility of the system, and promoting system resilience. The relationship between disturbance and resilience has been investigated by several researchers, (Holling 1973, Pimm 1988). Figure 2.2 shows this relationship in diagrammatic form.

The diagram suggests that continued fluctuation caused by an on going small external disturbance is likely to increase the system's resilience to a large expected fluctuation in the natural environment. These relationships between energy fluxes, biotic diversity, ecosystem stability and resilience have provided a major focus of research in ecology for many years. (Odum 1969, Green 1969, Margalef 1969, May 1973). It is thought that a degree of instability promotes species diversity, Walker (1990) states,

*"...instability in the environment promotes increased species diversity by allowing unstable mixtures of species to persist. However if the environment is too variable then species numbers again decrease, and this has lead to what is known as the 'intermediate disturbance hypothesis.'"*

May's work with model ecosystems, (May 1973) reinforced the notion that increased ecosystem diversity could lead to instability. Allen et al (1982) claim it is not the diversity in a system that is of importance but the connectiveness between its elements. Thus, increases in diversity may either increase or reduce stability depending on whether the system is over or under connected. From another perspective, Margalef (1969), simply describes the stability of a system as a resistance to change imposed by external perturbation.

## 2.7 ENERGY FLOWS, SPECIES DIVERSITY AND ECOSYSTEM DEFINITION

Regions in high latitudes receive less intense solar radiation and generally intercept less energy per unit area to power associated ecosystems. This is suggested to be a major determinant in the generally reduced diversity of species closer to the poles compared to the equator, (Wallace Arthur, New Scientist 29th June 1991). Plants in equatorial regions can intercept large amounts of incoming radiation, forming complex structures that provide food and shelter for associated animal life. Turner et al (1988) suggest that a higher rate of energy flux will generally be associated with bigger populations, (although this hypothesis is still untested).

Recently Cousins (1990) has conceptualised largest predators as energy sinks, and has suggested their use in the identification of a physical boundary around an ecosystem based on the territory over which the largest predators forage, (Ecotrophic Modules, ETM's). His paper provides a useful review of the development of the ecosystem as an entity and highlights a major weakness in ecology, in the words of Ghiselin (1987),

*"Ecologists are most unsure about the nature of their fundamental units and about what such units do"*

Despite Cousins ideas and theorizing by others, (Rowe 1961, Eldredge and Salthe 1985), the ecosystem remains an arbitrary measure to many, based on watersheds, geological features, or purely an appropriate area to measure. However, this has not inhibited the development of the study of cycles and flows of nutrients and water that occur in natural systems.

## 2.8 NUTRIENT AND WATER FLOWS IN ECOSYSTEMS,

Unlike energy, the flow of matter on a world basis is essentially closed, suggesting that the nutrients responsible for plant growth must be used again and again. From this basis nutrient and water flows tend to be treated as global cycles, (hydrological cycle, carbon cycle, nitrogen cycle). At the ecosystem boundary the flows are not closed as water and gases can flow across this boundary bringing a variety of nutrients needed for the sustenance of life, (transfer can also occur due to geophysical processes such as landslides and earthquakes). However, the cycles of many nutrients are regarded as relatively closed because of the rate at which they can be supplied from outside the ecosystem boundary is slow. Although there are many nutrients essential for plant and animal survival, (see Wild 1988, McDonald et al 1981), this section outlines only four of the most important cycles, hydrological, carbon, nitrogen and phosphorous.

### 2.8.1 The hydrological cycle,

Water is an essential component of all living tissues, providing them with their source of hydrogen. It acts as a carrier for many of the nutrients essential for life and is the medium in which nutrients enter plants. The hydrological cycle is a global system driven by the sun's energy. Evaporation from the oceans, soil and plant material causes vapour clouds to form which at some point release their water burden in the form of rainfall. This is taken up by plant rooting systems to compensate for the considerable losses through evapotranspiration, but additionally supplies soluble nutrients to plants. Although only a small amount of the earth's water is contained in plant and animal cells, (Cox and Atkin 1979), it is a limiting component in many ecosystems, resulting in poorly developed plant communities, few animals and unstructured soils. (i.e. deserts)

Ecosystems in many parts of the world have developed around specific water regimes, some plants being able to store considerable amounts of water, (ie bottle trees and cacti), and have developed structures that minimize the loss of water through evaporation. Areas with adequate rainfall and sunlight generally support a diverse range of fauna and flora.

### 2.8.2 The carbon cycle

Carbon is one of the basic elements of life and is closely associated with the energy flow through ecosystems, linking biotic and abiotic processes. Energy is stored in living organisms in the form of fixed carbon, initially entering the ecosystem via the uptake of atmospheric carbon dioxide. This is transformed by the process of photosynthesis into organic molecules, forming the basis for the carbon cycle within the grazing and detritus food chains. The release of energy through respiration leads to the degradation of these organic molecules, releasing carbon dioxide back to the atmosphere. The carbon cycle, particularly in the detritus community is discussed in greater detail in Chapter 3, 4 and 5.

Carbon is stored both above and below ground in differing proportions, largely dependant on climatic conditions. For instance in the warmer tropical climes a greater proportion of the ecosystem carbon is stored above ground in living material, (Schlesinger 1977). The slower decomposition that occurs in temperate climates means a greater proportion of carbon is found within detritus community within the soil. Table 2.1 provides a guide to the carbon contents and turnover rates of a range of ecosystems throughout the world,

Table 2.1, Distribution of detritus and biomass by ecosystem types, (adapted from Schlesinger 1977)

| Ecosystem type | World area | Detritus | Biomass |
|---|---|---|---|
| Tropical forest | 24.5 | 10.4 | 18.7 |
| Temperate forest | 12 | 11.8 | 14.5 |
| Boreal forest | 12 | 14.9 | 9 |
| Tropical savanna | 15 | 3.7 | 1.8 |
| Temperate grassland | 9 | 19.2 | .7 |
| Desert scrub | 18 | 5.6 | .3 |
| Extreme desert | 24 | .1 | .008 |
| Cultivated | 14 | 12.7 | .5 |

**World area** is in hectares * $10^8$

**Detritus** is expressed in mean total profile detritus in kgC $M^{-2}$ $yr^{-1}$, i.e kilograms of carbon in various states of decomposition per metre squared.

**Biomass** is expressed as kgsC $M^{-2}$ $yr^{-1}$, i.e. kilograms of live material per metre squared.

### 2.8.3 The nitrogen and phosphorus cycles,

The main reservoir of nitrogen is the atmosphere but, with the exception of a limited number of nitrogen fixing plants, this source is not available to most living organisms. Some nitrogen enters the soil dissolved in rainfall but most of the nitrogen utilized by green plants is made available through biological fixation by certain bacteria, actinomycetes and algae. The cycling of nitrogen in developed ecosystems is tight as it is a particularly valuable resource. However, if excess remains in the soil it is leached from the system in the form of nitrate. Similarly it can be lost from the soil surface due to the action of denitrifying bacteria, (see Addiscott et al 1991, Powlson 1992). Nitrogen will have a major impact on the productivity of ecosystems where sunlight and water are not limiting. The amount of nitrogen within the system is closely related to the carbon content, (Jenkinson 1989), and this means that systems deficient in nitrogen will be compromised in their ability to accumulate structural carbon. The carbon:nitrogen ratio is discussed in greater detail in section 3.8.1.

The main reservoir of phosphorus is sedimentary rather than atmospheric, and in this respect it differs to both carbon and nitrogen, (Cox and Atkins 1979). Plants take up soluble phosphate through their root systems and incorporate it in living tissues. When the plant dies this organically held phosphate enters the detritus system. Some is held within animal bodies, eventually to be returned to the soil in an inorganic form, some of which becomes available to the plants again. The soil store of phosphorus is generally much greater than the amount of phosphate available to the plant for growth, and in many situations it can be a limiting factor to growth. It binds particularly well with clay particles and is generally not leached out of the soil to any significant degree. Although all plants need phosphorus, some are more tolerant to deficiencies than others. This can influence the biotic make up of ecosystems and shape the ecological community that develops, i.e. certain areas within New Zealand are renowned for their phosphate deficient soils.

## 2.9 ENERGY FLOWS IN AGRICULTURAL SYSTEMS,

It has been emphasised that in non-agricultural systems sunlight provides the only energy source which can effect the scale and diversity of life within that system. Additionally energy flow affects a systems ability to recover from disturbance. Animal and plant species, both above and below ground, provide regulatory mechanisms for the cycling of nutrients and the flow of water through the

Figure 2.2 Relationship between resilience and system disturbance, (adapted from Holling 1984)

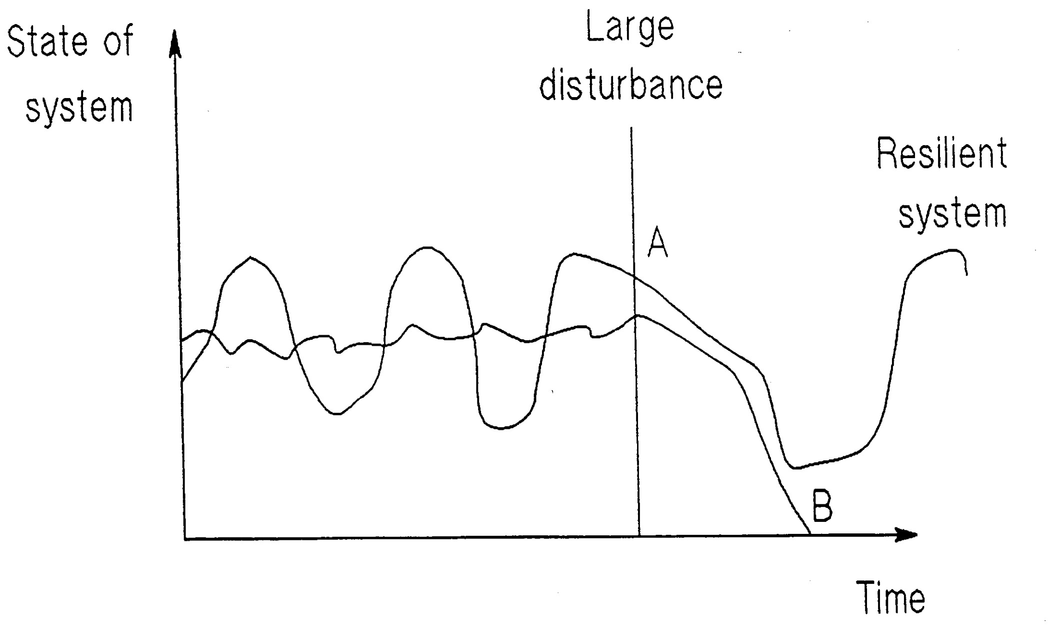
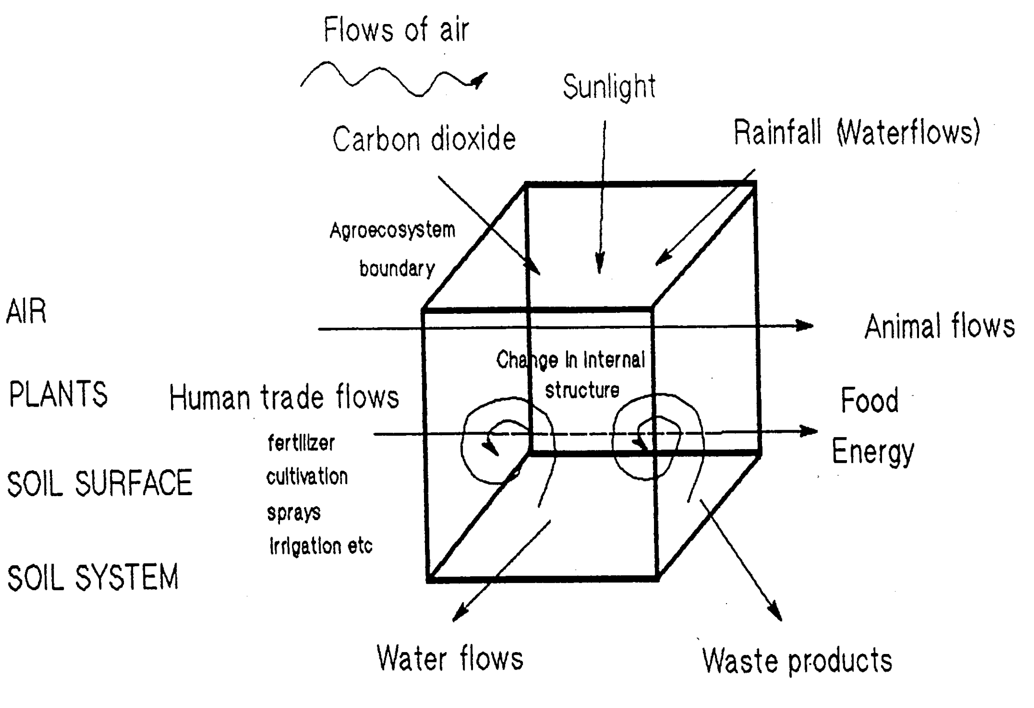



Figure 2.3 : The 3-dimensional agroecosystem,



agroecosystem. Agricultural activity influences these processes, altering the non-solar flows across ecosystem boundaries, and changing the internal structure of the ecosystem and thus its ability to utilize solar energy.

Agricultural activity in differing parts of the world has developed at various rates since the origin of agriculture, *(see Harris 1972 for interesting review)*. Since these early origins the degree of intervention in natural systems for the procurement of food has steadily increased. In recent history the ease of movement of both inputs and produce from agricultural systems has accelerated considerably. The import of "*Guano*" from South America to Europe, (as a source of phosphate), can perhaps be cited as a turning point in nutrient transfer across national frontiers, but this is overshadowed by the use of fossil fuels, not only as source of power on the farm, but also in the energy intensive process of the manufacture of nitrogen based fertilizers, which provide the primary plant nutrient to the growing crop.

This means that a typical British arable farm may utilize fossil fuel from the Arabian Gulf, nitrogen compounds manufactured in Eastern Europe, phosphates mined in North Africa and potash from North America. The control and use of these inputs is subject to an external policy environment which pays little attention to the natural processes underlying agricultural systems. The productivity of these systems is no longer constrained by the rate at which ecological processes can provide nutrients, (and water in irrigated systems), and this allows the continual export of high amount of energy, in the form of food, from the systems.

These systems which are no longer under the control of purely ecological processes are referred to as agroecosystems. The notion of the agroecosystem has evolved as a conceptual tool for evaluating and researching processes in agricultural systems, noting that agricultural systems share many common processes with natural systems, but varying functionally because of human intervention and in their openness with regard to the cycling of matter. Many researchers consider the agroecosystem to be an important concept, (Cox and Atkins 1979, Lowerance et al 1984, Odum 1984, Conway 1987, Gliessman 1989), and one which allows study of the impact of agriculture on the environment in its broadest sense.

Odum (1984) highlights four differences between natural and agroecosystems;

> *1. In addition to solar power, auxiliary energy from human and animal labour, fertilizers, pesticides, irrigation, and fuel powered machinery are added as subsidies to agroecosystems,* (Considerable research has been undertaken with regard to the level of external energy use in agriculture as much of this is derived from non-renewable resources. (see Dekkers et al 1974, Lockeretz 1983, Goldemberg et al 1988, Spedding 1974,1975,1982, Spedding and Walsingham 1975, Odum 1984, Pimental 1984, Martinez-Alier 1987, Taylor et al 1993).

*2. Biotic diversity in agroecosystems is reduced to maximise economic yields of desired products,* (For further reading on the effects of agriculture on biotic diversity see Risch et al 1983, Altieri and Letourneau 1984, Gliessman 1989, Perry et al 1989, Altieri 1991).

*3. Artificial selection rather than natural selection produces dominant plants and animals,* (It has been estimated that the world's agricultural landscapes are planted with only 12 species of grain crops, 23 vegetable crop species and about 35 fruit and nut species, (Fowler and Mooney 1990).

*4. Agroecosystems are under external, goal orientated control rather than internal control mediated by sub-system feedback.* (Giampietro et al 1992 recognize the reduction in this feedback stating,

*"...an increase of the harvested biomass can result in the deterioration of natural processes sustaining the environment. Excessive alteration in the abundance and distribution of the natural biota can eventually lead to a decrease in the biomass productivity of the managed agricultural ecosystem.")*

Vitousek et al (1986) estimated that the export as food from agroecosystems, (co-option), is somewhere in the region of 40% of Global Terrestrial Net Primary Production on a yearly basis. They estimate with current consumer patterns and a rising world population this is likely to increase to over 50% when the population rises to 150% of its 1986 level. Giampietro et al (1992) explore the effects of this large appropriation of NPP using the concept of biophysical capital to highlight the energetic differences between managed and natural ecosystems relating the amount of energy dissipated by an ecosystem, (Watts/kg of biomass) to the weight of standing biomass, (kgs of biomass per $M^2$). When the two are multiplied together a figure for Watts dissipated per unit area is arrived at. This is further extrapolated to give a figure for the energetic cost of maintaining each kilogram of standing biomass. Tropical rainforests are highly evolved and complex communities, nearing climax, and this means they have a high level of biophysical capital, (see Table 2.2)

Table 2.2 Comparison of energetic parameters in natural and managed systems, (adapted from Giampietro et al 1992)

| | GPP | PAWF | SB | BC | EC |
|---|---|---|---|---|---|
| | $Wm^{-2}$ | $Wm^{-2}$ | $kgm^{-2}$ | $Wm^{-2}$ | $Wkg^{-1}$ |
| Tropical for. | 4.5 | 49.9 | 60 | 54.4 | 0.9 |
| Decid for. | 1.5 | 16.6 | 40 | 18.1 | 0.5 |
| Tundra | 0.2 | 1.8 | 1.5 | 2.0 | 1.3 |
| Corn (USA) | 1.6 | 17.9 | 2.2 | 19.5 | 8.9 |

W Watts
GPP Gross Primary Production,
PAWF Plant active water flow,

SB Standing biomass,
BC Biophysical capital, (= GPP+PAWF)
EC Energetic cost to sustain the organization of 1kg of biomass on a yearly basis,

$$EC = (GPP+PAWF)/SB \quad \text{-Equation 2.1}$$

The table implies that a key difference between the managed and natural system is in the energy or biological capital that is dissipated per unit of biomass. In the American cornfield this is 8.9 W/kg whereas in the tropical rainforest this is 0.9 W/kg. This represents a very high thermodynamic cost per unit of standing biomass in agricultural systems or an inefficiency in the use of energy to maintain the dynamic structure of the ecosystem. In managing ecosystems the result of agricultural activity is to switch energy from processes which maintain the natural ecosystem, and to use it for the food and fibre needs of human society. This has to be compensated for by a constant stream of non-solar energy in the form of machinery, labour, fertilizers and pesticides. Giampietro et al (1992) conclude that the energy left in the natural processes of some ecosystems after human intervention is no longer sufficient to maintain the biophysical capital. They draw on a very clear analogy,

*"The human exploiter is acting like a truck driver who is short of cash and sells pieces of his truck to improve his income but who will soon no longer make a living out of being a trucker of goods."*

Thus, land based production may not only be unsustainable because of its use of non-renewable resources, but also because it is impacting on the wider biospherical processes and the ability of systems to maintain efficient energy interception.

## 2.10 VULNERABILITY IN AGROECOSYSTEMS

The intensity of agricultural activity varies throughout the world. In some areas complex home gardens are cultivated that mirror natural ecosystem properties closely, (Young 1991). At the other end of the spectrum are the types of agroecosystems that have developed in many parts of the western world. Chapter 1 argued these systems can be highly productive, but are increasingly being questioned because of the amounts of external inputs that are needed to maintain their productivity. They are also criticised because they often result in a loss of plant and animal habitat, lower the soil quality, and result in the loss of species diversity. Thus higher output from modern farming systems has been achieved by increasing the degree of intervention applied to food production systems, leading in many cases to rigidity and the need for constant regulation or control. Holling (1978) relates the need for high output to increased stability, (usually through increased control), to systems of less resilience. He exemplifies the fisheries of the great lakes which he describes as self-contained systems of low variability, high stability but low resilience.

In this thesis the effect of human intervention is interpreted as a spatial and temporally loss of agroecosystem structure in comparison with natural habitats, the farmer being able to control some of the flows in and out of the agroecosystem. Therefore the farm can be viewed as a three dimensional structure consisting of a depth of soil, surface vegetation and above this a depth of air. Figure 2.3 provides a representation of a 3-dimensional agroecosystem. The physical flows through the farm can be summarized:

1. **Flows of air**, (gaseous exchanges associated with respiration of plants and animals). In the open environment the flows of gases are generally beyond the control of the farmer, although within certain animal rearing systems the farmer can control the "atmosphere" within buildings. He may also control or alter microclimate via shading or the use of heaters etc. to keep frost off crops.

2. **Flows of water**, (rainfall, irrigation, streams etc). The farmer cannot control rainfall but can influence the addition of water to the system through irrigation and the rate of surface and ground water flows via drainage. The farmer can have a considerable impact on the nutrient flows contained within the water as it percolates through the soil,

3. **Animal flows**, (Movements of wild animals). Movement of wild animals across the farm boundary have diminished as agriculture has become more intensive. Farmers may actively try to eliminate animals such as pigeons, foxes and rabbits, or accept their limited presence. Their movement can be restricted by physical barriers, i.e. fences and dykes.

4. **Human trade flows**, (Inputs and outputs associated with production). The largest impact the farmer has upon the agroecosystem is in the inputs he uses in production and the output he sells from the farm. Labour is included within these inputs.

Concerns have already been raised in this chapter that many of the human trade flows used in agriculture are derived from non-renewable resources, but further that manipulation of the flows may be having a serious effect on the ability of some agroecosystems to continue functioning as an entity. In the following sections a desk top study is described which demonstrates a methodology, using National Soil Survey data, to highlight agroecosystems of England and Wales which could be vulnerable to the use of inappropriate farming systems.

## 2.11 CARBON AND AGROECOSYSTEM STRUCTURE

Section 2.9.2 introduced the carbon cycle and ensuing chapters discuss in greater detail the significance of soil carbon and organic matter in agroecosystem processes. At this conjuncture, carbon as a store for fixed solar energy, is used as a representative of agroecosystem structure to suggest that some areas of England and Wales may be vulnerable to inappropriate farming activities. A recent paper by Adger et al (1992) serves as a useful overview of the turnover of carbon with regard to various land management regimes. They highlight the fact that in temperate zones, (i.e the UK), the majority of the "fixed carbon" is held within the soil organic matter as opposed to the living tissue. This suggests that agriculture within the UK will have a large effect on the soil carbon pool. It is in areas of low soil carbon that the monitoring of the effects agricultural activity on the flows of carbon in and out of the soil could be critical.

The farmer can affect certain flows across the agroecosystem boundaries, whilst others lay beyond his influence. In some areas climatic and topographical features will effect the responsiveness of certain flows to his activities. For instance a bag of fertilizer may be used more effectively on lowland pasture where climatic conditions are more favourable than in the hills. In conceptualizing flows across the agroecosystem boundary carbon provides a simple measure that can be used to represent both the change in agroecosystem structure and the flow of inputs and outputs crossing its boundary. Carbon was selected as representative measure as it forms part of the agroecosystem structure, i.e organic matter within the soil and plants and animals above ground. It is embedded in many of the inputs and outputs crossing the ecosystem boundary, i.e Grain, animal products and carbon dioxide in the air. National Soil Survey data for England and Wales is used in conjunction with a GIS, (Geographic Information System), to examine the use of carbon as a useful measure of agroecosystem processes, (i.e change in structural carbon, due to flow in and out of the system).

### 2.11.1 Data collection and handling,

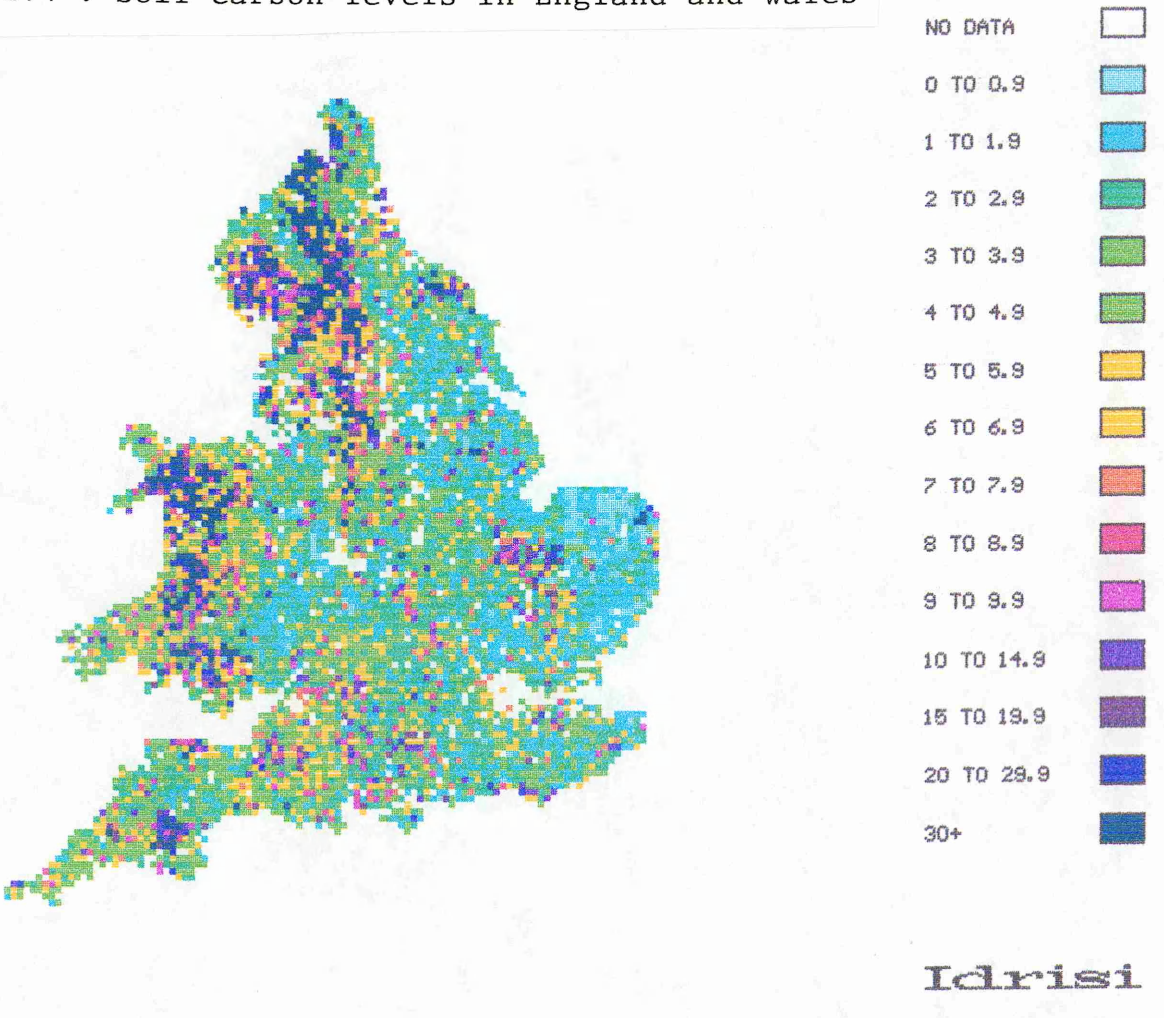
To measure the continuous changes in flows of carbon on a countrywide basis would be a massive task, and in reality the cost is prohibitive. In this analysis data for soil carbon is used in combination with the following site specific data which are used to represent potential carbon turnover:

**Soil pH:** Soil pH is usually between the ranges 4 to 9, with the majority of soils being within the ranges 5 to 8. Biological activity, and thus the loss of soil carbon from the soil falls with decreasing pH, with little activity occurring below a pH of 4. Peat based soils exemplify these conditions in which waterlogging and acidity leads to the build up of undecomposed organic matter due to a reduction in biological activity.

**Temperature:** Maximum biological activity of most soil organisms occurs at around 30C providing all other factors necessary for life are in place. At extremes of cold biological activity is reduced to near zero. Data representing the accumulated temperature above 5.6 C is used in the analysis. It is assumed that the higher the accumulated temperature the greater the biological activity and thus the rate of turnover of soil carbon.

**Soil Moisture deficit, (SMD):** Provides a representation of the moisture content of the soil. The higher the SMD the less moisture there will be in the soil, leading to reduced biological activity.

Figure 2.4 : Soil carbon levels in England and Wales



Similarly soils which are permanently waterlogged inhibit carbon turnover.

**Altitude:** With increasing altitude the amount and degree of agricultural activity is assumed to decrease. At low altitude the greater is the potential for agricultural activity, which will increase the turnover of soil carbon. Altitude is also represents a generalized measure of climatic conditions.

Data for altitude, pH, temperature and soil carbon was obtained directly from the LandIS data base at the Soil Survey and Land Resource Centre, Silsoe on computer disk and in ASCII format. The data set represents the whole of England and Wales in a series of 5Km grid squares, (approximately 5540), with the values for the given attribute within that square selected from a random site. The data for soil moisture deficits was taken from a published map in the Soil Survey Technical Monographs, (Hall et al 1977). A PC based Geographic Information System, (GIS), "*Idrisi*" was used for the interpretation of the data, the results of which are a series of attribute maps, which are overlaid to highlight areas of England and Wales that could be vulnerable to rapid depletion of soil carbon.

GIS are attracting considerable attention in the use and interpretation of large sets of data. For instance Cocklin et al (1992) use GIS in Environmental Impact Assessment and suggest specific questions can be addressed through the use of these systems. With regard to the overlay and relation of data they quote Manning (1990),

*"..Definition of current and potential areas of conflict has been valuable and has allowed us to target further investigations..."*

A recent review of GIS, (Davidson 1992), suggests that it is best to consider GIS as a set of tools to permit the collection, storage, retrieval and transformation and display of spatially referenced data. Friend (1992) commenting on environmental information systems in the third world sees GIS as a great aid to the production of environmental statistics although he stresses the need for research into the integration of such systems into the decision making process.

**2.11.2 The carbon map, (see Figure 2.4)**

Figure 2.4 provides an interesting overview of the current state of soils in England and Wales with respect to soil carbon. The map shows clearly the association between the areas of intense arable cropping, particularly in the east, and lower soil carbon content. Soils with organic carbon content of below 2%, (corresponding organic matter of about 3.4%) are numerous in the east of the country. There is a small area of soils in North Norfolk containing less than 1% soil carbon, (<1.7% organic matter). Figure 2.5 provides a graphical summary of information contained in the carbon map. 67% of soils contain less than 5% carbon. 18.6 % of soils have a carbon content of less than 2%, and 2.5% contain less than 1% of carbon.

Figure 2.5: Graphical representation of the carbon content of soils in England and Wales

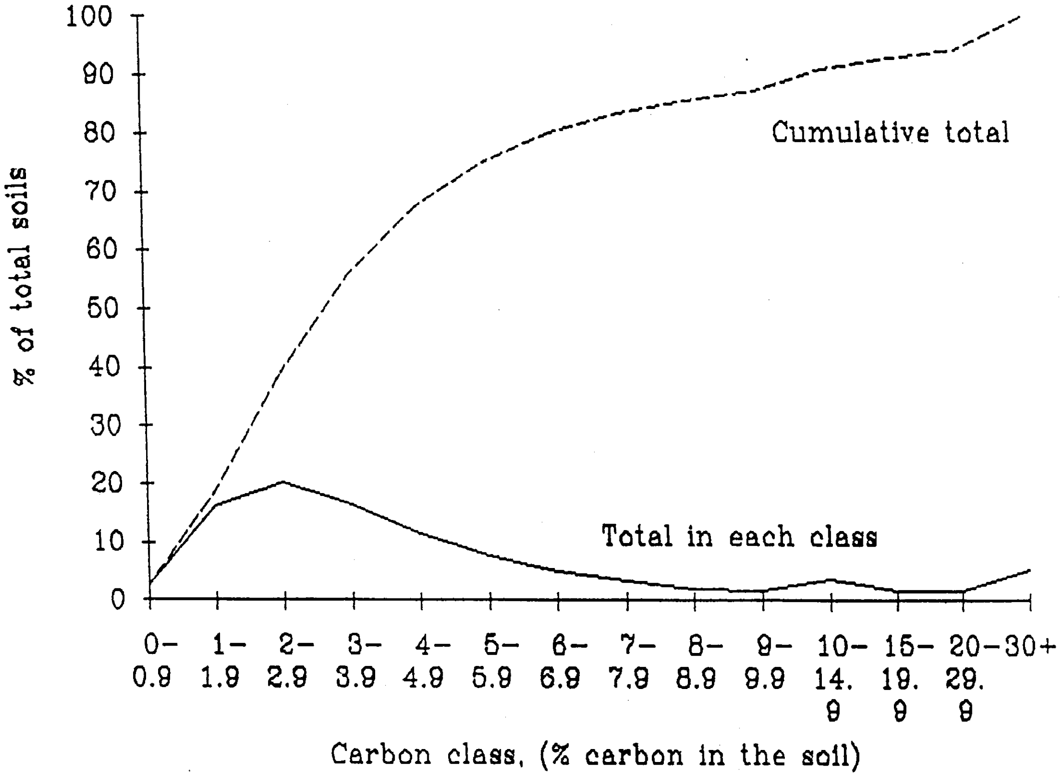



Figure 2.7 Graphical representation of the pH of soils in England and Wales

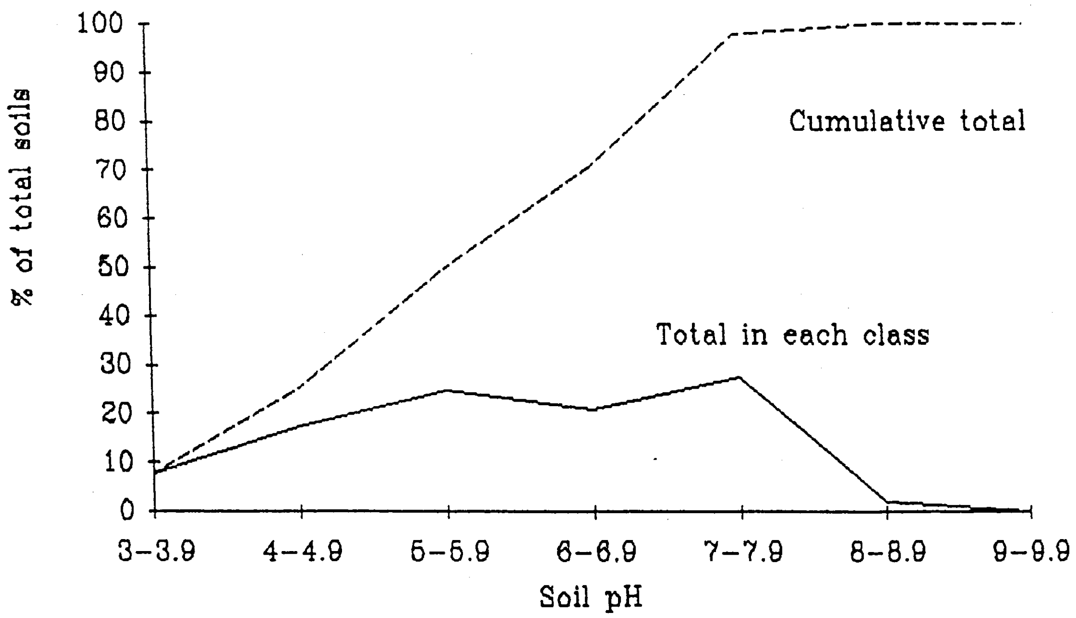
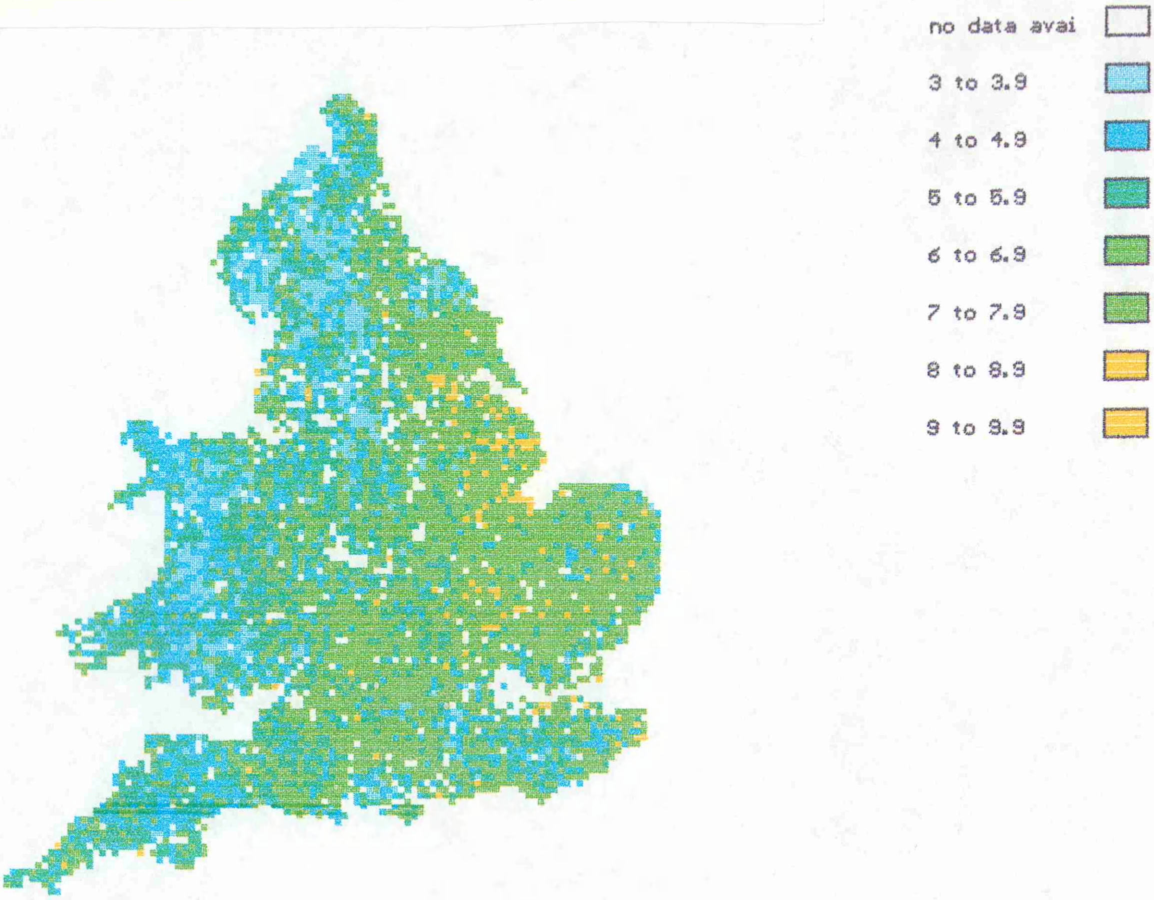


Figure 2.6 : Soil acidity in England and Wales



### 2.11.3 The pH map, (see Figure 2.6),

Details of soil pH are included because acidity has a major effect on rates of decomposition. Under acidic conditions decomposition slows down and eventually stops completely. This is the principle of many preservative processes and is in part responsible for peat soils. However, the farmer can have an effect on acidity by applying lime or chalk which indirectly affects the potential rate of decomposition. Figure 2.7 illustrates areas of England and Wales in each pH class. Soils of extreme acidity or alkalinity are scarce and 73% of soils fall between the ranges of pH between 5 and 8. The optimum pH for crop growth is usually quoted as between 6 and 7, dependant on the crop being grown.

### 2.11.4 Mapping the potential rate of carbon turnover,

Following the production of maps for each of the attributes, values within each attribute map were assigned a weighting and the four maps, altitude, SMD, temperature, and pH were additivily overlaid. (The maps for altitude, Soil Moisture Deficit, [SMD] and temperature can be found in appendix 1). For instance if a 5km square near Birmingham is considered its weighted values could be:

| | |
|---|---|
| Altitude | = 8 (corresponding to low altitude) |
| pH | = 6 (corresponding to pH between 5 and 5.9) |
| SMD | = 8 (corresponding to SMD 100-150mm) |
| Temperature | = 6 (corresponding to accumulated temperature above 5.6C of 1350-1549) |

This gives an accumulated value for that square of 28. The weighting for each of the attributes is given below:

pH

| | |
|---|---|
| No data | = 0 |
| 3-3.9 | = 1 |
| 4-4.9 | = 4 |
| 5-5.9 | = 6 |
| 6-7.9 | = 10 |
| 8-8.9 | = 8 |
| 9-9.9 | = 7 |

**Soil moisture deficit,**

| | |
|---|---|
| No data | = 0 |
| >200mm | = 5 |
| 150-200 | = 7 |
| 100-150 | = 8 |
| 50-100 | = 9 |
| <50mm | = 10 |

**Accumulated temperature,**

| | |
|---|---|
| No data | = 0 |
| 300-549 | = 1 |
| 550-749 | = 2 |
| 750-949 | = 3 |
| 950-1149 | = 4 |
| 1150-1349 | = 5 |
| 1350-1549 | = 6 |
| 1550-1749 | = 7 |
| 1750-1949 | = 8 |
| 1950+ | = 9 |

**Altitude**

| | |
|---|---|
| No data | = 0 |
| 700-800m | = 1 |
| 600-700m | = 2 |
| 500-600m | = 3 |
| 400-500m | = 4 |
| 300-400m | = 5 |
| 200-300m | = 6 |
| 100-200m | = 7 |
| 0-100m | = 8 |

The weightings given to each of the attributes is subject to debate and are meant only as a crude analysis so that a methodology can be demonstrated. The highest decomposition rate is assumed to occur when the pH is between 6 and 8. Very few soils have a pH of greater than 8, although it is assumed that very high alkalinity will reduce the rate of decomposition processes. No data has been found to substantiate this. Increasing soil moisture deficits are assumed to reduce the rate of decomposition and increased accumulated temperature is assumed to increase the rate of decomposition, (see data from Jenkinson 1990 in Chapter 4). Altitude is used as a crude proxy measure of human activity, assuming that this will be highest at low altitudes, and will decrease with increasing altitude.

A weakness within this analysis is that more or less equal importance is assigned to each of the attributes with respect to the turnover of carbon. Whilst it could be argued that various sensitivity tests could be undertaken, it is unlikely that the accuracy of this type of analysis could be improved without substantive fieldwork at a range of sites throughout the UK. Thus it is stressed that the results of this analysis should be treated with caution, although the analysis itself provides a useful method of working.

The four attribute maps when overlaid produced a further map which illustrates potential carbon turnover. High values within the map correspond to squares with high potential turnover rates. For simplicity of display these have been split into 6 categories, (see Figure 2.8). A value of 1 corresponds to a low potential turnover rate whereas a value of 6 corresponds to a very high turnover rate. The amount of land area falling into each category is represented graphically in Figure 2.9. The map of potential turnover rates of carbon was cross tabulated with the existing map of soil carbon. The aim of this cross tabulation was to highlight areas which may be vulnerable with respect to soil carbon. (i.e those areas containing low soil carbon but with high potential turnover rates). Figure 2.10 illustrates the results of this cross tabulation, highlighting areas which are low in soil carbon, i.e less than 2%, and have potentially high turnover rates, i.e. values of 5 or 6. This analysis demonstrates that 15.6% of the land area in England in Wales falls within this category.

It is recognised that the accuracy of the data analysis depends on the weighting given to the various attributes, and thus the calculation of areas of potentially high turnover rates and soil vulnerability are open to some criticism. However, the methodology for highlighting vulnerable areas using non time series data is thought to be useful. The analysis suggests that many areas of Eastern England are potentially vulnerable to loss of agroecosystem structure. Some soils in Norfolk contain only small amounts of soil carbon, the implication of which are discussed in greater detail in the following chapters. This desk top study has exposed the usefulness of GIS in dealing with large amounts of data, and facilitated the use of a national database to introduce soil carbon as a usable measure within the agroecosystem.

Figure 2.8 : Potential turnover rates of soil carbon in England and Wales

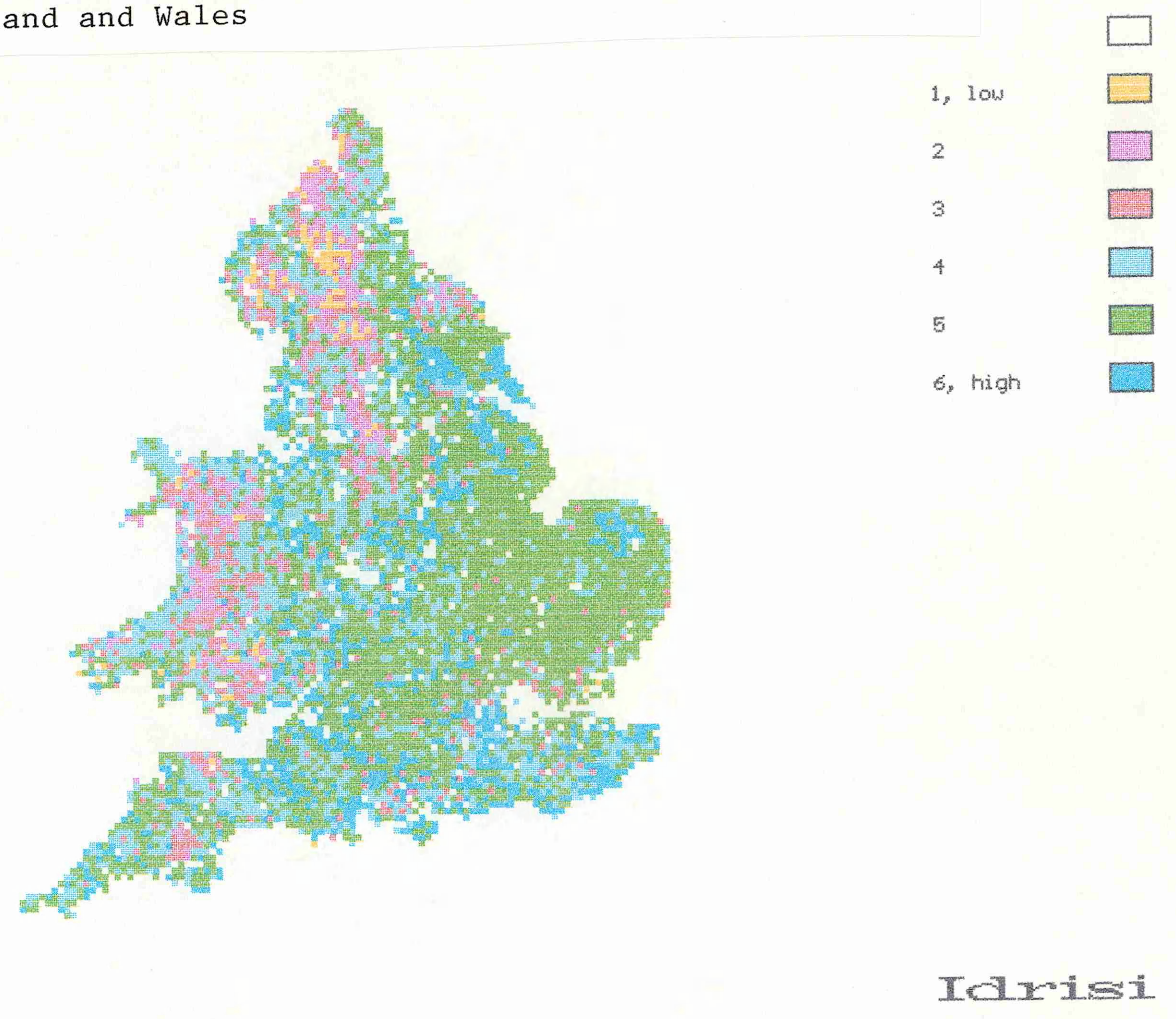


Figure 2.9 Graphical representation of the potential tirnover rates of soil carbon in England and Wales

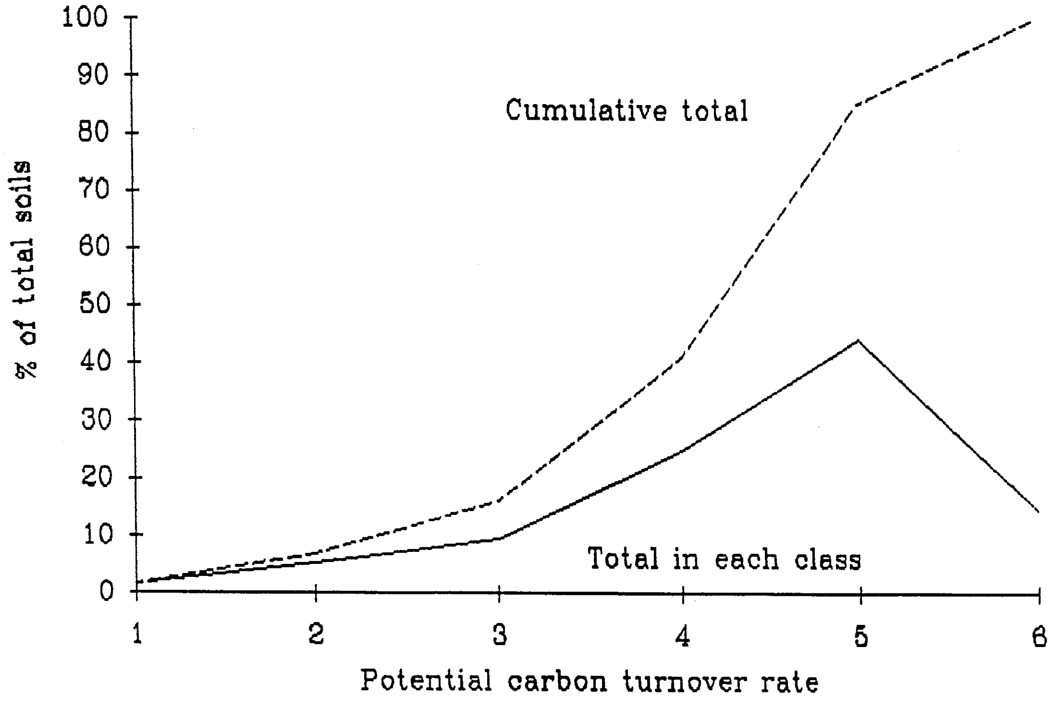
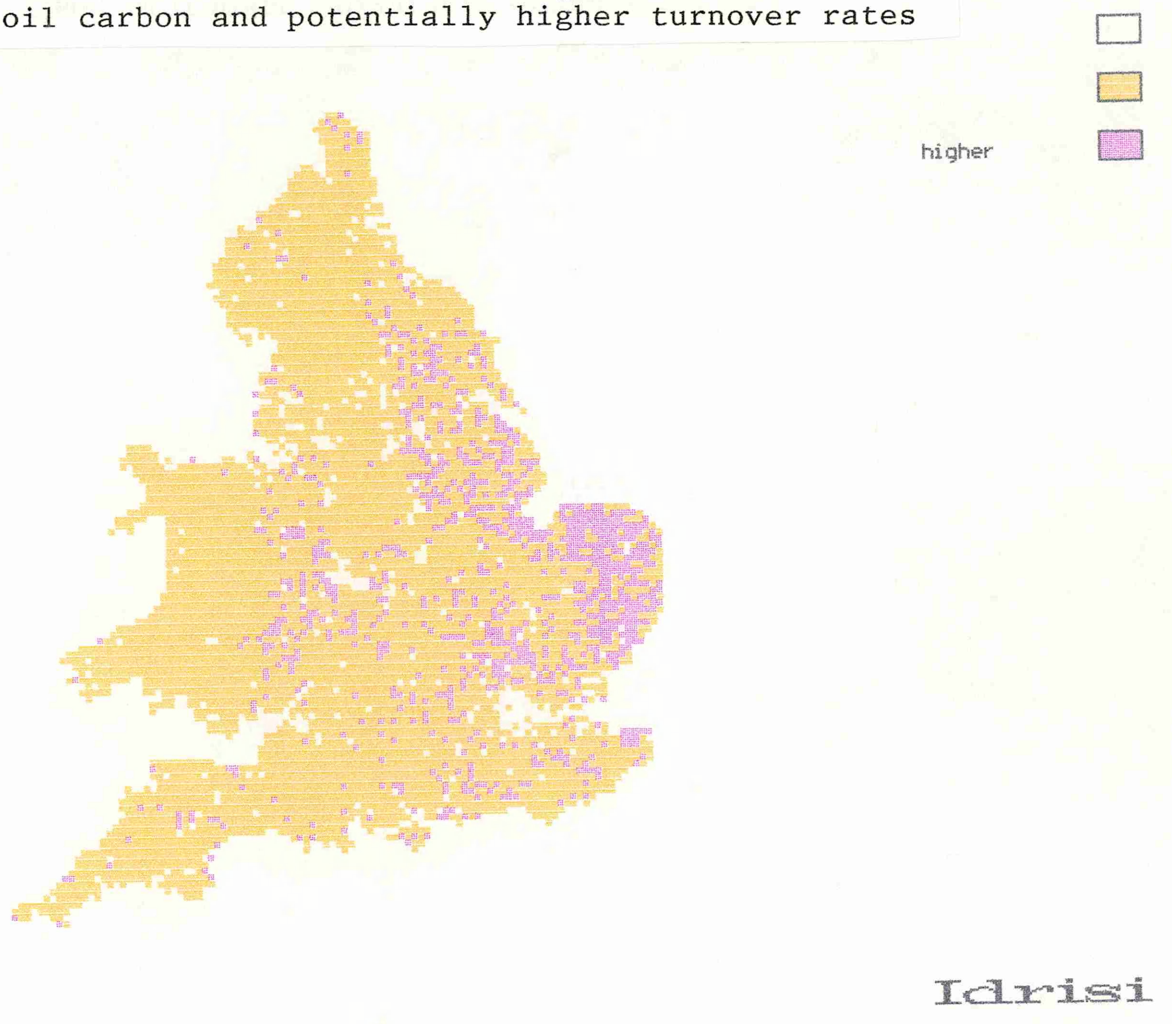


Figure 2.10 : Overview of soil in England and Wales with lower soil carbon and potentially higher turnover rates



## 2.12 AGROECOSYSTEM PROCESSES AND THE CONCEPT OF SUSTAINABILITY

The analysis of carbon undertaken in the previous section complements discussions earlier in the chapter which illustrated that farming activity changes energy flows across agroecosystem boundaries. Agroecosystem structure, as represented by soil carbon, is maintained by a constant flow of energy which supports the system in an ordered state. This energy is derived from both sunlight and human induced input flows. In agroecosystems there is necessarily an outflow of energy embodied in the food and other products derived from the land. However, in some systems the degree of intervention to produce food is so great as to question the ability of the system to maintain structure, and therefore to effectively continue the process of sunlight interception and conversion. The latter is seen within the thesis as a fundamental process which drives the functioning of agroecosystems.

The investigation of soil carbon provides information on the first interface explored within the thesis which relates the concept of sustainability to an important agroecosystem constituent which is responsive to changes in agricultural activity. Ecological theory suggests that energy flows are important in the diversity, resilience and adaptability of an ecosystem. These are crucial system attributes with respect to keeping options open in the future, which is argued to be a basic property of increasingly sustainable pathways.

As agroecosystem structure is lost, the ability to intercept and process solar radiation is diminished. This loss of structure is likely to be associated with a reduction in diversity, a decrease in resilience, (or an increase in vulnerability), and progress along pathways which are decreasing sustainability. In the ensuing chapters themes associated with agroecosystem structure and processes are pursued to isolate techniques for monitoring changes in agricultural activity so that appropriate increasingly sustainable pathways can be followed.

This chapter commenced with discussions on the concept of sustainability. Whilst modern agricultural systems override or ignore natural processes by the use of copious quantities of regulatory inputs it is likely that questions will continue to be asked about the sustainability of these systems. Many of the inputs being used in modern farming are derived from non-renewable resources, but perhaps more importantly the over exploitation of some agroecosystems may be compromising the ability to produce food in the future.

# CHAPTER 3: ASSESSING CHANGE IN THE AGROECOSYSTEM

*"A viable soil index will call attention to areas around the globe that are in need of immediate assistance with respect to topsoil preservation or that call for aggressive soil regeneration activities......and will reveal those areas where soil is improving, so we can study them and adapt those methodologies to improve soils elsewhere", (Haberern 1992)*

## 3.1 INTRODUCTION AND SUMMARY,

In Chapters 1 and 2 the process of change to increasingly sustainable systems was argued to involve a clear understanding of the current system and methods by which desirable change can be assessed. At the ecological level this is known to present problems, (Blaschke et al 1992). This chapter develops the agroecosystem theme focusing on the soil system to demonstrate changes in agroecosystem processes due to agricultural activity.

The theme of using soil carbon or organic matter to represent structure within the agroecosystem is pursued further. The interchangeability of soil carbon and organic matter are discussed before the chapter proceeds in the review of a range of literature on soil organic matter and its dynamics within the broader context of the soil biological system. The chapter develops the possibility of using measures within the soil biological system as indicators of change or for monitoring the effects of various cropping practices on wider agroecosystem processes.

The dynamics of soil organic matter are discussed, focusing particularly on the benefits of reasonable levels of organic matter in the soil system. The methods through which agricultural activity can affect the level of soil organic matter are explored. The use of soil organic matter dynamics as an indicator of the current state of soil systems, and as a means of assessing change are introduced. The chapter concludes with the reflection that although soils low in organic matter can remain productive in the short-term, the long-term productivity of these systems must be questioned.

This ties directly with the questions raised at the end of Chapter 2 which suggest some systems could be vulnerable with respect to loss of soil carbon. Many of the issues addressed in this chapter are referred to in Chapters 4 and 5. These chapters explore the second interface within the thesis which links the concept of sustainability and agroecosystem processes to agricultural activity, how the farmer crops the land, and the inputs he uses in doing this.

## 3.2 SOIL AND AGROECOSYSTEMS PROCESSES,

The soil is that part of the earth's crust that is the "*seat of biological activity*", (Russel 1969). Others consider the soil to be a living tissue, (Skujins 1967), with the soil solution acting as the blood of the soil as it circulates through a network of pores. Soil is a complex evolving medium consisting of both biotic and abiotic components; parent material, water, nutrients, and organic materials in the form of live plants and animals and dead organic material in various stages of decomposition. In undisturbed ecosystems these components are closely associated and combine to confer the physical, chemical and biological properties of that soil. Together with the prevailing climatic and hydrological conditions these determine the productivity of that ecosystem and thus the energy flow through the system, (see Chapter 2). Studying changes in soil processes, or the organic carbon structure could provide a useful measure of the state of agroecosystems for several reasons:

1. Soil processes are responsive to human intervention, Buringh (1984) estimates that on a world basis the soil only contains about three quarters of the organic matter it did before the spread of civilization and Doran and Smith (1987) point out that the forests and grasslands of North America declined to between 40 and 60% of their original organic matter levels following cultivation.

2. The processes within the soil are fundamental to plant growth and photosynthesis. Perry et al (1989) recognises the importance of the links between the soil and plants that grow on its surface, and how this links with the healthy functioning of the agroecosystem, stating,

*"Diversity in the plant community, the microbial community and the ecosystem as a whole plays a seminal role in buffering against disturbance and in maintaining healthy links between plants and soil,"*

3. The soil itself is the agroecosystem component with the least resilience, (Fresco and Kroonenburg 1992). Thompson (1992) specifically highlights the importance of the soil processes in a short discussion paper on Environmental Quality Objectives,

*"The first concern must be the protection of the function of the soil,- Carbon and nutrient cycling and storage, nutrient supply, water supply, filtration and storage and plant anchorage."*

Fixed organic carbon, can be viewed as stored energy within the agroecosystem and is contained within organic materials. It is generally accepted that multiplying by a figure of 1.72 can be used to convert the amount of carbon in the soil to the amount of organic matter. This is known as the Van Bemmelen factor. Grewal et al (1991) debate its value. This conversion is only an approximation based on the assumption that organic molecules contain a similar amount of carbon. The need for conversion arises because the terms soil organic matter and soil carbon are used interchangably in soil science and agriculture. This is further complicated because some soil tests rely on isolating the amount of organic matter in a sample, (i.e loss by ignition), whilst other titration methods rely on detecting the amount of organic carbon in samples. Thus organic carbon can be found in either living or dead organic material within the soil, see Table 3.1,

Table 3.1 An estimate of organic matter and proportions, dry weight in a hectare of soil to a depth of 15cm in a humid temperate region, (adapted from Buol and Hole (1972)

| | dry weight % | kgs/ha |
|---|---|---|
| Organic matter, live and dead, | 6 | 120,000 |
| Dead organic matter | 5.28 | 105,400 |
| Roots of higher plants | 0.5 | 10,000 |
| Micro-organisms | 0.2155 | 4930 |
| Non arthropods | 0.006 | 120 |
| Arthropods | 0.0046 | 100 |
| Vertebrates | 0.0021 | 42 |

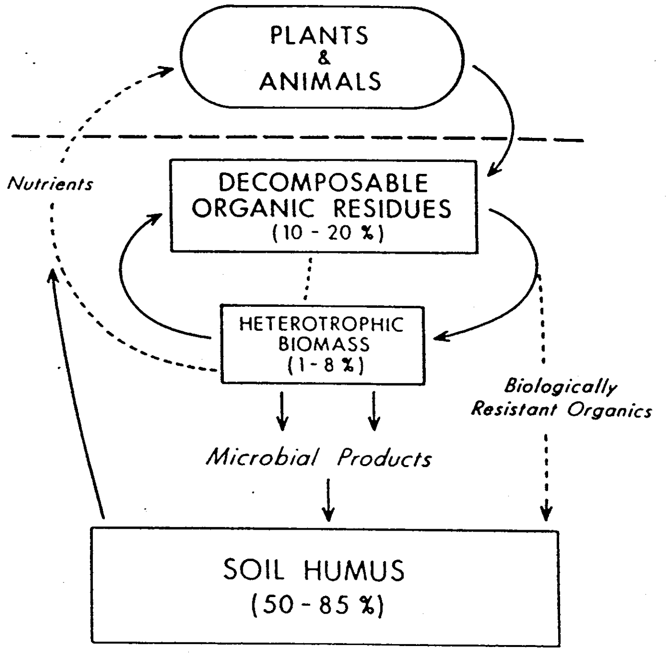
As plant and root material dies it collects on the soil surface where it starts to decompose under the action of both sunlight and microorganism activity, (Zlotin 1971). In undisturbed soils this surface litter provides both food and shelter for a range of sizes of animals. Soil animals incorporate organic material into the soil where further decomposition takes place. Eventually some of the material derived from surface litter and roots is decomposed to very stable humic compounds, which are relatively persistent within the soil. These humic compounds themselves are steadily decomposed to simpler molecules. During the entire decomposition process inorganic minerals are released, many of which can be taken up by the roots of growing plants, and others by other living soil organisms. A simplified representation of the relationships between living and non-living soil organic components is provided in Figure 3.1. Decomposition processes are extremely complex and a detailed review is well beyond the scope of this research. Elements of the decomposition process are discussed in greater detail by Edwards et al 1970, Dickinson and Pugh 1974, Anderson 1975, Edwards and Lofty 1977, Persson and Lohm 1977, Swift et al 1979, and Hole 1981.

### 3.3 THE SOIL COMMUNITY,

The dead plant and animal material provides both food and a home for a wealth of soil dwelling animals and plants. These organisms procure and release nutrients into the soil solution, modify the physical soil environment and distribute organic materials within the soil. The smallest micro-organisms consist of algae, protozoa, fungi and bacteria and they are involved mainly with the decomposition of organic materials, (Swift et al 1979). Larger soil animals are usually classified into three groups, (Wallwork 1970, Swift et al 1979):

1. **Microfauna**:-This group comprises of animals less than 200µm, (which is the limit to comfortable visibility with the naked eye). This category will include all of the protozoa, many of the nematodes and rotifers and some of the mites and springtails. Many of this group will spend a large portion of their lives in the soil, either in the soil solution or in air filled pores. Hendrix et al (1986) summarize the role of this group within the soil,

Figure 3.1 : Relationships between living and non living soil organic components, role in nutrient cycling, and relative proportion of total soil organic matter, (after Doran and Smith 1987)



*".. microarthropods, (mites and springtails) affect bacteria and fungi directly by grazing on microbial biomass and indirectly by fragmenting and consuming plant residue. The latter activity increases the surface area of the residue and enriches it via passage through the gut, thereby enhancing its quality as a microbial substrata and accelerating its decomposition."*

2. **Mesofauna**: -Mesofauna are usually considered as the animals of intermediate size from 200μm-1cm. These will include many of the arthropoda, molluscs and small enchytraeid worms. This group is dominated in most soils by the Collembola and Acarina which have generation times varying between a few weeks and several months.

3. **Macrofauna**:- Macrofauna are animals whose length is greater than 1cm. These include vertebrates, earthworms and larger members of the groups mentioned under mesofauna. Many of this group feed within the plant litter on the surface, only making occasional forays into the soil itself. (ie woodlice, some millipedes and centipedes). Others such as the earthworm spend a good deal of time beneath the soil surface, returning to the surface to feed at night.

The role many of the meso and macrofauna have in the detrital processes is not in the decomposition of cell walls and contents but in the shredding of material, increasing its surface area and rendering it less resistant to microbial attack. Collembola and Acarina produce faecal pellets which consist of well mixed organic matter which is of high surface area and in a state to undergo further microbial degradation. A second vital role is the mixing and transportation of plant debris from the surface to sub-surface horizons where conditions for microbial decay are usually more favourable, (Breymeyer and Van Dyne 1980). The larger soil animals will commute and break up the larger particles of detrital material.

The functional role of small organisms near to the bottom of the food chain, their numbers, mass and diversity has resulted in suggestion that they may provide an indicator of state of (agro)ecosystems, (Pimentel et al 1980, Holloway and Stork 1991, and Currie 1993 for theory). The use of such organisms as specific indicators within the soil system is discussed and investigated in greater detail in Chapter 5.

### 3.4 THE MOVEMENT OF ORGANIC MATTER FROM THE SURFACE AND THROUGH THE SOIL PROFILE IN NATURAL SYSTEMS.

Russell (1969) stated,

*"....The soil animals are, in fact, the major and often the sole agents for bringing plant leaf litter into the soil so that it becomes accessible to the soil organisms."*

It appears that although the field of soil zoology, (see Wallwork 1976), has investigated the effects of environment on animals, the way animals effect the soil is a much less investigated field, (Hole

1981). Of 130 detailed pedon descriptions in the US, only 22 note evidence of animal activity, (US soil taxonomy 1975). In his book on earthworms, Lee (1985) suggests the disintegration, decomposition and incorporation of litter result from a combination of solution by percolating rainwater, a minor component of atmospheric oxidation, but most importantly from the "decomposer industry".

The digging activities of the soil invertebrates are argued by Ghilarov (1967) to cause direct infiltration of surface material through their feeding habits. Indirect infiltration occurs through the dragging in [to the soil] of organic fragments as water drains through the vertical pores created by the invertebrates. Earthworms are often cited as major movers and incorporaters of surface debris. Edwards et al (1970) commented that earthworms are capable of consuming nearly all of the litter fall from the forest floor, (3000 kgs/ha), in the absence of other soil animals. They conclude the amounts of litter consumed by other macro-arthropods to be as much as a third of the total.

Although data exists on the disappearance of litter from the surface, (Van Der Drift 1963, Edwards et al 1970, Dickinson and Pugh 1974, Swift et al 1979), its rate of movement down through the profile is less well documented. Working with forest soils in the Netherlands, Van Der Drift (1963) recorded litter disappearance rates of upto 4200kgs/ha in a year, but its final stratification through the profile can only be guessed. Similar work by Raw (1962) estimated that the earthworm species Lumbricus terrestris removed about 1.2 tonnes/ha dryweight of leaves from the surface in an English apple orchard. This was during the winter period only, and consisted of greater than 90% of the autumn litter fall.

In undisturbed temperate soils the main animals working at depth will be earthworms, some of which are known to feed on the surface and defecate underground, (Lee 1985). Recent work by Balesdent et al (1990) studying the incorporation of maize debris suggests that 10-20% of the original plant residue carbon ended up below a depth of 30cm within a 17 year period. Although they do not discuss how the carbon arrived in such a position, it can be speculated that movement was either undertaken by soil animals or by water movement through the channels they make, (earthworms in particular). Other soil animals such as millipedes, centipedes and woodlice are likely to stay closer to the surface. Acarina and Collembola do play a role in the transport of debris but they are smaller and usually inclined towards predatory or saphrolytic activity within the soil body itself.

Mixing and transportation of plant debris by the soil animals often enhances conditions for microbial decay. The larger soil animals will commute and break up the detrital material. For instance the common earthworm pulls leaf material into its burrows to a depth of 10cm or more. They will often emerge at night to feed on surface litter, or may be forced to the surface when their burrows become waterlogged. Persson and Lohm (1977) recognise that many of the larger soil animals feed on the microbial biomass and often ingest plant debris because of the microbes associated with it. This is generally beneficial because detrital material is often shredded and moved during the process, with the possibility that microbial populations may be dispersed by such activity.

It is extremely difficult to estimate the amount of surface material that enters and moves through the soil as a result of water flows. It has already been stressed that this flow is enabled by the borrowing and feeding activities of the larger soil animals. In undisturbed moist soils, (without surface cracking), the activities of soil animals is likely to be the major facilatator in the incorporation of surface debris. Once the organic matter has been well mixed into the soil it conveys many beneficial properties to the soil system.

### 3.5 ORGANIC MATTER AND NUTRIENT SUPPLY

It is generally accepted that soil organic matter contributes to soil fertility in a number of ways, (Johnston 1986). The continual breakdown, (oxidation), of organic materials provides mineral nutrients for new plant growth, and is closely associated with the cycling of many plant nutrients. Specifically these are nitrogen, phosphorous, sulphur and a host of trace elements. The importance of the relationship between carbon and nitrogen is recognized by Rosswall and Paustain (1984), who stress that most of the nitrogen is held in organic material and the losses from the system are regulated by biotic processes. Nutrient release is determined by the amount and rate of breakdown of organic materials within the soil, which is in turn dependant on climatic conditions.

The stabilized humic material within the soil will generally release nutrients at a slower rate than freshly added organic material. Cultivation can have a dramatic effect on both the rate of decomposition of this stabilized organic matter and fresh labile material. However, the nutrients released by the decomposition process do not necessarily become immediately available for plant growth and may be "locked up" within the detritus biomass. The amounts of these nutrients that become available to the growing plant will depend on their concentration within the organic material. The addition of fresh organic matter low in nitrogen may mean that any nitrogen that becomes available in the soil will quickly be immobilized by the soil biomass, to be released at a later date, (Wild 1988). Avnimelech (1986) sees this as a control mechanism which prevents the leaching of applied ammonium fertilizers. However, it can also be problematic, (Powlson 1992). Leaching in general will be reduced by well incorporated organic material because of its high cation exchange capacity. This is the result of the formation of carboxyl and phenolic groups during humification, (Wild 1988). Conversely, the addition of organic materials of poorer quality are sometimes viewed as locking up soil nutrients and making them unavailable to plant growth in the short-term.

Nutrient release from organic matter is argued to be poorly controlled whereas inorganic fertilization allows a higher degree of control over the timing of nutrient availability to the plants. The arguments and mechanisms surrounding nutrient release and mobilization are complicated and a complete review of nutrient and organic matter interactions is beyond the scope of this work but the author would recommend the following for both general reading and more detailed analysis, Allison 1973, Wild 1988, Chen and Avnimelech 1986, Soil Society of America No. 19 1987.

## 3.6 ORGANIC MATTER AND THE PHYSICAL CHARACTERISTICS OF THE SOIL,

The organic materials act as binding agents within the soil, holding individual particles together. An excellent review of the role of organic matter in aggregate stability is provided by Tisdall and Oades (1982). The faeces and associated digestive products of many soil organisms aids this stability. For instance, residues left by earthworms often increase aggregate stability, (in Dutch Polders the aggregate stability was increased by 70% following the introduction of earthworms). Wallwork (1976) suggested the slime associated with molluscs ( which often move well below the soil surface), is a very good soil binding agent. The same principle is true for all soil animals that add saliva to debris as they ingest it.

Bulk density of soils is usually reduced by the presence of organic materials, (Khaleel et al 1981), and soil organisms such as earthworms increase the pore space within the soil, (Edwards and Lofty 1977). [Bulk density is a measure of the tightness with which soil particles are packed together and is closely correlated to aeration within the soil]. Avnimelech (1986) suggests that in soil low in organic matter, soil aeration becomes a limiting factor and cannot be simply offset by ensuring adequate nutrients and water. Good soil structure is therefore essential. Soil erositivity is decreased as the degree of well incorporated organic matter in the soil increases. The exception are peat based or organic soils which may contain very high amounts of organic matter (>30%), and are therefore susceptible to erosion under certain conditions. The ability of mineral soils containing high levels of incorporated organic matter to resist erosion can be summarized:

1. Organic matter on or near the surface will reduce splash erosion by reducing the direct impact of rain on the soil, (Imenson et al 1986 noted a close relationship between organic matter content of the soil and rain erosivity).

2. Aeration increases as soil organic matter level rises, this in turn improves drainage. Compaction of the soil increases water runoff and reduces infiltration. Flows of water at or near the surface are the precursor of severe rill and gully erosion. Low (1972) reported that the impact of continuous cultivation was to decrease the amount of soil organic matter, increasing bulk density and reducing infiltration, aeration and root growth.

3. Water holding capacity tends to increase with rising soil organic matter levels, mainly due to the increased pore space within the soil. Soils can hold more water before reaching field capacity. (Khaleel et al 1981 reported correlations between field capacity and soil organic matter)

4. The nature of the humus means that surface aggregates are bound together and become less susceptible to both wind and water erosion. In a paper, "Beneficials in agricultural soils," Boucher(1990) suggests that for every 1% increase in soil organic matter, soil loss may be reduced by 10%.

## 3.7 ORGANIC MATTER AS AN INDICATOR OF THE STATE OF THE SOIL SYSTEM

*"Loss of structure, organic matter and the actual soil is hard if not impossible to compensate for,", (Pimentel et al 1987)*

The dynamics of organic matter has been shown to be of importance in the cycling of nutrients, maintenance of soil structure , prevention of erosion and the diversity of soil organisms, ( see also Nye and Greenland 1960, Allison 1973, Doran and Smith 1987). It is evident that organic matter plays a vital role in many of the processes within the soil and therefore provides an indicator of the state of the soil system. Agricultural activity impacts upon the amount of organic material within the soil, it distribution throughout the profile and its rate of turnover. This volume of organic structure, (see Chapter 2), is important in agroecosystem processes for several reasons:

1. Organic matter can be regarded as a nutrient storage bank, and increasing organic matter is likely to increase the storage capacity of a given soil. House et al (1984) suggest that the reduction in soil organic matter due to tillage leads to a reduction in the potential storage capacity of the soil, thus opening the system to the possibility of excess leaching. Stigliani (1991) commenting on chemical time-bombs suggests,

*"... a decrease in the organic matter content, leading to a decrease in the cation exchange capacity will result in a decreased capacity of the soil for adsorbing heavy metals."*

2. Maintaining a larger "Volume of habitat" may improve the species diversity and system resilience is likely to be improved. Wood 1991 states,

*"......soil population is vital to the fertility and structure of soils. The functioning of the population involves complex interactions between the component species, which we are slowly beginning to understand."*

3. Increasing the volume of roots may allow access to previously underexploited soil reserves,

*"Regardless of root architecture, increasing the size of the root system and the duration of its contact with the soil appears to have advantages for the use of soil resources,"* (Atkinson 1989).

4. The water storage capacity of the soil is likely to be increased, increasing the volume of organic structure,

5. Maintenance of carbon within the soil likely to reduce global carbon dioxide levels.(ie acting as a sequestrating mechanism, Hall et al 1991, Jenkinson et al 1991).

Although it cannot be argued that soils of low organic matter content are no longer productive it can be generally assumed that soils very low in organic matter are more susceptible to erosion, suffer from poor structuration and need a constant input of nutrient if production is to be maintained, (Chen and Avnimelech 1986). Mineral soils of higher organic matter status are usually better structured and are less likely to erode. In the following sections the effects of agricultural activity on the dynamics of soil organic matter are discussed. The present organic status of soils in the UK are illustrated together with the perceived advantages and disadvantages of positive management of soil organic matter.

## 3.8 THE IMPACT OF AGRICULTURAL ACTIVITY ON THE DYNAMICS OF SOIL ORGANIC MATTER

The primary mechanism by which agriculture influences the dynamics of soil organic matter are by controlling the return of surface debris to the soil, through the crop being grown and the harvesting method. Cropping influences the amount and the quality of plant debris and root material being returned to the soil system. These relationships are outlined in Figure 3.2.

Inputs used in the growth of the crop will influence the quantity of crop produced and thus the return of root and plant material. Fertilizers and certain chemicals can have both a direct effect, (by increasing the amount of crop grown), and an indirect effect on the movement and rate of decomposition of organic materials in the soil via their effect on the soil community. The effect of fertilisation can be demonstrated by data from the long-term experiments at Rothamsted. Plots which have received higher amounts of nitrogen during the past 150 years have higher levels of soil organic matter in the surface profiles. Plots receiving organic fertilization in the form of 35 tonnes of farmyard manure, (FYM), directly influence the amount of plant debris entering the soil which explains the large effect its application has had upon soil organic matter, (see Table 3.2).

Fertilizer and pesticide inputs applied during the growing cycle of a crop to boost yield are likely to increase the amount of organic matter returned to the soil within the constraints of that particular cropping system. However, the effect of that cropping regime, particularly associated cultivation and export of material at harvest, is likely to have an overriding influence on the dynamics of soil organic matter within that particular agroecosystem. For instance, the ploughing of virgin land for arable cropping generally results in a rapid loss of soil organic matter which gradually slows, often reaching a lower, relatively stable state after many years, (Lucas et al 1977, Schlesinger 1977).

Figure 3.2 : A diagrammatical representation of the influence of agricultural practice on the soil organic matter cycle.

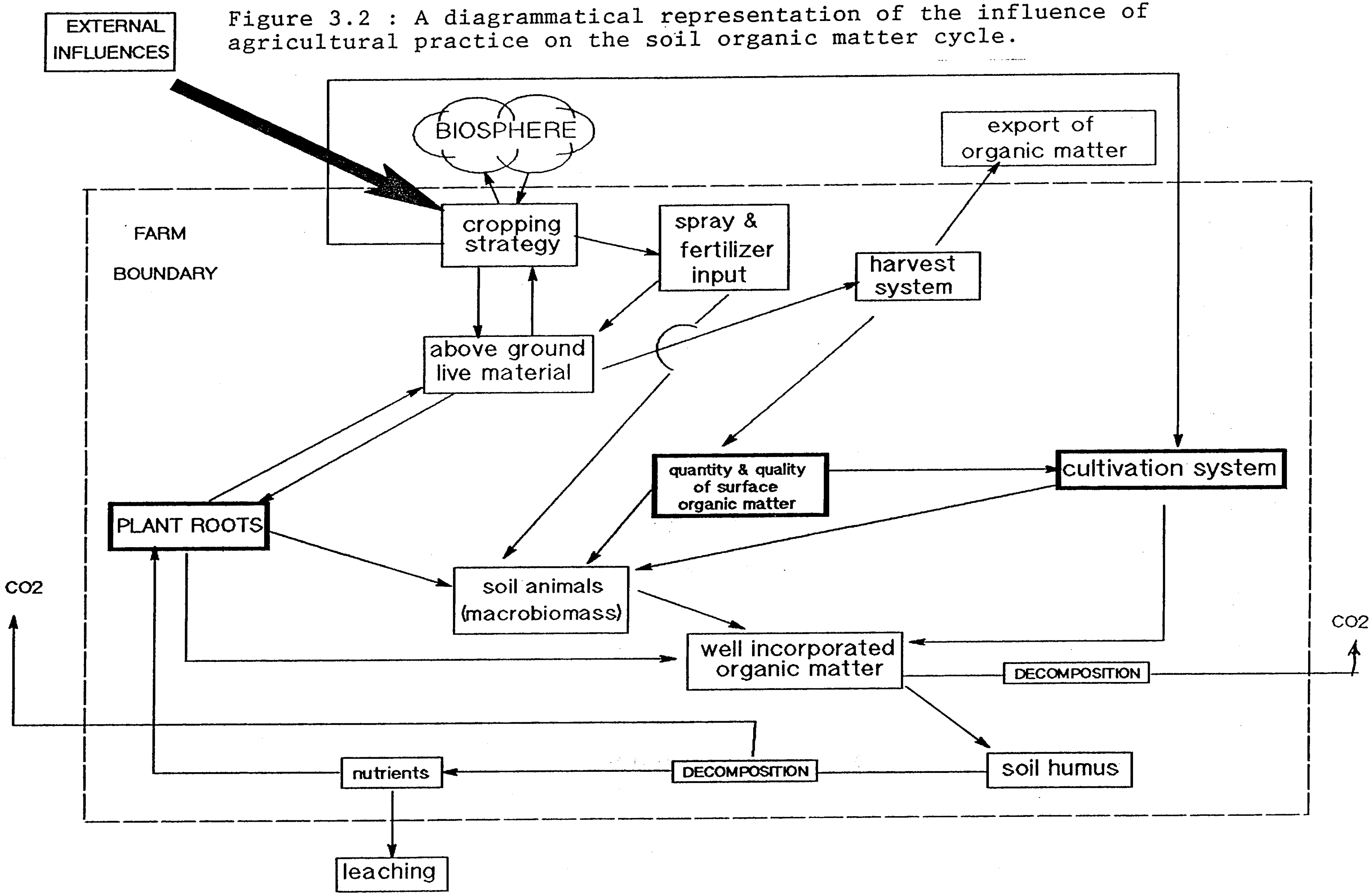


Table 3.2 Total percentage organic matter content of the top-soil, (0-23cm) in the Broadbalk continuous wheat experiment 1865-1987, (adapted from Glendining and Powlson 1990),

| | Plot number, fertilizer treatment and date started | | | |
|---|---|---|---|---|
| | 22, FYM 1843 | 5,N0 1843 | 6,N1 1852 | 8,N3 1852 |
| Year | % organic matter | | | |
| 1865 | 3.13 | 1.90 | N/A | N/A |
| 1914 | 4.33 | 1.77 | 1.92 | 2.21 |
| 1944 | 4.05 | 1.80 | 1.92 | 2.11 |
| 1966 | 4.35 | 1.90 | 2.08 | 2.11 |
| 1987 | 4.64 | 1.78 | 1.94 | 2.16 |

N0=0, N1=48, N3=144, kgs of N per hectare respectively
FYM = 35 tonnes of FYM per hectare,
Figures adapted from %N in top soil by assuming a C:N ratio of 10:1, and carbon to organic matter scaling factor of 1.72.

Voroney et al (1981) suggest that after 70 years cultivation the organic carbon had decreased by 36% in the "A" horizon, (soil horizons are discussed in more detail in section 4.5). Mann (1986) reviewed the changes in soil carbon storage after cultivation and found all soils high in carbon (>5%) lost at least 20% of this following cultivation. A recent UK review carried out by Howard and Howard (1991) considering the changes in organic matter content of soils following a change in land use provides a great deal of information on the effects of agricultural practices on the soil organic matter. They consider that for a given farming system, the soil organic matter content tends towards a value that is characteristic of that system on a given soil in a given climate. They use data from the Rothamsted Highfield grass-arable conversion to demonstrate that soil organic matter fell by about 40% in the first twenty years of cultivation, see Figure 3.3.

In the following three sections the effects of agricultural activity on the soil organic matter is considered under three headings, (see bold boxes in Figure 3.2): Quantity and quality crop debris returned to the soil surface: cultivation: return via the root system.

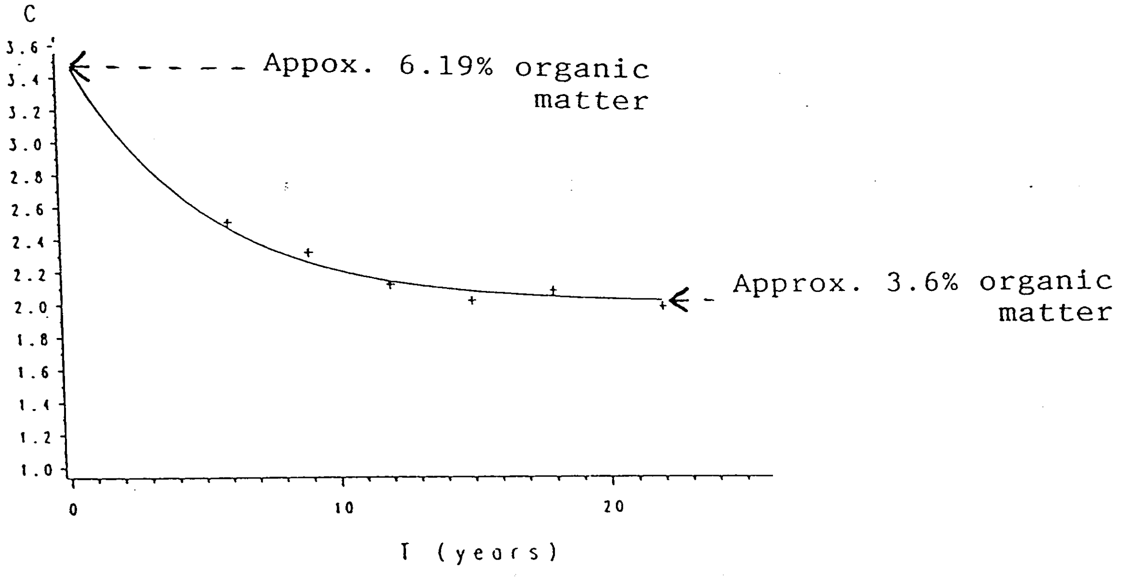
### 3.8.1 The quality and quantity of crop debris and soil organic matter,

Campbell et al 1991 stated,

*".....because crop residues are the primary substrata for organic matter replenishment in soils, changes in crops and their management can exert significant influence on soil quality."*

The amount of plant debris returned to the surface of the soil each year is a function of the crop grown, the inputs used upon it and the amount of biomass taken away at the end of the year. Table 3.3

Figure 3.3 : The effects of ploughing out of grassland on the soil carbon, (after Howard and Howard 1991).



illustrates the expected returns of organic matter to the soil system for a wheat crop,

Table 3.3 Expected returns of organic matter to the soil from a wheat crop depending on inputs and harvesting system, (kgs/ha),

| | grain yield | straw | stubble | roots |
|---|---|---|---|---|
| Low input | 4000 | 2000 | 800 | 1200 |
| Medium input | 6500 | 3500 | 1200 | 2000 |
| High input | 8000 | 4500 | 1500 | 2500 |

**Sources,**

Barraclough PB and Leigh RA (1984), Journal of Agricultural Science, 103, 59
Jenkinson DS (1990), Phil Trans Soc 13 361-368
Nix J (1993), Farm Management Pocketbook, 23rd Edition, Wye College
Van Veen JA and Paul EA (1981), Canadian Journal of Soil Science, 61, 2, 198

The amount of root material and straw returned to the soil depends on how well the crop grows. Therefore high yields of grain will be associated with strong root systems and often more straw and chaff. If the straw is baled and taken from the field along with the grain the organic material returned to the soil is limited to the chaff and the root material. In some crops the roots, (or part thereof), are removed, (i.e. carrots, potatoes etc), and this can limit the return of organic materials still further. However, it is not only the amount of organic matter returned that is important, but also its quality, as this affects the rate of decomposition.

The importance of the quality of the residue is highlighted by Wood and Edwards (1992) who consider that crop rotations, owing to the differences in amount and chemical composition of crop residues, may affect soil organic matter concentration and potential mineralisation. One measure of residue quality is ratio of C:N, (carbon:nitrogen), within the plant material, as it is often the availability of nitrogen which controls the rate of decomposition. Swift et al (1979) suggest the biota that decompose the organic materials have a C:N ratio within their body tissues of about 6:1. However, straw may have a C:N ratio of 60:1, (Voroney et al 1981), and therefore the rate of decomposition will be governed by the availability nitrogen within the soil for the biota to utilize.

The rate of decomposition can be further retarded by high amounts of lignin in the plant material. Slow decomposition associated with lignin means it has often been linked with the formation of more resistant organic matter within the soil. However, carbon labelling experiments have shown that even substrates such as glucose, which decompose rapidly still contribute to the stable organic materials in the soil. In fact a wide range of crops decompose to leave about a third of their initial carbon in soil after a period of a year, ( Paul and Van Veen 1978). This suggests that although the quality of organic material may govern rates of decomposition processes in the short term, over longer time periods it is the quantity of material returned to the soil which provides a more important determinant of soil organic matter content.

### 3.8.2 Plant roots and soil organic matter,

In some agroecosystems the return of surface plant debris is small due to low litterfall, high export and straw burning. In these systems plant roots provide the major source of organic matter input into the soil, (Hansson et al 1991). Plants vary considerably in rooting pattern and depth, leading to a "stratified" return of debris. Kramer (1983) recognises that plants have characteristic root patterns, although these can be greatly modified by soil conditions. Water tables can considerably effect the depth of rooting and in some free draining soils rooting can occur to considerable depths. For instance maize roots can often be found at a depth of 2M whereas roots of alfalfa, (lucerne) have been recorded at 10M, (Kramer 1983). Durrant et al (1973) considering root growth in relation to soil moisture of field crops found that barley and sugar beet were capable of rooting to well in excess of 100cm whereas potatoes were extracting water from a depth of 80cm. Rooting depths of crop plants are illustrated in Figure 3.4.

In growing and penetrating through soils a large amount of organic material is slothed off into the soil surrounds, and dead root material is returned by both annual and perennial crops. Addition of organic matter to the soil by these mechanisms can be considerable as between 50 and 70% of plant production is likely to be below ground growth, (Flitter 1991, Reichle 1977). The adoption over a period of time of shallow rooting crops can reduce the amount of deep rooting material entering the soil, the consequence of which could be the gradual loss of organic material in deeper soil horizons. Roots below the cultivation layer will improve soil structure in this region, where the formation of vertically orientated pores is a necessity for free drainage and further root development, (Goss 1991)

In agricultural terms, perhaps the greatest distinction can be drawn between annual and perennial crops. In the latter roots, root cells, hairs and tips are constantly being renewed, and this decaying material supplies a continuum of organic materials to the soil. These perennial systems are not usually cultivated, (see next section), and this not only allows the plant root systems to become well established but aids the formation of a healthy soil community.

### 3.8.3 Cultivation and soil organic matter,

Generally, in well drained soil of reasonable pH, as the amount of plant debris increases so will the level of activity of both microbes and larger soil animals. On arable soils annual cultivation is often used to incorporate surface residues, this operation frequently occurring shortly after harvest. Incorporation has two main effects on the dynamics of soil organic matter: Firstly it gives very good mixing of debris and soil leading to favourable conditions for microbial

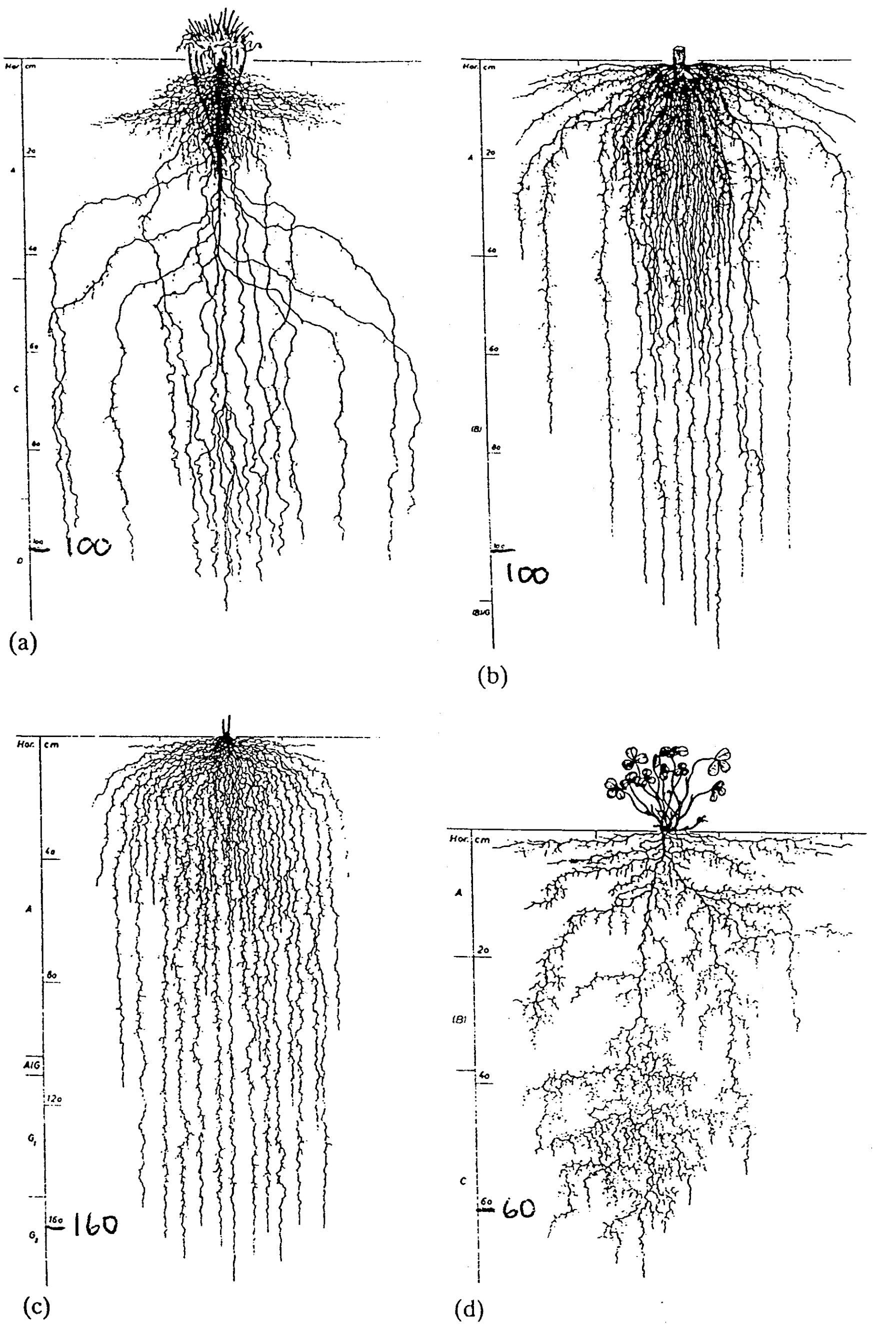


Figure 3.4 Root systems of (a) sugar beet, (b) maize, (c) wheat and (d) clover. (From Kutschera, L., *Wurzelatlas Mitteleuropäishcer Ackerunkräuter und Kulturpflanzen*, 1960.)

decomposition, (Voroney et al 1981), but conversely this disturbance can kill a proportion of the fauna and flora living in the soil, (Madge 1981, Edwards 1984).

Microorganisms can multiply rapidly to utilize well incorporated fresh organic matter, and this is evident in the flush of activity following ploughing. This food supply may be enhanced because cultivation is likely to expose older organic material in the soil to further attack. This can lead to rapid mineralisation of carbon and high respiration losses. Rapid recovery/reproduction associated with microbial life means that cultivation can increase activity, providing a well mixed food source within the soil microclimate, (Voroney et al 1981).

However, populations of larger soil animals may be kept at a permanently suppressed level due to annual cultivation. Edwards and Lofty (1982) estimated changes in population of earthworms on ploughed, chisel ploughed and direct drilled soils. They found that on direct drilled soils the populations of the deep burrowing Lumbricidae Terrestris and Allolobophora Longa increased 17.5x's over the 8 years of the experiment. The effects on shallow burrowing A. Caliginosa and A. Chlorotica were not as dramatic but the populations of these still increased 3.5x's over the period. The complexity of cultivation and soil organic matter dynamics is highlighted by Raw (1962), studying the burial of apple leaves by earthworms. He states,

*"...Clearly cultivation could be used to bury leaves and in some circumstances may be a desirable way of doing so, but by disturbing the earthworm burrows, cultivation would be an alternative rather than a supplement to leaf burial."*

House et al (1984) summarize the effects of cultivation on the distribution of soil organic matter through the soil profile. No-till systems, (as they are popularly referred to in America), create profiles in which the soil organic matter is stratified through the soil, with the bulk of the activity being near the surface. These systems maintain the complex biological interactions often seen in nature and are likely to be less leaky in terms of nutrients, (see Figure 3.5). This stratification is demonstrated by data from Buyanovsky et al (1987) comparing data from arable soils and unbroken prairie, (Table 3.4)

Table 3.4 illustrates that the organic content of the native prairie is much higher at the surface, but falls off rapidly with depth. The arable soil is subject to regular cultivation which encourages rapid oxidation of organic materials in the surface horizon. The native prairie has a surface horizon which is high in organic matter with a low bulk density. The difference between the two soils diminishes with increased depth, although it should be noted that even at a depth of 35cm-36cm the prairie contains about twice as much organic material as compared to the arable land. This suggests that surface cultivation has an impact on the soil to considerable depth.

Figure 3.5 : Carbon stratification in cultivated and uncultivated soils,

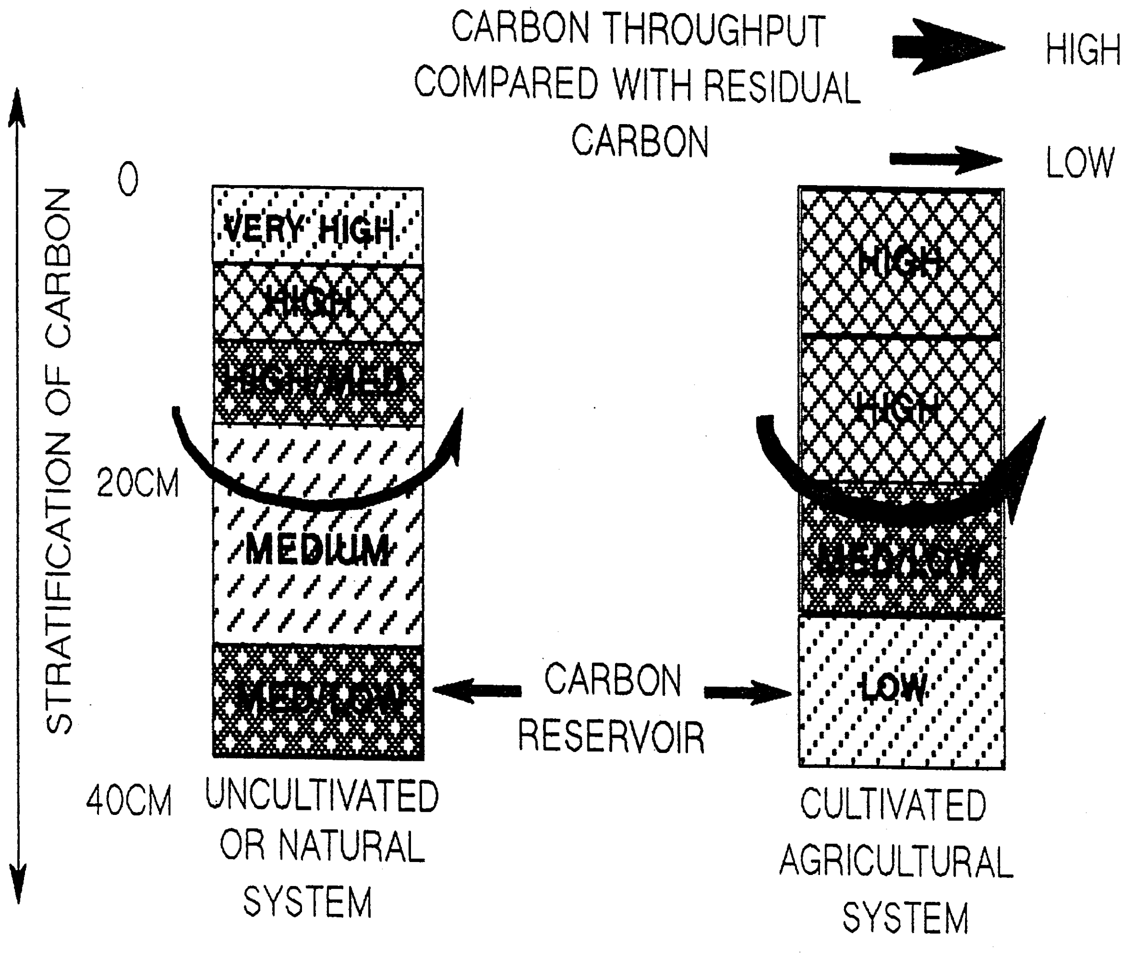


Table 3.4 Characteristics of soils under winter wheat and unbroken prairie, (Buyanovsky et al 1987)

| Horizon, | Depth cm | OM% | Bulk Density gms/cm$^3$ | pH |
|---|---|---|---|---|
| Winter wheat, | | | | |
| Ap | 0-13 | 2.9 | 1.37 | 6.1 |
| A1 | 13-20 | 2.5 | 1.35 | 6.0 |
| A2 | 20-28 | 1.7 | 1.33 | 5.3 |
| B1 | 28-36 | 1.1 | 1.29 | 5.2 |
| Native prairie, | | | | |
| A11 | 0-5 | 6.4 | .95 | 5.2 |
| A1 | 5-25 | 3.6 | 1.31 | 5.0 |
| A2 | 25-35 | 2.1 | 1.42 | 4.8 |

Changes in these deeper horizons are slower, and it is known that organic materials in some deeper soils are extremely old, (see Table 3.5). The impacts of the loss of this deeper soil organic matter is not known, indeed rates of change in this sub-surface soil have rarely been recorded over long periods of time.

Table 3.5 Radiocarbon age of organic matter in soil collected from Broadbalk, Rothamsted, (after Jenkinson and Raynor 1977)

| Sampling depth cm | Organic carbon % | Age in years yrs |
|---|---|---|
| 0-23 | .94 | 1450 |
| 23-46 | .61 | 2000 |
| 46-69 | .47 | 3700 |

A review paper by Hendrix et al (1986) discusses the effects of "conventional and no-tillage agroecosystems" on the detritus food webs in the soil. They state that nutrient mobility is generally increased in tilled soils, due partly to the fact that ploughed soils often show increased organic matter decomposition and nutrient mineralisation. The conclusions of Hendrix et al clearly have implications within a sustainable systems framework, where the cycling and supply of nutrients is critical to the productivity of the system. Within this context the effects of cultivation can be firstly seen to be unlocking nutrients within the soil and making them available to the growing plant. This accelerated decomposition is not confined to the fresh plant material added to the soil, as the older stable humic elements within the soil are also oxidised faster. The net effect is that cultivation, although a necessary part of the majority of farming systems, has lead to a dramatic depletion of soil organic matter.

## 3.9. THE LEVEL OF ORGANIC MATTER IN UK SOILS AND THE BENEFITS OF ITS POSITIVE MANAGEMENT

Most cultivated soils in Britain have an organic matter contents of between 2 and 10%, (with the exception of organic soils.) see Table 3.6,

Table 3.6. Ranges of soil organic matter of farmland in Britain under a number of land use regimes, (after Church and Skinner 1986),

| | % Organic Matter | | | | | |
|---|---|---|---|---|---|---|
| | <2 | 2-5 | 5-8 | 8-10 | 10-13 | >13 |
| Arable | 11 | 67 | 15 | 3 | 2 | 2 |
| Ley arable | 4 | 56 | 31 | 6 | 2 | 1 |
| All rotation | 8 | 62 | 22 | 4 | 2 | 2 |
| Continuous grass | - | 18 | 40 | 23 | 13 | 6 |

There were worries about the depletion of soil organic matter due to "modern cultivation" during the late 1960's. This inspired a Agricultural Advisory Council review, "Modern Farming and the Soil", more commonly known as the Strutt Report, (HMSO 1970). The report concluded that instability of soil structure, (particularly on sand and silt soils ), could develop when organic matter falls below 3%. They recommended,

*" ...soil science advisers should consider ways and means of monitoring organic matter levels more extensively. We see value in establishing minimum organic matter levels for different soils and situations, below which adverse changes in soil behaviour may be expected, so that farmers can be warned when these levels are being approached."*

However, very little monitoring was initiated following the publication of the report to enforce its recommendations and several regions of the country now contain soils with an organic matter below 3% . Figure 3.6 shows areas of England and Wales with an organic matter content of less than 3.5%. These regions coincide with some of the most productive land in the UK, illustrating that low levels of soil organic matter are not necessarily reflected in lower yields. There is no doubt that loss of organic matter can be compensated for to a point, by increasing artificial plant nutrients, maintaining soil condition through cultivation, and the use of chemicals to offset loss of soil system resilience. However, the reduction in soil organic matter is of particular concern because it conveys many positive benefits to the soil environment if managed properly. Doran and Smith (1987) argue the benefits of positive management of soil organic matter, its importance being demonstrated in Figure 3.7.

Part of the problem with "investment" in soil properties is that the dividends tend to show in the longer-term, annual depletion of organic matter can be very gradual and therefore problems are assumed not to

Figure 3.6 : Soils of England and Wales with an organic matter content of less than 3.5%, (from soil survey data).

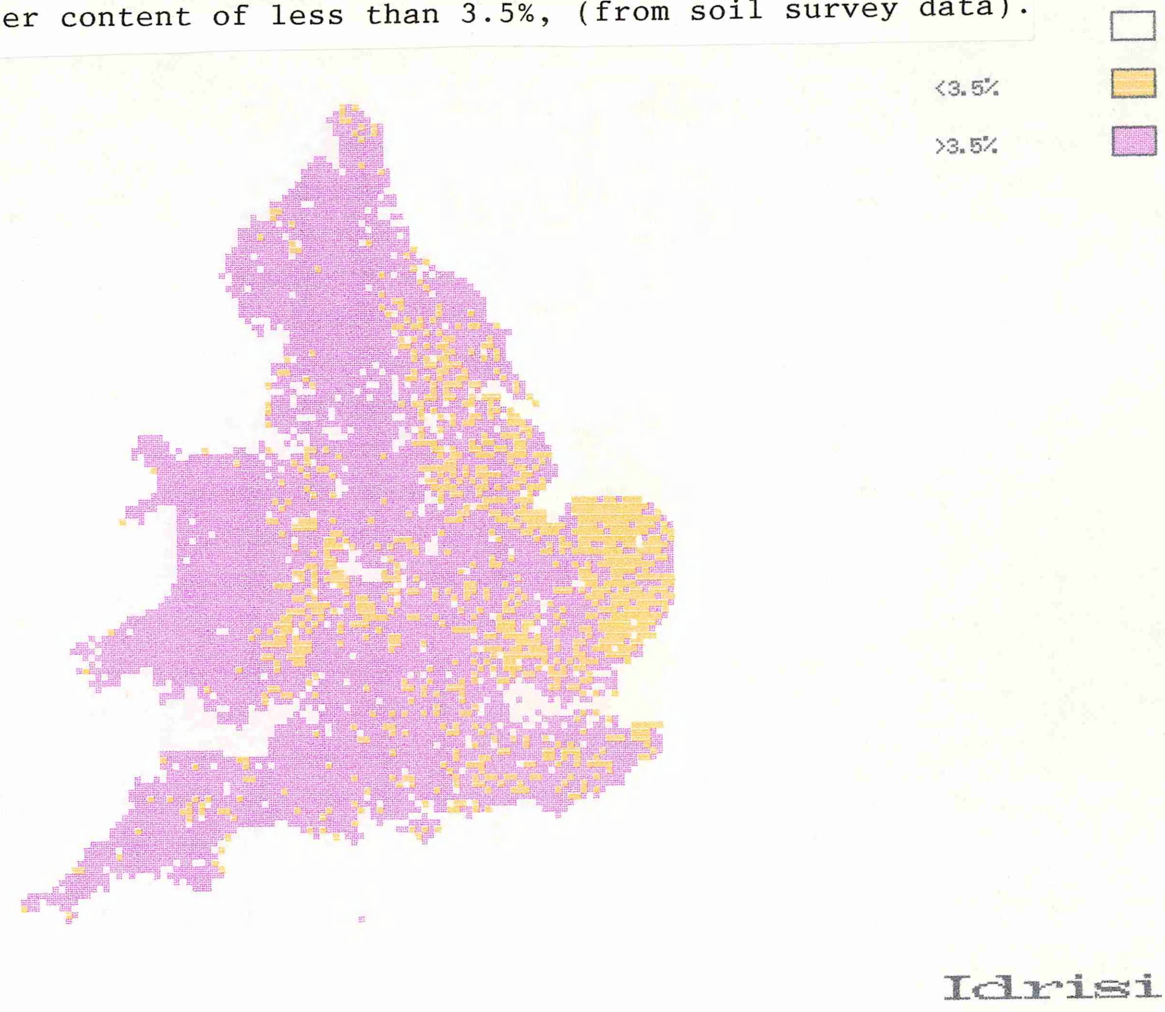
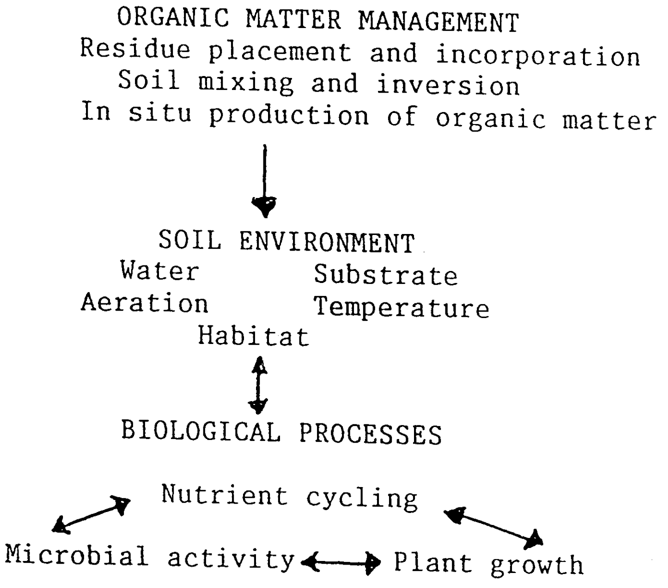


Figure 3.7, A diagrammatic representation of the importance of the correct management of organic matter, (after Doran and Smith 1987).



exist, or are easy to offset by using increased inputs to the system. This is highlighted by Pimentel et al (1987) who concluded in a paper reviewing soil erosion,

*"The limited availability of fossil fuel energy resources and their cost, which is expected to increase make it unlikely that fertilizers and other inputs can offset severe land and water degradation problems, especially in impoverished nations."*

In an earlier paper, (Pimentel et al 1980), it is suggested that on American farmland about 47 litres of gasoline-equivalents per hectare per year are used to offset the degradation of the land. The UK is not usually classed as an impoverished nation and soil erosion and degradation rarely receives attention. However, a major review of "Soil Erosion in Britain", (Hodges and Arden-Clarke 1986), shows that erosion is a widespread and increasing problem. They suggest that 44% of our arable land may now be at risk, although this process may be slow, highlighting the long-term cycles associated with soil properties,

*"On deeper soils regular erosive losses may be maintained for 100 or 200 years without any loss of productivity. Nevertheless, these losses are not acceptable since they cannot be safely continued indefinitely."*

Johnston (1986) compares the low levels of organic matter on the Rothamsted plots, (see Table 3.2), with arable soil throughout England. He considers the current levels of organic matter in many English soils, (comparatively high compared to Rothamsted), owe much to the long periods when they were under grass during the depression years, and thus have been cultivated for shorter periods. He concludes that if continuous arable cropping remains the norm in commercial practice, levels of organic matter could well decline to the low values at which we have found benefits from extra organic matter. In a later article in the Farmer's Weekly he suggests there may be a critical level of organic matter somewhere between 2.5% and the 3% recommended by the Strutt report in 1970, (Farmer's Weekly, 30th April 1993).

Another recent article in the popular farming press, (Peter Bullock, Farmer's Weekly 8th January 1993) indicates that 15% of the soils in England and Wales, mainly under arable cropping, suffer from dangerously low levels of organic matter. The article goes on to suggest that it is unlikely that current intensive agriculture can be carried out into the future on upto 40% of the soils in England and Wales.

## 3.10 THE POSSIBILITY AND EFFECTS OF INCREASING THE AMOUNT OF SOIL ORGANIC MATTER

Increasing the amounts of soil organic matter in impoverished soils could reduce the amount of cultivation needed through better structuration, and improve the cycling of nutrients within the soil by allowing the development of a healthier decomposter community, (see Hendrix et al 1986). The soil may also be less prone to drought, (Johnston 1986), and more resistant to erosion, (Pimentel et al 1987). However, there are strong arguments from within the current soil science paradigm that this is not a beneficial move. Several reasons are usually quoted,

1. Attempts to increase soil organic matter by incorporating more debris will lock up valuable nitrogen at a time when the crop needs the nutrient. Subsequent release of nutrients is difficult to either predict or control and this may lead, in the case of nitrogen, to high loss through leaching.

2. Many residual chemical sprays do not work well in soils of high organic matter content,

3. The presence of decomposing residues in the soil can affect the germination of ensuing crops, encourage pests such as slugs and may lead to carry over of disease.

4. Increased cultivation may be needed to incorporate the organic matter,

From the perspective of current farming systems these are all valid arguments. However, the sustainability of these existing systems has already been questioned and it is the process of change to increasingly sustainable systems that is being investigated. It seems likely that in the long-term, farming systems based on soils of low organic content are going to become increasingly unsustainable as the inputs needed to maintain production from this soil become scarce. It is becoming even more important to understand the effects of agricultural activity on the processes within the soil, particularly those associated with organic matter cycling. This chapter has illustrated that soil organic matter dynamics are complicated. Little is known about the consequences of changes in the vertical distribution of organic materials due to the effects of agricultural activity on the surface. This deeper material is often of considerable age. In theory the gradual depletion of this very old organic material is reducing the overall volume of organic structure, which may be difficult to compensate for.

In the next chapter a model is developed which treats the soil systems as a dynamic carbon/ organic matter structure and allows the investigation of the change in this structure over time depending on agricultural activity as represented by the types of crops grown, the inputs used, and the method by which the crop is harvested. These are seen as the main mechanisms through which the farmer can impact upon the movement of organic material within the soil. This contrasts with many of the existing models which have concentrated on the rates of decomposition of organic materials within the soil. The model, (MOVEMOD), is seen as part of the development and exploration of the interface which considers the relationship between farming practice and agroecosystem processes.

# CHAPTER 4: THE SOIL SYSTEM AS A DYNAMIC CARBON STRUCTURE: A SOIL ORGANIC MATTER MOVEMENT MODEL

*"The long-term productivity of a terrestrial ecosystem is closely related to the quality and quantity of its organic matter. Quality and quantity of soil organic matter are the results of numerous processes relating to the cycling of mineral nutrients and energy within the soil," Agren and Bosatta (1987).*

## 4.1 INTRODUCTION AND SUMMARY

In the previous chapter the effects of agricultural activity on the movement of organic matter within the agroecosystem were explored. It has been suggested that soil organic matter may provide an indicator of whether a change in cropping practice resulted in an increase in the ecological sustainability of land based production. Agricultural activity effects both the rate of decomposition and the movement and incorporation of organic materials within the soil. The former has been the subject of considerable research, yet the mechanisms of actual incorporation appear to have received less attention. The latter warrants consideration because some farming activities, i.e those associated with cultivation etc, appear to replace rather than supplement natural ecosystem processes. Many measures of soil carbon or organic matter relate the amount of these soil constituents without highlighting their distribution in the profile. This location is of importance with respect to the concept of volume of organic structure raised in the previous chapters.

This chapter initially reviews some of the decomposition models that exist. These are used as the basis for a soil organic matter movement model, (MOVEMOD), which highlights the complexity of the three dimensional soil structure. The model uses soil organic matter to explore the impact of agricultural activity on the agroecosystem, developing the second interface which was introduced at the end of Chapter 3.

Conclusions are reached which suggest this type of modelling is useful to explore and investigate relationships, and as an agenda setter and issue raiser. Soil organic matter provides a useful measure of the current state of the soil system but it is suggested that the amount of soil organic matter in the surface horizon may be a poor indicator of whether changes in agricultural activity are a step toward increasingly sustainable systems. The model highlights a general lack of information on the vertical movement of soil organic matter through cultivated systems, or the effects of loss of deeper organic materials, both of which could be important aspects of long-term soil management.

## 4.2 MODELLING SOIL ORGANIC MATTER DYNAMICS: A REVIEW OF EXISTING MODELS,

Considerable research interest has developed in recent years concerning the decomposition of carbon and organic matter within the soil system because of its importance in ecosystem processes. Research has been undertaken to aid in the understanding of these processes at the soil and field level, (Parton et al 1983,1987, Jenkinson 1990) , and at national and global scales, (Hall et al 1991, Jenkinson et al 1991).

In this chapter information pertaining from existing research is assimilated to investigate the way in which agricultural activity affects the "volume of organic structure". From this perspective it is not only the amount of soil organic matter in the cultivated horizon that is of interest, but its movement and distribution throughout the soil profiles. Several models have been developed to consider organic matter decomposition, and these have been used as a source of information to design a model to explore the movement of organic materials through the soil and the effects of agricultural activity upon this.

Jenkinson (1990) provides a short review of existing soil organic matter models, dividing them into 4 classes, dependant on how they treat rates of decomposition. The base models are the single compartment models, increasing in complexity through to multicompartmental models and finally, arguably the most difficult to model, the non-compartmental models which represent the decomposition process as a continuum, the mathematics of which are relatively complicated. Some of these models reflect the effects of agricultural practice on soil organic matter, (to varying degrees), whilst others are concerned purely with the cycling of organic matter or carbon through undisturbed or natural soil systems.

Early equations developed to represent the decline in soil carbon used a decomposition constant which assumed fixed rates of organic matter breakdown. Jenny (1941) used the following equation, which was developed further by Nye and Greenland 1960,

$$dN/dt = A - kN$$ (Equation 4.1- after Jenny 1941)

where A= rate of annual addition of carbon,
k= the decomposition constant per year,
N= soil carbon content at a given time.

The equation demonstrates that the rate of decomposition of organic matter is dependent upon the amount of organic matter present in the "pool" and a decay constant which in this case is specific to a given site. This equation was further developed by Paul and Van Veen (1978) who split the organic fraction into stable and labile pools, i.e they recognised that soil organic matter contained several fractions which decompose at differing rates. They also developed the concept of physically protected organic matter. For instance in undisturbed soils some of the organic materials held within the soil are protected from decomposition by the complex nature of the soil structure itself. Following cultivation, this protection can be lost, making this material susceptible to microbial decomposition.

Lucus et al (1977), developed a soil carbon dynamics and cropping practices model, which used varying decomposition rates and investigated the effects of nitrogen and cropping practice on the soil carbon level, (see Figure 4.1). Rate of microbial decay, (i.e. the rate at which organic matter entering and within the soil is broken down), was related to the ratio of old humus to new, aeration, moisture, and temperature. Their conclusions after running the model for a simulated 150 years under conditions of continuous corn, heavily fertilized, were that soil carbon gradually increased where initial amounts of carbon in the soil were low. Their projections suggested that in soils of low carbon content the gain in carbon due to fertilization is greater than the loss of carbon due to continuous cultivation. This is an interesting conclusion and agrees with data given by Jenkinson (1989) who suggested a very small but gradual increase in carbon content of soils which had been under the plough for a significant period of time.

The CENTURY model described by Parton et al (1983,1988), (Simulation of soil organic matter formations and mineralisation in semi-arid ecosystems), was designed to investigate,

*"..the impact of differing agricultural practices on the transformation of carbon and nitrogen in the soil and the resulting impact on crop yield."*

The model is based on 5 carbon pools with plant residue flowing into the first two, ie structural (lignin etc) and metabolic, (easily broken down). The three other compartments are the soil carbon pools and consist of active, slow and passive carbon pools. The turnover times are 1 to 5 years for the structural pool, 0.1 to 1 year for the metabolic pool and 10 years, 50 years and a 1000 years respectively, for the active, slow and passive pools. This illustrates that some fractions of the organic matter decompose very quickly, whilst others, i.e the passive pool, are extremely resistant. The rate of decomposition is calculated for each of these fractions by multiplying the decay rate variable by the temperature and moisture for any given month.

Decomposition rate is again a function of the amount of carbon being added, the moisture content, (Moisture is a function of the annual rainfall compared to the rate of transpiration), soil temperature, and a decomposition variable, k, depending on the "state" of the carbon. This is analogous with the data analysis described in Chapter 2, in which carbon turnover was related to soil moisture and temperature. Cropping is represented by the removal of a fixed percentage of carbon from the system. The model runs on monthly time steps, with cultivation being represented by changes in decomposition rates during the months in which it occurs. Without cultivation they simulated soil formation over a 10,000 year period. The model showed that the majority of the increase in soil carbon occurred in the first 2500 years. The model suggested after 60 years of cultivation of virgin land the soil carbon and nitrogen had been depleted by approximately 25%. This loss of soil organic matter following ploughing of virgin land is widely accepted, (Lucas et al 1977, Howard and Howard 1991). Fertilization of a spring wheat/fallow regime slowed the depletion of soil carbon in comparison to unfertilized simulation, suggesting

Figure 4.1. Soil humus model: Typical yearly changes for a well drained loam, Mitchigan soil, (after Lucas et al 1977).

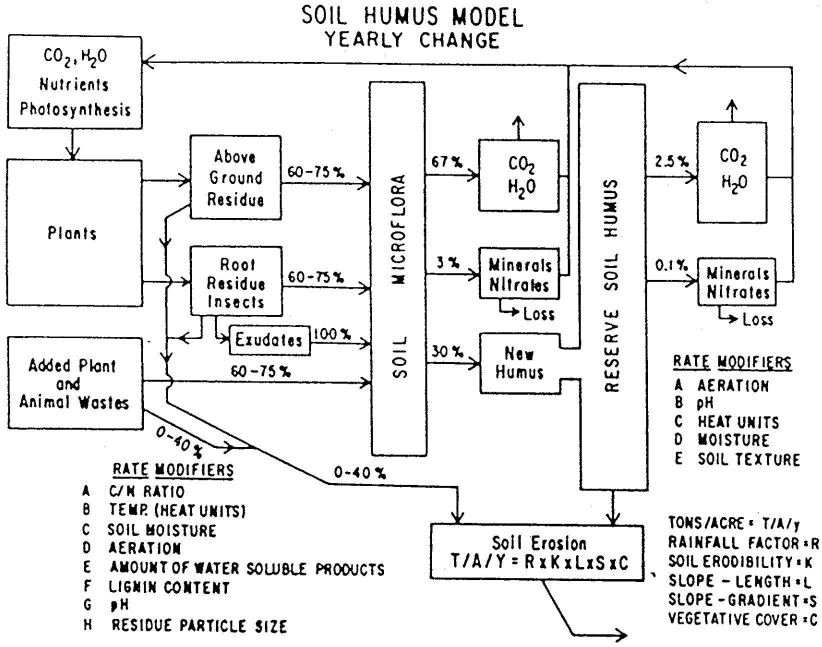
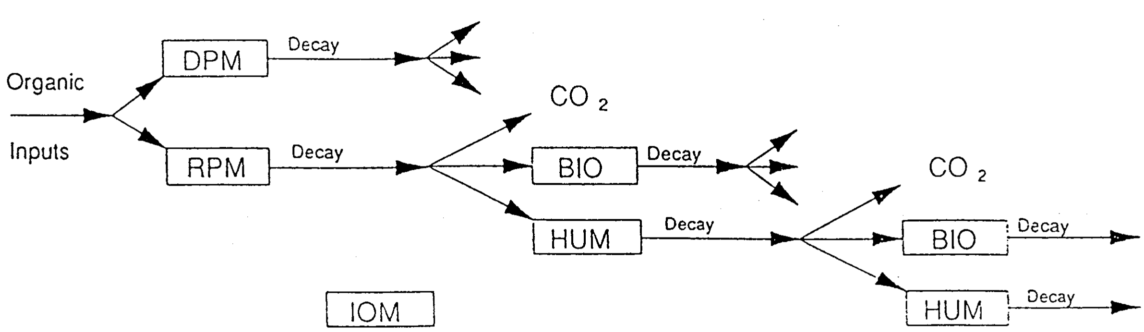



Figure 4.2 Flow of carbon through the Rothamsted turnover model, (after Jenkinson 1990)




Flow of carbon through the Rothamsted turnover model. (DPM, decomposable plant material; RPM, resistant plant material; BIO, microbial biomass; HUM, humus; IOM, inert organic matter.)

that an increase in crop yield reduces the rate of soil carbon depletion.

Van Veen and Paul (1981), developed a computer simulation model that investigated organic matter at more than one depth. The model was built to obtain a better understanding of the quantitative aspects of the decomposition of a complex substrate such as crop residues and subsequent microbial productions. They also recognised that the actual decomposition rate varies depending on the "state", (or quality), of the organic matter added, splitting the organic material added into three fractions; easily decomposible compounds, hemicellulose, and lignin. Lignin is associated with structural support in plants, and, because of its complex structure, it is more resistant to microbial decay. Hemicellulose lies somewhere between lignin and the easily decomposible sugars in its rate of decomposition. Van Veen and Paul describe the variation in decomposition rate depending on soil temperature and moisture. Together with soil pH these are the three most important aspects influencing the decomposition rate. The model differed from those previously mentioned in that it simulated three soil horizons down to a depth of 80cm, although exchange between "layers" were ignored. In the context of movement of soil organic matter down through the profile this would appear to be a significant omission, particularly in soils which are uncultivated because soil animals are capable of moving large amounts of organic matter into and down through the soil.

Van Der Linden et al (1987) developed a model based on the earlier model of Van Veen and Paul (1981). Their attempt to simulate the organic matter levels of established arable fields of North-Western Europe is different to many models which consider the ploughing out of virgin lands or carbon accumulation under grassland. In these situations the "physical" protection of organic matter, (which may be of great importance in undisturbed land), is likely to be of less importance. They conclude that prolonged input of only roots and stubble is likely to lead to a substantial decline in the soil organic matter. To maintain soil organic matter they suggest additions of plant material should occur little and often, rather than infrequent and relatively high dressings.

The NCSoil sub-model (see Molina et al 1987) of the massive NTRM model, (Nitrogen, Tillage and Residue Management), computes changes in carbon and nitrogen, specifically in the shorter term. Based on a compartmental model where residues pass into resistant and labile pools, (i.e. a slow and a fast turnover compartment), eventually to end up in a "passive organic phase". This latter phase was assumed to have no effect on the dynamics of the system in the short term and thus acted as a sink. The passive phase does not interact and this is the primary reason why the model is not accurate over longer time spans, as in reality this very resistant organic matter, (passive), is both formed and decomposed, albeit at slow rates, (i.e it does interact).

Jenkinson et al (1987), Jenkinson (1990) describe the Rothamsted model for turnover of organic matter. This is based on the earlier model developed by Jenkinson and Raynor (1977). Their initial model, (1977) was one of the first to introduce the concept of compartmentalizing organic matter into "pools" of varying resistance to decomposition. The later model is based on similar principles. The first two of the five compartments are added to on a monthly basis depending on crop residues. These are called decomposible plant material and resistant plant material, (i.e lignin etc), see Figure 4.2.

This incoming material is either evolved as carbon dioxide, or incorporated into microbial biomass, or humified organic matter. Humified organic matter decomposes to give carbon dioxide and microbial biomass. Jenkinson describes this type of model as being useful for predictive purposes providing they have been tested over a wide range of conditions and are not used outside their timespan. This is especially the case if the model outputs have been adjusted to correspond to reality by adapting parameters to give the desired fit. The model moves in monthly steps with the soil carbon declining at a rate dependant on a set constant k. A value for k is usually derived by fitting the model to data from litter bag experiments, laboratory incubations or short-term field incubations in the case of short run decomposition models. In models run over longer timespans, data can be derived from prolonged field incubations using $^{14}C$-labelled organic matter or from long-term agronomic experiments. Decomposition of the organic matter entering the soil occurs at a rate dependent mainly on the temperature, moisture, and a decomposition constant, k, for that pool. Although they were able to fit the model reasonably well to data from the long-term experiments at Rothamsted, they recognise a clear problem with this type of modelling,

*"It is difficult to devise critical tests for non-rigid, multicompartmental models,...usually the best that can be done is to put them through such experimental hoops as are available , rejecting those that cannot be made to jump cleanly."*

This type of modelling is most useful for bringing together scattered data and using it in a form which allows the testing of hypotheses against what really happens in reality. Jenkinson (1990) suggests this type of multicompartmental model is only of limited use in the latter case, because often they are fitted to reality. However, he considers that as long as they are widely tested, they could be used for predictive purposes.

Ågren and Bosatto (1987) developed a non-compartmental model arguing that the decomposing organic matter can be split into interacting substrates of differing qualities, all of which give varying decomposition properties. They model decomposition as a continuum, in which they analyse the implications of fresh litter quality on the formation of soil organic matter and mineral cycling within the soil. This objective is achieved through the derivation of equations to show the steady state levels of carbon and nitrogen in the soil. Their conclusions suggest the quality of the substrate, the initial microbial biomass and the suitability of that biomass to decompose the given substrate as very important factors in the long-term behaviour of carbon and nitrogen in the soil. The slow decomposition of poor quality material might help to explain the lower rates of turnover of carbon in some terrestrial ecosystems.

In addition to these models the author has been in contact with the Institute of Terrestrial Ecology who are in the process of developing their own model, (see Howard and Howard 1991), and the Soil Survey at Silsoe may also be developing a model in the near future. Modelling of organic matter dynamics is also occurring within climate change programmes.

## 4.3. MOVEMOD: AIMS AND OBJECTIVES

As recognised by Van Veen and Paul (1981), part of criteria for the use of a soil model is for qualitative analysis of linkages, and one of the primary objectives of this research activity has been the collection and interpretation of scattered scientific evidence into a useful assemblage. Although MOVEMOD derives much of its information from existing models, (see previous section), it has several specific differences:

1. The emphasis is on exploring the effects of changing agricultural practice on a range of agricultural systems, by considering how the farmer can impact on the system. Three main mechanisms are explored: what the farmer grows, the inputs he uses to grow it, and the method/amount he chooses to harvest.

2. It demonstrates trade offs between cultivation and natural mixing by including a compartment that include macrobiomass. Other models sometimes include compartments for the microbiomass but these are involved with decomposition and not physical movement.

3. It specifically sets out to represent the physical movement of organic matter vertically through the soil, and not just its decomposition. Balesdent et al (1990) argue that the effect of annual tillage cannot simply be represented by the effect it has on soil organic matter decomposition. This is because annual cultivation alters other factors that govern the amount of organic matter in the soil, i.e annual input of organic matter and the way in which this incorporated.

The objective associated with the construction of MOVEMOD is to investigate the use of soil organic matter as an indicator of agroecosystem change. The model is viewed as a research tool to link cropping practices which the farmer has control over and which can be influenced by policy, to the impacts on soil and thus agroecosystem processes.

**The specific aims of the model are:**

1. To investigate the possibility of increasing soil organic matter content within existing agricultural systems,

2. To demonstrate the impact of surface cultivation on the movement of organic matter through the soil profile,

3. To investigate the extent to which agricultural activity influences the soil organic matter in deeper horizons,

4. To explore the possibility of using carbon or soil organic matter as an indicator of change,

## 4.4 CHOOSING AN APPROPRIATE MODELLING TECHNIQUE

Section 4.2 provided a review of some of the existing soil organic matter models. These ranged from simple compartmental models to complex models in which decomposition is treated as a dynamic continuum. MOVEMOD is a simple time sliced stocks and flows model using monthly time steps. While it is recognised that more elegant modelling techniques exist, and that a complex dynamic model could be constructed to represent the decomposition and movement as a continuum, these were felt to be beyond the requirements of this research project for several reasons.

Firstly, this modelling exercise makes up only one part of a multi-method research approach and is thus constrained by time. Secondly, data availability is limited for some of the parameters when trying to run on monthly time steps. This would be further exaggerated if smaller time steps were introduced. Thirdly, and perhaps of most importance, the level of enquiry provided by this type of model is consistent with the research as a whole, and provides the relevant information.

## 4.5 DISCUSSION AND PRESENTATION OF THE MODEL

The "Excel" spreadsheet was initially used as a tool to develop the model which runs using monthly time steps. The model was later rewritten in Turbobasic to allow faster running of the program, and increased ease of interaction. It is envisaged that specific trends/pathways can be isolated over a 25- 50 year running periods. The model can be run over longer time periods but the output should be treated with increasing caution. The boundaries used in the development of the model are the soil conditions that exist in the established farmlands of middle England. The majority of these soils have organic matter contents of between 1 and 10 %, (see Church and Skinner 1986). Peat soils which contain above 10% organic matter have differing dynamics and cannot be investigated by the model. This shortfall is accepted as most arable land in the UK is based on mineral soils with the exception of the peat based fenland soils. The pH of the soils are presumed to be at levels normally found on well managed farm land, (5.5-7). Low pH levels are known to have major effects on litter decomposition, (Wild 1988), but it is presumed that farmers striving for optimal levels of output will not restrict the use of lime to offset acidity to a degree that impinges on the decomposition process. Climatic conditions have an overriding influence on both rates of movement and decomposition of organic materials. The model utilizes data for monthly average temperatures and rainfall for middle England, although these parameters can be altered if desired.

The Rothamsted model described by Jenkinson et al (1987,1990), forms the basis for many of the calculations involving the decomposition of organic matter. This has allowed the author to investigate organic matter movement, without the additional burden of developing equations representing decay. The equation for amount of decay during a month in a particular pool is given by,

$$x = (1-e^{-abck}) \quad \text{-(Equation 4.2- after Jenkinson et al 1987, 1990)}$$

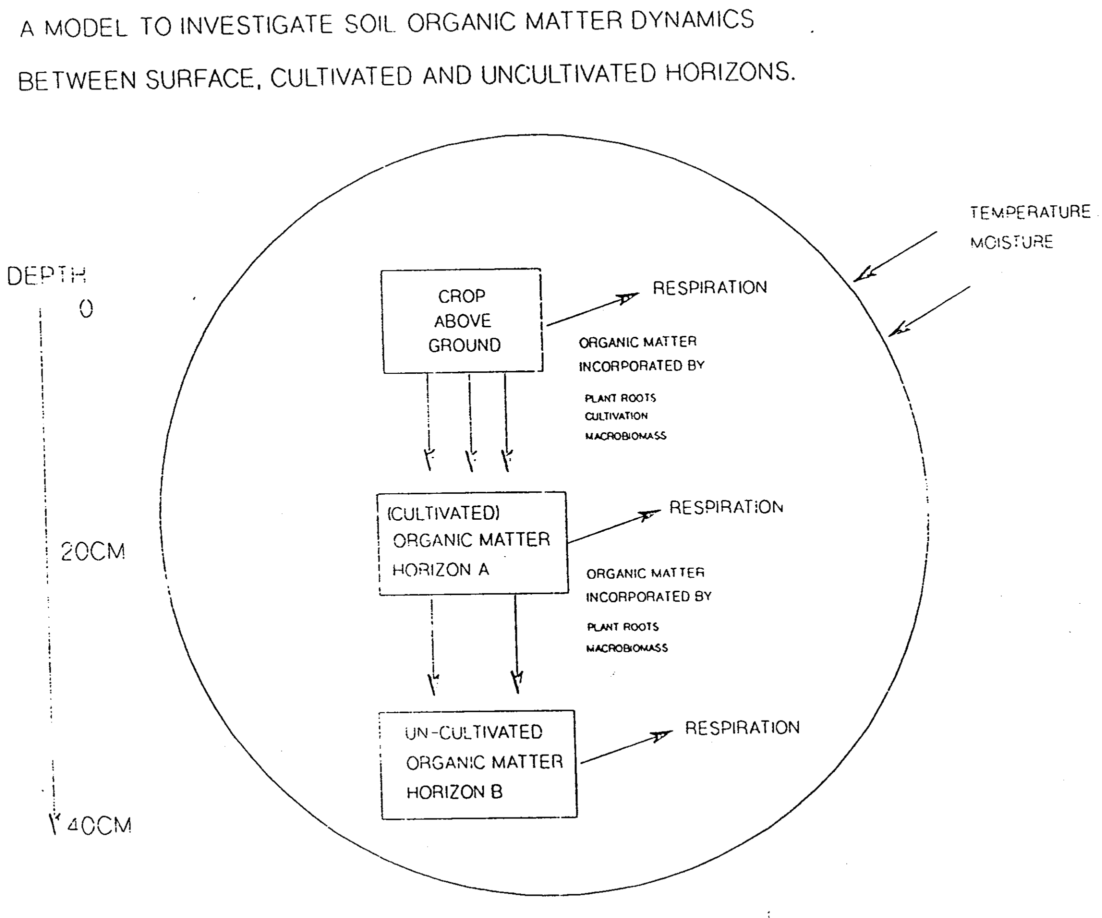
where, x= Amount of decay
e= 2.718
a= temperature rate modifying factor
b= moisture rate modifying factor
c= plant retainment factor
k= decay rate constant for the compartment.

MOVEMOD does not use the parameter "c" because the plant retainment factor is eclipsed by cultivation factors used in its compilation. To further simplify MOVEMOD the microbial pool has been incorporated with more resistant plant material into a "dynamic organic matter pool". The Rothamsted model was initially developed to "fit" the Rothamsted soils, whereas MOVEMOD is designed to encompass a wider range of soils. MOVEMOD is structured upon three interacting layers or horizons: the soil surface, the potentially cultivatable A-horizon, and the uncultivated B horizon. Although it is recognised that some sub-soiling and moling takes place well below 20cm, this is done infrequently and is not aimed at inverting the soil, but rather to panbust or to enable drainage. Soil horizons are formally classified, (see Wild 1988), however the use of A & B horizons within the model is only loosely associated with this formal classification. It is assumed the A horizon is the one immediately below the soil surface, and the B horizon underlies this.

Three layers were thought to provide the simplest method to represent the way in which agricultural activity can impinge on the vertical movement of organic matter, and thus the volume of organic structure. Plant debris accumulates on the surface, cultivation directly effects the surface layer of soil, and the sub-surface layer is indirectly affected by actions in the surface layer. Figure 4.3 provides a diagrammatic representation of the model.

In terms of soil classification the "horizon" depth will vary greatly depending on specific sites, soils and their past histories. However, for the purpose of the model both of the soil horizons represented are assumed to be 20cm in depth. It is recognized that in many soils biological activity can be found to considerable depth, (some earthworms can burrow to several metres, Lee 1985), but the model concentrates on the top 40cm, within which the majority of activity occurs. Edwards and Lofty (1969) note that in woodland the majority of animals are found in the surface litter, in grassland they are usually in the top 5cm, and in arable land in the top 15cm. A decrease in numbers and biomass within a given taxon as depth increases is confirmed by the experiments described in Chapters 5 and 6. The use of an average cultivation depth is

Figure 4.3 A diagrammatic representation of MOVEMOD



arbitrary. Whatever the depth of this boundary, it is the change in processes due to cultivation that are important and not only the actual depth at which it occurs. Where no cultivation takes place the soil tends to be more stratified, (see Figure 3.5).

## 4.6 AGRICULTURAL ACTIVITY AND SOIL ORGANIC MATTER MOVEMENT,

The dynamics of organic matter movement have already been discussed in Chapter 3. In the first instance the model considers the mechanisms through which organic matter can be incorporated within the soil and the influence of cropping practice upon these. Incorporation of organic matter is assumed to occur via three main mechanisms: movement by or due to the activity of soil animals, (macrobiomass), the ingression and subsequent death of plant roots, and cultivation. These mechanisms are shown in Figure 4.4 which highlights a section of the more complicated diagram illustrated in Figure 3.2.

### 4.6.1 Incorporation by Macrobiomass, (see section 3.3 for further discussion)

For the purpose of this model the macrobiomass are considered to be those soil animals greater than 250µm in length, and although they can be implicated in breakdown of organic matter, (see Edwards et al 1970, Breymeyer and Van Dyne 1980), in undisturbed soils they have a significant role in the movement and incorporation of organic material from the soil surface into the soil, (Raw 1962, Edwards et al 1970). In temperate climates these soil animals are mainly the earthworms and some of the larger arthropods, (Edwards et al 1970). Section 3.4 suggested that water infiltration through channels created by the macrobiomass provides an indirect means of incorporation. However, due to lack of hard data and for simplification, the model makes no attempt to separate this "indirect" incorporation from the direct physical movement due to the soil animals.

The model assumes a larger amount of material will be moved down through the soil profile than will be moved back towards the surface. The figures used in the model are thus net downward movement rates. This does not detract from the importance of movement and subsequent mixing that occurs against the forces of gravity, (Hole 1981). Agricultural activity influences the amount of incorporation undertaken by the macrobiomass by limiting their supply of food, and the amount of material available for them to incorporate. Secondly, cultivation has a direct physical effect on the macrobiomass population, usually reducing their population severely, consequently reducing the amount of incorporation they undertake.

### 4.6.2 Incorporation by Plant roots, (for further discussion see section 3.8.2).

Plant roots add organic material to the soil as they grow, particularly from root caps which are continually slothed off as the root penetrates cracks and pores within the soil. In annual root crops the majority of root death occurs with the senescence of the above ground material and this adds dead material to the soil throughout the

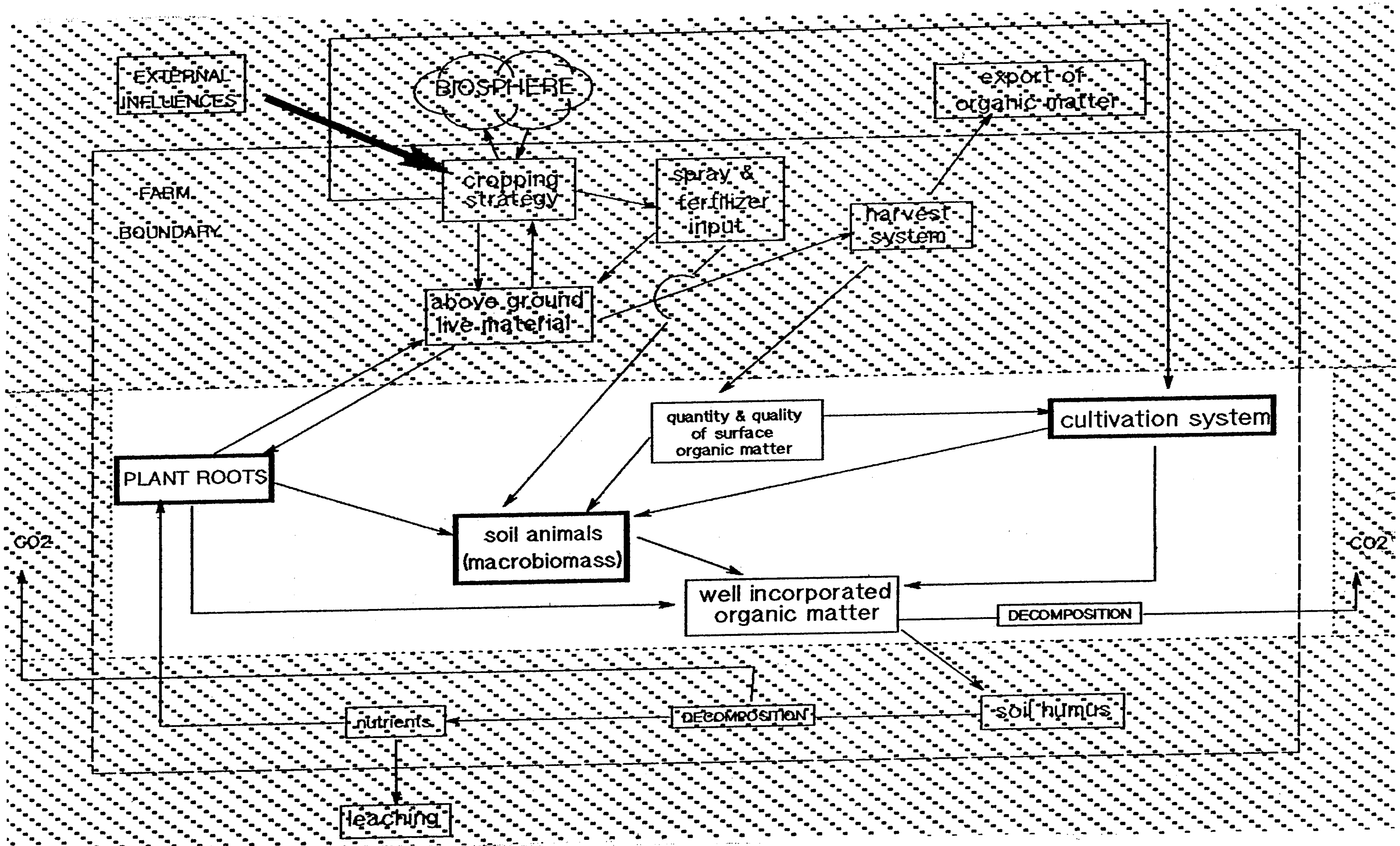



Figure 4.4 : Diagrammatic representation of the mechanisms through which organic materials can enter soil within the agroecosystem,

profile. Perennial plants continually turnover roots as they explore new regions of soil.

### 4.6.3 Incorporation by Cultivation, (for further discussion see section 3.8.3).

One of the primary aims of cultivation is to mix plant debris/crop residues into the soil, and indeed this may be the sole reason for cultivation in some agricultural systems. The degree and depth of mixing varies considerably under various cultivation regimes. For instance normal ploughing inverts the soil completely with surface debris often being buried en masse. Other forms of cultivation, for instance discing, do not bury the trash to the same degree, but mix it more evenly through the surface soil. The depth of cultivation chosen will depend on a number of factors such as soil type, amount of trash, subsequent cropping etc. Ploughing, (one of the deeper forms of surface tillage), is unlikely to be to a depth greater than 30cm, (12"), and is more usually undertaken to a depth of about 20cm, (8"). Heavy discing can penetrate to at least plough depth on lighter soils, whereas other forms of tillage such as spring tines and harrows are usually only concerned with making a surface tilth.

## 4.7 ORGANIC MATTER MOVEMENT THROUGH THE MODEL

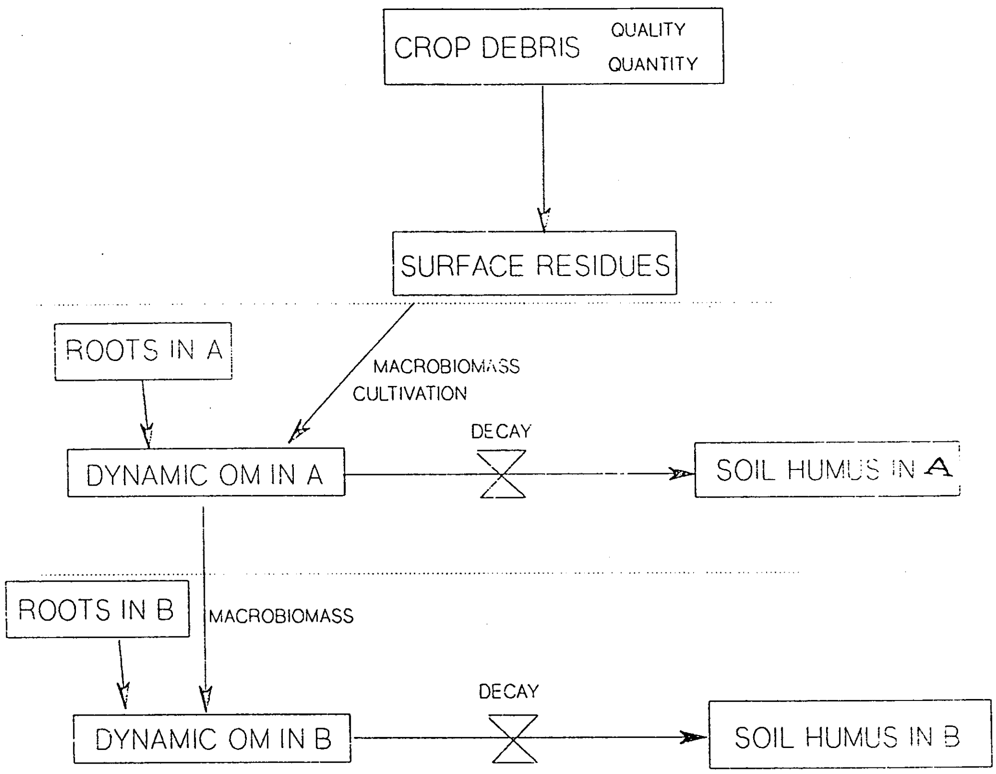
Initially the model requires several "known" data to be imputed at the beginning of a run. These are the organic properties of the soil under investigation and the associated climatic conditions. From these the model calculates several indirect variables. The main output from the model is the relative change in soil organic matter of the "A and B" horizons, the surface debris and the macrobiomass, (although several other variables could be investigated if desired). A flow diagram of organic matter through the model is provided in Figure 4.5. **(A copy of the turbobasic programme is included in appendix 2).**

Organic matter accumulates in the agroecosystem from the crop debris or residues that are left in the field and the root material which is contained within the soil. The model investigates the flow of organic matter vertically through the soil system assuming that organic matter enters the soil by three mechanisms, all of which are influenced to some degree by agricultural activity, (see Figure 4.5). Surface organic matter/ residues and root material flow into the dynamic organic matter pool in A where they are either decomposed to more stable humic compounds, (soil humus in A), or they are moved deeper into the soil by the macrobiomass. Once in the B horizon they can undergo further decomposition to soil humus in that horizon. The movement from the surface to the A layer can be undertaken by either cultivation or macrobiomass. The macrobiomass and roots provide the only means of transfer for organic materials into the deeper uncultivated soils.

## 4.8 DETAILED DESCRIPTION OF THE MODEL

Where appropriate the mathematical expressions are included together with the code used to represent variables within the turbobasic

Figure 4.5 Diagram demonstrating the flow of organic matter through MOVEMOD



programme. All figures used are either percentages or kilograms per hectare. The model has been developed using monthly time steps and calculates output on a monthly basis, the results are presented graphically, *(az is a monthly counter used throughout the model).* The description of the model is split into 3 parts:

1. Mechanisms involved in the movement of organic matter,

2. Factors associated with the decomposition of organic matter,

3. The organic matter pools or compartments within the model,

Flows of material occur throughout the month, whereas stocks of material are summed at the end of each month. For instance the amount of organic matter decomposed in a given month, for instance month 2, (az), is dependant partly upon the organic matter present in that pool at the start of that month, or the end of the last one, i.e month 1, (az-1).

## 4.9 MECHANISMS INVOLVED IN THE MOVEMENT OF ORGANIC MATTER,

The model considers three mechanism associated with the movement of organic materials into the soil: The macrobiomass, cultivation and plant roots.

### 4.9.1 Macrobiomass, *(code 1)*

Buol (1972) estimated macrobiomass to be 0.2% of total soil organic matter and this provides a rough guide for initial values. The model calculates the macrobiomass each month depending on the organic matter in the A horizon, the amount of organic matter on the surface and the macrobiomass in the previous month. If cultivation takes place in a given month the population of macrobiomass is reduced. It is recognized that the macrobiomass population changes throughout the year depending on climatic conditions and natural breeding cycles, (Persson and Lohm 1977). However for the purposes of the model an average monthly population is assumed.

```
l(az)=((5*l(az-1)+((k(az-1)+x(az-1)+ab(az-1))*.002))/6)*m(az)
```
(Equation 4.3 )

where az= monthly counter,
l= macrobiomass,
k= Organic matter on the surface at the start of month,
x= Dynamic organic matter in the A horizon at start of month,
ab= Soil humus in A
m= cultivation factor,

The equation relates the macrobiomass in a given month to the food source, i.e organic matter on the surface, and the amount of organic matter already in the soil, with greatest weighting been given to the former. If cultivation occurs in a given month then the overall population is reduced depending on the severity of cultivation.

### 4.9.2 Cultivation, *(code m and n)*

*Code m: Cultivation and macrobiomass,*

The model allows a yearly decision to be made concerning the impact of cultivation on the soil organisms, through two cultivation factors. The effect of cultivation on the macrobiomass population is represented by m. If the agricultural system being investigated does not undergo cultivation in a given year then this factor remains at a value of 1. However, if the system is cultivated this value changes to 0.5 for deep cultivation such as ploughing. (Edwards 1984 suggested that ploughing can reduce soil animal numbers by upto 50%. Other workers have noted the deleterious effects of ploughing on soil animal numbers, Wallwork 1976, House and Parmelee 1985). Intermediate values can be chosen depending on the severity of cultivation. For instance if the soil is lightly disced a value of 0.8 may be imputed etc.

*Code n: Cultivation and the decomposition process,*

Cultivation is known to have a beneficial effect on the actual decomposition process, through mixing and aeration. This is represented by code ac. If cultivation takes place then this factor remains at 1. However if cultivation does not take place then decomposition rates within the soil are assumed to be reduced to a half of their cultivated rates, (by imputing .5 in this column). Balesdent et al (1990) found within conventional and no-till regimes that mineralisation rates of carbon within the soil were about twice as high under the conventional tillage regimes. They suggest that this may be due in part to the release of physically protected organic matter, as suggested in section 4.2.

### 4.9.3 Roots in A, *(code w)*, Roots in B, *(code ah).*

Each year a value for the amount of root material returned to the soil is imputed into the model, *(code am)*. This is assumed to occur in one input during the autumn of the year, i.e when the crop is harvested. Initially 75% of this root material is assumed to be within the top 20cm and a further 25% is assumed to be in the 20-40cm horizon. It is recognised that this ratio can vary considerably and this is explored through sensitivity analysis in section 4.15.

w(az)=.75*am(az) (Equation 4.4)
ah(az)= .25*am(az) (Equation 4.5)

where
- w= roots in A
- ah= roots in B
- am= annual input of root material
- az= monthly counter

## 4.10. FACTORS ASSOCIATED WITH THE DECOMPOSITION OF ORGANIC MATTER,

This section considers the factors affecting the rate of decomposition. Temperature and moisture were highlighted in chapter 2 as important factors associated with the turnover of organic materials in the soil. Modification factors are described which are then used in an equation described by Jenkinson (1990) to represent decay in various organic matter compartments. Although the temperature and mositure regimes can be altered at the start of a model run, these are assumed to be constant during the run itself. It is possible that the model could represent changes in average mositure and temperature over the period of the model run, although this would require modification to the programme itself. Within the aims of the model it was not thought to be necessary to demonstrate the effects of global climate change, or annual fluctuations in climate.

### 4.10.1. Temperature modification factor, *(code q)*

The model assumes average monthly surface temperatures from the Agricultural climates of England and Wales for the Bedfordshire region. These can be altered depending on the location of the soil being studied. The above reference also records the soil temperature at a depth of 30cm but these vary little from the surface temperature. For this reason the same set of temperature figures are used for both the A and B horizons.

It can be assumed within the climatic conditions of the UK that the warmer the soil the greater the activity of the soil biomass, providing the soil moisture is not limiting. Van Der Drift (1963) concluded in his study of forest soils that soil moisture is a more important factor limiting activity than temperature. Dickinson (1974) quotes temperatures of 27-35 C for maximal activity, but notes that "substantial" activity will still take place below 5C. Similar temperatures are quoted for maximum activity by Edwards et al (1970). Jenkinson (1990) calculates a temperature modification factor which relies on the average monthly temperature to be imputed. This can be represented graphically, (see Figure 4.6).

Temperature Modification Factor = $47.9/\{1+e^{106/(X+18.3)}\}$-(Equation 4.6- after Jenkinson et al 1987,1990),

where X= Average monthly temperature.

### 4.10.2 Soil moisture modification factor, *(code s)*

Soil moisture can limit the activity of the soil biota. Data from Jenkinson (1990) suggests that when the soil moisture deficit falls below 20mm the activity of the biomass is progressively restricted. Soil moisture deficit is usually measured by subtracting the amount of water lost through evaporation from the rainfall, and often quoted on a monthly basis. Figures for soil moisture deficits have been adapted from the Agricultural climate of England and Wales, for the Bedfordshire region. These figures can be altered depending on soil type and position.

```
If r(az) > 20 then s(az) = 1 - ((r(az) - 20) * .03)
if r(az)<=20 then s(az)=1      -(Equation 4.7)
```

where r= soil moisture deficit, s= soil moisture modification factor

The model assumes that for every 1mm increase in soil moisture deficit below 20mm, the moisture rate modifying factor is reduced by 3 %. ie When soil moisture is not limiting the modification factor is 1, at

Figure 4.6 : Variation in temperature rate modification factor with temperature,

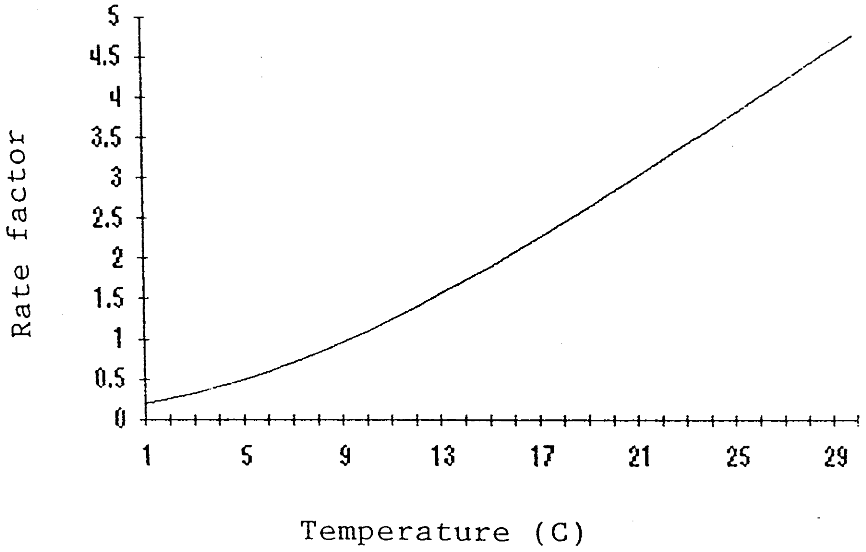
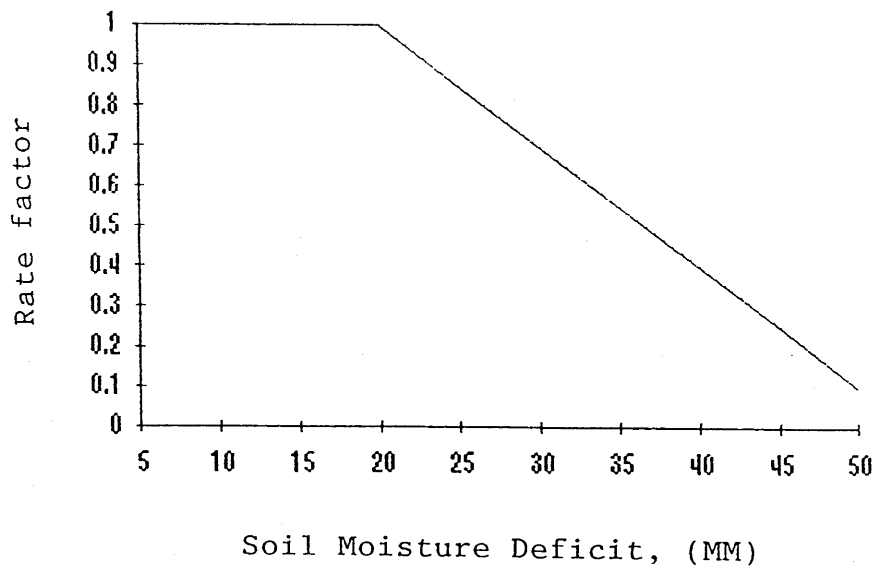



Figure 4.7 : Variation in the moisture rate modification factor with Soil Moisture Deficit, (MM)



40mm of soil deficit the figure is 0.4 and at 50mm it is 0.1. This is represented graphically in Figure 4.7.

### 4.10.3 Temperature moisture modification factor, *(code t)*

Is simply the soil moisture factor multiplied by the temperature factor.

### 4.10.4 Rates of decomposition

Many of the equations used for decomposition rates are adapted from the Rothamsted model, ( see Jenkinson et al 1987, Jenkinson 1990). They suggest that incoming plant and root material will fall into two categories, decomposible plant material, (DPM), or resistant plant material,(RPM), which decompose with differing rate constants. They assume 79% DPM and 21% RPM for wheat straw. The relationship between DPM and RPM can be varied in this model each year through a variable which represents the "quality of litter and stubble". The model includes the microbial biomass within a dynamic organic matter pool, (so named because within it decomposition occurs relatively quickly). The dynamic pool represents microbial biomass, incoming resistant plant material and any plant material from previous months that has resisted decomposition. The equation for decay of the various fractions is taken from Jenkinson (1990) who assumes each pool undergoes biological decomposition by a first order process, (see Equation 4.2),

The monthly decomposition factors for the A horizon have been derived from Jenkinson (1990). The constant for the dynamic pool is taken as a value midway between the value Jenkinson (1990) uses for microbial biomass, (0.66), and resistant plant material, (.3), i.e 0.43. These are initially reduced by half in the B horizon as no data is available on expected decomposition rates in the deeper soil, but are subject to a sensitivity analysis later in the chapter.

| | A Horizon | B Horizon |
|---|---|---|
| k for Dynamic organic matter = | .43/12 | .215/12 |
| k for soil humus = | .02/12 | .01/12 |
| k for decomposible plant material = | 10/12 | 5/12 |

Jenkinson (1990) uses a plant retainment factor to compensate for whether a crop is growing or not. This is not included in the calculations as the two cultivation factors used in MOVEMOD provide a similar modification.

## 4.11 ORGANIC MATTER POOLS,

There is one surface pool which is added to by crop debris and depleted either by cultivation and macrobiomass activity. Within each of the two layers or horizons, (A & B), there are two pools: dynamic organic matter and soil humus.

### 4.11.1 Crop Debris, *(Quantity=code e, quality=code c)*

Values need to be imputed at the start of each year for the amount and quality of crop debris returned to the surface of the soil. This can be undertaken manually at the start of each year, or set automatically at the start of the model run. Van Veen and Paul (1981) used annual input rates for continuous wheat cropping of 897 kgs/ha of carbon in the litter and 529 kgs/ha of carbon in the roots. This equates to actual inputs (using the standard conversion of organic matter containing 58% carbon) of 1540 kgs/ha of litter and stubble and 900 kgs/ha of roots. Similarly a grass ley may return 1700 kgs/ha of plant debris and 2000 kgs/ha of plant roots. Table 3.3 shows the expected return of plant residues from a crop of winter wheat in the UK.

The quality of plant residues varies considerably. (see Van Veen et al 1984). The carbon to nitrogen ratio is often quoted as an indicator of quality of material being returned to the soil. The model uses a crude indicator of quality, relying on the operator to exercise judgement about the quality of the material. A value of 0.9 represents a "high" quality residue with a high carbon:nitrogen ratio that will decompose relatively easily. Jenkinson (1990) would treat this material as one with a high proportion of decomposible plant material) A figure of 0.1 represents a poor quality residue in terms of decomposition time, high in lignin and hemicellulose, (i.e resistant material) with a poor carbon:nitrogen ratio. For example woody debris is generally of low quality because of its high lignin content, (value 0.1-0.3). Straws of cereal crops are of intermediate range, (values 0.4-0.75), and crops like peas, beans are of higher value, (0.7-0.9).

### 4.11.2 Surface residues, *(code K)*

The amount of the crop debris that remains on the surface of the soil in a given month is firstly dependant on the addition of debris in relation to cultivation, (if the soil is cultivated). If cultivation takes place then all the surface debris is incorporated into the A horizon, and the surface is presumed to be free from debris until the next harvest. If cultivation does not occur and there is debris on the surface then some of this is moved into the soil by the macrobiomass, either by pulling in of debris directly, for instance by earthworms, or by surface feeding and underground defecation. Although a wealth of data exists on the disappearance of litter from the surface, (Edwards et al 1970, Swift et al 1979, Dickinson and Pugh 1974, Van Der Drift 1963), much of this data concerns natural or uncultivated systems. This is not surprising as litter disappearance on cultivated land is normally a "managed process", utilizing varying forms of cultivation, see sections 3.8.3 and 4.6.3.

Work in forest soils by Van Der Drift (1963) in the Netherlands recorded litter disappearance rates of upto 4200kgs/ha in a year. If a macrobiomass of 525 kgs/ha ( for a soil of about 10% organic matter) is assumed and that about a half of the total litter that disappears is actually being incorporated into the A horizon by the macrobiomass, (because some weight is lost due to leaching, respiration and microbial attack-see Edwards et al 1970), then a figure for kilograms of plant litter moved into the A horizon per kilogram of macrobiomass can be estimated, (code o),

ie      4200/(2*525)

This suggests that approximately 4.0 kg of organic matter moved into the A horizon in a year by each kg of macrobiomass. Thus in the model it is assumed that each kilogram of macrobiomass is capable of commuting an average 4kgs of plant debris in a year, depending on the temperature and moisture regime. The amount commuted monthly is the macrobiomass in that month multiplied by a modified monthly movement rate which is dependant on the moisture and temperature situation in that month. This monthly movement rate is such that when all the months are added up the movement of plant debris into the A horizon in one year cannot exceed 4 times the average total macrobiomass. (ie 4kgs of plant debris per kilo of macrobiomass).

if m(az)<1 then o(az) = k(az-1), (Equation 4.8)
if m(az)=1 then if k(az-1)>l(az)*t(az)/2 then o(az)=l(az)*t(az)*4/12
else o(az)=k(az-1)/2    (Equation 4.9)

where
- m= cultivation factor for macrobiomass
- o= organic matter moved from surface to A
- k= organic matter on the surface at start of month
- l= macrobiomass in the soil
- t= temperature/moisture modification factor
- az= monthly counter

Equation 4.8 shows that if cultivation takes place in a given month, i.e.(m<1), all of the organic matter on the surface at the beginning of the month is moved into the soil. Equation 4.9 shows that if cultivation doesn't take place in a given month, a proportion of organic matter lying on the surface will be commuted into the soil, (if there is any organic matter on the surface). In calculating the amount of litter remaining on the surface a distinction must be made between the movement of organic matter into the A horizon and the disappearance of debris from the surface. Zlotin (1971) found using litter bags that a large portion of the surface litter actually disappeared due to photochemical oxidation. Thus it must be made clear that disappearance of organic material from the surface does not signify the arrival of an equivalent amount of organic material in the soil. It is assumed that for every 1kg that disappears from the surface, 0.5kg is lost as carbon dioxide, via oxidation or respiration and 0.5kgs is moved into the A horizon by the macrobiomass. Thus,

if m(az)<1 then k(az)=k(az-1)+e(az)-o(az),  (Equation 4.10)
if m(az)=1 then k(az)=k(az-1)+e(az)-(2*o(az)) (Equation 4.11)

where
- m= cultivation factor for macrobiomass
- k= surface litter at end of month
- e= additions in straw and stubble
- o= organic matter moved to the A horizon.

#### 4.11.3 Stock of dynamic organic matter in A, *(code x)*,

A starting value needs to be imputed for the dynamic organic matter in A, and this will depend on the soil under study. Organic matter enters this compartment/pool through either root material, macrobiomass or cultivation. Once in this compartment organic matter undergoes further decomposition to soil humus or is moved by the macrobiomass to the B horizon. When 2kgs are moved by macrobiomass, 1kg is lost to respiration, (hence the multiplier of 2 in equation 4.12), and whenever 4kgs of organic matter changes state due to decomposition then 3kg is lost as carbon dioxide and 1kg is retained within the dynamic organic matter or soil humus as humic material or microbial biomass, (hence the multiplier of 4 in equation 4.12). The latter agrees approximately with Lucas et al (1977) who suggest that plant and animal debris are likely to leave about a 30% residue in the form of soil humus.

x(az)=(w(az)+o(az)+x(az-1))-(y(az)*4)-(ac(az)*2) (Equation 4.12)

where
x= stock of dynamic organic matter in A
az= monthly counter
w= shallow roots
o= surface organic matter moved to A
y= soil humus formed in A
ac= organic matter moved to B

The movement of organic matter into the A horizon by the macrobiomass, cultivation and plant roots have already been discussed, (see Chapter 3). Organic matter leaves this pool either by decomposing to soil humus, (see next section), or by being transported by macrobiomass. The movement between the A and the B horizon, *(code ac)*, is going to be considerably less than the movement between the surface and the A horizon. No data has been located that suggests a rate of organic matter movement within the soil. A guesstimate of one tenth of the rate of movement at the soil surface has thus been assumed, (i.e. .4 instead of 4- see equation 4.13), although the effects of altering this are explored using sensitivity analysis. At a depth of 20cm the only transfer by macrobiomass is likely to occur by feeding in the top layer and either defecating or dying in the deeper B horizon. It is unlikely that recognisable plant material will be dragged in to this depth. Further, only a small proportion of the macrobiomass will be operating at a depth of greater than 20cm, i.e the earthworms.

ac(az)=(l(az)/12)*.4 (Equation 4.13)

where
ac= organic matter moved to B, az= monthly counter
l= macrobiomass in the soil

#### 4.11.4 Stock of soil humus in A, *(code ab)*

The soil humus pool is the material which is less readily decomposed than the dynamic organic matter. However this fraction is constantly being added to from the dynamic pool and similarly undergoes decomposition itself, albeit at a slower rate than the dynamic pool. The equation for the amount of soil humus formed in A is,

$$y(az)=(((w(az)+o(az))*(c))*(1-2.718^{(-10/12*t(az))})+(x(az-1)+(w(az)+o(az))*(1-c))*(1-2.718^{(-.143/12*t(az))}))*n/4$$

(Equation 4.14)

where
y= soil humus formed in A
az= monthly counter
w= roots in A
o= organic matter moved from surface to A
c= quality of organic matter, (see 5.9.1)
t= temperature moisture modification factor
x= stock of dynamic organic matter in A
n= cultivation factor for decomposition, (see 5.8.2)

Equation 4.14 shows that a fraction of the roots and organic matter from the surface decompose quickly, some of which adds to the stock of soil humus. The remaining fraction of these components plus some of the dynamic organic matter pool decompose at a slower rate to add to the stock of soil humus. (As with the dynamic pool it is assumed that for every 4 kgs that are decomposed, 3 are lost as carbon dioxide- hence the division factor of 4 in equation 4.14).

The equation for the amount of soil humus in A that is in itself decomposed is,

$$z(az)=(ab(az-1)*(1-2.718^{(-.02/12*t(az))}))*n$$ (Equation 4.15)

where
z= soil humus decomposed in A
az= monthly counter
ab= stock of soil humus in A
t= temperature moisture modification factor
n= cultivation factor for decomposition

Equation 4.15 illustrates that decomposition is dependent on the amount of soil humus at the end of the previous month, a decomposition constant for humus, 0.02, and whether or not cultivation took place in that year. Decomposition is increased if cultivation takes place.

#### 4.11.5 Stock of dynamic soil organic matter in B, *(code aj)*

The movements into this pool and the decomposition are similar as for the dynamic organic matter in A. Cultivation doesn't supply any organic material to this horizon, this is supplied either by plant roots or by macrobiomass movements. The vertical movement of organic matter between the cultivated and non-cultivated soil layers is not well documented for arable soils yet is important with respect to the concept of three dimensional structure raised in Chapters 2 and 3. Stock of dynamic soil organic matter in B is represented by,

$$aj(az)=(aj(az-1)+ah(az)+ac(az))-(ai(az)*4)$$ (Equation 4.16)

where
aj= stock of dynamic organic matter in B
az= monthly counter
ah= roots in B
ac= organic matter moved from A to B
ai= soil humus formed in B

Equation 4.16 illustrates that the stock of dynamic organic matter at the end of a month is a function of that in the previous month, plus any additions from roots or from transfer from the A layer, but minus any that undergoes further decomposition to enter the stock of soil humus. For every 1jg of soil humus that is formed in B, 3 kgs are lost as carbon dioxide. This is represented by the dividing factor of 4 in equation 4.17.

### 4.11.6 Stock of soil humus in B, *(code ae)*

This is similar to the A horizon except that the rates of decomposition are halved. Soil humus forms, *(code ai)*, at a rate constant of .215 per year and is decomposed, *(code ag)*, at a rate constant of .01 per year. No information was available for decay constants deeper in the soil. Van Veen and Paul (1981) used the same decay constant for all three layers in their model, but this is unrealistic as conditions for decomposition are likely to deteriorate with depth. The effects of varying the decay rate in the B layer are explored through sensitivity analysis in Section 4.15.

The equation for the soil humus formed in B is,

```
ai(az)=((ah(az)*(c))*(1-2.718^(-5/12*t(az)))+((ah(az)*(1-
c))+ac(az)+aj(az-1))*(1-2.718^(-0.215/12*t(az))))/4 (Equation 4.17)
```

where
- ai= soil humus formed in B
- az= monthly counter
- ah= roots in B
- c= quality of incoming organic matter, (see 5.9.1)
- t= temperature moisture modification factor
- ac= organic matter moved from A to B
- aj= stock of dynamic organic matter in B

Equation 4.17 shows that a fraction of the roots and organic matter from the A layer decompose quickly, some of which adds to the stock of soil humus. The remaining fraction of these components plus some of the dynamic organic matter pool decompose at a slower rate to add to the stock of soil humus at the end of the month.

The equation for the amount of soil humus in B that is in itself decomposed is,

```
ag(az)=ae(az-1)*(1-2.718^(-.01/12*t(az)))          (Equation 4.18)
```

where
- ag= soil humus decomposed in B
- az= monthly counter
- ae= stock of soil humus in A
- t= temperature moisture modification factor

Equation 4.18 illustrates that decomposition is dependent on the amount of soil humus at the end of the previous month, and the rate at which it decomposes, governed by a constant for soil humus in B of 0.01.

4.12 OUTPUT FROM THE MODEL,

The model can record a host of changing variables, although the main graphic output associated with the aims of the model are monthly changes in the surface debris, the soil organic matter in the A and B layers, and the weight of macrobiomass. The graphic output represents soil organic matter as a percentage, assuming that each hectare contains 2500000kgs of soil in a 20cm horizon. Thus,

%OM A = ((dynamic organic matter in A + soil humus in A) /2500000)*100
*(code h)* (Equation 4.19)

%OM B = ((dynamic organic matter in B + soil humus in B) /2500000)*100
*(code i)* (Equation 4.20)

4.13 ACTIVITY SEQUENCE ASSOCIATED WITH THE USE OF THE MODEL,

The model can run under a variety of conditions, although the base model is set up to simulate decomposition conditions associated with middle England. The following sequence demonstrates the decisions that need to be made to run the model:

1. Is the temperature and moisture information used in the base model adequate for the region being investigated? If not it needs to be altered,

2. Over what time period is the model to be run? It is suggested that this should not exceed fifty years,

3. What starting conditions for the model are to be used? These should be prepared with respect to the amounts of organic matter in the A and B horizons,

4. The model allows interaction on a simulated yearly basis to impute cropping parameters, or allows the setting up of these automatically at the start of the run.

5. What type of cropping regime is going to be represented? If the model is set for manual annual input it will ask for the following information annually :

   a. The degree of cultivation,

   b. The plant debris returned to the soil surface each year,

   c. The amount of root material returned each year,

   d. The quality of the debris returned each year.

The output of the model is written to data files which are then processes into the "Excel" spreadsheet package and interpreted graphically.

## 4.14 APPLICATION OF THE MODEL,

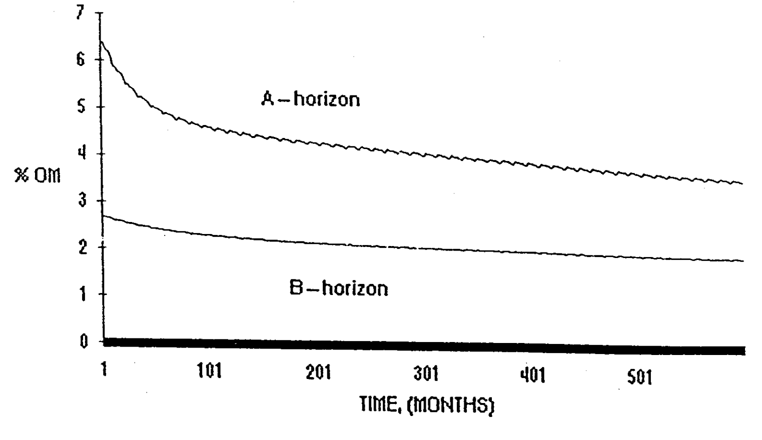
Two phases of validation are undertaken before the model is used to investigate the 4 research aims stated in section 4.3. Sensitivity analysis is carried out on several of the variables, particularly those which have been difficult to verify from existing data. The aims of the model are discussed in relation to model runs where appropriate, and the chapter finishes by drawing conclusions about the compilation and use of the model.

### 4.14.1 Initial validation

Initial validation involved general testing to see if the model could represent the ploughing out of uncultivated soil, and the effects of ensuing cultivation on soil organic matter. This run demonstrated the model could produce sensible results similar to those found by other researchers. Figure 4.8 illustrates the results of a 50 year run in which a continuous cultivation regime was applied to soils initially containing 6.4% organic matter in the top 20cm and 2.68% in the 20 to 40cm horizon. It is assumed that the soil is cultivated heavily each year, (i.e ploughed), and a cereal crop of some form planted. This is assumed to return 1800kgs/ha of root material and 1000kgs/ha of stubble and chaff in each year. The straw is baled and carted from the field. The material returned to the soil is assumed to be 70% DPM, (i.e. quality factor = 0.7). This regime would correspond to the ploughing out of permanent pasture and adopting a continuous cereals regime producing average yields over a 50 year period.

The model run shown in Figure 4.8 illustrates a rapid decrease in soil organic matter following cultivation, similar to the findings of other researchers, (Lucas et al 1977, Voroney et al 1981 -see Table 4.1, Howard and Howard 1991 -see Figure 3.3). This occurs both in the A and B horizons, and is most rapid in the initial 10 years, due to the reduction in the return of organic materials, and the rapid oxidation of previously "protected" organic materials within the soil.

Figure 4.8: Initial validation run demonstrating the effects of ploughing out of permanent pasture on the organic matter content of the A and B layers,



After 50 years of continuous cultivation the A horizon had lost 45% of its original soil organic matter and was still declining. The B horizon had lost 22% of its original soil organic matter reaching a reasonably steady level at around 2% organic matter. The weight of macrobiomass in the soil had declined by half. Voroney et al (1981) found following the ploughing out of virgin grassland that the 0-15cm horizon lost 55% of its organic carbon in the first 70 years of cultivation, and the 15-40cm horizon lost 29% of its organic carbon in the same time period. Table 4.1 shows their model data, the experimental data they used for validation and the data from the movement model,

Table 4.1: Percentage decrease in organic carbon following 70 years cultivation of native grassland, (adapted from Voroney et al 1981)

| | Voroney model | Experimental (Voroney) | MOVEMOD |
|---|---|---|---|
| A-horizon | 55 | 57 | 45 |
| B-horizon | 29 | 22 | 22 |
| 40-80cm | 22 | 20 | n/a |

It is suggested that the percentage loss in the "A" horizon of MOVEMOD is not as large as in Voroney et al's work because the model has been run over only 50 years instead of 70 years. Whilst MOVEMOD could be run over a longer 70 year time period, this would be beyond the timeframe in which it was designed to run, (see section 4.5). Although running the MOVEMOD for 70 years increases the fit between the experimental data and the "A" horizon, it also reduces the degree of "fit" between the experimental data and the "B" horizon. Thus it has to be accepted that although MOVEMOD can demonstrate generally observed trends, the specific magnitude of these may not fit in exactly with the wide range of data that is available for validation.

### 4.14.2 Wider validation,,

Having established that the model can demonstrate generally observed trends following the cultivation of virgin land or undisturbed soil, a second validation was undertaken using data presented by Jenkinson (1990) to consider change in agricultural systems. This relies on recorded changes in soil organic matter of the Broadbalk experiments at Rothamsted, (see Chapter 5 for further information about the Broadbalk plots). Jenkinson uses 4 scenarios to test model performance. Three are based on the changes in soil organic matter following the establishment of the trial plots in 1843. The fourth simulation of the soil organic matter in the Broadbalk Wilderness following its fencing and establishment in 1882. Model runs were undertaken to simulate the 4 scenarios using the initial values and conditions for the A-horizon presented by Jenkinson (1990). The four runs are:

Run 1: Unmanured plot, cultivated annually and drilled with wheat. Straw removed at harvest,

**Run 2**: Fertilized plot receiving 144kg/ha of Nitrogen, 35kgs/ha of Phosphate, 90 kgs/ha of Potash, 12 kgs/ha of Magnesium. Cultivated annually and drilled with wheat. Straw removed at harvest. This would approximate to a commercial wheat growing situation,

**Run 3**: Organically fertilized plot receiving 35t/ha of Farm Yard Manure, cultivated annually, drilled with wheat, straw removed at harvest,

**Run 4**: Wilderness, left without cultivation, natural regeneration with all dead material returning to the soil surface.

Table 4.2 gives details of the input variables used in the four runs of MOVEMOD.

Table 4.2: Details of the input variables used in each of the four validation runs,

| | RUN1 | RUN2 | RUN3 | RUN4 |
|---|---|---|---|---|
| Cultivation | Heavy | Heavy | Heavy | None |
| m | .5 | .5 | .5 | 1 |
| n | 1 | 1 | 1 | .3 |
| Soil humus in A | 50000 | 50000 | 50000 | 33000 |
| Dynamic OM in A | 1600 | 1600 | 1600 | 1400 |
| Soil humus in B | 24000 | 24000 | 24000 | 19000 |
| Dynamic OM in B | 1000 | 1000 | 1000 | 1000 |
| Input in litter | 800 | 1200 | 6400 | 3000 |
| Input in roots | 1200 | 2000 | 2000 | 3000 |
| Quality of debris | .7 | .7 | .75 | .79\.2 |

N.B. The two values for quality of debris used in run 4 are similar to Jenkinson's model which assumes herbaceous vegetation for the first 25 years, changing to woody plants in the latter 25 years. This is reflected by a "blip" in graph for run 4 presented in Figure 4.9

The value "m" refers to the effect of cultivation on the macrobiomass, a value of 0.5 referring to heavy cultivation, a value of 1 meaning no cultivation has taken place. "n" represents the effect of cultivation on the decomposition process. A value of 1 under the ploughed regime suggests that the decomposition of organic matter is faster than that under the uncultivated regime represented by a value of 0.5. The results of the 4 runs are presented in Figure 4.9.

Several points are raised by the 4 model runs. Firstly the generally low rates of change in organic matter within the B-horizon, even when large amounts of organic matter are being added to the surface. Secondly, under annual cultivation, high output systems maintain the soil organic matter at an elevated level because of the increased return of plant debris and root material associated with the higher yields. A comparison of the output of MOVEMOD in relation with the Rothamsted model is provided in Table 4.3.

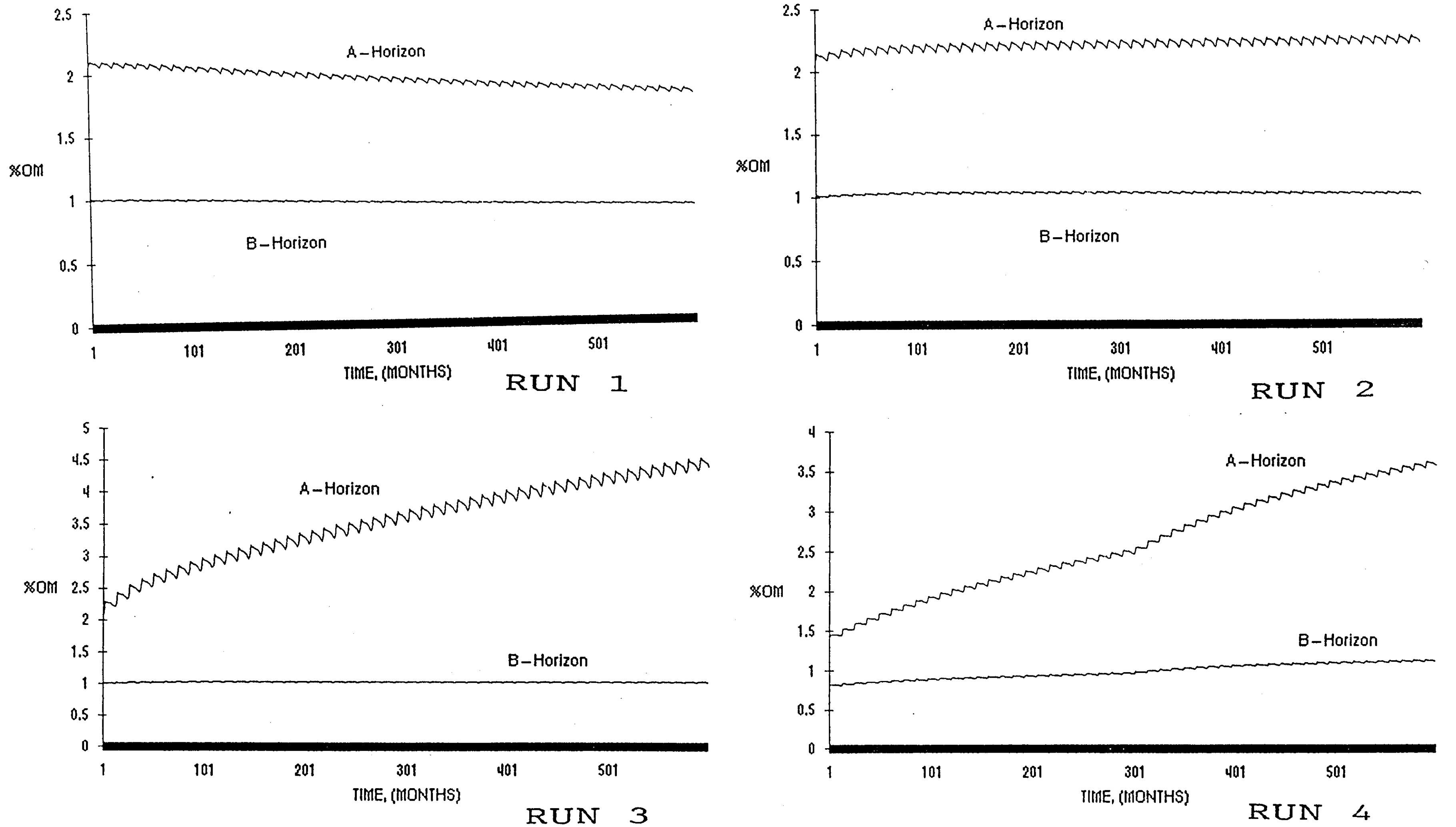



Figure 4.9 : Model validation for the A-horizon based on 4 model runs,

Table 4.3: A comparison of the changes in organic matter over 50 year runs of MOVEMOD in comparison with estimates taken from the Rothamsted model discused by Jenkinson 1990,

| | Rothamsted model A-horizon | | MOVEMOD A-horizon | | MOVEMOD B-horizon | |
|---|---|---|---|---|---|---|
| | start | end | start | end | start | end |
| RUN 1 | 2.06 | 1.92 | 2.06 | 1.78 | 1.0 | 0.89 |
| RUN 2 | 2.06 | 2.33 | 2.06 | 2.21 | 1.0 | 1.01 |
| RUN 3 | 2.06 | 4.26 | 2.06 | 4.41 | 1.0 | 1.02 |
| RUN 4 | 1.37 | 3.57 | 1.37 | 3.58 | 0.8 | 1.12 |

**N.B.** The figures for the Rothamsted model were obtained assuming a carbon to organic matter conversion factor of 1.72, with an estimated 250000 kgs of soil in the top 20cm. Starting organic matter levels for the B-horizon are based on estimates for the Broadbalk plots of 1% in the 23 to 46cm horizon, (Jenkinson 1990).

Although the output from MOVEMOD does not correspond exactly with that of the Rothamsted model the validation illustrates that the changes are in the right direction and of similar magnitudes. MOVEMOD differs from the Rothamsted model in that it allows exploration of the effects of specific changes in cropping practice on the amounts and vertical movement of soil organic matter.

## 4.15 SENSITIVITY ANALYSIS,

It is beyond the scope of this chapter to display sensitivity analysis for all of the variables used during the compilation and subsequent testing and running of MOVEMOD. However, the sensitivity of output to changes in variables for which little or no research information was available, and which "best estimates" had to be utilized are included below, these are:

1. Movement of surface debris to the A horizon in arable soils,

2. Movement of organic matter from the cultivated into the uncultivated layer, (from A to B),

3. The decomposition constants assumed in the B horizon

4. The rooting pattern, with respect to the splitting of roots between the A and B horizons.

### 4.15.1 Movement of surface debris to the A horizon,

In soil that is ploughed or disced, organic matter is automatically mixed into the A horizon. However, when no cultivation takes place organic matter is moved into the surface horizon due to the direct or indirect activity of the soil animals, (see section 3.4). It is assumed in the base model run that each kilogram of macrobiomass in the soil is capable of moving 4 kilograms of organic matter from the surface in a year. This figure was derived from rather scanty research evidence, (see section 4.11.2). A sensitivity analysis was undertaken assuming 3 rates of movement from the surface to the A horizon: 2, 4 and 6kgs/ha/year. The starting parameters for each run are those of Run 2, (see 4.14.2), although using an uncultivated rather than a cultivated regime. The results of a model run over 50 years on the soil organic matter in the A-horizon are presented in Figure 4.10.

The runs suggest that soil organic matter content of the A-horizon is not particularly responsive to the rate at which the macrobiomass move plant debris from the surface. The straight line under the 3 model runs represents the same system under a cultivated regime, suggesting that the increase in soil organic matter in the A-horizon in Figure 4.10 is also a function of the reduced rate of decomposition of the existing organic materials due to the absence of cultivation.

### 4.15.2 Movement of organic matter from the cultivated into the uncultivated layer, (from A to B),

It is assumed in the base run of the model that each kilogram of macrobiomass move only a tenth as much material from the A to B horizons as they do from the surface into the A horizons. Quantitative research data on movement of organic material by deeper burrowing animals, i.e. earthworms, is difficult to isolate. Figures 4.11 a & b demonstrate the effects of doubling or halving the assumed rate of transfer by macrobiomass using the conditions in Run 2 of the model validation in both a cultivated and no- till situation, (see section 4.14.2)

Figures 4.11 a & b illustrate soil organic matter in the B-horizon is affected by the value imputed for the rate at which macrobiomass can move organic matter from the A to B horizons. However, the differences are small, even under a no-till regime, reinforcing the notion that soil organic matter in this deeper B-horizon is not very responsive to change in the relatively short period simulated by the model.

### 4.15.3 The decomposition constants assumed in the B-horizon

The decomposition constants assumed in the B-horizon of the model base run are half of the value of those in the A-horizon, which are derived from Jenkinson (1990). These values were selected because decomposition progresses at a slower rate in the deeper soil horizons, (see Table 3.5). The model was run to test the sensitivity of organic matter in the B-horizon to values assumed for the decay constants. Three values for the decay constants are used based on those presented in Table 4.3. These were either double or halved to give low, medium and high values. The results of the three runs on the soil organic matter in the B-horizon are presented in Figure 4.12

Figure 4.12 suggests that soil organic matter levels in the B-horizon are sensitive to the values used for the decay constants. However, the runs suggest that the "medium" values used in the model base run are sensible. Large fluctuations in the soil organic matter in the B-horizon would not be expected under the starting parameters used in Figure 4.12.

Figure 4.10 : Sensitivity of soil organic matter in the A-horizon to three possible movement rates by macrobiomass under a no-till regime,

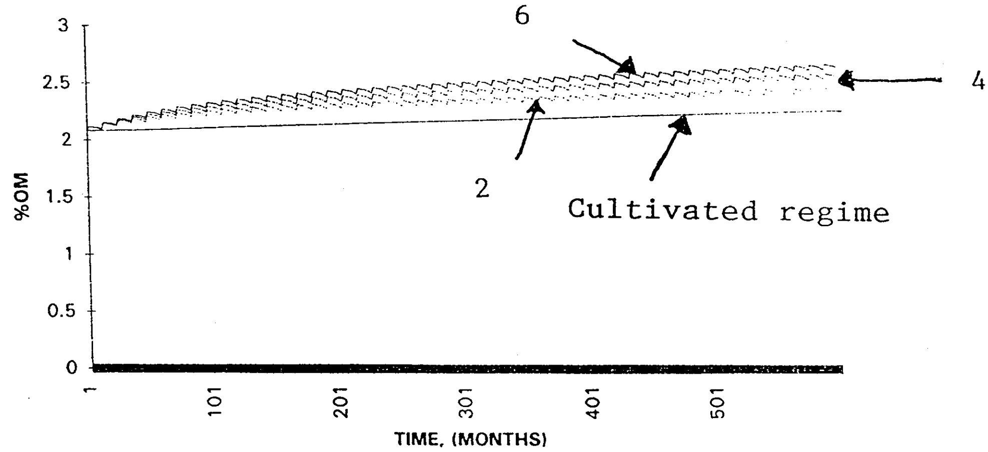
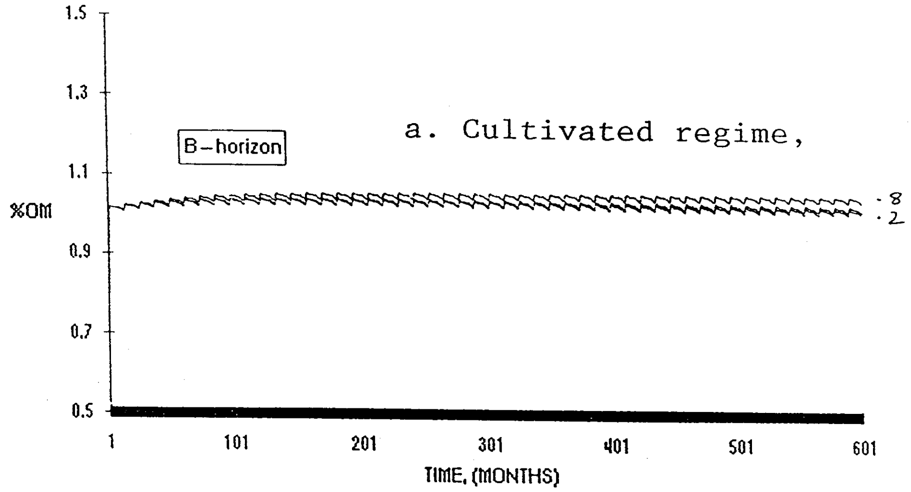
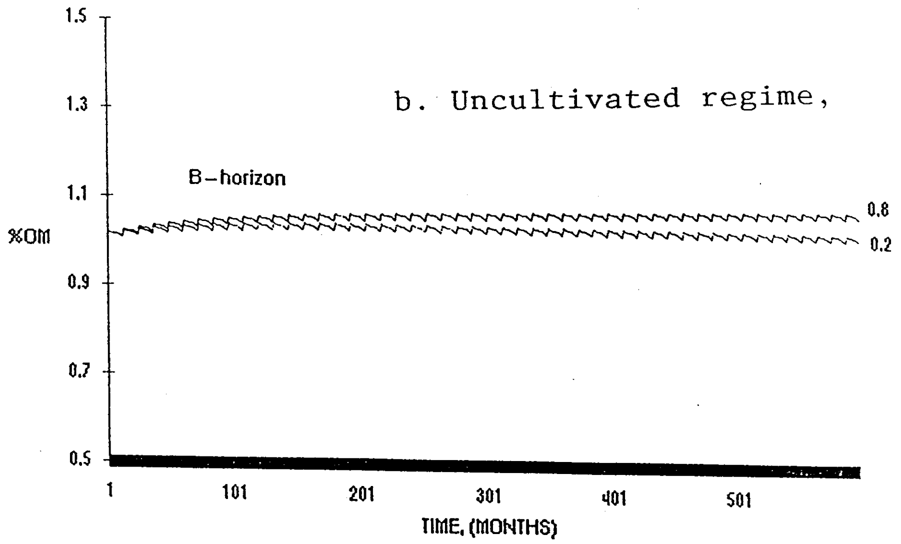



Figure 4.11 Varying rate of movement by macrobiomass from the A to the B horizon,



### 4.15.4 Rooting patterns

Rooting patterns and distribution vary considerably depending on the species of plant being grown and the soil and climatic conditions. The variation and difficulties in recording rooting attributes have already been discussed in section 3.8.2. The base model assumes that 75% of the root material is returned into the A-horizon, and 25% into the B-horizon. Figure 4.13 demonstrates the effect of varying root distribution within the A and B horizons on the soil organic matter in each. Starting parameters from Run 2, (see 4.14.2) are used. The figure shows data based on a 50:50, 75:25, and 87.5:12.5 split of roots between the A and B horizons. The results of the three model runs suggests that root distribution can have an influence on the soil organic matter content of both the A & B horizons in the long-term. However, the base value of 75:25 probably represents a best average for a wide range of crop types growing in variety of soils.

## 4.16 THE POSSIBILITY OF INCREASING SOIL ORGANIC MATTER CONTENT WITHIN EXISTING AGRICULTURAL SYSTEMS, (AIM 1)

It was suggested in Chapters 2 and 3 that some soils in England and Wales are already very low in organic matter and continued depletion of others may make continued cropping in some regions difficult. This section investigates whether soil organic matter can be increased on cultivated soils, and if so at what rate. Three mechanisms for manipulating organic matter are investigated: the quantity of debris, the quality of debris and the rooting system.

### 4.16.1 Quantity of plant material returned,

Soils that are continuously cultivated tend towards a soil organic matter content dependent upon the annual return of organic matter to the system. On established arable soils fluctuations in the amounts of plant debris returned to the soil will influence the level of soil organic matter. Figure 4.14 illustrates the effect of three levels of return of plant debris each year using the starting parameters of Run 2. The three levels are:

1. Straw is taken from the field and only the stubble and chaff is returned, (1000kgs/ha),

2. Straw is incorporated from a short strawed wheat variety, (2000 kgs/ha),

3. A heavy straw crop is incorporated from a longer strawed wheat variety, (4000kgs/ha)

Figure 4.14 illustrates it is possible to gradually increase the amount of soil organic matter within the context of current farming practice, although this rate of increase is likely to be slow. (Adding 4000kgs/ha each year for fifty years only results in an average annual increase of .027% per annum increase in the A horizon. The graph supports the findings of Van Der Linden et al (1987) who suggest that

Figure 4.12 The sensitivity of the soil organic matter content of the B-horizon to changes in the value of the decay constants,

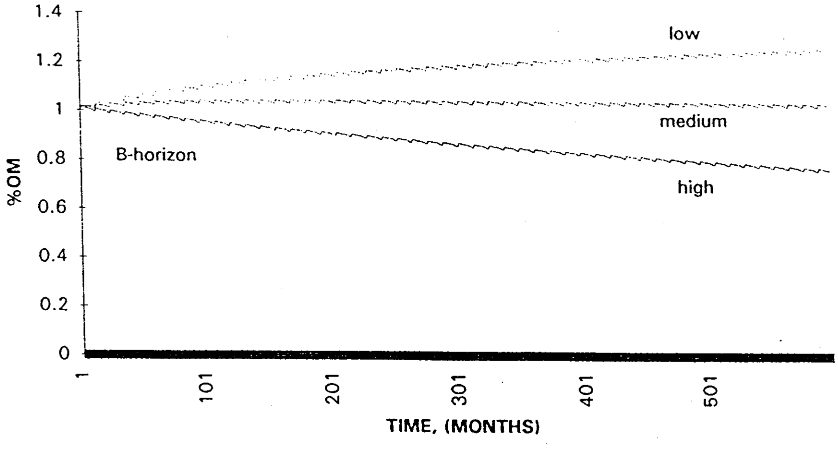



Figure 4.13 The effect of varying rooting pattern on soil organic matter in both the A & B horizons,

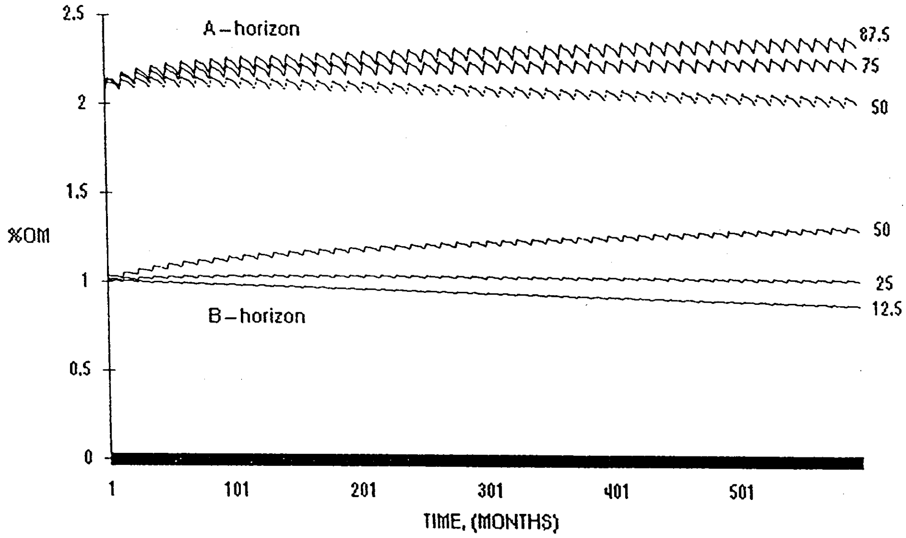
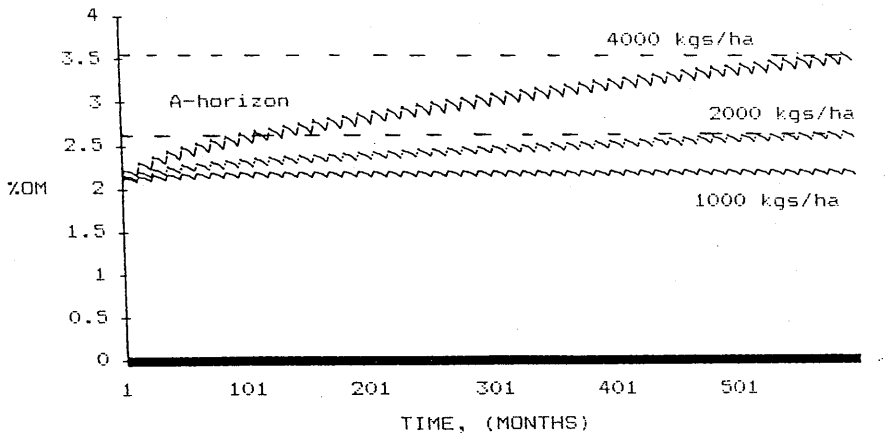



Figure 4.14 : The effect of 3 levels of straw incorporation on soil organic matter,



returning only roots, stubble and chaff to soils of reasonable soil organic matter content is unlikely to maintain this soil component. Figure 4.14 is somewhat unrealistic in that it assumes a continuous wheat cropping system, when in reality many arable farms rely on rotation. Table 4.4 illustrates input parameters for a common arable rotation which are used to produce Figure 4.15.

Table 4.4: Model input parameters for an all arable rotation.

| Rotation 1: A | 5 year all arable rotation, | | | |
|---|---|---|---|---|
| | straw | stubble/chaff | roots | quality |
| Winter wheat | 2000 | 1000 | 1800 | 0.7 |
| Winter Barley | (baled) | 1000 | 1500 | 0.75 |
| Oilseed Rape | 1500 | 800 | 1800 | 0.65 |
| Winter wheat | 2000 | 1000 | 1800 | 0.7 |
| Peas | (baled) | 500 | 1000 | 0.85 |

Figure 4.15 demonstrates that within the confines of a normal arable rotation with relatively large quantities of straw being returned to the soil three years out of five, increases in soil organic matter from a low level, (i.e about 2%), are very slow. It can be envisaged that in situation where a greater proportion of the straw is removed the return of plant debris may not even be enough to maintain the already low levels of soil organic matter.

### 4.16.2 Quality of plant materials returned

Plant residues containing less nitrogen or high proportions of lignin and hemicellulose initially decompose less rapidly within the soil. In the agricultural context there are problems associated with returning large amounts of residues of low quality to the soil. Firstly, because they decompose slowly they only release nutrients at the same slow pace. Secondly because they tend to have high carbon : nitrogen ratios the microorganisms temporarily "lock up" any available nitrogen during the decomposition process, (see section 3.8.1). This has lead to claims that the efficiency of applied nitrogen is subsequently reduced, and crop growth inhibited. Figure 4.16 shows simulated build up of organic matter using starting parameters from Run 2 in section 4.14.2 and three differing qualities of plant debris:linseed, (0.5), wheat, (0.7) and pea, (0.9).

Section 3.8.1 suggested that the quality of residue added had little effect on the carbon remaining within the system after a long period of time. The model output agrees with this, suggesting the manipulation of the quality of residues added to the soil may be a poor method of increasing the organic matter content of the soil. However, the model suggests that poorer quality residues could contribute slightly more to the soil organic matter, although addition of these residues may have a larger detrimental effect in the short term as free nitrogen will be taken up rapidly by microorganisms during the initial decomposition stages.

Figure 4.15 : The effect of an all arable rotation on soil organic matter levels in both the A and B horizons over a 25 year period.

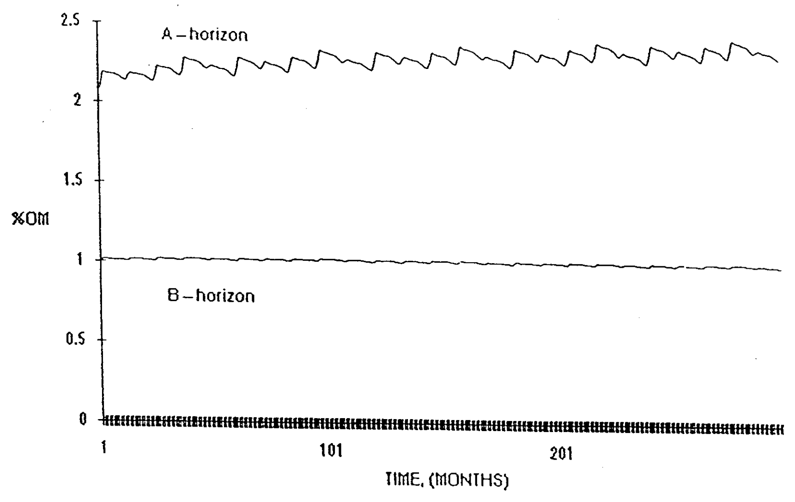



Figure 4.16 The effect of changing the quality of plant debris on soil organic matter over a 50 year period,

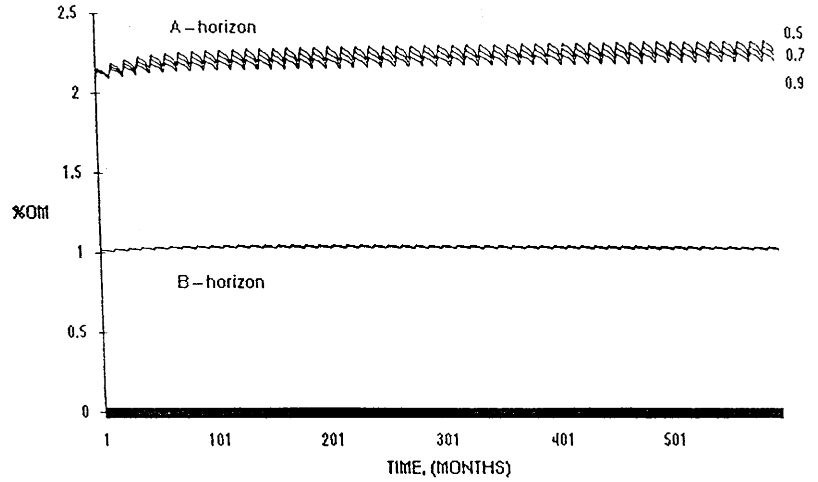
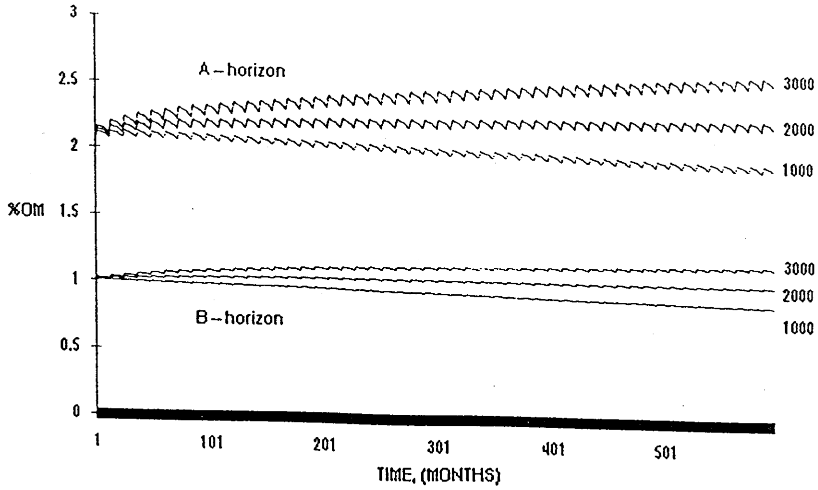



Figure 4.17 The possibility of manipulating return of organic matter to the soil via rooting systems.



### 4.16.3 Variation in the weight of root material returned to the soil,

The sensitivity analysis undertaken in section 4.15.4 demonstrated that rooting pattern can have an effect on the amounts of organic matter in both the A and B horizons. Assuming a ratio of 75:25 for roots in the A & B horizons the possibility of manipulating soil organic matter by using crops with varying "weights" of rooting systems is investigated in Figure 4.17. Input values from RUN 2 in section 4.14.2 are used with three levels of root input: 1000kgs/ha, 2000kgs/ha, 3000kgs/ha. The results of this model run illustrate that weight of roots can effect soil organic matter. Of interest is the possibility of increasing or maintaining deeper soil organic matter by the selection of appropriate crops. Root growth develops in tandem with above ground growth, indicating that high output systems may help to maintain soil organic matter in cultivated systems. This agrees with figures adapted from Glendining and Powlson (1990)- see Table 3.2, and suggests if the land is going to be annually cultivated, soil organic matter is best maintained by growing high yielding healthy crops.

## 4.17 THE IMPACT OF SURFACE CULTIVATION ON THE MOVEMENT OF ORGANIC MATTER THROUGH THE SOIL PROFILE, (AIM 2),

It has been shown that organic matter found deep in the soil can be of considerable age, (Jenkinson and Raynor 1977), and that its dynamics are slower than surface materials. Very little data has been found to represent the movement of organic materials down through the soil, and the mechanisms are not well documented. Similarly data for the movement of organic matter from the surface under no-till arable regimes is not well documented. Time series data over long periods that records changes of soil organic matter in both the surface and deeper soil horizons is scarce. This is partly because of the time and difficulty involved with assessing and recording changes below the surface.

As discussed earlier in Chapter 3 cultivation is one of the primary methods through which agricultural activity influences soil organic matter, both mixing surface debris within the soil and enhancing decomposition. Figure 4.8 demonstrated the effects of cultivation on virgin soil leading to a rapid loss of soil organic matter due to oxidation and subsequent microbial attack. However, cultivation is necessary in the majority of arable systems to bury large amounts of surface trash which would otherwise act as a barrier to germination of the subsequent crop, or provide a medium for the carry over of disease. This has become increasingly necessary following the straw burning ban in 1992. This suggests that in an annual cropping system, if cultivation does not take place, only a small amount of debris should be returned to the surface to avoid a build up of this material. Large amounts of debris can be incorporated using cultivation, which in itself affects soil structure and the soil organic matter content, (Balesdent et al 1990, Raw 1962). Figure 4.18 demonstrates a system in which high levels of plant debris, (4000kgs/ha), are returned to the soil surface each year under a cultivated regime, compared with an uncultivated system with only 800kgs of plant debris returned each year.

Figure 4.18 demonstrates that soil organic matter levels can be increased in the A horizon with only small inputs of surface debris. To maintain a similar level of increase under the cultivated regime a higher level of plant debris return each year is required. However, it is of interest to note the differences in the weight of macrobiomass under each regime. The model suggests that although the return of debris is considerably less in the no-cultivation example, the macrobiomass population is maintained at a higher level because of the absence of cultivation, see Figure 4.19. The effect of including periods of no-cultivation in a rotation on the soil organic matter are highlighted in Figure 4.20 which compares the arable rotation in Table 4.4 (previous section) with a longer 8 year rotation in which a 4 year temporary ley is included, see Table 4.5.

Table 4.5: An 8 year mixed grass/ arable rotation,

| | straw | stubble/chaff | roots | quality |
|---|---|---|---|---|
| Winter wheat | 2000 | 1000 | 1800 | 0.7 |
| Winter wheat | 2000 | 1000 | 1800 | 0.7 |
| Winter Barley | (baled) | 1000 | 1500 | 0.75 |
| Oilseed Rape | 1500 | 800 | 1800 | 0.65 |
| | | Dead leaves | | |
| Temporary grass clover ley | 0 | 3000 | 2500 | 0.85 |

Figure 4.20 illustrates that the inclusion of grass in the arable rotation can significantly boost the levels of soil organic matter in the A-horizon over a relatively short time period of 25 years. This is due to the absence of cultivation during the period of the ley, the relatively high return of plant debris to the soil surface, and the continuity within the soil system which is provided by the perennial grass plant. Unfortunately there has been, and continues to be a gradual decline in mixed farms, i.e those growing crops and carrying stock. The need for grass leys in the traditional arable areas of the UK is therefore diminishing.

## 4.18 THE EXTENT TO WHICH AGRICULTURAL ACTIVITY INFLUENCES THE SOIL ORGANIC MATTER IN DEEPER HORIZONS, (AIM3),

The construction of the movement model has involved the simplification of what is an extremely complex system. The effects of cultivation practice on the decomposition of materials within the soil is well documented, however little is known about the rates of movement of organic materials through arable soils. Cultivation on the surface has impacts on the deeper soil structure. The formation of physical pans within the soil due to the effect of heavy cultivation are well known, as are the impacts of cultivation on soil animals, i.e. earthworms. Less well documented is the subsequent effect of cultivation on the distribution of organic materials within the soil. The development MOVEMOD has indicated a lack of information concerning the rates of

Figure 4.18 The interaction between cultivation, return of plant debris and soil organic matter,

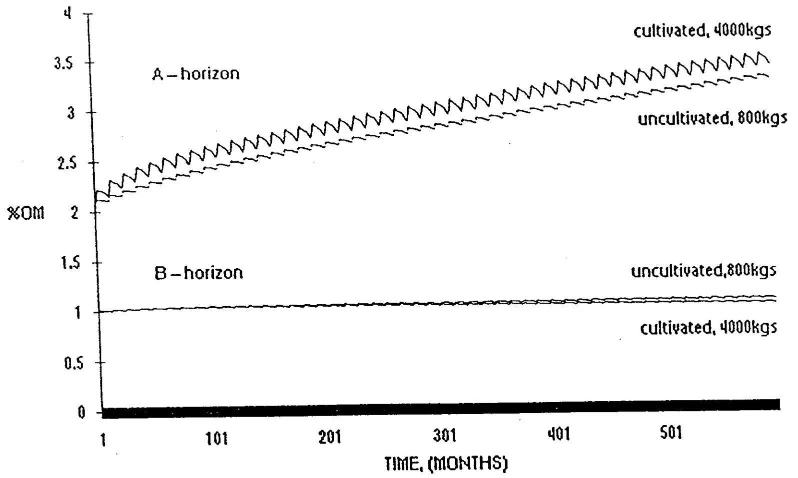



Figure 4.19 . Comparison of Macrobiomass populations under cultivated and uncultivated regimes,

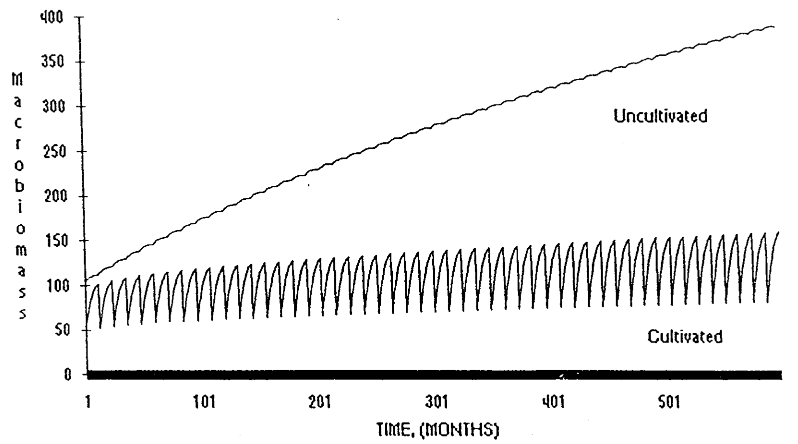
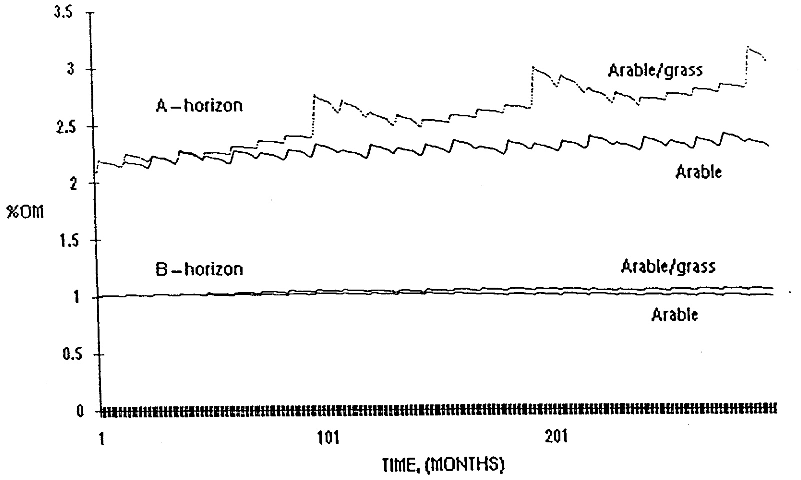



Figure 4.20 The effects on soil organic matter of including a period of no-cultivation within an arable rotation.



movement of organic materials from the surface soil into deeper horizons in agricultural systems.

However, surface cultivation, the quantity and quality of plant debris returned to the soil appeared to have little effect on the organic matter in the B-horizon. Increasing the amount of macrobiomass, or the rate at which they move material between the A and B horizons had little effect on the soil organic matter in the deeper horizon. Figure 4.20 demonstrates the importance of the values assumed for the decomposition constants used in the B-horizon, although at the same time suggesting that the approximations used in MOVEMOD are acceptable because runs mirror the slower changes in soil organic matter generally observed in the deeper soil horizons.

Rooting depths and patterns were shown to have an impact on the organic matter found in these deeper horizons. However, root growth is extremely varied even under what appear to be similar conditions, i.e one variety of wheat in a given field. Figure 4.13 and Figure 4.17 both demonstrated that the amount of root material entering the B-horizon is one method in which soil organic matter in this horizon could be influenced. Many agricultural crops can root to considerable depths, (see section 3.8.2), suggesting that where soil conditions are suitable, rooting is the major mechanism for the "movement" of organic matter into the deeper horizons. However, in situations where shallow rooting crops are grown continually, or where agricultural activity inhibits root development, (i.e the formation of pans or waterlogging), this deeper soil organic matter will gradually be depleted.

## 4.19 THE POSSIBILITY OF USING CARBON OR SOIL ORGANIC MATTER AS AN INDICATOR OF CHANGE, (AIM4)

It was suggested at the start of Chapter 3 that soil organic matter may provide a guide as to the current state of an agroecosystem and possibly act as an indicator of the effects of a change in agricultural practice on the agroecosystem as a whole. Investigations of soil organic matter dynamics, aided by the construction of MOVEMOD suggest that soil organic matter provides a useful indicator of the present state of the soil system. Soil organic matter has been shown to be associated with many agroecosystem processes and it is a constituent of the agroecosystem whose dynamics are affected by many aspects of agricultural practice. However, simply measuring the amount of soil organic matter gives only a static indicator informing little about its dynamics within the soil. Further, changes in soil organic matter in established arable land are generally slow, (see Figure 4.14).

The use of soil organic matter as an indicator as to whether a change in cropping practice is beneficial with respect to agroecosystem processes is of limited use in the short-term. It would be better used in combination with short-term indicators which are more responsive to changes in agroecosystem processes. The use of soil organic matter as an indicator is further complicated by the number of factors that can influence its dynamics within the soil, and the small annual changes recorded by the model could simply be a result of differing climatic conditions within a given year.

### 4.20 CONCLUSIONS: MANAGING SOIL ORGANIC MATTER WITHIN CURRENT AGRICULTURAL SYSTEMS,

In recent years there has been a move away from mixed farming in which grass would have been a part of many rotations. Most arable farmland is now cultivated annually and in some instances this has lead to the depletion of soil organic matter to low levels. The model confirms that annual cultivation is a main determinant in the levels of soil organic matter. If soil organic matter is to be maintained at reasonable levels on soils that are annually cultivated, the model suggests that the return of organic matter needs to be considerably higher than just the roots, stubble and chaff of cereal crops. If cultivation does not take place or the intensity of cultivation is reduced then the soil organic matter can be maintained by the return of smaller amounts of plant debris, and indeed this is desirable to avoid the build up of surface debris.

A trade off exists between the incorporation of organic matter by cultivation and that undertaken by soil animals. These processes substitute rather than enhance each other. If large quantities of organic material are returned to the soil surface, (i.e. following the ban on straw burning), then, within the context of annual cropping, some form of cultivation regime will need to be adopted to keep the surface clear for the next crop. This has two effects:

1. Some of the macrobiomass capable of distributing the organic matter below the soil surface will be killed as a result of cultivation and their activity temporarily disrupted,

2. Any surface plant debris is mixed evenly to cultivation depth, (say 20-30cm if ploughed), thus negating the "effort" that would have been required in a no-cultivation regime to move the surface material to that depth.

This has implications for the organic materials moved into the sub-surface soil by the macrobiomass. i.e. In soils of low organic content, cultivation is likely to have little impact on the amount of debris moved by macrobiomass down into the deeper soil. This is substantiated by the model. The other main mechanism for incorporating organic materials into the soil is via the root system. Section 3.8.2 demonstrated that rooting systems vary considerably in their distribution and their overall weight. Figures 4.13 and 4.17 illustrated that rooting patterns can have an effect on the distribution of organic matter throughout the soil profile, and selecting plants which have a greater weight of deeper roots may be one of the few mechanisms available to alter the distribution of organic matter throughout the horizons of arable soils, although many variables are involved in rooting patterns.

Section 3.9 highlighted concern regarding the organic content of some of the soils within England and Wales. However, it is still economically viable in the short-term to offset the effects of low soil organic matter with a range of input options. Whether this cropping policy is having any long-term deleterious effects is uncertain. If low soil organic matter is leading to the accelerated erosion of soil it is unlikely that such cropping policies are sustainable. The model suggests that within the context of present arable cropping the scope for increasing the amount of organic matter within the soil is limited, and even where it does exist the rate of increase may be slow, (see Figure 4.14). The replacement of deeper soil organic materials is even more difficult, and little is known about the effects of the gradual depletion of this old organic store on the (agro)ecosystem as a whole. In the context of earlier discussions, (see Chapters 2 and 3), continual arable cultivation appears to lead to a decrease in volume of organic structure.

Annual cultivation is a major determinant in organic matter dynamics as is the quantity of material returned to the soil each year. If it becomes desirable to increase the soil organic matter in some soils these two "inputs" to the system will require close scrutiny. In these situations some form of perennial cropping may be desirable as this limits the degree of soil disturbance and allows the reestablishment of a healthy detritus community. However, at present the replacement of productive annual systems with perennial systems is financially unfavourable. Whereas only a small percentage of the soils of England and Wales contain very low levels of organic matter, there are regions in which soils are vulnerable to organic matter depletion. In these areas it is appropriate to be aware of soil organic matter dynamics and to maintain this asset, at least at its current level. The model illustrates that once depleted, soil organic matter is a resource that is replaced slowly. Appropriate soil management, considering cultivation, quantity and quality of organic material returned to the soil, and the rooting capabilities of crops should ensure long-term productivity from the UK's valuable soil systems.

The development and use of the model suggests that further research could be usefully carried out in the following areas,

1. The dynamics of the actual movement of organic materials down through the soil profile in a range of cultivated and no till arable systems,

2. The role and relative importance of deeper organic materials in agroecosystem processes,

3. The degree to which an active soil detritus community can replace soil cultivation in the movement of plant debris from the soil surface.

4. The possibility of manipulating rooting characteristics to increase soil organic matter levels.

It was suggested in Chapter 2 that the investigation of carbon flows and structure could be used as a method for exploring the impact of agricultural activity on the agroecosystem. The development of MOVEMOD has lead to the investigation of a variety of processes within the agroecosystem, particularly the soil. It has enabled and required the acquisition and collation of information from a number of sources. In this context the compilation of the model has provided an excellent learning process. The model has raised issues about the rates of movement of organic matter through the soil system, and questioned the importance of deeper processes within the soil. The evolving agroecosystem can certainly be viewed from one perspective as a changing carbon structure, although the model suggests that in well established agroecosystems these changes are at best sluggish at the surface and much slower below the surface. Thus whilst soil organic matter may provide a long-term indicator of the state of the agroecosystem, its use as a monitor of short-term change is limited.

# CHAPTER 5: USING SOIL INVERTEBRATES AS A MEASURE OF HUMAN IMPACT ON THE AGROECOSYSTEM,

*"At this stage, (of current knowledge), the best approach would be to assess populations and biomass of major groups of biota without attempting to record data on all individual species present in a given ecosystem", Pimentel et al (1980)*

## 5.1 INTRODUCTION AND SUMMARY

In the previous chapter a soil organic movement model, MOVEMOD, was used to demonstrate the effects farming activities can have on the organic matter content of the soil. The chapter concluded that soil organic matter is a useful measure of the current state of a soil, although its use as an indicator of change in the short-term may be limited by the slowness of change of this soil component on arable land. Further, measuring only soil organic matter content highlights little about the processes or the functional diversity within the soil. Bodysize spectra are finding increasing credence as a measure of the impact of human activities on the (agro)ecosystem.

There is considerable research interest in the use of size based spectra of one part of the "community" to provide information about the ecosystem as a whole. Since predation is size dependent, bodysize spectra link with established research associated with food webs and research on energy flows in ecosystems, (see Chapter 2). Chapter 3 highlighted the importance of soil invertebrates in agroecosystem processes which were developed and demonstrated in the modelling chapter, (Chapter 4). The principle underlying the experiments undertaken in this chapter is to use simple bodysize spectra of soil invertebrates as a proxy measure for the quantity and diversity of the fauna which reflects the overall condition or health of the agroecosystem in which the measures are taken. These experiments are seen to complement the discussion undertaken in Chapter 3 and the development of MOVEMOD in Chapter 4, in the exploration of the second interface within the thesis which links farming activity to agroecosystem processes.

The experiments were undertaken to test the hypothesis that bodysize spectra could be used:

1. To differentiate between differences in cropping practice with respect to their impact on the agroecosystem,

2. As a simple measure of the biological processes within the soil that could be incorporated in wider scale soil monitoring schemes.

The Broadbalk long-term trials at Rothamsted were identified as a suitable site for sampling because of their long recorded history. Two sets of sampling were undertaken in the spring and autumn of 1991. These experiments were designed to provide exploratory tests of a measurement technique that could, if successful, be used later on agroforestry trials, (see Chapter 6). It is concluded that bodysize techniques can be used effectively to differentiate between quite small differences in cropping practice, although the techniques and the theoretical knowledge upon which they are based need further development.

## 5.2 SOIL ANIMALS AS A MEASURE OF AGROECOSYSTEM IMPACT,

Chapter 4 demonstrated the mechanisms by which agricultural practice can impact on the soil system, illustrated via the use of a soil organic matter movement model. MOVEMOD demonstrated that changes in soil organic matter can take place over considerable time periods, particularly the replenishment of organic matter on arable farmland. In the short-term the analysis and recording of organic matter may be an inappropriate measure of changes in soil processes due to modification in farming activity. The model illustrated the key role of soil fauna and flora in the processes of movement and decomposition within the soil and this raised the possibility of using them to provide an indicator of the impact of farming on agroecosystem processes. Hole (1981) in a review of the effects of animals on the soil suggests they may serve as,

*"A sensitive indicator of the states of soils and the impacts of environmental changes."*

The investigation of the role of soil fauna and flora in agroecosystem processes is not a new concept. For instance research has been undertaken to study the micro-organisms in the soil, (Swift et al 1979, Lopez-Real and Hodges 1986), invertebrates, (Edwards 1984, Madge 1981, Coleman and Hendrix 1988) and larger invertebrate such as earthworms, (Edwards and Lofty 1980,1982, Lee 1985, Clements et al 1991). Recent research work being undertaken by El Titi (1992) in Germany uses several bioindicators, (earthworms, mites and collembola), to compare integrated farming systems with conventional systems and to monitor ecological impacts. However, some researchers consider that the processes and complexity of the relations between elements of the soil biological system are not well researched. For instance Haberern (1992) comments that,

*"Surprisingly, the intricacies of soil biology remain virtually unknown."*

It appears that although the field of soil zoology, (see Wallwork 1976), has investigated the effects of environment on animals the way animals effect the soil is a much less investigated field. (Of 130 detailed pedon descriptions in the US, only 22 note evidence of animal activity, US soil taxonomy 1975). Commenting on environmental quality, Thompson (1992) states,

*"...information on the faunal populations of British soils is either scant or dispersed, and this for a resource on which we rely for food, timber and many more basic ecological functions."*

This lack of biological research into the soil is highlighted by Golley(1986) who comments about ecosystem ecologists, *"they have reasoned from a perspective of physics when energy flow is concerned and chemistry when nutrient cycling is of interest .....This has given ecosystems ecology a peculiarly non biological character."*

As discussed in Chapter 2, the impact of Lindemans (1942) paper, "The trophic-dynamic aspect of ecology," focused ecological research for the next 30 years on the energy fluxes between trophic levels. The end of the International Biological Programme, (IBP), which relied greatly on trophic level approach, has been highlighted as having limitations. Instead of reappraising ecosystem studies many ecologists moved away from research into big ecosystems to the

*"minutiae of predation or simple interactions between parasite and host", Cousins (1985).*

This left the central problem of assessing ecosystems, or ecosystem components containing many species, open.

**5.2.1 The importance of bodysize,**

Despite a general move away from the study of large ecosystems, ("big ecology"), marine biologists refocused on Charles Elton's earlier work on the "pyramid of number", (Sheldon et al 1972, 1973, Thiel 1975, Platt 1984). Elton's classical study at Spilzbergen in 1921, (Elton 1927), described the animal community as a pyramid of number, in which size was an important feature which determined whether one animal could prey on another. Platt (1984) summarizes the reasons for rekindled interest in bodysize measurements,

*"Once a size based spectrum has been constructed for a particular sample or station, we already have considerable potential information about the physiology of the community"*

This sampling of one part of the ecosystem in a community is discussed by Stork and Gaston (1990) in relation to estimating biodiversity. They argue that our knowledge of world species is far from complete but,

*"Detailed knowledge of the number of species in one group might then allow us to estimate the diversity in others."*

They go on to briefly mention the increasing interest in bodysize as a useful measure. This interest is reflected in a recent review by Cocklin et al (1992) who note that biotic size spectra are finding increasing credibility as a means of environmental monitoring, and when combined with data about species richness and biotic composition may provide a useful guide as to the cumulative effect of human activity. Similar views are expressed by Friend and Rapport (1990).

Terrestrial data collection to illustrate the Eltonian pyramid is difficult to isolate, as accurate bodysize analysis across a total community is a massive task. Peters (1983) recognises this and suggests that there is no intrinsic flaw in a "partial approach" providing the limitations are recognised, i.e. that the part analysed does not necessarily behave like an entire community.

The importance of size based principles are better developed in marine ecosystems with size based spectra being analysed by Sheldon 20 years ago, (Sheldon et al 1972, 1973). This is mainly because the use of automatic particle collectors make such analysis easier. Research carried out by Damuth (1981) after studying over 650 references suggests that if details of bodysize and numbers in a portion of the bodysize range is known then assumptions could be drawn for the population as a whole. He represented this analysis in graphical form, see Figure 5.1. Ecosystem studies based on the distribution of organisms of different sizes are limited, (Anderson 1975, Persson and Lohm 1977), despite a comprehensive theoretical appraisal by Cousins (1980). Using a trophic continuum model he concludes that species diversity, energy fluxes and ecosystem *(spatial)* heterogeneity are closely linked. Recent views expressed by Cocklin et al (1992) and Friend and Rapport (1990) suggest that knowledge about the distribution of organisms of different sizes may enable us to make assumptions about the wider environment.

**5.2.2 Animal numbers, Bodysize and ecological sustainability: What can we learn?**

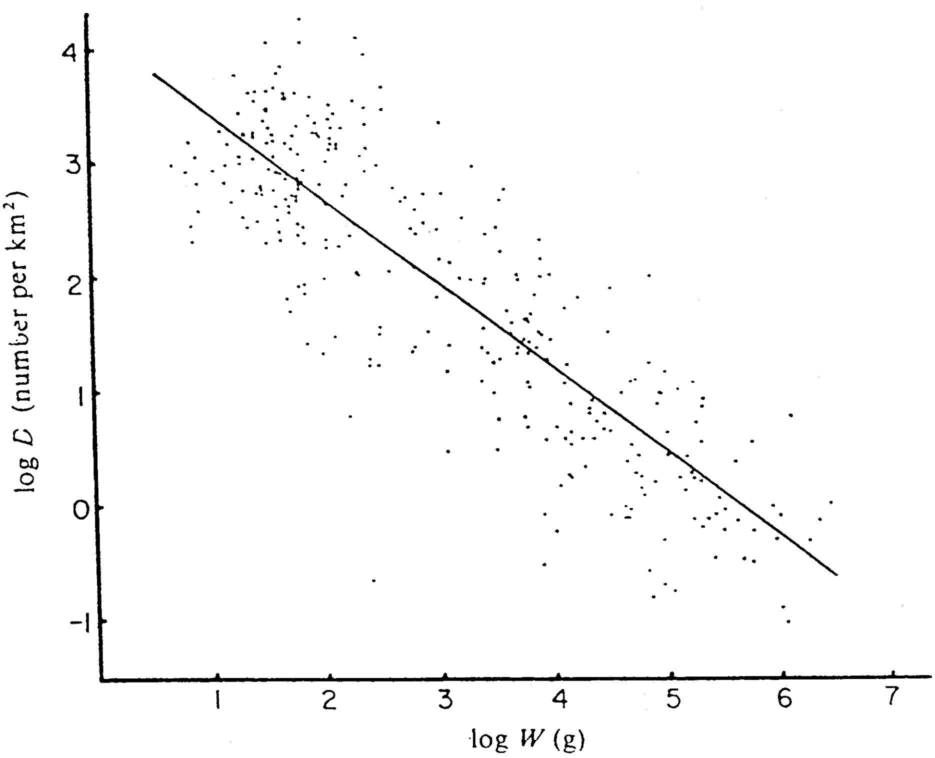
Chapter 1 and 2 discussed the concept of sustainability and this has been interpreted in terms of energy flows and sunlight interception, water and nutrient flows, and overall productivity of the agroecosystem. The measure of abundance and bodysizes within an ecological community can be linked with all of these attributes. Peters (1983) suggests that the aggregation of populations into mixed species assemblages of similar body size is a form of community analysis which should prove useful in the treating of ecosystem processes such as bioaccumulation, site productivity, energy flow and nutrient processing. This implies that the use of abundance and bodysize spectra could be useful tools in the investigation of ecological sustainability. This is in agreement with Cousins (1991) who suggests the study of bodysize classes within a given taxon.

Four possible measures can be identified:

1. **Total number of animals in particular taxonomic groups.** This is a relatively easy measure to obtain and has been used before to study differences between various farming practices, (Edwards 1984, Madge 1981). In its crudest form this provides a useful comparison which gives a general indication of community well being and is a size based methodology to the extent that taxa are each size limited.

2. **Total animal biomass.** This measure gives an indication of the total weight of animal life in the community without necessarily pin-pointing whether it is made up of a few larger animals or many smaller ones. Total biomass within a taxon can be a indicator of food supply and thus biomass accumulation, or as a measure of man's relative impact on the (agro)ecosystem.

Figure 5.1: Population density(D) compared with mean adult bodymass(W) for 307 mammal primary consumers: each point represents one species, (after Damuth 1981),




Population density ($D$) compared with the mean adult body mass ($W$) for 307 mammal primary consumers; each point represents one species. Density values for each species are the mean of the means from each locality from which data were reported for the particular species. (Data are from the literature for the years 1950–79, derived from 115 journals and numerous books, ~650 references in all.) The line represents the least-squares regression line, $\log D = -0.75 (\log W) + 4.23$; $r = -0.86$, standard error of the slope = 0.026.

**3. Average bodysize.** Animal numbers tend to diminish rapidly with increasing size and these observations have been made within numerous ecosystems, (Ghilarov 1967, Elton 1973, Thiel 1975). Where numerous small animals exist it is possible that they could support, (although they do not necessarily), a relatively high number of larger animals. However, as Peters (1983) emphasises, community processes tend to be dominated by the smaller animals. Thus,

*"Removal of larger species and individuals may have little effect on the rest of the community, and the destruction of the smallest size classes could be disastrous."*

Thus, if an (agro)ecosystem change leads to a shift in the community size based spectra to smaller animals then mass specific rates will increase. From this viewpoint smaller average size within a given taxon means that the community must process energy and nutrients more rapidly per gram of biota, but that there will be reduced integration and interactions, (Peters 1983). In deep sea benthos, Thiel (1975) hypothesises that communities based on small animal size are associated with constantly low food availability and he goes on to say that in general size distributions of soil organisms is regulated by energy budget.

**4. Graphical representation in the form of bodysize spectra.** These allow a quick visual impression of the relative population to be ascertained, giving an indication of total numbers and size. Of importance is the distribution of animals along the horizontal axis as in ecological terms the animals of larger mass are of greater significance in terms of order than the smaller ones, (Cousins 1988).

Equations exist, (Persson and Lohm 1977, Peters 1983, Jorgenson 1979), that link bodysize to a host of environmental, ecological and physiological parameters. However, these are not generally pursued in this research. The data is used mainly for comparisons between differing agricultural practices on the same site and not for absolute comparisons of such parameters as biomass production, respiration and energy fluxes across a range of (agro)ecosystems.

## 5.3 ISOLATING THE APPROPRIATE MEASURE: WHICH SECTION OF THE COMMUNITY TO INVESTIGATE?

It was demonstrated in the formulation of the soil organic matter movement model in Chapter 4 that the soil fauna play a significant role in the movement and decomposition of organic materials within the soil. For the purpose of this piece of research there was a need to isolate a group within the detritus community that could be assessed relatively simply, without sophisticated equipment. The selected measure needed to be generalizable so that the possibility exists for it to be related to wider physical and chemical descriptors of the soil in future research.

Pimentel et al (1980) strongly recommend focusing on the ecology of invertebrates as a measure of the impact of man on the wider ecosystem. They recognise that to assess all of the species at this level is probably not a possible task. The use of invertebrates as biodiversity indicators are highlighted by Holloway and Stork (1991) who note their generality of distribution, versatility, response to perturbation, statistically significant abundance and relative ease of sampling makes them suitable indicators.

The soil dwelling arthropoda amongst the invertebrates are directly involved in both the movement and decomposition of organic materials and are, (as seen in the Chapters 3 & 4), responsive to farming practice. Additionally they have the added bonus of being countable, (i.e they are large enough to see with an ordinary microscope and are not so numerous in the soil as to make accurate measurement and counting too difficult). The problem of using larger invertebrate as a measure, particularly in the smaller plots at Rothamsted, is that they are capable of moving quite considerable distances across the surface, (For instance, earthworms have been recorded as being capable of moving up to 19m in a single evening across the surface of the ground, Mather and Christensen 1988). Although soil dwelling arthropoda do move laterally the distances involved are smaller, especially within the orders Acari and Collembola which are generally the most numerous within the soil, (Wallwork 1970). For these reasons the phylum arthropoda was selected for further study as an indicator of the effects of various agricultural practices on soil processes.

Research by Persson and Lohm (1977) undertaken as part of the International Biological Programme describes the extensive use of invertebrate measurement in Swedish Grassland Soil to attain the energetic significance of Arthropods and Annelids. This provides one of the few comprehensive studies of the use bodysize spectra in relation to agricultural land. However, they make no attempt to utilize the bodysize spectra to differentiate between various cropping practices, and little evidence has been found to illustrate the use of bodysize spectra to measure the impact of a range of agricultural practice. Therefore it was necessary to investigate and develop the technique further before it could be confidently employed as an assessment technique.

### 5.3.1 Selecting an appropriate measuring methodology,

Ideally to produce accurate spectra which can be related directly to theory concerning ecological processes they should comprise of data based on bodymass. (see sections 5.2.1 & 5.2.2) Unfortunately mass measurement of individual small animals is problematic and generally time consuming, (Edwards 1967). Individual mass can be derived from accurate measurement of length and width, with subsequent conversion by species specific equations. Persson and Lohm (1977) use such equations to estimate total biomass based on a range of research work and Edwards (1967) relates weight to length for the major arthropoda orders. He states,

*" ...it is comparatively simple to measure the lengths of small animals with a micrometer eyepiece even after they have been preserved, (**i.e. following tullgren extraction**), but it is very difficult to obtain live weights of large numbers of soil animals even if they have been extracted from the soil unharmed."*

In this set of experiments two relatively simple methods of expressing the size relationships were investigated:

1. The use of length only measurements, expressed in terms of cumulative bodylength and average bodylength per animal,

2. Bodylength/bodymass equations were derived from other research work, (Persson and Lohm 1977) which in turn were used to estimate bodymass.

Part of the experimental agenda was to develop a general technique that could be widely applied by the non-specialist. The equations relied on the measurement of bodylength and the identification of the taxon to which the individuals belonged, the majority of these either being Collembola or Acarina. Invertebrates which didn't belong to these taxon were categorized by their shape and the appropriate equation used for the conversion of length to mass, (either to be elongated like most collembola, or orbital shaped like many of the mites).

### 5.3.2 Deriving equations for bodymass,

Estimated bodymass was represented by two equations derived from the research work undertaken on the energetic significance of Arthropods and Annelids, (Persson and Lohm 1977). They represent dryweight of Collembola species by the expression, (pp58)

$$\log W = \log a + b\log L$$

- (Equation 5.1 -after Persson and Lohm 1977)

W = dryweight in µgms
a & b are species specific constants
L = Length in mm

A series of values of Loga and b are listed for 13 species of collembola and these were averaged to provide a generalized expression for all collembola species.

$$\log W = 1.012 + 2.68\log L$$

-(Equation 5.2- adapted from Persson and Lohm 1977)

However, this expression gives dryweight and to convert to a fresh weight basis it was assumed that collembola on average are 32% drymatter. This figure is taken from an average figure expressed by Edwards (1967). An equation for the Acarina (mites) was also derived from the work of Persson and Lohm (1977). They provide tables, (pp120 &121) which relate liveweight and length for 41 species within the four main Acarina families, (Mesostigmata, Prostigmata, Astigmata and Cryptostigmata). An equation was imputed which was a generalized representation of bodyweight in terms of length. In this case the equation was derived by inserting values for mass and length into a computer package, (Curvefit, Lancaster Shareware) which gave the best fit geometric regression line through the set of co-ordinates.

This is expressed as,

$$W = 152 * L^{3.245} \quad \text{(equation 5.3)}$$

W = liveweight in μgms
L = length in mm

The weights in this case were already expressed in liveweight terms and thus required no conversion.

As the majority of the invertebrates identified within the soil samples are members of the orders Acarina or Collembola the above two equations convert the length to mass with reasonable accuracy for the majority of the invertebrates identified. However, for those invertebrates not falling into the above two orders the equations were used for orders of similar shape. i.e. orders shaped generally similar to Collembola, (long and thinner), or Acarina, (more orbital shaped). This allowed all of the arthropoda to be converted from length to mass with a reasonable degree of accuracy. A few of the invertebrates collected through the funnels did not belong to the arthropoda phylum and although these were recorded they were not included in the final presentation of results. These animals were all worms, either Enchytraeidae or Lumbricidae.

## 5.4 SELECTING AN EXPERIMENTAL TEST SITE,

Extensive research into the effects of agricultural practice on the soil invertebrate was undertaken by Edwards and Lofty in the 1970's and 1980's at Rothamsted Experimental Station. (Edwards and Lofty 1975, 1977, 1980, 1982). Much of their research work focused on the Classical Field Experiments established at Rothamsted between 1843 and 1856. Although their experiments provide a comprehensive overview of the effects of agricultural practice on invertebrate populations their results were only presented in terms of total numbers.

Having contacted the Entomology Department at Rothamsted a preliminary visit was undertaken to view the Broadbalk Winter Wheat plots, (one of the first Classical Experiments established in 1843), and the equipment available for extraction of soil invertebrates, (Tullgren funnel, see Appendix 3). The plots are on a slight slope of brown earth clay soils with a relatively high clay content. These plots were seen as an ideal sampling site because of the different treatments individual plots had received over a long time period. In addition to the arable plots a small area of the field has been left untouched since 1881 when it was fenced off from the main trial site. This "wilderness" area is now seen as one of the few land abandonment sites in the UK.

Subsequently, permission was applied for and granted to sample the Broadbalk plots in the spring and autumn of 1991 and to utilize the extraction facilities at the Experimental Station. At the same time contacts were made within the Biotechnology department at Cranfield to utilize their microscope facilities for recording the extracted invertebrate.

## 5.5 SAMPLING THE BROADBALK PLOTS,

The experiments at Rothamsted had three principle aims,

1. To investigate the experimental methodology associated with the extraction and recording of soil invertebrate, (with a view to using it later on silvoarable agroforestry plots, see Chapter 6)

2 To suggest appropriate methods for presenting and utilizing the results of soil invertebrate analysis,

3. To test the hypothesis that soil invertebrates can be used to differentiate between the effects of differing cropping practices on the soil system,

The spring samples were taken on the 10th June 1991, with 11 different plots being sampled, 6 samples being taken from each giving a total of 66 soil samples. The experiment was designed to analyse differences between the continuous wheat and rotation, 4 differing levels/types of nitrogen fertilization and cultivated versus uncultivated areas. Soil conditions were moist without being excessively wet.

The autumn samples were taken on the 20th September 1991. The crop had been cleared from the plots although they were still un-ploughed. Following 5 weeks of sunny weather the soil was fairly dry. Exactly the same plots were sampled as in the spring with the exception of the cut wilderness which was not resampled. Details of the plots sampled are given in Figure 5.2. The autumn samples allowed seasonal variations in populations to be investigated, however, several modifications were made to the experimental design,

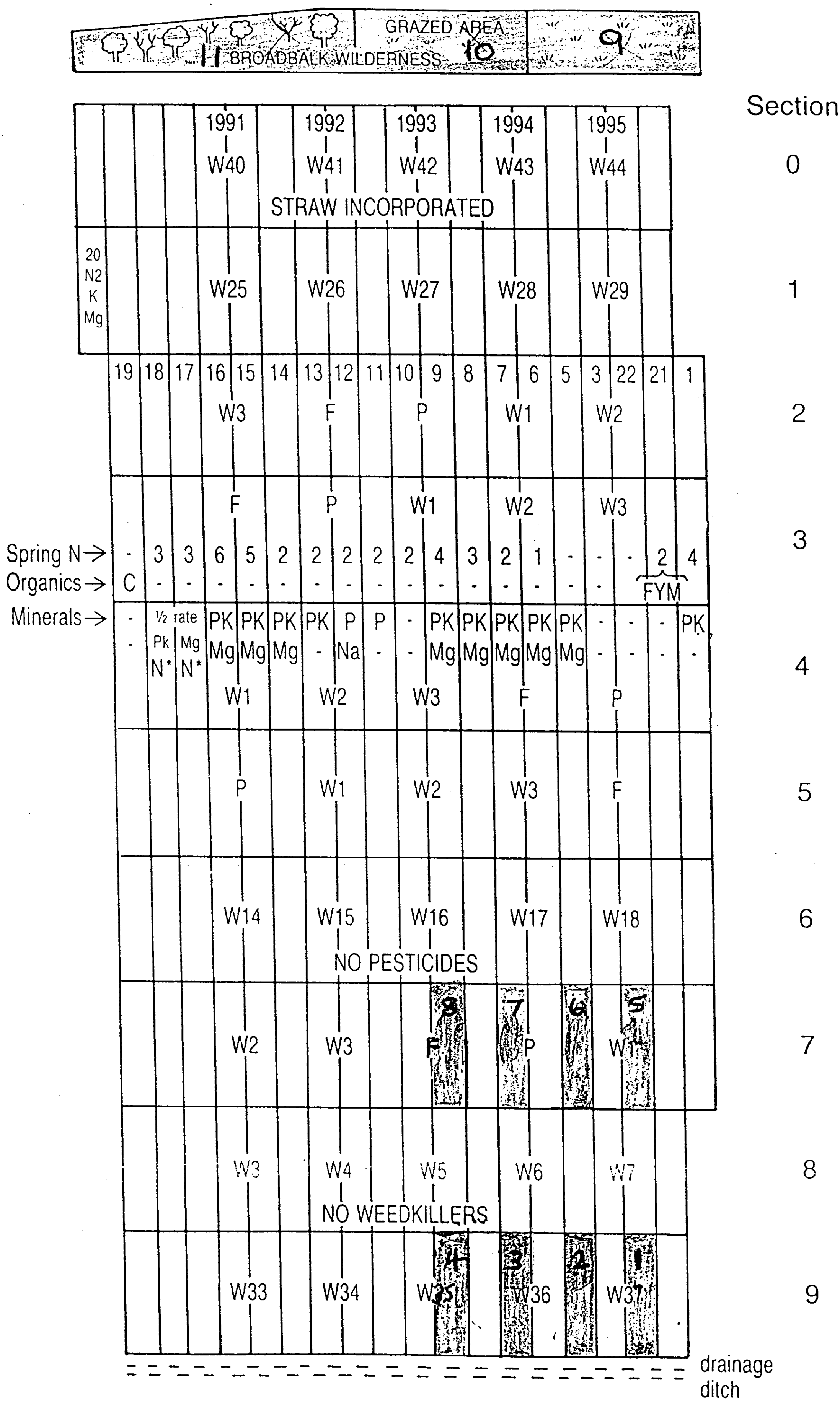
1. Samples were taken from the surface 15cm and the sub-surface 15cm to assess changes in the arthropod community with depth. This was undertaken partly to investigate the volume of structure concept raised earlier in thesis,

2. The numbers of samples undertaken at each treatment and depth were cut from six to five to facilitate quicker analysis, but also because of the restriction imposed by the number of Tullgren funnel available for use,

3. Invertebrates were measured to a greater accuracy to allow more effective statistical analysis.

In the autumn each plot was sampled 5 times at each depth, except for the grazed and wooded wilderness which were only sampled 4 times at each depth. Total number of soil samples taken was 96.

Figure 5.2 Diagrammatic representation of the Broadbalk Classical Experimental plots. The plots sampled are shaded and numbered 1 to 11, (adapted from AFRC 1991).



5.5.1 Details of the plots sampled, (Autumn and spring, see Figure 5.2)

1. Continuous wheat, (in 33th year), Farm yard manure applied at 35000kgs/ha

2. Continuous wheat, (in 33th year), No nitrogen applied

3. Continuous wheat, (in 33th year), 96 kgs/ha of nitrogen applied,

4. Continuous wheat, (in 33th year), 192kgs/ha of nitrogen

5. 5 course rotation, (fallow, potatoes, wheat, wheat, wheat),in with second wheat, Farmyard manure applied at 35000kgs/ha,

6. 5 course rotation, (fallow, potatoes, wheat, wheat, wheat), in with second wheat, No nitrogen applied,

7. 5 course rotation, (fallow, potatoes, wheat, wheat, wheat),in with second wheat, 96kgs/ha of nitrogen applied,

8. 5 course rotation, (fallow, potatoes, wheat, wheat, wheat),in with second wheat, 192kgs/ha of nitrogen applied,

9. Cut wilderness, (only sampled in the spring)

10. Grazed wilderness,

11. Wooded wilderness.

5.5.2 Extraction and recording,

A short account of the extraction and recording of the soil invertebrates is provided below. A more detailed account of the experimental equipment is provided in Appendix 3 and a review of this technique and others used in for soil extraction can be found elsewhere, ( American Society of Agronomy 1982, Southwood 1978, Edwards 1991). Samples were taken at random within each of the plots with a soil corer, 6.35cm in diameter and 15cm deep. Samples were transferred the same day into the bank of Tullgren funnels at Rothamsted. The general principle of extraction using the funnels is that heat, (from a lightbulb), is directed onto the surface of the sample causing the invertebrates in the soil to move away from the heat. This forces them out of the base of the funnel, which consists of a sieve, and into a small collecting jar which contains alcohol to preserve them. (The sieve itself places a physical restriction on the size of the invertebrates collected, in this case a 1mm sieve was used.) The samples were left in the funnels for a week for extraction, the experiment being observed daily to check each of the lightbulbs and to ensure the maintenance of a temperature differential, (which is regulated by a refrigeration unit within the room).

Care was taken to avoid smearing the sides of soil clod because this inhibits the "escape" of soil invertebrates. The heat from the bulbs dries out the soil, and unless the natural channels in the soil remain intact soil animals may well not be able to get out of the soil, and therefore will not be recorded. Once extracted each sample was analysed under a microscope, fitted with a micrometer graticule.

The number of individuals, their size and the order to which they belonged were recorded, (ie Collembola, Acarina, Thysanoptera etc). The spring samples were recorded to an accuracy of 0.25mm as initially this was thought to be sufficient for the rapid analysis being sought. However, following the compilation of results of the spring samples it was decided to measure the autumn samples to an accuracy of 0.1mm. This increased the time needed for recording each sample. Each sample took between 30 minutes and an hour to record at this more accurate level and generally not more than four samples were recorded in a day. This avoided tiredness to the eyes and boredom, both of which could add to the inaccuracy of the results. To avoid "experimental favouritism" the samples were renumbered by colleagues and the numbering scheme kept secret until after the recording had been completed.

### 5.5.3 The presentation of the results,

The results from the analysis are presented in several forms. Firstly an overall impression is expressed by using comparative spectra showing bodylength classes along the horizontal axis and numbers of individuals in each class on the vertical axis. (This is similar to the presentation used by Persson and Lohm 1977). The size spectra are expressed graphically from 0 to 6mm. Secondly the results are presented in tabular form for easier comparison and statistical analysis. Figures for numbers of invertebrates, cumulative bodysize and diagrammatic spectra are presented as numbers/$M^2$ so that comparisons can be made with similar research where appropriate. The tabular expression of the results represents the invertebrates recorded between 0 and 2mm. The invertebrates above 2mm are not included in the tabular analysis for several reasons,

1. The occurrence of these larger animals is low and erratic and the sample size is not large enough to provide sufficient animals of this size for realistic assessment. ( i.e There are so few of the larger animals that it is not possible to tell whether they occur by chance or are indeed a true representation of the community structure. Thiel 1975 researching benthic communities found a similar problem when using grabs to sample in the Aleutian trench).

2. The equations used to convert length to mass are based mainly on results of research for the smaller size range with the equations used becoming increasingly inaccurate for larger animals.

3. The spectra presented suggest there are two distinct populations. The sampling technique employed for these experiments has allowed the smaller arthropods to dominate the results. If the larger arthropoda are to be analysed then a more appropriate

technique would need to be used. (i.e possibly using larger sieves on the funnels, or using different sampling methods).

Section 5.2.2 outlined important bodysize and abundance measures. These are presented in tabular form. Bodysize is represented as both length and mass and conclusions drawn about the use of these measures. Results from the spring and autumn sampling are analysed in turn, although the main implications of the technique itself are presented at the end of the chapter. The spring samples were mainly exploratory and aimed to test and explore. This meant no statistical analysis was undertaken on the spring results.

### 5.5.4 The use of statistics with bodysize data,

Statistical tests are traditionally used to determine the probability that the observed differences between two samples signifies that the populations sampled are themselves really different, (Siegel 1956). Many tests make assumptions about the nature of the population from which the samples are being drawn, one of the "parameters" being that the populations are normally distributed. It is from this that the notion of parametric tests originates. The bodysize distributions produced in subsequent sections are not normally distributed, negating the usefulness of parametric tests.

This has lead to the investigation and use of distribution free or non-parametric tests. In analysing the distributions and by comparing 2 samples within a bodysize class it is possible to tell which distribution has the greater value within a given class, as well as ranking the differences. This suggests that the Wilcoxson Matched Pairs Signed Rank Test is appropriate. This is one of the more powerful non-parametric tests and has been used to compare bodylength distributions, (see table 5.2).

### 5.5.5 Results form the spring sampling,

This first exploratory use of the bodysize technique to investigate the effects of a range of agricultural practices demonstrated differences between the various plots sampled in terms of total numbers of invertebrates, average bodylength and mass. Figures 5.3 to 5.13 are bodylength spectra which provide one method of presenting the results of this first series of samples. Figures 5.14 and 5.15 provide a summary of a number of measures for each plot sampled.

Within the rotational and continuous plots the highest number of invertebrates were found in the plots receiving 35000kgs/ha of farmyard manure each year. Number of invertebrates rose with increasing levels of inorganic fertilizer applied. However, within individual treatments, for instance the plots receiving 96kgs/ha of inorganic fertilizer, the highest number of invertebrates were consistently found in the continuous wheat plots as opposed to the rotation. Of the three areas sampled within the wilderness it was the cut plot which contained the highest number of invertebrates, although numbers of invertebrates in all three of the wilderness plots were of a similar order of magnitude.

Figure 5.3 Continuous wheat, FYM

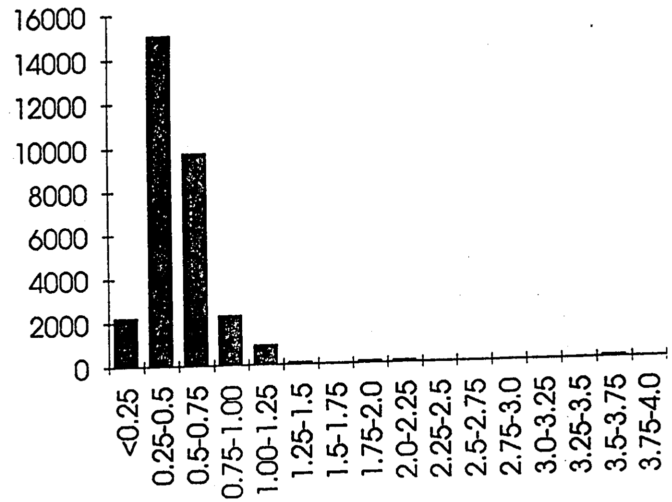



Figure 5.4 Continuous wheat, No nitrogen

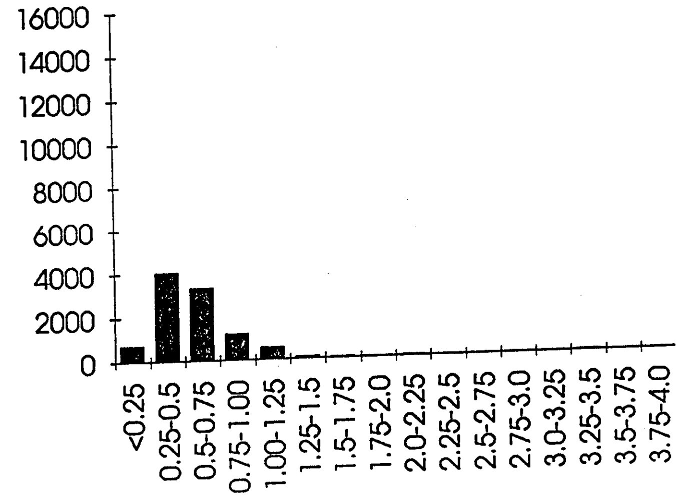



Figure 5.5 Continuous wheat, 96 kgs/ha of N

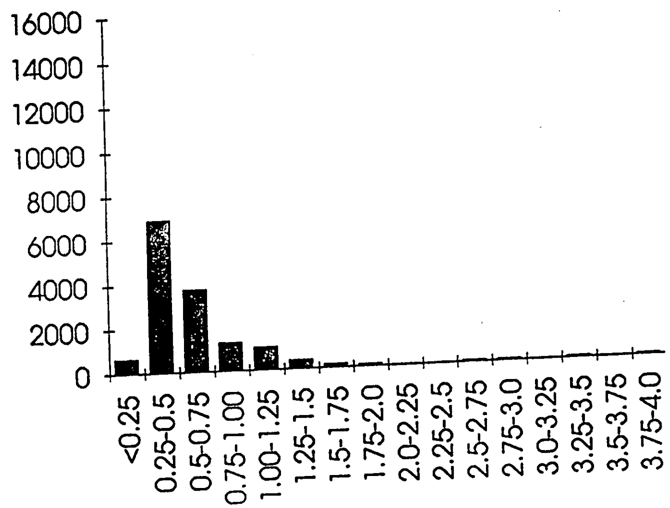
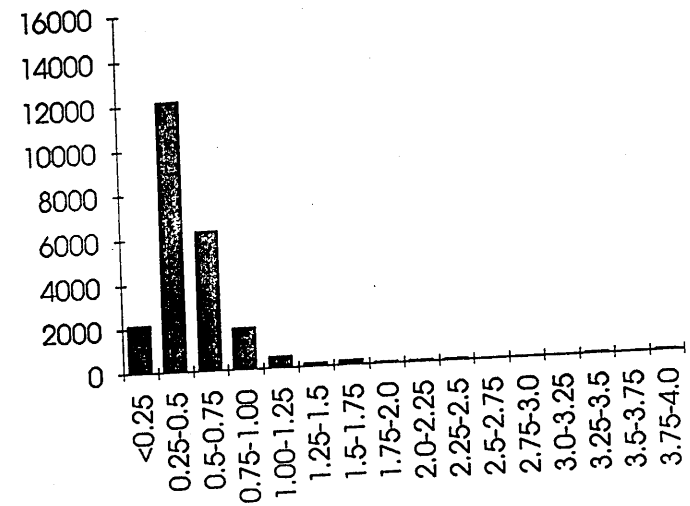



Figure 5.6 Continuous wheat 192 kgs/ha of N




HORIZONTAL AXIS: BODYLENGTH IN MM
VERTICAL AXIS: NUMBER OF INDIVIDUAL ANIMALS/M2

Figure 5.7 Rotation, FYM

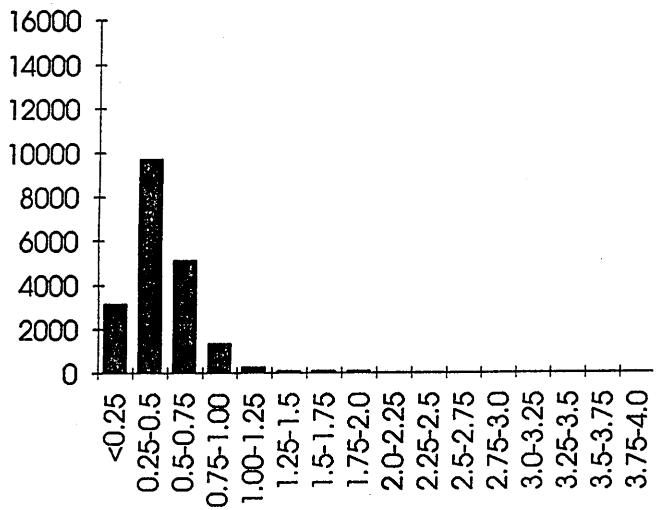



Figure 5.8 Rotation, no N

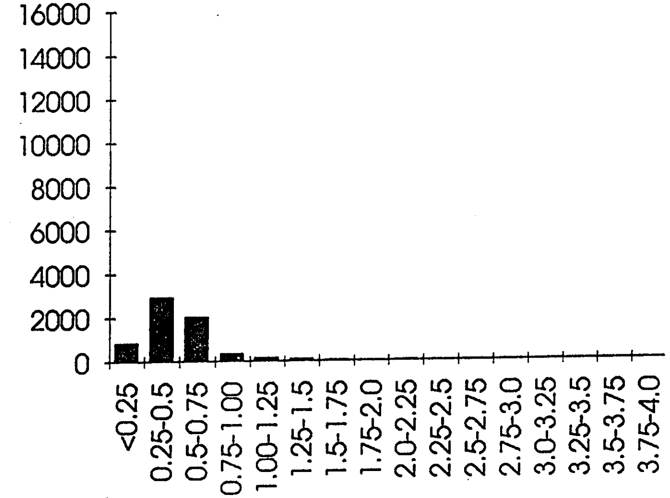



Figure 5.9 Rotation, 96 kgs/ha of N

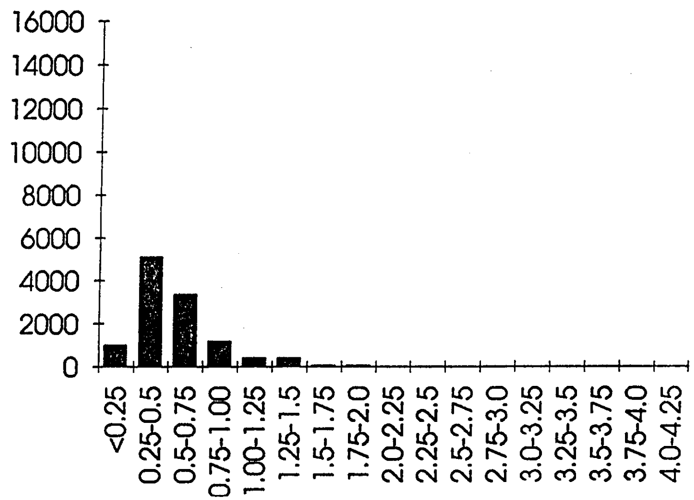
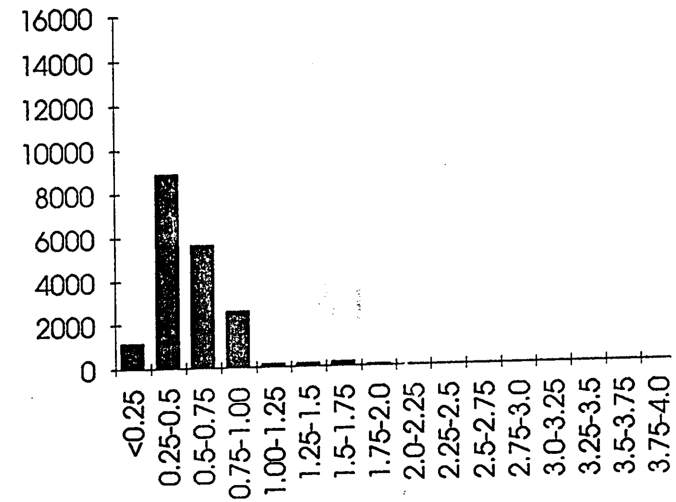



Figure 5.10 192 kgs/ha of N



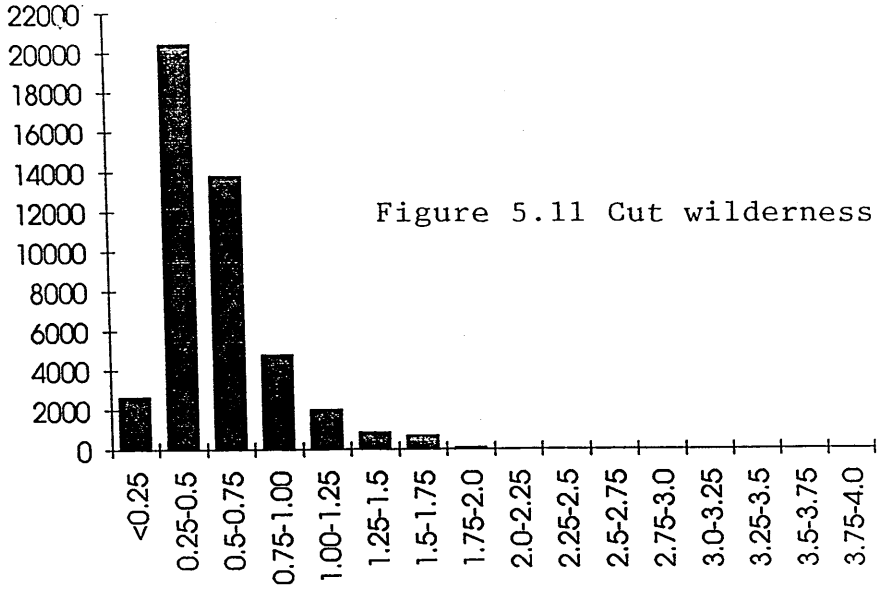



Figure 5.11 Cut wilderness

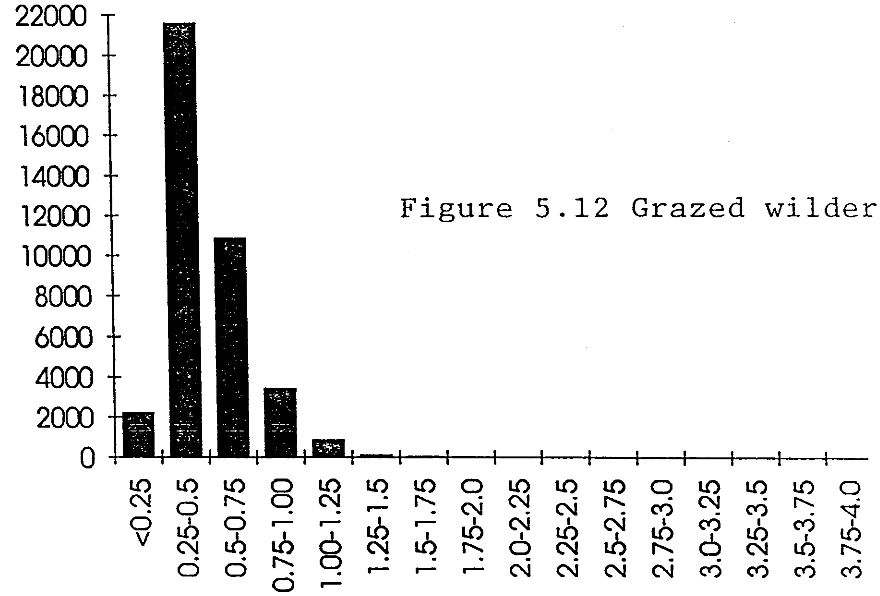



Figure 5.12 Grazed wilderness

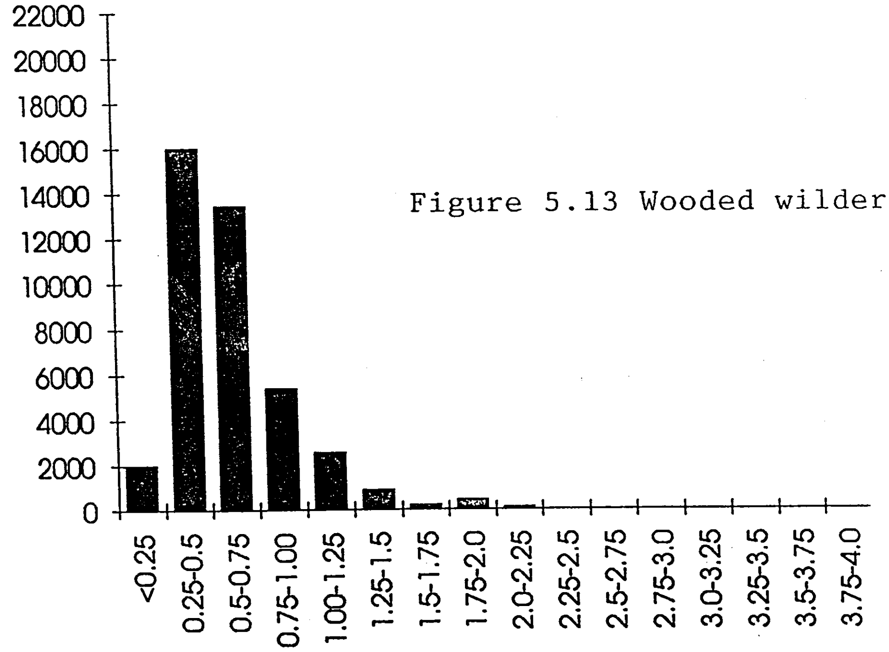
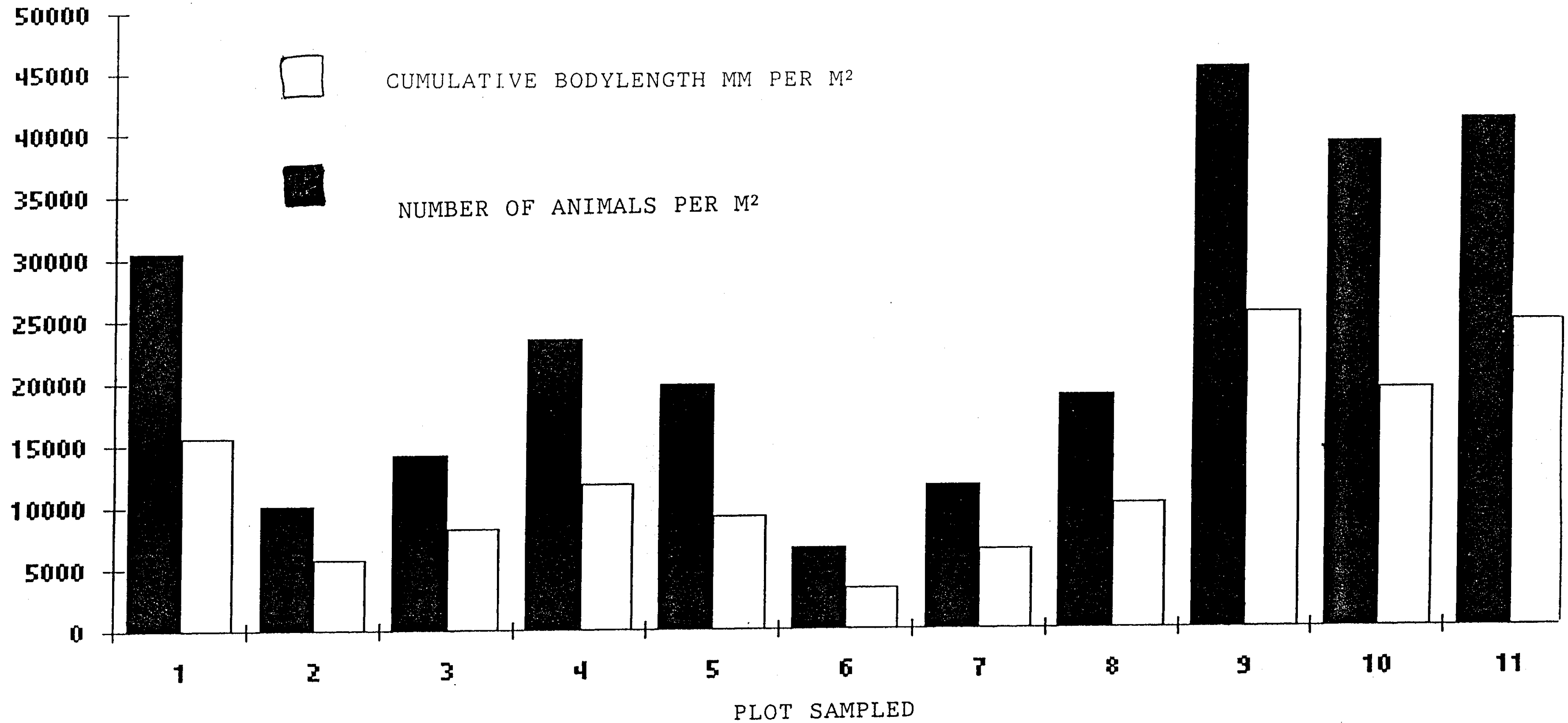
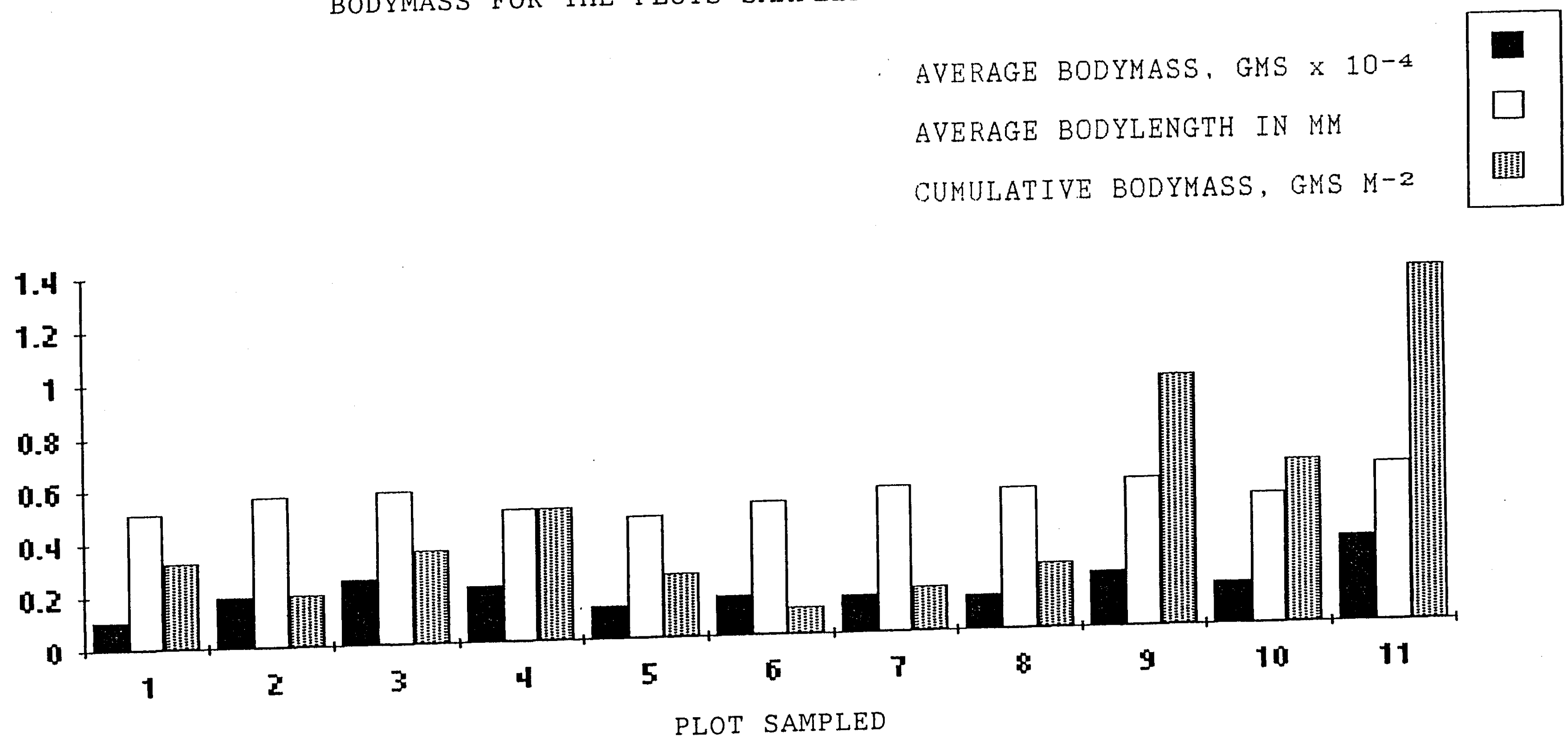



Figure 5.13 Wooded wilderness

5.14 : NUMBER OF ANIMALS AND CULMATIVE BODYLENGTH FOR EACH OF THE 11 PLOTS SAMPLED IN THE SPRING



5.15 : AVERAGE BODYLENGTH, AVERAGE BODYMASS AND CUMULATIVE BODYMASS FOR THE PLOTS SAMPLED IN THE SPRING



Cumulative bodysize is represented by two measures, length and mass. Increasing the level of fertilization increases both the cumulative length and mass of soil arthropoda per $M^2$. The continuous wheat plots receiving farmyard manure indicate that bodylength is not always a suitable indicator of bodymass. This is confirmed by the analysis of results from the wilderness in which the wooded area has the highest mass per $M^2$, but the cut area has the greatest number of invertebrates and the highest cumulative bodylength. As with the measure of total numbers, the rotational plots have a lower bodymass per $M^2$ at all levels of fertilization when compared to the continuous wheat plots.

The results for average bodysize are difficult to interpret from this first set of samples. The relatively large mass of individuals on the wooded wilderness is a reflection of the undisturbed soil system and the supply of detritus material near the soil surface. Plots receiving organic fertilizer appear to support invertebrates of smaller bodymass on both the rotational and continuous wheat plots. The continuous wheat plots receiving inorganic fertilization support invertebrates of a larger average size than the rotational plots.

The purpose of the bodysize spectra provided in Figures 5.3 to 5.13 is to give an easy to assess graphical representation of the results which compares the total numbers of invertebrates and their bodylength for each of the individual plots sampled. The peak numbers per bodysize class consistently fall within the 0.25 to 0.5 class, although there is considerable variation in the numbers recorded on the different plots. In comparing distributions on the continuous and rotational, the former consistently has the highest peaks within treatments and the higher number of individuals per treatment. It is interesting to note that in the spring only a few invertebrates greater than 2mm were recorded. This is in contrast to the spectra of the autumn samples, (Figures 5.16 to 5.25), in which a considerable number of animals greater than 2mm were recorded. This could be due to the timing of sampling or the differing soil conditions at the time the two samples were taken.

## 5.6. CONCLUSIONS AND IMPLICATIONS OF THE SPRING SAMPLING

The initial samples taken at Rothamsted were designed to assess the usefulness of using simple measures of bodysize as an indicator of the differences within the soil community under different agricultural practices. These spring samples acted as a form of pilot to test the technique, the degree to which it could be simplified, and to highlight problems that may need rectifying in the second set of experiments. It was hoped that the spectra would demonstrate differences in bodysize categories containing highest number of invertebrates. This was not the case and the maximum number of animals fall into the same length category in each spectra. It was therefore concluded that the use of 0.25mm wide categories, although simple from a recording point of view, may not be accurate enough for this type of analysis. The results suggest that bodysize spectra can be used to demonstrate the effects of differing agricultural practices on the soil system. The results highlight differences between the numbers and cumulative length and bodymass of soil invertebrates on the cultivated arable land in comparison to the uncultivated wilderness. However, this initial set of samples also suggests that this technique is capable of differentiating between smaller differences in agricultural practices such as rotation and continuous wheat and between levels of fertilization. For instance total numbers of soil invertebrates and cumulative bodymass differed with fertilization treatment.

Organic fertilization, (i.e. farm yard manure), provides a valuable food source to a host of soil animals and modifies the soil environment. Therefore, it is to be expected that of the arable plots, those receiving farm yard manure contained the highest numbers of soil invertebrates. Within the plots receiving inorganic fertilizers the number of soil invertebrates generally increased at higher levels of inorganic fertilization. This trend was found in both the continuous wheat and rotational plots. This agrees with similar research, (Edwards 1984). He concludes that higher fertilization increases the size and yield of the wheat crop, increasing the amount of debris returned to the soil in terms of stubble, chaff and root material. This provides a food source for the soil animals, increasing the soil organic matter content and thus modifying the soil environment. One of the observations derived from MOVEMOD, (see previous chapter), is that increasing the amount of root and plant debris returned to the soil by growing high yielding crops, (i.e. higher nitrogen input), is likely to increase the soil organic matter content.

Although the organically manured plots generally contained higher numbers of invertebrates, each individual tended to be of lower mass leading to a reduction in the measure of cumulative bodymass on these plots. The reason for this is not clear, but it does suggest that simply recording numbers of soil invertebrates may not be an accurate indicator of the total soil animal biomass present. The suppression of animal numbers on the rotational plots was commented on by Edwards (1984) in a review of the effects of agricultural practice on soil animals. He suggests that this is usually the case, although he states that little research has been undertaken in this respect. The reasons for this general suppression of animal numbers under rotational cropping is thought to be due to several factors:

1. Discontinuity in the types of detritus entering the soil, causing variation in food source and favourability to differing members of the soil population,

2. The inclusion of root crops in the rotation reduces the amount of organic matter returned to the soil and thus the amount of food available to the soil animals, (This is made evident later by the reduction in soil organic matter evident in Table 5.3). The rotation on the Broadbalk plots includes potatoes.

3. Rotations including fallow or possibly spring crops have the effect of reducing the amounts of organic materials returned to the soil again impacting on the organic content of the soil and the

detritus community (The rotation at Broadbalk also includes a fallow year).

The higher number of invertebrates and cumulative bodymass in the wilderness area is due to the absence of cultivation, allowing the establishment of a stable soil community. The modelling work described in the previous chapter identified cultivation as a major determinant in agroecosystem processes. Similar effects on soil animals due to cultivation have been recorded by Edwards (1984) & Madge (1981). Of the 3 plots sampled in the wilderness area the cut wilderness plot contained the highest number of invertebrates, although the highest bodymass was found in the wooded area. The wooded area is the least disturbed of all the sites perhaps allowing a higher degree of community interaction, explaining the larger cumulative mass and bodysize, (see Peters 1983). Comparison of actual numbers of soil invertebrates per $M^2$ with other research is not easy to carry out because of the differences in sampling times, conditions and locations. However, figures presented by Edwards and Lofty (1969) at Rothamsted following conversion from numbers per 2.5" corer to numbers per $M^2$, show 38160 Acarina and Collembola per $M^2$ for plots receiving organic manure. These populations are of a similar magnitude to the figures recorded in this set of experiments.

In conclusion this initial set of samples provided information on the processes involved in the sampling of one element of the soil community, suggesting that this method for looking at soil processes is worthy of further consideration. However, it has highlighted the difficulties in the analysis of results and the statistical conclusions that can be drawn from them. The generally higher figures of total numbers and cumulative biomass in the wilderness area and the suppression on the rotation plots suggests that spatial diversity of plants rather than temporal diversity with regard to cropping is important in the maintenance of the soil community. Spatial diversity could be enhanced by the inclusion of perennial plants into the cropping rubric. The continuity perennial plants offer to the soil community is likely to have an important influence on soil processes.

## 5.7 RESULTS OF THE AUTUMN SAMPLING AT ROTHAMSTED,

Analysis of the results of the autumn analysis was undertaken in a similar manner to that in the spring. Results are again presented in terms of bodylength spectra showing bodylength increments along the horizontal axis and numbers of invertebrates on the vertical axis, Figures 5.16 to 5.25. Table 5.1 illustrates numbers and bodysize analysis for recorded invertebrates in the range 0 to 2mm. (see also Figures 5.27, 5.28, and 5.29 for graphical representation).

### 5.7.1 Number of invertebrates,

**Surface 15cm:** The differences between the plots in the surface measurement is not as well defined in comparison to the spring sampling. The largest numbers of invertebrates are still found in the wilderness and this is greater than those found on the arable soil. The plots receiving the farmyard manure contain the highest numbers of

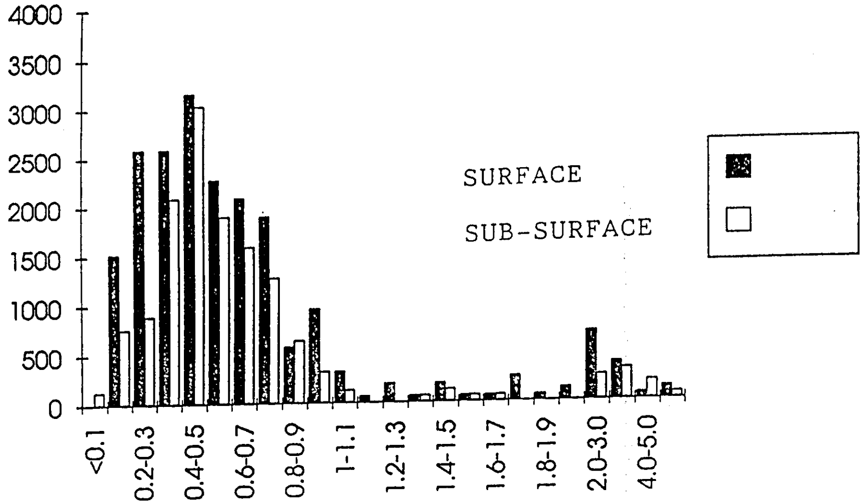



Figure 5.16 Continuous wheat, FYM

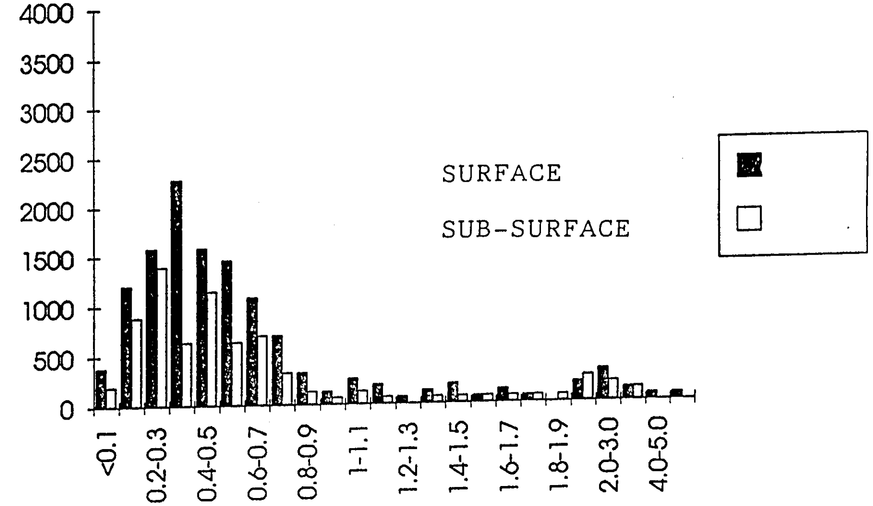



Figure 5.17 Continuous wheat, no nitrogen

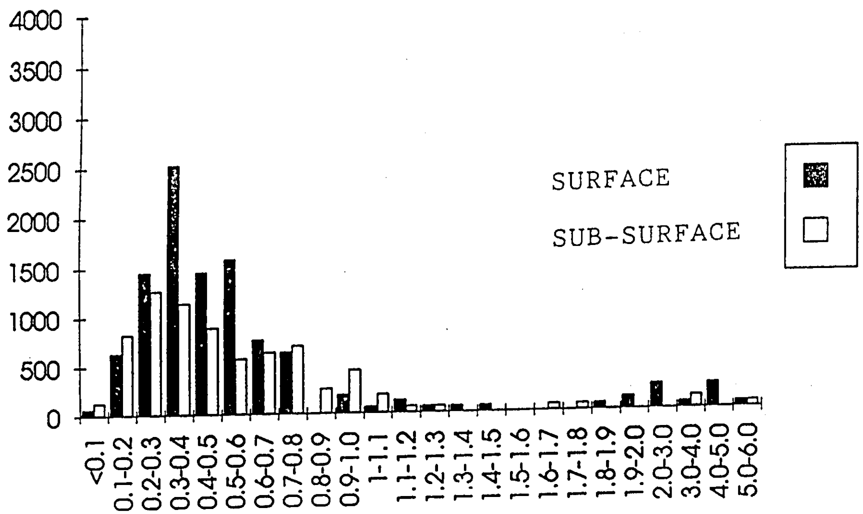



Figure 5.18 Continuous wheat, 96 kgs/ha of N

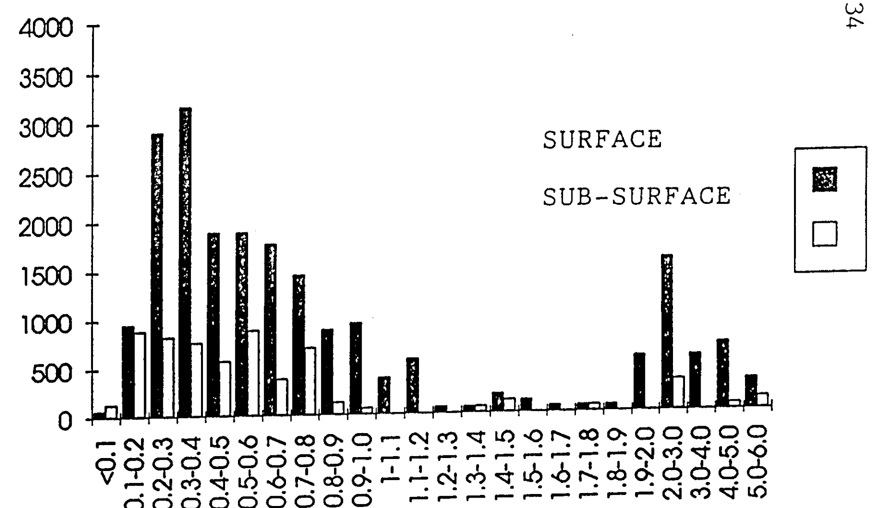



Figure 5.19 Continuous wheat, 192 kgs/ha of N

HORIZONTAL AXIS, BODYLENGTH IN MM
VERTICAL AXIS: NUMBER OF INDIVIDUALS/M2

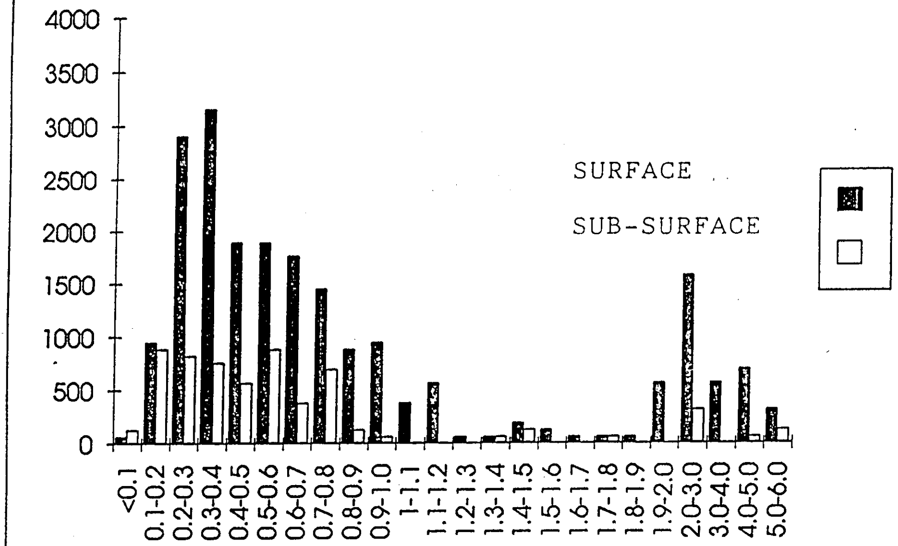



Figure 5.20 Rotation, FYM

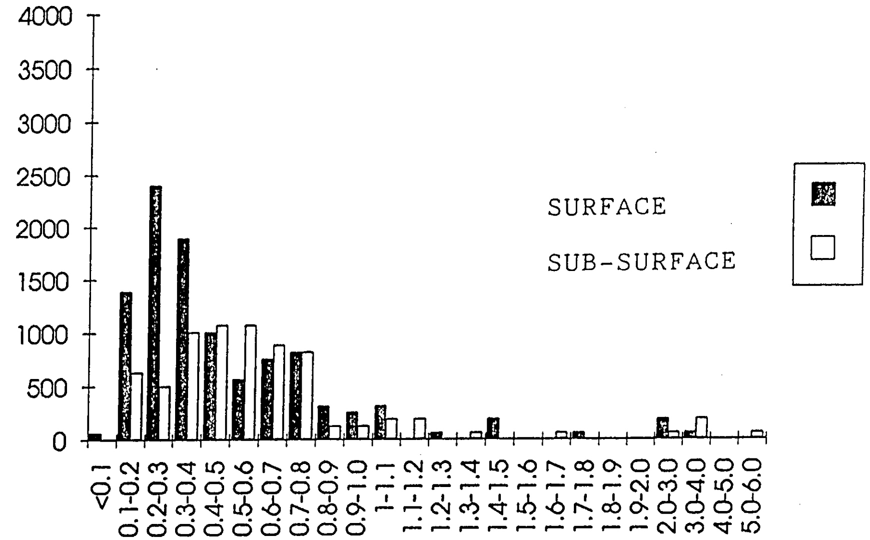



Figure 5.21 Rotation, no nitrogen

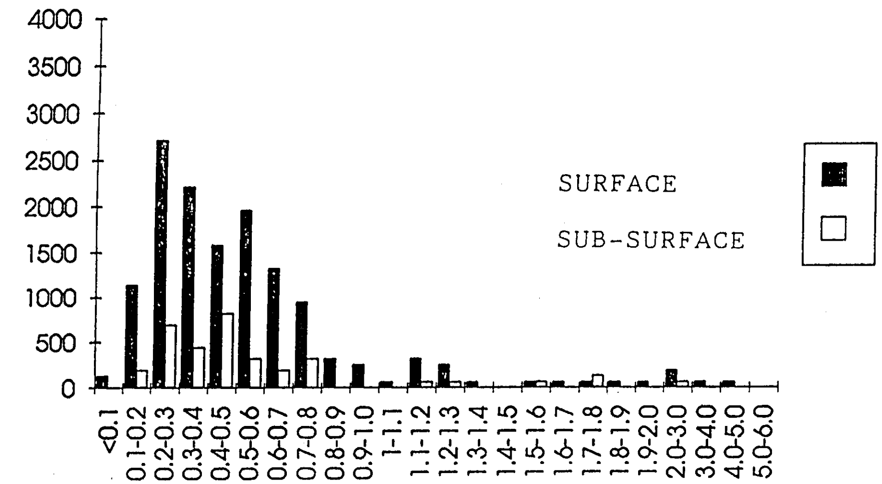



Figure 5.22 Rotation, 96kgs/ha of N

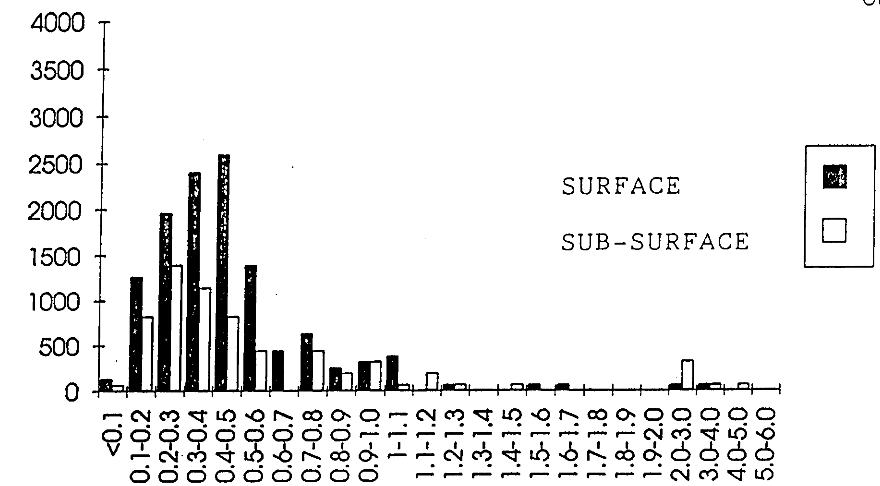



Figure 5.23 Rotation, 192kgs/ha of N

HORIZONTAL AXIS, BODYLENGTH IN MM
VERTICAL AXIS: NUMBER OF INDIVIDUALS/M2

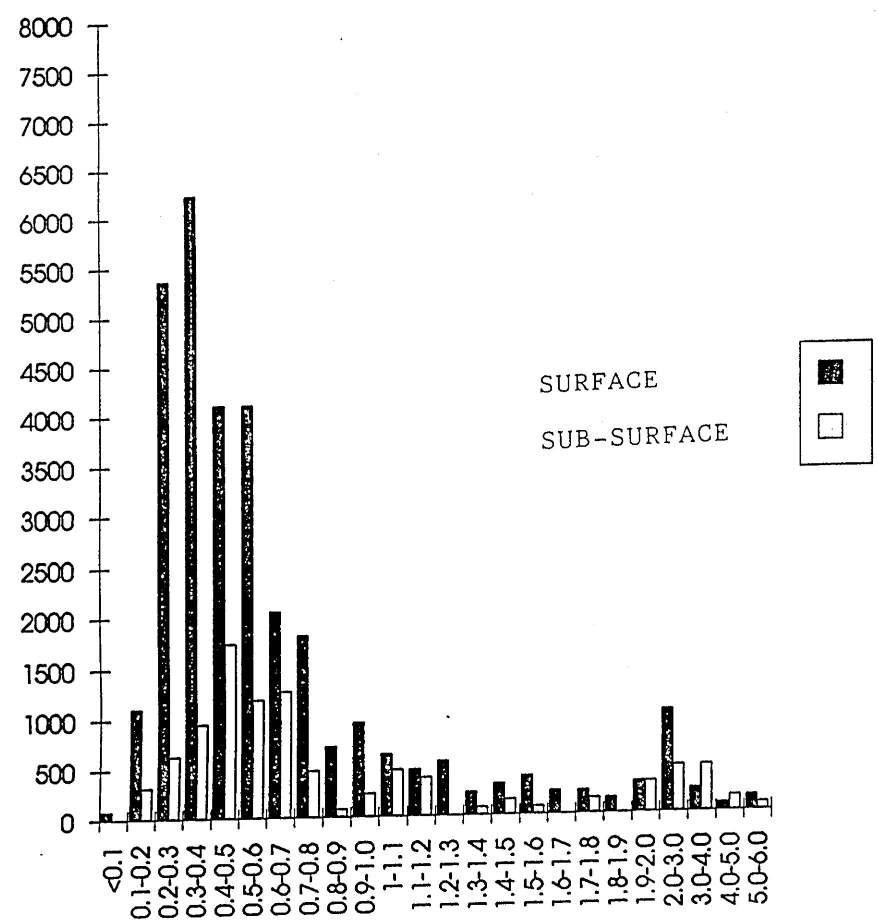



Figure 5.24 Wooded wilderness

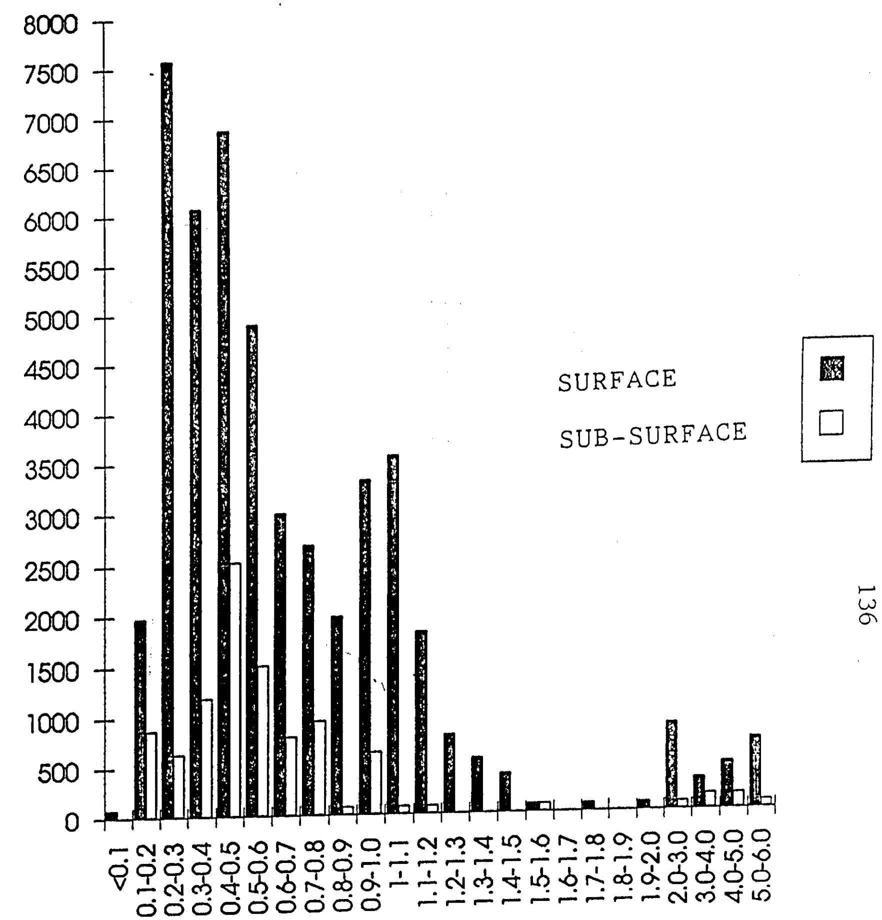



Figure 5.25 Grazed wilderness

(NB. SCALES ARE SAME SIZE FOR BOTH WILDERNESS AND ARABLE GRAPHS)

HORIZONTAL AXIS, BODYLENGTH IN MM
VERTICAL AXIS: NUMBER OF INDIVIDUALS/M2

Table 5.1 Number of animals, cumulative bodylength and bodymass per M² from the Autumn samples at Rothamsted. Bodysize range 0-2MM

A = Numbers of animals per M²
B = Cumulative bodylength, MM per M²
C = Average bodylength in MM
D = Bodymass per M² in gms
E = Average bodymass in gms x $10^{-5}$

| | A | B | C | D | E |
|---|---|---|---|---|---|
| **CONTINUOUS WHEAT** | | | | | |
| FARMYARD MANURE | | | | | |
| surface 15cm | 18770 | 10276 | 0.55 | 0.39 | 2.07 |
| sub-surface 15cm | 12956 | 6806 | 0.53 | 0.22 | 1.69 |
| surface + sub-surface | 31726 | 17082 | 0.54 | 0.61 | 1.92 |
| NO NITROGEN | | | | | |
| surface 15cm | 11944 | 6304 | 0.53 | 0.25 | 2.09 |
| sub-surface 15cm | 6762 | 3543 | 0.52 | 0.19 | 2.80 |
| surface + sub-surface | 18707 | 9847 | 0.53 | 0.44 | 2.35 |
| 96KGS/HA OF NITROGEN | | | | | |
| surface 15cm | 9859 | 4847 | 0.49 | 0.22 | 2.23 |
| sub-surface 15cm | 7268 | 3687 | 0.51 | 0.15 | 2.06 |
| surface + sub-surface | 17127 | 8535 | 0.50 | 0.38 | 2.21 |
| 192KGS/HA OF NITROGEN | | | | | |
| surface 15cm | 18012 | 10396 | 0.58 | 0.49 | 2.72 |
| sub-surface 15cm | 12134 | 5776 | 0.48 | 0.23 | 1.89 |
| surface + sub-surface | 30146 | 16172 | 0.54 | 0.72 | 2.38 |
| **ROTATION** | | | | | |
| FARMYARD MANURE | | | | | |
| surface 15cm | 17569 | 10055 | 0.57 | 0.65 | 3.69 |
| sub-surface 15cm | 5498 | 2575 | 0.47 | 0.14 | 2.54 |
| surface + sub-surface | 23068 | 12630 | 0.55 | 0.79 | 3.42 |
| NO NITROGEN | | | | | |
| surface 15cm | 11060 | 4932 | 0.45 | 0.15 | 1.35 |
| sub-surface 15cm | 6762 | 3675 | 0.54 | 0.18 | 2.66 |
| surface + sub-surface | 17822 | 8607 | 0.48 | 0.33 | 1.85 |
| 96KGS/HA OF NITROGEN | | | | | |
| surface 15cm | 13588 | 6888 | 0.51 | 0.36 | 2.64 |
| sub-surface 15cm | 3286 | 1731 | 0.53 | 0.07 | 2.13 |
| surface + sub-surface | 16874 | 8620 | 0.51 | 0.43 | 2.54 |
| 192KGS/HA OF NITROGEN | | | | | |
| surface 15cm | 11944 | 5413 | 0.45 | 0.15 | 1.25 |
| sub-surface 15cm | 6004 | 2733 | 0.46 | 0.12 | 1.99 |
| surface + sub-surface | 17948 | 8146 | 0.45 | 0.27 | 1.5 |
| **WILDERNESS** | | | | | |
| GRAZED WILDERNESS | | | | | |
| surface 15cm | 56643 | 33482 | 0.59 | 0.91 | 1.6 |
| sub-surface 15cm | 11771 | 6078 | 0.52 | 0.30 | 2.54 |
| surface + sub-surface | 68414 | 39562 | 0.58 | 1.22 | 1.78 |
| TRUE WILDERNESS | | | | | |
| surface 15cm | 37051 | 20333 | 0.55 | 1.43 | 3.8 |
| sub-surface 15cm | 10586 | 7049 | 0.67 | 0.15 | 1.41 |
| surface + sub-surface | 47637 | 27335 | 0.57 | 1.58 | 3.31 |
| **AVERAGES** | **14473** | **7826** | **0.525** | **0.677** | **2.33** |

invertebrates in both the continuous wheat and the rotational plots and the magnitude of the numbers is similar to those found in the spring. However, the relationship which existed for increasing levels of inorganic fertilizer is not evident in the autumn rotational plots.

The grazed wilderness contains a larger number of invertebrates than it did in the spring and it is this plot that contains the highest number of animals. The numbers of invertebrates in the wilderness plots are generally 2 to 3 times greater than those found in the arable soil. This is similar to that found during the spring sampling.

**Sub -surface 15cm:** The number of invertebrates found in the sub-surface region differs considerably from the surface. In every instance there are fewer invertebrates in this soil horizon than on the surface. The differences between the wilderness and the arable plots is reduced in the sub-surface, with both of the wilderness plots and the continuous wheat, (farm yard manure and 192kgs/ha of N), containing comparable numbers of animals. This is probably because the majority of invertebrates in the undisturbed wilderness soil are found near the surface in the litter layer. In the arable plots the organic matter is more evenly mixed resulting in a greater proportion of soil animals below the soil surface. Included in Table 5.1 are figures for surface plus sub-surface. These show the higher overall numbers of invertebrates in the wilderness and on the arable plots receiving farm yard manure. These plots also contain higher levels of soil organic matter, (see Table 5.3), highlighting the association between numbers of soil invertebrates and soil organic matter content.

### 5.7.2 Cumulative bodysize

**Surface 15cm:** Figures presented in Table 5.1 for cumulative bodylength and bodymass illustrate that the wilderness plots and those arable plots receiving farm yard manure contain higher amounts of bodymass per $M^2$. The wilderness results raise questions about the use of bodylength or mass as an appropriate relative measure. The grazed plots contain the highest cumulative bodylength whereas the wooded area contains the highest mass. The relationship between length and mass is discussed in detail in section 5.11.

**Sub-surface 15cm:** The figures for length and mass are consistently lower in the sub-surface measures than those taken on the surface. Interestingly the highest cumulative bodylengths in the sub-surface are found in the continuous wheat plot receiving farm yard manure and 192kgs/ha of fertilizer. However, the highest mass in the sub-surface layer is found on the grazed plots, this being approximately three times greater than on the other plots. Results presented for the sum of surface and sub-surface soils illustrate the higher levels of cumulative bodymass in the wilderness plots.

### 5.7.3 Average bodysize, (all autumn samples)

Bodylength differences are limited although the wilderness area has the highest average values for bodylength when the surface and sub-surface are totalled. There appears to be no apparent relationship on

Table 5.2 Probability of means of the bodysize distributions being the same,

| | z | p | Sign. |
|---|---|---|---|
| **Continuous wheat, surface,** | | | |
| No nitrogen and farmyard manure | -2.8849 | .0039 | ** |
| No nitrogen and 96kgs of nitrogen | -2.2077 | .0273 | * |
| No nitrogen and 192kgs of nitrogen | -2.8373 | .0045 | ** |
| **Continuous wheat, sub-surface** | | | |
| No nitrogen and farmyard manure | -1.851 | .064 | ns |
| No nitrogen and 96kgs of nitrogen | -3.251 | .0014 | ** |
| No nitrogen and 192kgs of nitrogen | -2.5013 | .0124 | * |
| **Rotation, surface,** | | | |
| No nitrogen and farmyard manure | -3.6586 | .0003 | *** |
| No nitrogen and 96kgs of nitrogen | -2.3082 | .0210 | * |
| No nitrogen and 192kgs of nitrogen | -0.155 | .8767 | ns |
| **Rotation, sub-surface,** | | | |
| No nitrogen and farmyard manure | -0.8057 | .420 | ns |
| No nitrogen and 96kgs of nitrogen | -2.6566 | .0079 | ** |
| No nitrogen and 192kgs of nitrogen | -0.1811 | .8563 | ns |
| **Continuous wheat 192 kgs,grazed wilderness** | | | |
| Surface | -3.6429 | .0003 | *** |
| Sub-surface | -1.4772 | .1396 | ns |
| **Continuous wheat 192kgs, wooded wilderness** | | | |
| Surface | -3.6857 | .0002 | *** |
| Sub-surface | -0.0162 | .9870 | ns |
| **Grazed wilderness and wooded wilderness** | | | |
| Surface | -2.8438 | .0045 | ** |
| Sub-surface | -0.1136 | .9096 | ns |

* Significant at the 99% level
** Significant at the 99.9% level
*** Significant at the 99.99% level

the arable soil either between plot treatments or between sampling depths. Results for average bodymass are similar, although the sub-surface samples of the grazed plots contain the largest average individual mass.

### 5.7.4 Comparing the bodysize spectra,

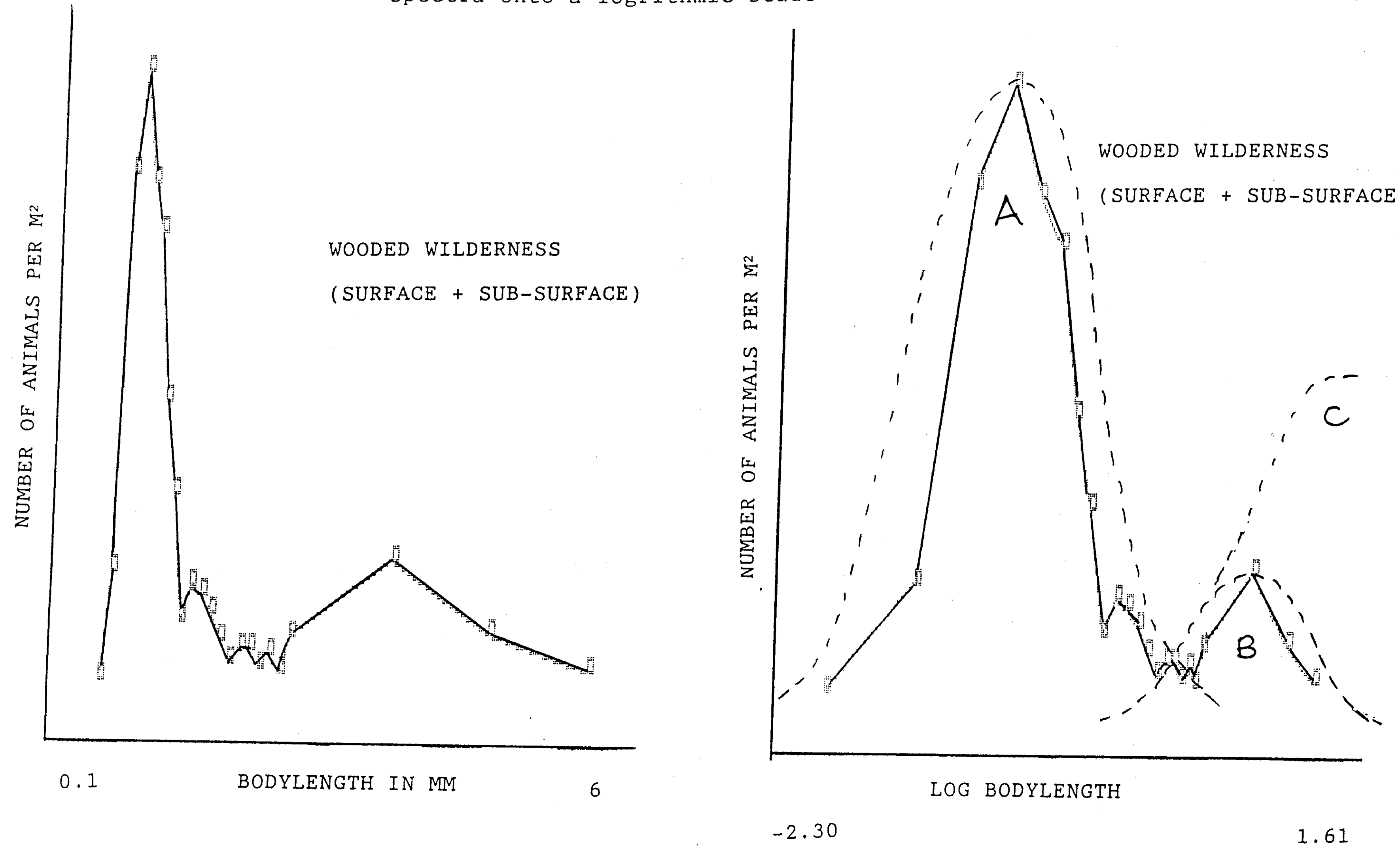
Figures 5.16 to 5.25 provide bodysize spectra for the various plots sampled. Each graph contains information for both the surface and the sub-surface measurements, with figures expressed as number of invertebrates per $M^2$. The spectra provide a useful visual comparison of the differences between the plots. For instance on the continuous wheat plots the larger number of animals on the farm yard manure and high nitrogen plots can be seen. Simple statistical analysis of the distributions has been undertaken using the Wilcoxson Matched Paired Signed Rank Test. This is a non parametric test which allows the probability of the two populations having the same mean to be calculated. Table 5.2 illustrates the results of using the test on a number of the bodysize distributions.

All of the bodysize spectra have a positive skew and are similar shape to distributions presented by other researchers, (see Persson and Lohm 1977). Several researchers have investigated the relationship between bodysize and population density, and the subject is reviewed by Currie (1993). He explains the apparent differences in shapes of distribution between research that ranges across several taxonomic groups, (for instance the work of Damuth 1981 presented in section 5.2.1), compared to that which only investigates one taxon. Many workers plot bodysize on a logarithmic scale, (see Lawton 1989), and within a given taxon this usually produces the lognormal distribution which is bell shaped. Figure 5.26 illustrates the conversion of the bodylength plots for the wooded wilderness, (surface + sub-surface) onto a logarithmic scale. This suggests that there are possibly two distinct size distributions. However, both ends of the size scale could have been curtailed by experimental design. Smaller animals were not recorded for two reasons. Firstly the tullgren funnel apparatus relies on the soil animals being motile, and secondly the magnification provided by the microscope was limited. Larger animals were perhaps precluded from collection by the size of sieve used in the funnels. Thus the second distribution , (B), could be the start of a second distribution, rather than a complete distribution in its own right, (see dotted line C). This has important implications for the design and restrictions placed on the experimental techniques used.

## 5.8 COMPARING THE SPRING AND AUTUMN SAMPLES,

Of particular interest in the spring plots is the increasing cumulative bodymass and length that corresponded to increasing levels of inorganic fertilizer application. This relationship was not as prominent in the autumn samples although the continuous wheat plot receiving the highest level of inorganic fertilization did contain comparatively high numbers of invertebrates, cumulative length and mass. This was not reflected at the same levels of fertilization in the rotational plots. However the plots receiving farm yard manure

Figure 5.26 Example of the conversion of bodylength spectra onto a logrithmic scale



continued to contain comparatively high numbers of invertebrates, bodylength and mass although the wilderness area continued to have the highest levels overall.

The arable plots receiving farm yard manure are in essence receiving a valuable nutrient source for both the growing crop and the soil invertebrate community. The crop grows well, intercepting comparatively high levels of incoming radiation because the plants are larger, healthier and cover more of the ground area. This results in a well developed root system which during the growing season, and particularly at harvest, ensures a relatively high level of organic material is returned to the soil system. This is reflected in the higher levels of soil organic material and animal biomass found in the plots. Results from MOVEMOD highlighted the importance of root material as a source soil organic matter in both cultivated and uncultivated soils.

The wilderness plots do not receive any external nutrients, except perhaps small amounts of nitrogen in rainfall, (Jenkinson 1990), but have two "advantages" in terms of the soil community over the arable soil. Firstly, they are not disturbed annually by cultivation which as MOVEMOD demonstrated can result in rapid oxidation of some of the organic matter. Secondly, in the case of the wooded wilderness no annual harvest is taken, and the grazed wilderness is only stocked at low rates and much of the nutrients consumed by the sheep are recycled in their dung. This ensures a high return of organic matter to the soil resulting in conditions which are favourable for the building up of the invertebrate biomass, particularly in the surface 15cm.

In the plots receiving inorganic fertilizer it could be expected that higher nitrogen levels would increase the amount of plant debris being returned to the soil, suggesting that the animal biomass would increase with increasing level of fertilization. This was indeed the case in the spring sampling, although it was not possible to draw the same conclusions from the autumn sampling. The reason for this lack of comparison was because the higher nitrogen treatment on the rotational plots contained relatively few soil invertebrate. The lack of differences between nitrogen treatments in the autumn may have been related to the abundance of fresh organic matter on the plots following harvest. At this point in the year even the relatively low yielding plots would have a considerable amount of plant debris on the surface, ensuring an adequate food supply for soil invertebrates. The overall difference in the numbers of invertebrates between the spring and summer is not large, although seasonal fluctuations in soil populations are to be expected. In a Swedish study of the "Ecology of arable land", Andren et al (1990) found that on cultivated barley land the populations of microarthropods were high in April and June, reaching a peak in July. By November the populations had fallen off rapidly. Similarly, research work undertaken by House et al (1985) found that on conventionally tilled land the total number of microarthropods were highest in June and declined steadily throughout the summer period reaching a low in October.

The relatively dry summer in 1991 may have had an effect on invertebrate numbers, and could have impinged on the extraction technique itself, (the soil could have dried out very rapidly once in the funnels, possibly trapping some of the invertebrates). There are fluctuations in overall populations due to conditions, time of year and dominant species, but the size and type of experiment needed to investigate these variables is well beyond the scope of this present research. This makes it difficult to suggest an ideal time(s) for sampling. The soil samples were easier to obtain in the spring when the soil was moist. However, the bodysize spectra for the autumn samples illustrated a greater range of bodysizes which could favour sampling at this time.

## 5.9 ORGANIC MATTER, NUMBER OF INVERTEBRATES AND BODYSIZE,

Despite yields, fertilization and many other parameters being recorded at Broadbalk the data on organic matter contents of the plots is not as comprehensive and in many cases is calculated from the percentage of nitrogen in the soil, (AFRC 1991). The results of testing since 1944 are provided in Table 5.3.

Table 5.3: The soil organic matter contents of several of the Broadbalk plots, expressed as %

| Year tested* | Farmyard manure* | No nitrogen* | 96kgs/ha of nitrogen* | 192kgs/ha of nitrogen | Wilderness ** |
|---|---|---|---|---|---|
| 1944 | 4.05 | 1.80 | 2.08 | 1.96 | |
| 1964 | | | | | 4.64 |
| 1966 | 4.36 | 1.87 | 2.02 | 1.99 | |
| 1985 | | | | | 5.45 |
| 1987 | 4.64 | 1.78 | 2.13 | 2.11 | |

* Figures adapted from % soil nitrogen, assuming a C:N ratio of 10:1 and a conversion factor of x's 1.72 to convert carbon to organic matter.
Figures taken from Glendining and Powlson (1990)

** Figures for organic carbon were obtained from Jenkinson et al (1991) using a factor of x's 1.72 to convert from carbon to organic matter.

The soil organic matter is relatively low in the Broadbalk soils compared to that on a nationwide basis, (see Soil Survey maps in Chapter 2). This is due to the years of continuous cultivation, (even before the experiments were set up in 1843), and the continual baling and removal of straw. The soil organic matter levels on the plots not receiving farm yard manure have remained more or less constant, (estimated from %N), since they were first recorded in 1865. Table 5.3 shows small differences in soil organic matter content for the plots receiving no nitrogen, 96kgs/ha of nitrogen and 192kgs/ha of nitrogen. Soil organic matter in the latter has been increasing steadily over the last 50 years. The plots receiving farm yard manure and the wilderness area contain at least twice as much organic matter as the afore mentioned plots and the content is still increasing. This higher soil organic matter level was noticeable when sampling in the dry autumn, the soil core being easier to obtain on the farm yard manure plots and in the wilderness, presumably due to effects of organic matter on bulk density and moisture retention, (Johnson 1986)

A relationship emerged between the number of invertebrates recorded and the organic matter content of the soil. These detrital relationships have been discussed by several researchers, (Swift et al 1979, Dickinson and Pugh 1974), and has been analysed in greater detail in the previous chapter during the formulation of MOVEMOD. However, the weakness of using organic matter as the sole measure of soil well being is perhaps demonstrated most appropriately by the continuous wheat plots receiving 192 kgs/ha of nitrogen. The organic matter levels are similar, although slightly higher than the other inorganic plots yet the number of soil invertebrates and overall bodymass is consistently higher than the plots receiving lower levels of inorganic nitrogen. The plots receiving farm yard manure have organic matter levels twice as high as in the above plots yet the numbers and total bodymass in these plots is not significantly different from that in the continuous wheat plots receiving the highest level of fertilization.

## 5.10 THE INFLUENCE OF DEPTH ON NUMBERS AND THE BODYSIZE MEASUREMENTS.

The design of the autumn samples specifically allowed for the investigation of depth effects. The results demonstrated that both total numbers and total bodymass are generally less as soil depth increases. This agrees with the research presented by House and Parmelee (1985). The results demonstrated some of the relationships and principles used in the soil model developed in Chapter 4, particularly the concentration of soil invertebrate in the surface 15cm in the uncultivated wilderness plots. However, the results for cumulative bodymass on the uncultivated soils demonstrates the rapid reduction in the total mass of invertebrates as depth increases. In this deeper horizon the difference in cumulative bodymass between the arable and wilderness soils becomes much smaller.

## 5.11 CONCLUSIONS AND IMPLICATIONS FROM THE BODYSIZE RESEARCH AT ROTHAMSTED,

Chapters 3 and 4 focused on the use of soil carbon or organic matter as a means of representing and monitoring the effects of changes of cropping on agroecosystem processes. This has been referred to as an exploration of the second interface within the thesis, (see chapter 1). Chapter 4 concluded that whilst organic matter may provide a useful indicator of the state of the system, changes in the level of this soil constituent on established arable farmland is generally slow. This questions the use of organic matter as a short term indicator of the effects of a change in cropping practice on wider agroecosystem processes. The use of bodysize measures has been explored in the experiments described in this chapter because of the possibility that it may provide a more responsive method of monitoring.

The principle underlying these experiments is to use simple bodysize criteria associated with soil invertebrates as a proxy measure for the overall condition of the agroecosystem in which the samples are taken. The soil scientist, biologist or zoologist could argue with some justification that this type of measure is an over simplification of the processes occurring in that system. However, there is considerable research interest in the use of size based spectra of one part of the "community" to provide information about the community as a whole, and in particular as a measure of functional diversity, (Cousins 1991).

It was envisaged that bodysize spectra could provide an indicator of the state of the system and represent the differences in agroecosystem processes under varying cropping practices within the same area. Section 5.2 inferred the experiments at Rothamsted had three principle aims which provide the basis for discussions and conclusions arising from this research.

### 5.11.1. Investigation of the experimental methodology and recording,

The equipment and experimental methodology associated with the extraction of invertebrate from soil samples is well documented, (see Appendix 3). No serious problems were encountered with the sampling and extraction using the tullgren funnels at Rothamsted, although this provided a useful learning process in soil experimentation and associated techniques. The recording of extracted samples is inevitably constricted by time and expertise but should be undertaken to a degree of accuracy which is appropriate to the use of the results. It is unnecessary to record to species level using extremely accurate measures of length and width if less accurate measures can provide the required information. The problems associated with obtaining accurate mass measurements for the smaller soil arthropods was discussed in section 5.3.2. In these experiments, mass was derived from a series of equations based on length and shape. This demonstrated that bodylength is not necessarily a good enough proxy measure for bodymass due to variations in shape and specific weights of individual species.

Recording to taxonomic order level was undertaken which inevitably led to some inaccuracy in the mass conversions. However, this compromise has allowed the investigation of an assessment technique which is gaining increasing credence in theory, but one which is difficult to carry out in practice. Larger scale experimentation by specialists would be useful to determine the degrees of overall precision that can be obtained from differing levels of recording and analysis, and from this the degree of simplification that can be most appropriately applied to this form of monitoring technique.

The size range over which the measurements are taken is an important constituent of experimental design. The size range recorded in this experiment was purposely constrained by the size of the sieves used in the tullgren funnels. This meant that the vast majority of the arthropods collected were below 2mm in length. Little experimental research exists in which samples have been taken across a range of animal bodysize groups. Further research in this area is needed to substantiate some of the theoretical claims discussed at the beginning of this chapter. Within the soil it would be interesting to relate bodysize measures of invertebrates to other commonly used biological measures such as micro-organism activity and earthworm populations.

These experiments suggest that spring and early summer is a favourable time for sampling on arable land because the soil has had time to stabilize following the previous years cultivation, soil conditions for extracting cores should be favourable, animals populations should be near their peak and any fresh organic material from the previous harvest should be well incorporated in to the detritus community. However, if resources allow it would be beneficial to take several measures throughout the year. This is an area that requires further investigation.

### 5.11.2 Appropriate methods for presenting and utilizing the results of this type of analysis,

The relationship between numbers, individual bodysize and cumulative bodysize is complicated. Average individual bodysize was found to be extremely variable and therefore the suggestions of Peters (1983) that bodysize can be used to represent interactiveness within the community could not be substantiated. If the cumulative mass of a small part of the soil population can be used to make generalizations about overall community structure then these experiments could provide initial information on the design of future analysis methods. Theory relates bodysize spectra to energy flows in ecosystems, (see section 5.2.1). This suggests that it is not just the numbers of animals within a taxon that is important, but also their bodysize. Figure 5.27 illustrates the average bodylength of individuals on all of the plots sampled in the autumn.

The differences that exists across the range of plots is small although the wilderness plots contain animals of a slightly larger average size. The measure of total invertebrate biomass per $M^2$ represents both the numbers and the size of individuals, but used alone informs little about the individual size. Individual size is important because communities based on animals of smaller average size process energy and nutrients more rapidly and will be less integrated and interactive.

### 5.11.3 The possibility of using soil invertebrates to differentiate between the effects of differing cropping practices on agroecosystem processes,

Numbers, cumulative length and mass of soil invertebrates have been shown to be affected to varying degrees by different forms of human intervention on the soil system. The spring samples built up considerable promise for the later samples taken in the autumn, suggesting that this technique may be able to detect quite small changes in levels of inorganic fertilization. The autumn results did not provide the same degree of clarity as the spring sampling. However, they confirmed that techniques based on the sampling of soil

Figure 5.27 Average bodylength of soil animals on plots sampled in the autumn

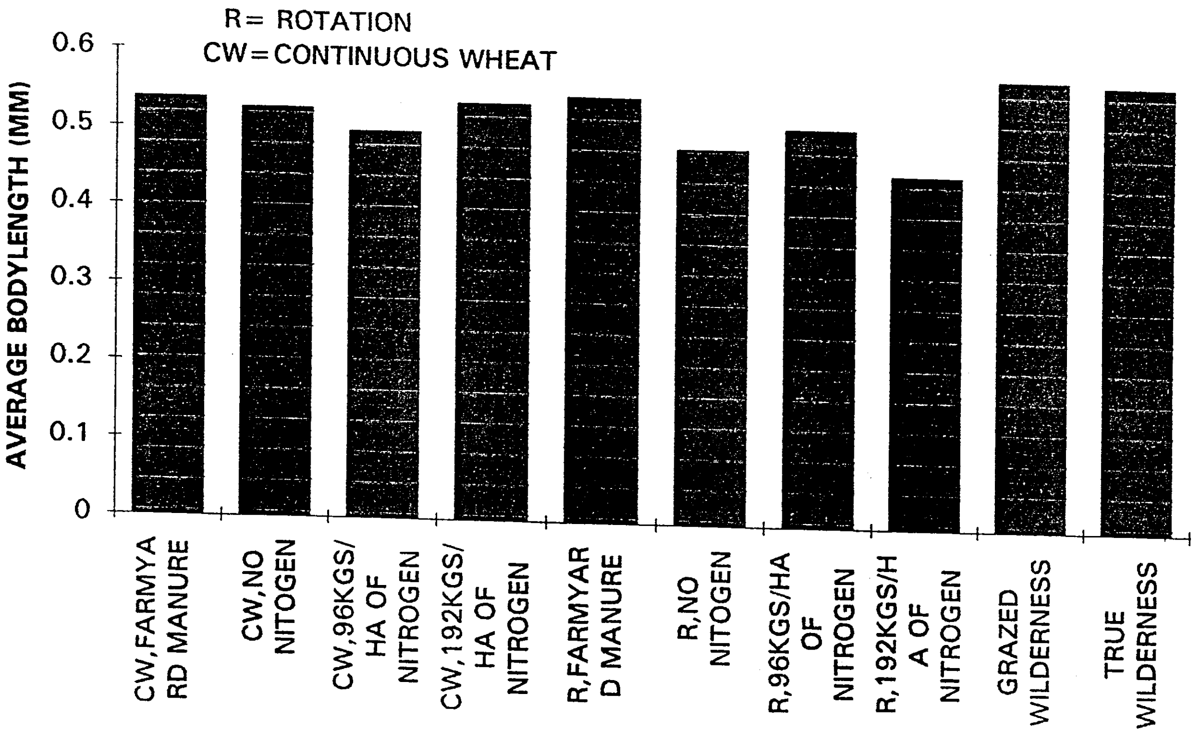



Figure 5.28 Number of animals per $M^2$ on plots sampled in the autumn

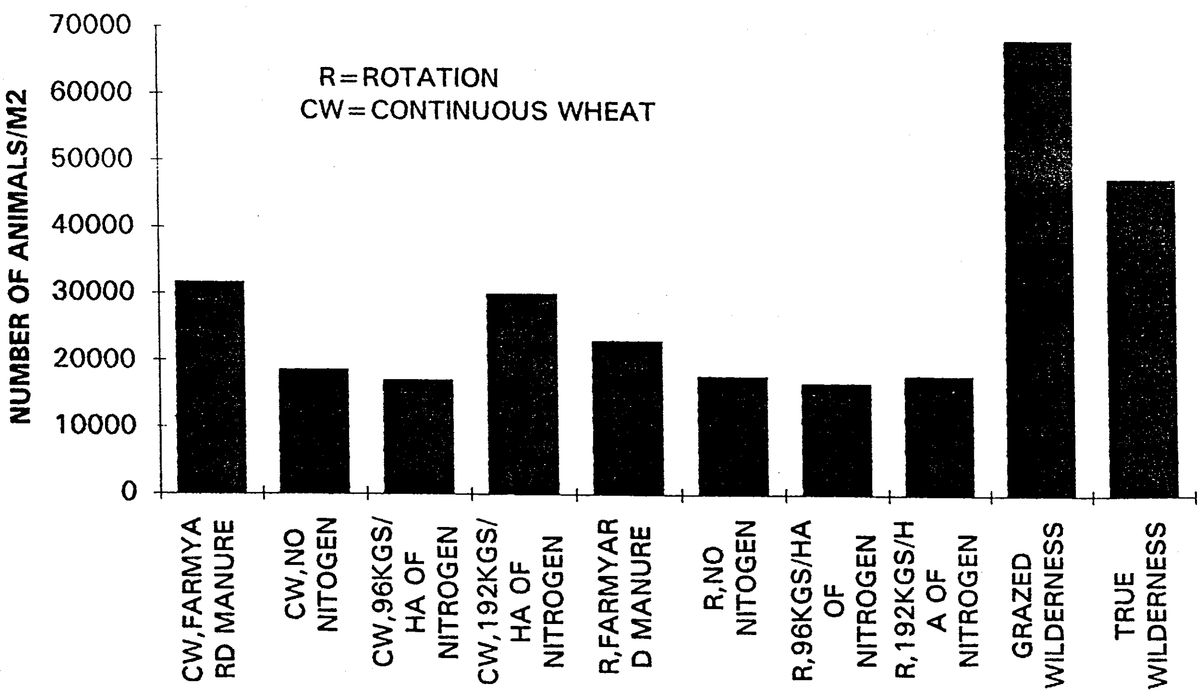
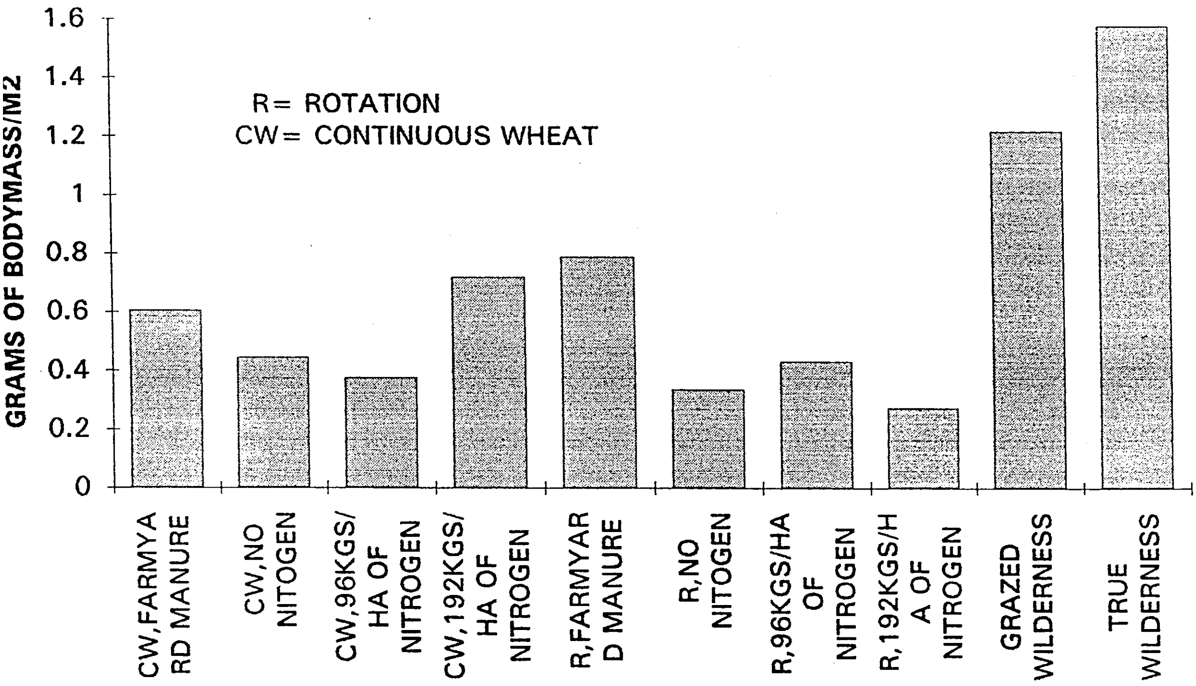


Figure 5.29 Total bodymass per $M^2$ on plots sampled in the autumn



invertebrates can differentiate between cultivated and uncultivated soil, (i.e the wilderness and the arable soils) and those receiving considerably different levels of "resource" input, (i.e. 192 kgs per hectare of nitrogen and farmyard manure as compared to no nitrogen regimes.

Agricultural activity effects the soil invertebrates indirectly by influencing their food supply or directly via cultivation which can alter the physical environment in which they live, in some cases to such an extent that a proportion of the larger animals are killed, (see Chapter 3). In systems that are not disturbed annually by cultivation, (i.e the wilderness plots), the detritus community within the soil has become well established, this being reflected in the higher number of invertebrates and cumulative bodymass in this region. On the cultivated arable land the continued annual disturbance of the soil system results in a less well developed detritus community. Figures 5.28 and 5.29 present figures for the total number of recorded invertebrates and the total bodymass in the top 30cm per $M^2$ from the autumn samples. Bodymass and number of animals are generally lower in the rotational plots in comparison with those under continuous cultivation. This is thought to be associated with the reduced return of organic matter under the rotation which includes a root crop and a years fallow.

These experiments suggest that analysis of the effects of agricultural activity using soil invertebrates is capable of distinguishing between larger differences in systems or input levels, i.e cultivation or no cultivation, high nitrogen versus no nitrogen and could provide a relatively simple tool for testing the effect of changes in cropping practice on the soil processes within a given agroecosystem. Thus the hypotheses that the use of bodysize measures can be used in wider scale monitoring is not undermined by these experiments and a considerable amount of information is potentially available from their use. It is suggested that assessing change in soil processes at the local and national level due to changes in cropping practice will become a fundamental part of the process of change to increasingly sustainable systems. Therefore analysing invertebrate populations could provide one of a number of tools in the assessment of agroecosystem processes. In Chapter 6 bodysize analysis is used in conjunction with organic matter testing to investigate the effects of a silvoarable agroforestry system on agroecosystem processes.

# CHAPTER 6: SILVOARABLE AGROFORESTRY: AN ECOLOGICALLY AND AGRONOMICALLY VIABLE ALTERNATIVE FOR TEMPERATE ARABLE LAND?

*"Intercropping, agroforestry, shifting cultivation and other traditional farming methods mimic natural ecological processes, and their sustainability lies in the natural models they follow. This use of natural analogies suggests principles for the design of agricultural systems that make effective use of sunlight, soil nutrients, rainfall and biological resources", Altieri(1991)*

## 6.1 INTRODUCTION AND SUMMARY,

Chapter 1 introduced the concept of silvoarable agroforestry systems and the reasons for increased research interest in this innovative form of cropping within the UK. This chapter forms the first part in the use of silvoarable agroforestry as a research medium or case study through which the overall research approach is applied. The previous 3 chapters have investigated the impacts of a range of farming activities on the soil system, using soil organic matter and invertebrate measures. In this chapter the development of agroforestry systems in the UK is investigated in more detail, concentrating particularly on the ecological and agronomic aspects of its introduction, (financial, economic and social implications are pursued in the ensuing chapters). This chapter has two principle aims:

1. To investigate the general characteristics of agroforestry systems which suggest it is a cropping innovation that can contribute to the increased sustainability of land based production,

2. To explore the effects of a silvoarable system on the soil processes using the measures introduced in Chapters 4 and 5.

Initially this chapter outlines the different types of agroforestry practice and briefly reviews agroforestry practice and research in other parts of the world. The theoretical and practical applications of agroforestry systems are discussed and developed using a diagrammatic conceptual model. This reinforces many of the concepts discussed in Chapters 2 and 3 which referred to the interception of incoming radiation, cycling of nutrients and volume of structure theory. The effects of agroforestry systems on the soil are investigated and an experiment is described which was designed to examine the effects of a silvoarable system on the soil organic matter, (see Chapters 3 and 4), and the size structure of soil invertebrate populations, (see Chapter 5). Results of these experiments are presented and used in discussion concerning the wider ecological implications of the uptake of agroforestry systems on UK arable farmland.

## 6.2 DEFINING AGROFORESTRY,

Carruthers (1990) in a review of the potential and prospects for agroforestry in the EC describes agroforestry as an ancient and widespread practice involving the integration of trees and crop plants or livestock. However, in modern temperate agroforestry systems the integration with trees is usually more deliberate than the above definition suggests. A definition provided by Steppler and Nair (1987) is more specific,

*"...the deliberate integration in space or time, of woody perennials with herbaceous crops and/or animals on the same land management unit."*

Agroforestry is not a new concept, (Carruthers 1990), it is the re-introduction or re-establishment of what may have been traditional practice in many areas. However, the existing framework associated with modern farming systems in countries like the UK make this introduction both complex and exciting. There are many types of agroforestry systems and these are the subject of a book, "Agroforestry: Classification and Management", (Macdicken and Vergara 1990). A simpler classification is provided by Young (1991) under 3 main headings:

**Agrosylvicultural**, (trees with crops):

Rotational:
Shifting cultivation, Improved tree fallow,
Spatial mixed:
Trees on cropland, Plantation crop combinations, Multistory tree gardens,
Spatial Zoned
Hedgerow intercropping,Boundary planting, Trees in erosion control structures, Windbreaks and shelter belts, Biomass transfer

**Sylvopastoral** (trees with pastures and livestock)

Spatial mixed:
Trees on rangeland or pasture/parkland, Plantation crops with pasture,
Spatial zoned
Live fences, Fodder banks

**Tree Crop Predominant**

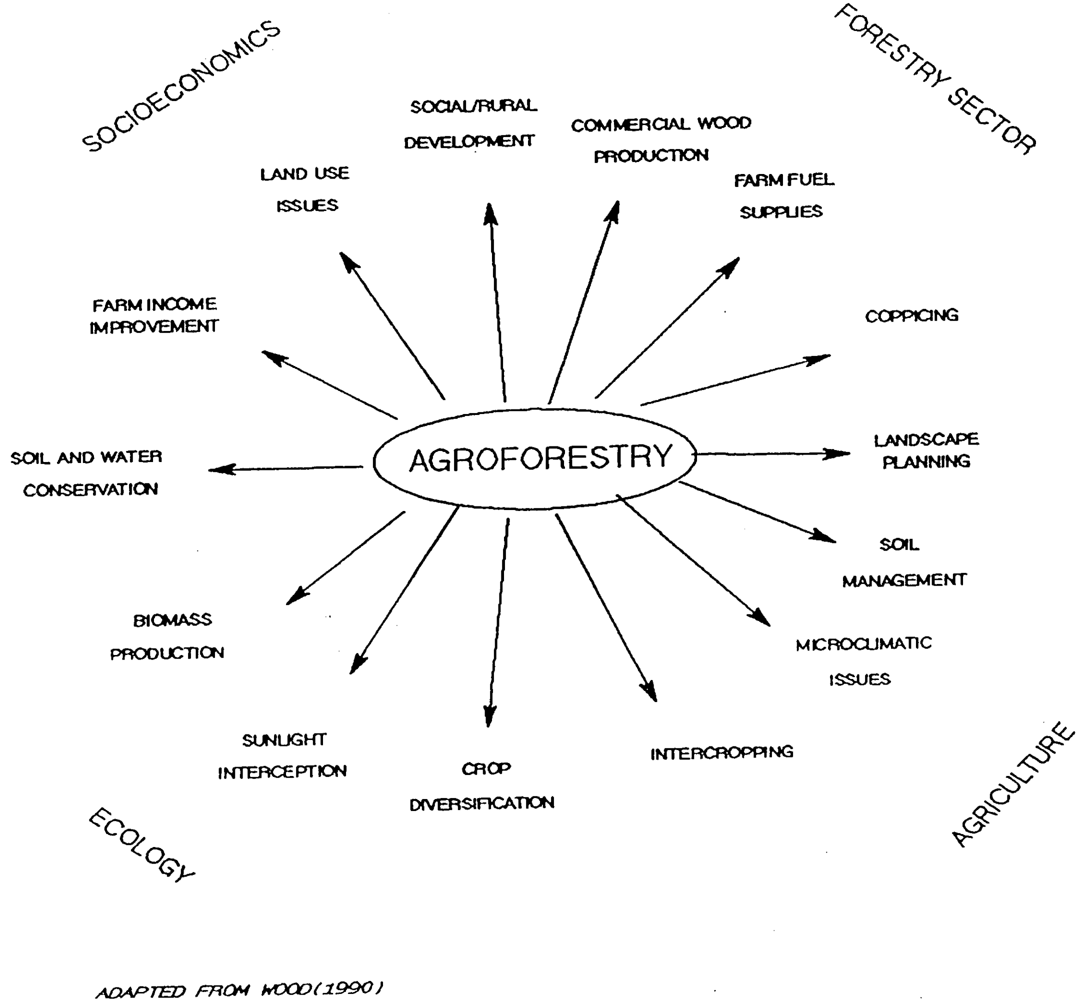
Woodlots with multipurpose management, Reclamation forestry leading to multiple use,

This wide range of systems included under the umbrella term "agroforestry" means the issues surrounding this type of cropping practice are extremely diverse. Wood (1990) represents this diverse range of issues and approaches in diagrammatic form, Figure 6.1,

## 6.3 AGROFORESTRY SYSTEMS AROUND THE WORLD,

A complete review of world agroforestry systems is beyond the scope of this research but useful texts include, (Huxley 1983, Jarvis 1991, MacDicken and Vergera 1990, Young 1991). In a review of the potential

Figure 6.1 Issues/approaches in agroforestry, (adapted from Wood 1990).



of intercropping in North America, Williams and Gordon (1992) stress that considerable development has taken place in agroforestry in tropical countries in recent years and that this has led to increased interest in temperate regions. Temperate agroforestry is generally less well developed and not as widespread as in the tropics, arid and semi-arid climates, often being associated with less well developed countries.

New Zealand is one of the few developed nations in which agroforestry systems are widely established, mainly centred on silvopastoral systems, (Anderson et al 1985, Knowles 1991). These include grazing within plantation forestry, or the planting of radiata pine into existing pastures, (Knowles 1991). Similar systems are practiced in Chile, and Australia has developed interests in agroforestry, (Moore 1992, Prinsley 1992). There is increasing interest in the development and use of agroforestry systems in North America, ( Byington 1990, Lawrence and Hardesty 1992, Williams and Gordon 1992), although many of the latter systems are indigenous and based upon the mixed livestock and tree enterprises. Italy is one of the few countries within the European Community where agroforestry is commercially practiced. These silvoarable systems in the Po valley are designed upon poplar trees intercropped with maize and soyabean. However, this intercropping is usually limited to the first 3 or 4 years after the planting of the trees whilst they are relatively small. It seems that this practice is diminishing because of economic and technical problems, (Carruthers 1990).

## 6.4. AGROFORESTRY IN THE UK: INTEREST, RESEARCH AND DEVELOPMENT.

Carruthers (1988) outlined 5 specific reasons for considering agroforestry systems in the UK:

*1. The present and anticipated future demand for forestry products and levels of national self-sufficiency,*

*2. The high proportion of the UK land which is farmland together with the current problems of agricultural surplus,*

*3. Theoretical and practical experience shows that agroforestry is feasible and in some cases more profitable than forestry or agriculture alone,*

*4. Agroforestry may be socially, organisationally and financially more acceptable to farmers than plantation forestry, offering interim income from the agricultural component, greater flexibility and scope for the gradual adoption of forestry,*

*5. Agroforestry systems may be more desirable from a conservation viewpoint than plantation forestry or agriculture, providing attractive landscapes, promoting habitat diversity and preventing soil erosion.*

Since the publication of the above paper, set-aside options have become part of arable farming and this has added momentum to the need to find acceptable alternative land use practices. Several studies have shown that agroforestry could be financially beneficial to the farmer under certain conditions, (Thomas 1991, Newman and Wainwright 1988, Thomas et al 1992), and this has intensified research interest within the UK.

Agroforestry in the UK is confined to a number of research and development sites, ( Alcock and Thomas 1987, Carruthers 1988, Newman et al 1990), although UK expertise in world-wide agroforestry is much more extensive, (Burley and Wilson 1989). There are the remains of abandoned systems such as those set up by Bryant and May in the 1960's and 70's, (Beaton 1987). Research is coordinated and discussed by researchers throughout the UK at regular agroforestry forums, and information disseminated through an informal magazine/journal, "*Agroforestry Forum*". Both silvopastoral and silvoarable research is being undertaken in the UK. There are a series of silvopastoral sites which are referred to collectively as the National Network Experiment. Of these, Angelsey, Bwnydd Mawr and North Wyke were planted in the autumn of 1987, Glensaugh and Johnstown Castle in spring 1988 and Loughall in the spring 1989. These sites are managed to an agreed protocol which aims to standardise treatments across sites. The main species planted is Sycamore at 100 and 400 stems/ha with a forestry control of 2500 stems/ha. MAFF, (Ministry of Agriculture, Food and Fisheries), AFRC, (Agriculture and Food Research Council), and the Forestry Authority are involved in agroforestry research together with other institutions, i.e. Long Ashton Research Station, Leeds University, Manchester University, Institute of Terrestrial Ecology, Silsoe College, University of Reading, University of North Wales and Edinburgh University. Four examples of systems under investigation in the UK are described below to give some idea of the spatial and temporal diversity of research work.

1. The Glensaugh National Network Experiment is studying Sycamore, hybrid larch and Scots pine grown at a variety of densities and undergrazed with sheep, (this is one of a number of network sites throughout the UK),

2. Newman et al 1991 describe a silvoarable system in which poplar trees are planted in rows spaced at 14M across the field. The trees are harvested regularly, possibly every five years to produce wood for energy.

3. The Middle Claydon Ash Silvopastoral trial is part of a MAFF funded project to determine the feasibility of producing quality hardwood timber on fertile lowland sites in Britain in silvopastoral systems.

4. MAFF have supported a new series of trial sites planted in March 1992 to test 3 new clones, i.e. Beaupre, Trichobel and Gibecq at 10 x 6.4M spacings.

A range of sites are described in a report, (Newman et al 1990), which is a study of the design, productivity and light use efficiency of silvoarable systems in the UK. This chapter reviews silvoarable systems in more detail, firstly theoretically, and then experimentally. A specific site is described later in section 6.6 which is one form of silvoarable agroforestry based on widely spaced rows of poplar trees. Although many other spatial combinations of trees and crops exist all are based on a perennial tree crop interacting with a conventional cropping system. Research work, (Ong et al 1991, Szotts et al 1991, Young 1991), suggests that this is likely to lead to the modification of both the above and below ground environment.

## 6.5 AN EXPLORATION OF THE ECOLOGICAL AND AGRONOMIC ISSUES SURROUNDING AGROFORESTRY SYSTEMS,

Tree/crop interactions in temperate zones are not as well documented as for agroforestry systems in other climes, and much of the research cited in this section has been undertaken in non-temperate climates. In many of these cases it is the magnitude of the effects that may differ and not the principle processes. It is widely accepted that basic concepts of intercropping can be usefully extended to agroforestry systems where information is generally limited. (Willey et al in Ong et al 1991).

A considerable amount of literature and research exists, both theoretical and practical, on interactions in intercropping systems, (Mead and Willey 1980, Willey 1985, Gliessman 1987,1989, Vandermeer 1989, Carrol et al 1990, Bulson 1992), and to a lesser extent agroforestry, (Newman 1986, Young 1991, Ong et al 1991, Szotts et al 1991). Interactions in agroforestry systems are often classified into above and below ground categories for research purposes, (Ong et al 1991). Ong et al (1991) suggest the following beneficial above and below ground interactions:

Above ground,

1. Temporal sharing of physical resources,
2. Improvement of photosynthesis of the mixed canopy
3. Amelioration of the microclimate,

Below ground,

1. Spatial sharing of below ground resources,
2. Nitrogen transfer from leguminous trees,
3. Improvement of soil physical characteristics.

They are careful to point out that there are several adverse effects which are "rarely mentioned", i.e. competition for water, alleopathy and pest build up. Interactions associated with tree and crop combinations within a temperate silvoarable system are represented in Figure 6.2. The diagram is based upon information from various research work and the extrapolation of theoretical concepts. These are developed in the ensuing sections.

The presence of trees effectively increases the volume of agroecosystem structure described in section 2.5, (also see Figure

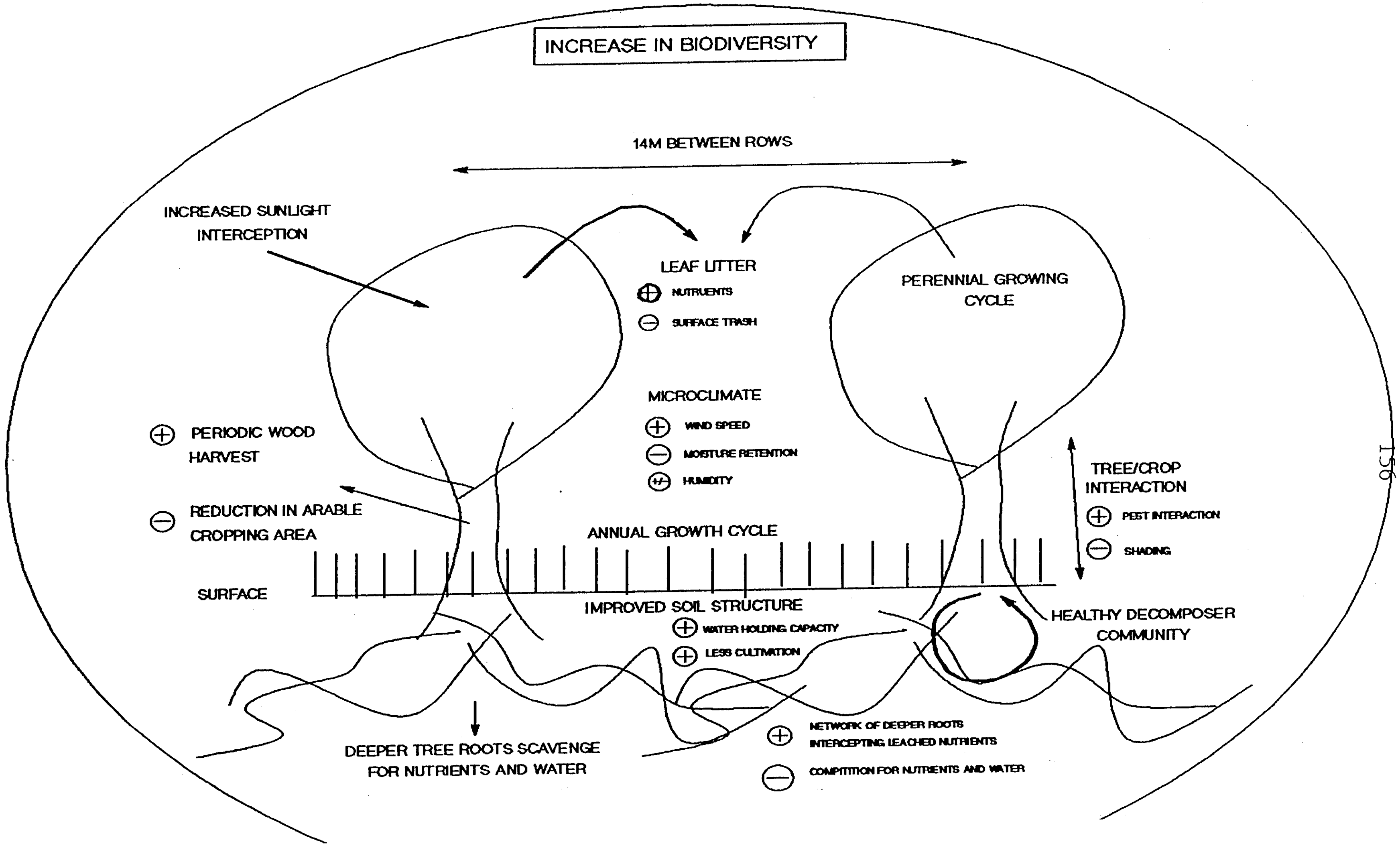



Figure 6.2 Interactions associated with tree and crop combinations within a temperate silvoarable system

2.1). However the interactions which result from the combination can be both beneficial and disadvantageous to the tree or the crop. For instance the competition for space. This occurs on the lateral plane of the soil surface with the planting of trees immediately reducing the area that can be planted with the non-woody crop. However, this competition for space extends upward effecting light interception and below ground to affect the rooting pattern of both trees and field crops. This will influence the productivity of the both the tree and field crop and thus the overall productivity of the system.

### 6.5.1 Productivity of agroforestry systems,

Land Equivalent Ratios, (LER's) have been developed to give an indication of the overall productivity in intercropping systems. Willey (1985) describes the theory behind LER's in some detail. Newman (1986) uses the measure to evaluate output from a pear/vegetable system and Bulson (1992) from a non-woody wheat/field bean intercrop.

LER can be represented by the following equation,

LER= (YiA/YsA)+(YiB/YsB) *-(Equation 6.1-after Newman et al 1990)*

where

YiA=Yield per unit area of intercropped crop A
YsA=Yield per unit area of solecropped crop A
YiB=Yield per unit area of intercropped crop B
YsB=Yield per unit area of solecropped crop B

A LER of 1 represents normal drymatter production under monocropping. Thus a figure of 1.2 under an agroforestry system would represent an increase in drymatter productivity of 20%. An early use of LER's in UK agroforestry systems recorded values in excess of 2 for a pear and vegetable system, (Newman 1986), although a figure of 1.14 calculated for the poplar arable trial at Manor farm, Wolverton, (Newman et al 1991), is perhaps more representative of cereal/tree combinations. One of the criticisms of LER is that it doesn't necessarily represent usable yield, (Bulson 1992). This is important as for some cash crops there is a minimum size below which the value of the crop is much lower, i.e. strawberries, potatoes. Therefore an intercropping system could well increase the overall drymatter production but reduce value of saleable product. In many cases the yield of the main crop is reduced slightly by the presence of trees. Table 6.1 presents figures from the silvoarable system at Leeds University, illustrating a reduction in pea yield due to the presence of trees,

Table 6.1 Yields of threshing peas per unit sown area at 14% moisture in 1990, (after Incoll et al 1991).

| Replicate | Yield $tha^{-1}$ | | Yield reduction (%) |
|---|---|---|---|
| | Control | Silvoarable | |
| 1 | 5.37 | 4.57 | 15 |
| 2 | 5.36 | 4.97 | 7 |
| 3 | 6.45 | 5.98 | 7 |
| 4 | 6.30 | 5.81 | 8 |
| Mean | 5.88 | 5.33 | 9.3 |

### 6.5.2 Light interception,

In theory an agroforestry system provides two tiers, (or more in the case of home gardens), of photosynthetic material and thus may be capable of intercepting a higher amount of incoming radiation. Plants utilize incoming radiation with low efficiency, (Spedding, 1975 suggests an upper theoretical limit of around 5%, and in a crop of wheat estimates this to be 0.8-1%). Energetically it should be possible to increase the overall interception per unit area by optimizing the photosynthetically available surface area. The possibility of increasing the amount of sunlight intercepted was discussed in Chapters 1 and 2, and interpreted as a desirable attribute in increasingly sustainable production systems. Agroforestry systems could provide one means of intercepting a higher proportion of the incoming radiation. However, the relationship between the interception of incoming radiation and photosynthetic area is complex because of the shading effect of the trees as they grow above the crop canopy.

Experiments undertaken by Newman et al (1990) suggest that many understory crops are tolerant to quite high degrees of shading. In a silvopastoral trial with poplars they found that a 55% reduction in photosynthetically active radiation, (PAR), due to shading gave only a 11% reduction in sward total drymatter productivity, and a 80% reduction in PAR reduced productivity by only 21%. Photosynthetically active radiation is that proportion of the incoming sunlight, usually about 50%, that can be potentially utilized by the photosynthetic apparatus of the plant. A shading model, (Newman et al 1990), can be used to estimate the degree of shading suffered by the understory crop depending on orientation and height of trees and this may be useful in matching understory rotation to tree age on short rotation systems. (i.e. where the trees are cut every five years)

Temporally, advantages arise from mixed cropping if the main periods of maximum foliation, (and therefore growth), differ. Ong et al (1991) describe an intercropped system of pigeonpea and sorghum suggesting that the former was unable to utilize incoming radiation efficiently during the first couple of months of the growing season. When planted in combination with sorghum 52% of incoming radiation was utilized compared to only 22% if the pigeonpeas were solecropped. Agroforestry systems could be visualised in this country with an arable crop such as winter oilseed rape intercepting radiation early in the spring, in combination with Ash which comes into leaf much later in the spring. The two species thus have temporally different demands for light. Following harvest of the oilseed rape in late July/ early August, the Ash trees would still be making use of at least some of the incoming radiation at a time when the ground would be otherwise completely bare.

### 6.5.3 Microclimatic changes,

Agroforestry systems are often attributed with the amelioration of microclimate, (Huxley 1983). The effects of shading will influence the moisture regime within the trees, generally reducing transevaporation in hot weather. This results in an increase in moisture retention which is likely to be beneficial in drier months. Conversely shading may increase the local humidity which could encourage fungal disease within the arable crop, (i.e. mildew, rusts etc), and is likely to increase the time period required for the soil to dry out following wet weather. This may have implications with regard to the timeliness of cultivations.

The reduction in windspeed across the surface of the field crop is thought to have a beneficial yield effect. For instance a review undertaken by Kort (1988) on the crop enhancing properties of trees when acting as a windbreak demonstrated mean increases in wheat yields of 24% over 14 experiments.

### 6.5.4 Biotic diversity,

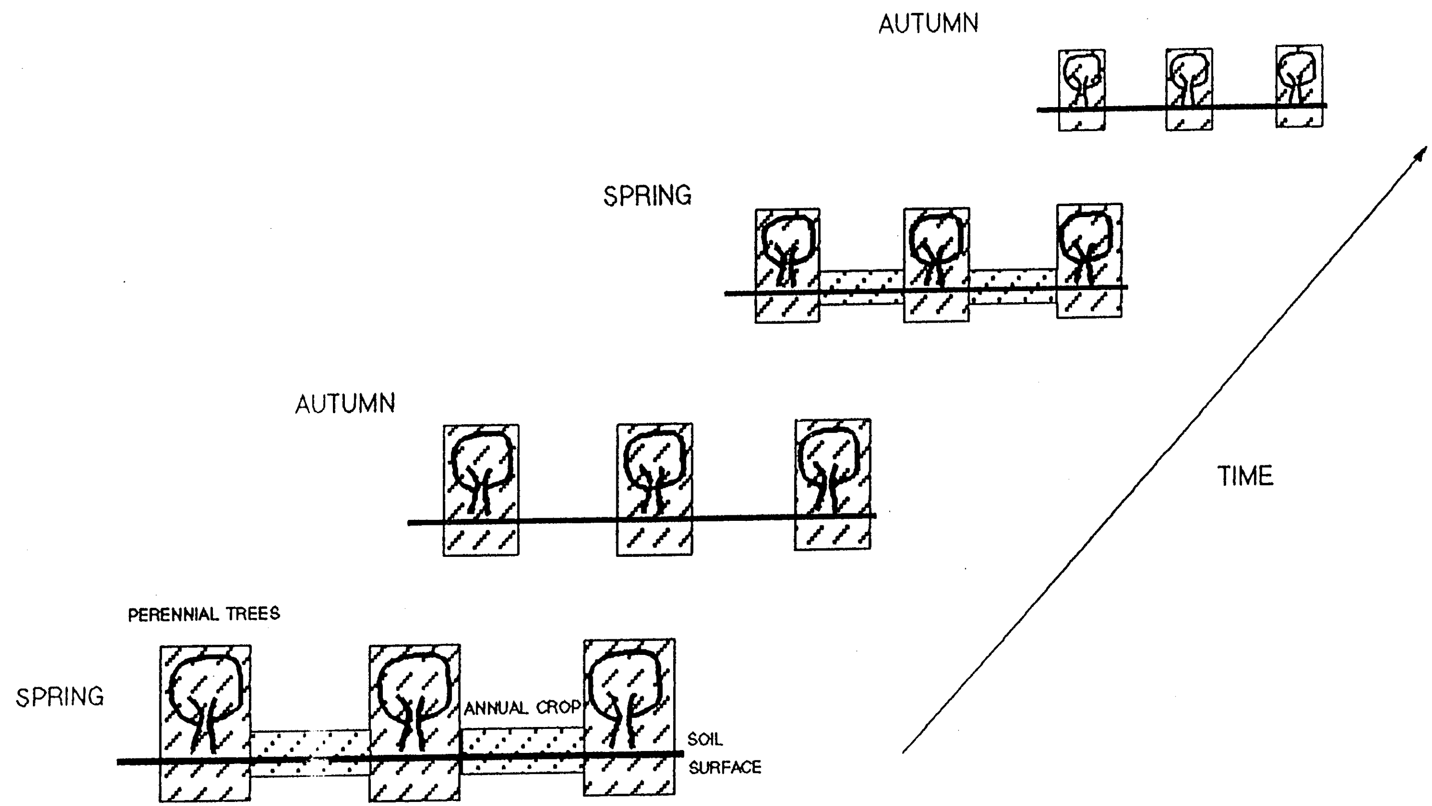
The importance of biotic diversity in lower input cropping systems is highlighted by Altieri(1991),

*"The correct spatial and temporal assemblage of crops, trees, animals, soil and so on enhances the interactions that sponsor yields dependent on internal sources and the recycling of nutrients and organic matter, and on trophic relationships among plants, insects or pathogens which enhance biological pest control."*

Planting two species within the same spatial area is obviously a direct increase in the number of main species present. Monoculturalistic cropping systems have attracted increasing criticism due to the associated loss in plant diversity. This can be interpreted as a reduction in potentially available habitat which has a knock-on effect in animal populations, (Gliessman 1987).

Specific quantitative research on the wider implications of agroforestry for biotic diversity on temperate farmland is sparse. Two recent reviews, Prinsley (1992) reviewing agroforestry in Australia, and Carruthers (1990) in the EC, state only that agroforestry probably increases local biodiversity and may provide a wider diversity of habitats for wildlife. Tree/crop combinations may be considered beneficial to a variety of animal life because they provide habitats at several "tiers". The perennial nature of the trees provides a continuity of habitat which is beneficial to

Figure 6.3 Changes in volume of structure over time in a silvoarable system.



wildlife, and is another potential advantage associated with the maintenance of a high volume of structure, (see Chapter 2). This is in contrast to the annual harvesting and loss of habitat associated with arable cropping. These relationships are represented in Figure 6.3.

Depending on the method and spatial pattern of planting the trees provide an area of undisturbed soil in which other "weed" species may colonize with associated increases in animal and plant diversity. Normal hedgerows illustrate this phenomena on a smaller scale, (see Sotherton 1985). From the ecologists point of view these increases in species diversity may be beneficial, but agronomically it could present problems. Incoll and Corry (1990) describe a silvoarable system based on production hedges at Leeds University in which research is presently being carried out to investigate pest interactions associated with this form of spatial cropping.

### 6.5.5 Pest, weed and disease interactions,

It has been suggested that the microclimate created by the trees can effect foliar disease in the field crop, (section 6.5.3). Trees may also harbour pests or act as an intermediate host for diseases which affect the main crop. This can be exaggerated by the ingression of weeds around the base of trees. However, considerable research has been undertaken on pest interactions in intercropped systems. Risch et al (1983) explored 150 studies in which the effects of agroecosystem diversification on insect herbivores was examined. Their analysis showed 53% of the herbivore species decreased in diversified systems, 18% increased, 20% showed a varied response and 8% recorded no change.

A review of vegetation diversity and insect pest outbreaks is provided by Altieri and Letourneau (1984). They question, *(and doubt)*, whether the pest problems of modern agriculture can be alleviated within the context of the present capital intensive structure of agriculture. In a later paper, Altieri (1991) suggests that biodiversity created as a result of multiple cropping, intercropping and agroforestry may allow improved pest management. In the UK a recent study by Bulson (1992) into the intercropping field beans and wheat didn't record any reduction in pests or diseases although did report that weed growth was suppressed by greater/ better ground cover in the intercropped system.

Hedgerows can act as reservoirs for infection and for weed seeds, suggesting that care needs to be taken in the management of rows of trees within arable fields. In some of the trials established in this country, (Newman et al 1991), the tree row has been planted into a polythene mulch. In the above trial this has persisted for the first 5 years, limiting the ingression of weeds. After this time period the possibility exists to use a wood chip mulch, similar to that used in parklands, to prevent weed ingression. This could be produced from the lower branches which are progressively brashed up to ease machinery access and to produce a high quality butt log. Evidence of damage due to the presence of larger pests like rabbits and pigeons is limited. Pigeons may thrive in a system in which arable crops contain rows of trees where they could roost. Rabbits may find the strip of rough surrounding the trees useful for cover.

### 6.5.6 Wind and water erosion

In a book that reviews agroforestry for soil conservation in mainly non-temperate countries, Young (1991), suggests that direct experimental data on the effectiveness of agroforestry in controlling erosion is at present scanty. In temperate climes most of the research work that exists is based on shelterbelts or studies that have investigated the effects of single trees on the soil system, (rather than combinations). However, this research provides a wealth of relevant data. Trees are known to reduce the windspeed across the soil surface, Kort (1988), and this is discussed by Byington (1990) as a major benefit from the use of agroforestry systems in North America. The American dust-bowl conditions of the 1930's demonstrated the ability of the wind to erode and reap havoc in ill managed farming systems. This helped to promote the wide scale use of trees to reduce surface windspeed. In the UK the problems of wind blow are generally not as severe as in some parts of the world, although the flat sandy areas of Eastern England are prone to blow. For instance young sugar beet plants in the early spring can be cut off or uprooted by the blowing soil. Prinsley (1992) suggests that shelterbelts in Australia can cut the surface windspeed by up to 50% and their use needs developing further in arid and semi-arid areas.

The effects of trees on water erosion is subject to a complex mix of interactions. The leaves of trees have a direct effect by reducing the impact of raindrops on the soil surface, (see work by Imenson and Verstraten 1986 on raindrop impact). The practice of cutting foliage from the trees and laying it on the surrounding earth is popular in many tropical countries, (Young 1991). This form of mulching is particularly useful in areas where intense seasonal rainfall coincides with the times of the year when the land is bare.

The extensive tree root systems help to bind the surface soil, reducing the likelihood of lateral movement. Indirectly the trees may add to the organic matter content of the soil enabling it to hold more water before it reaches field capacity. Further, the uptake of water by the tree itself may extend the period of time before the soil becomes saturated. Once the process of water erosion has begun, (for whatever reason), the presence of trees, and more specifically their root network may prevent the escalation of the erosion by reducing the momentum of surface run off. (Further reading on the mechanisms, types and scale of erosion can be found in Wild 1988 and Pimentel et al 1987).

### 6.5.7 The tree root network,

It has already been suggested that the extensive rooting patterns of tree roots aids erosion control. The perennial nature of trees makes the root system a relatively permanent part of the holistic soil structure. Roots are generally associated with "opening up" the soil, increasing aeration and providing channels for drainage, as they penetrate in search of water and nutrients, (Russel 1969). Goss (1991) suggest they aid in the formation of vertically orientated pores which are necessary for free drainage and further root development. Plant species have characteristic rooting patterns, although these can be modified greatly by soil conditions, (Flitter 1983). The nature and extent of tree roots make them difficult to study, although research work on tree roots has progressed considerably in recent years, (Atkinson 1980,1990). Rooting systems of plants have already been discussed in section 3.8.2)

Tree roots are generally more extensive than conventional annual crops such as wheat, (although wheat will root to depths of over 1M in good conditions). The ability of tree roots to extend laterally is demonstrated by work undertaken by Raw (1962) in apple orchards at 10M intervals which suggests that after 7 years the roots had met across the rows. Aggressive rooting trees such as poplar and willow can have rooting systems that extend over quite considerable distances. Beaton, (personal communication 1992), claims the roots of poplar trees spaced at 14M in a silvoarable trial near Milton Keynes, (see section 6.9) may have met across the rows in the 5 years since their establishment. The "aggressive" rooting of these trees is demonstrated by guidance notes for the planting of trees in the proximity of gas mains. This suggests willows and poplar should not be planted within 10M of a main.

Little research has been undertaken to investigate the extent to which the tree roots affect soil structure beyond the immediate vicinity of the trees. This need exists in both tropical and temperate systems, (Beaton 1992 personal communication, Ong et al 1991). Although the highest density of roots is found close to the tree, (Atkinson 1990), a substantial amount of rooting activity occurs away from the base of the trees. Under silvoarable systems this is likely to be in, or under soil which is cultivated annually. Campbell et al (1989) describe a silvopastoral system in which wildcherry trees are planted into pasture land mainly dominated by rye-grass. They were studying the rooting patterns, undertaking soil water and nutrient analysis as well as studying plant growth. Excavation of the trees to study lateral rooting patterns demonstrated that the tree roots that had extended the greatest distance were found below the top twenty centimetres. In this uncultivated B horizon there were less grass roots, perhaps explaining the proliferation of tree roots in this section of the soil.

Similar research on silvoarable rooting systems is not widespread. Research at Leeds University studies the impact of tree roots and nitrate leaching although not specifically in a agroforestry context. However, rooting patterns are closely linked with nutrient and water availability and uptake which are discussed in sections 6.5.9 and 6.5.10.

**6.5.8 Soil organic matter effects,**

The proliferation of roots adds organic material to the soil through the slothing of root tips as the system expands, and the natural death and turnover of existing roots. Between 50 and 70% of plant growth is likely to be below ground and it is suggested that the turnover and losses of organic matter is greater in the roots than in aerial material, (Reichle 1977, Flitter 1991). Goss (1991) suggests that a large proportion of the carbon in the root system contributes to the soil organic matter as death and decay occurs.

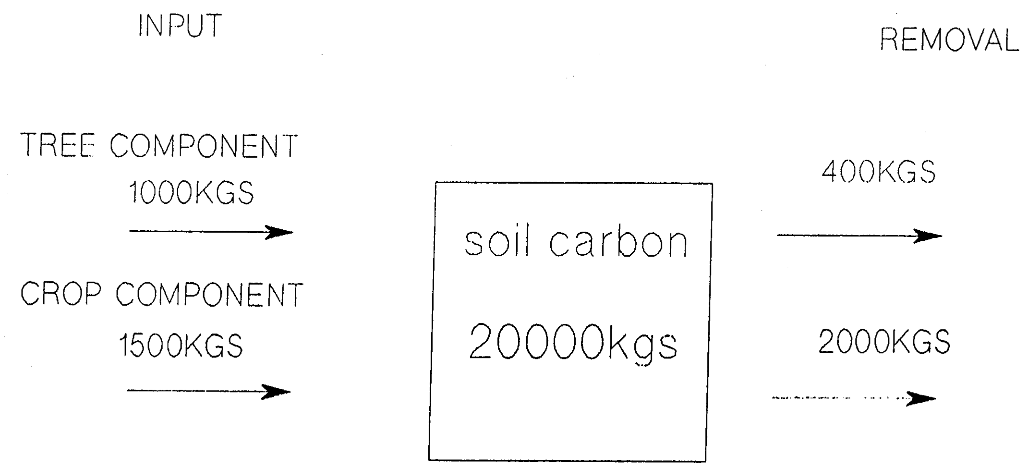
Decaying foliage adds to the organic material on the surface. The amounts of leaf litter produced by trees in temperate agroforestry systems is not well documented. Young (1991) gives a range of leaf production in humid and semi-humid climates of between 1000 and 8000 kgsDm/ha/yr. Data for temperate mixed hardwood coppice is presented by Van Der Drift (1963) and gives additions of organic material to the forest floor in the order of 3000-4000kgs/ha fresh weight per year. Howard and Howard (1991) present various data for the accumulation of soil carbon under forest in the UK, and this suggests that forest clearance and replanting corresponds to a rapid loss of carbon after cutting with gradual accumulation as the new forest grows. An estimated carbon balance under a temperate agroforestry system is illustrated in Figure 6.4.

In combination both roots and foliage provide a significant return of organic material to the soil. This quantity of organic matter will be extremely important in some silvoarable systems where the entire above ground annual crop is harvested. (i.e the grain and the straw.), or in systems where the soil organic matter levels are already low. Chapter 3 discussed the important role organic matter has within the soil system, and MOVEMOD described in Chapter 4 demonstrated the possibility of increasing the amount of material returned to soils low in organic matter within the constrains of conventional farming systems. Agroforestry systems can be argued to have two further benefits with respect to organic matter. Firstly, there is an area of land, (even in silvoarable systems), which is not cultivated. This is likely to reduce the amount of carbon lost directly to the atmosphere due to oxidation, (see Chapters 3 and 4), and may aid the establishment of a healthier soil community, (see Chapter 5). Secondly, the tree roots may be more fibrous than normal annual crop roots and this is likely to slow the decomposition process down. The role of organic matter and the associated detritus cycle, (and soil communities), in soil process is well documented, (Swift et al 1979, Dickinson and Pugh 1984) and has been discussed in detail in Chapter 3. Current knowledge suggests that if farming systems are to become less reliant on external nutrients these processes and soil communities are going to play a vital role in the development and maintenance of soil fertility, (Wood 1991).

### 6.5.9 Nutrient availability and cycling

Nutrient availability and cycling is closely linked with the organic materials and the soil fauna and flora within the soil, (see Chapter 3). Within the majority of temperate silvoarable systems the supply of nutrients from the soil will be supplemented by plant nutrients added in the form of either organic or inorganic fertilizers. In section 6.6.1 it was argued that in some systems an overall increase in

Figure 6.4: A simple carbon balance under temperate agroforestry, (adapted from Young 1991)




NET CHANGE

| | |
|---|---|
| TREE COMPONENT | +600KGS |
| CROP COMPONENT | -500KGS |
| AGROFORESTRY SYSTEM | +100KGS |

Assumptions made

1. 2Mkgs/ ha of topsoil with 1% carbon content

productivity could be achieved using agroforestry compared to conventional cropping. This indicates that there will be an increased demand for plant nutrients. This demand can be met from 3 sources:

1. An increased supply of external nutrients in the form of fertilizers,

2. An increased supply due to enhanced efficiency of utilization of those nutrients within the soil,

3. Exploitation of additional soil reserves,

Young (1991) states that agroforestry systems promote more closed nutrient cycling than conventional agricultural systems. Several mechanisms are involved:

1. The extensive root network picks up any excess nutrients in the soil, which may otherwise be leached, and returns them back to the surface through the cycling of leaf litter,

2. The extent of tree root systems allows them to scavenge for nutrients at depths beyond those normally associated with normal crops. These are again returned to the surface through leaf litter,

3. The gradual increase in soil organic matter suggests that the organic component of the soil may release higher levels of nutrients into the soil system.

However, data to confirm these hypothesis is scanty even in tropical soils and is almost non existent for the high input/ output systems of the UK. Szotts et al (1991) state,

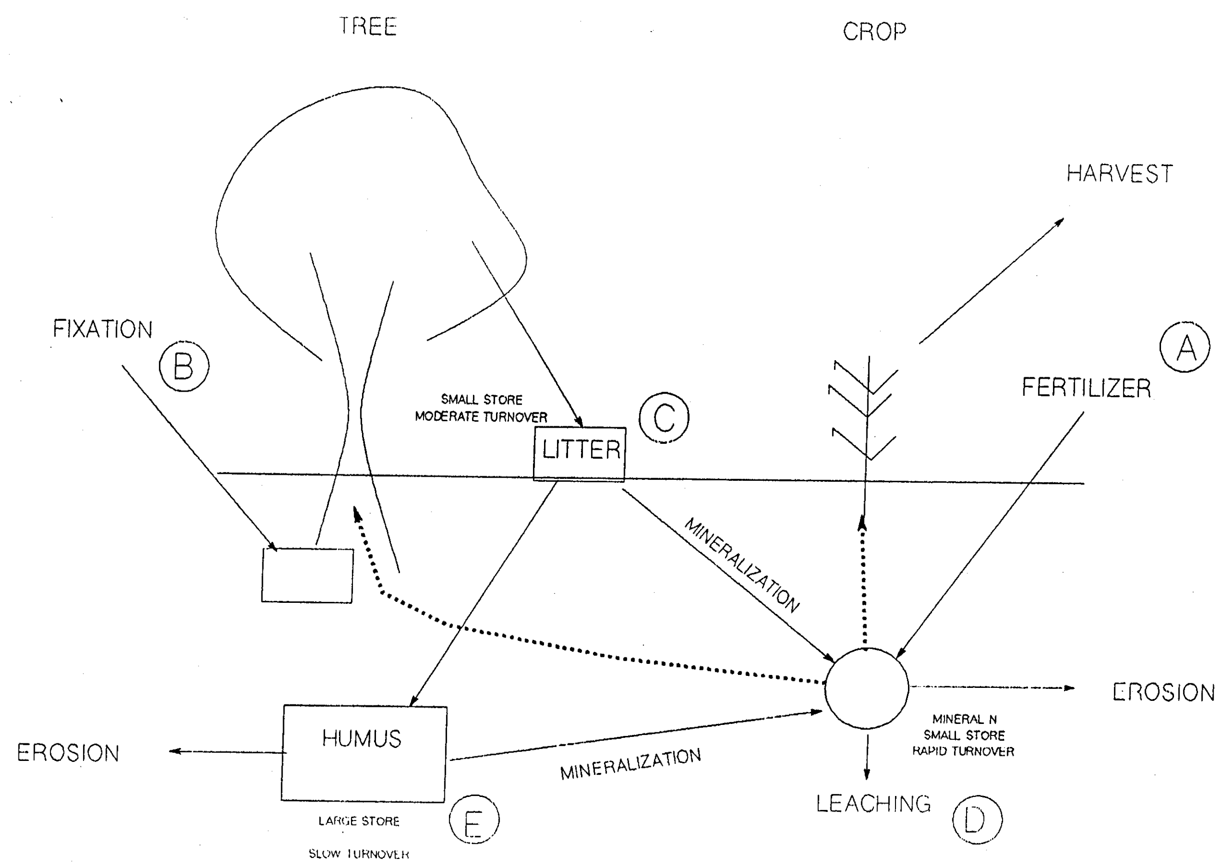
*"...there needs to be greater consideration of basic soil/plant interactions in processes which affect sustainability and performance of agroforestry systems and how these processes vary with soil type."*

The exploitation of nitrogen fixing trees is widespread in many parts of the world. (Young 1991, Ong et al 1991). Nitrogen is usually considered to be the first limiting nutrient in plant growth, (Wild 1988), and is applied in large quantities in the UK. Young (1991) illustrates a simple nitrogen cycle under an agroforestry system based on nitrogen fixing trees, (see Figure 6.5)

In Figure 6.5 the closer cycling of nutrients is claimed because the trees can reduce leaching, D, possibly increase the soil supply through fixation, B, bring nutrients back to the surface in litter, C, and possibly make better use of the large store within the soil, E. A combination of these processes should reduce the amount of fertilizer, A, that is required.

Phosphorous is often regarded as the second limiting nutrient in agricultural system. Its extraction by plants from the soil can be aided by Mycorrihizae, (see Wild 1988), which effectively expand the

Figure 6.5 A simple nitrogen cycle under an agroforestry system based on nitrogen fixing trees, (after Young 1991)



root system of the plant in exchange for carbohydrates, (Young 1991). This leads to increased availability of phosphorus within the soil for plant growth. Tree roots can theoretically obtain nutrients like phosphorous from areas of the soil that may not be available to normal non-woody plant. This is then deposited back on the surface in leaf litter. Table 6.2 gives an indication of the main plant nutrients that could be returned via tree leaf biomass.

Table 6.2 Estimate of nutrients in leaf biomass, expressed in kilograms of plant nutrient returned per 100 kilograms drymatter of leaf biomass, (adapted from Young 1991),

| Nutrient | % in leaf | Nutrient return (kgs/ha/yr) |
|---|---|---|
| Nitrogen | 2.0-3.0 | 2.0-3.0 |
| Phosphorous | 0.2-0.3 | 0.2-0.3 |
| Potassium | 1.0-3.0 | 1.0 -3.0 |

The degree to which trees do "tighten" the nutrient cycle, and thus alleviate the wastage of external nutrients has not been fully investigated. Perhaps of even greater interest /concern is the degree to which the tree crop may deprive the annual arable crop, (and usually the most profitable), of nutrients. Research has been carried out in non temperate countries using root barriers of polythene. These experiments are costly and complex and the generalization of the results is poor. Productivity per unit of external input is perhaps a more useful measure in this context.

### 6.5.10 Water availability and cycling

Ong et al (1991) suggest that availability and competition for water may be one of the "rarely" mentioned drawbacks of some agroforestry systems. The exposure of increased photosyshthetic plant material above ground is likely to increase the demand for water, (through transevapouration). Growing conditions will govern the extent to which this is a problem, and in arid and semi arid countries this is likely to be a major concern. In a temperate climate such as the UK this problem is not as severe, although certain areas of eastern England do suffer from dry periods in mid summer. This may be somewhat counterbalanced by a reduction in transevapouration due to shading, (see section 6.5.3). The water retention properties of the soil are likely to be modified if the agroforestry system leads to an increased level of organic matter within the soil, and this may be enhanced by a generally improved soil structure.

In wet soils there is some suggestion that the trees may actually help to dry out the soil, improving its workability and allowing cultivation for longer periods of the year, or the establishment of a cash crop instead of rough grazing. This phenomena can often be seen where trees are planted on wet land, although this is only hypothesized for structured agroforestry systems and little research work has yet been found to verify or refute these claims. Agroforestry systems are used in some parts of the world to alleviate salinity problems that are caused by the replacement of deep rooted perennial forests with shallow rooted annual agricultural species. Prinsley (1992) provides an overview of this strategy in Australia, although salinity is not generally recognised as a problem in the UK.

## 6.6. ECOLOGICAL AND AGRONOMIC EVALUATION OF SILVOARABLE SYSTEMS IN THE UK

In the previous sections some of the complexity regarding the study of agroforestry systems has been discussed. This highlighted the general need for further studies of rooting pattern and nutrient cycles within the soil system. Research issues are further confused because the majority of investigative work has been undertaken in non-temperate climates, and in very different farming systems. However, several major themes associated with productivity, soil condition and nutrient cycling suggest that agroforestry systems could contribute both ecologically and agronomically to farming systems in the UK. The remainder of this chapter focuses on the effect of a silvoarable system on soil processes using soil organic matter analysis and bodysize parameters as methods for studying soil processes. (see Chapters 3,4 and 5).

Several alternative sites exist within the general locality for the study of silvoarable systems, (see Newman et al 1990), and from within these a site near to Milton Keynes was selected for study. The site at Manor Farm, Wolverton is easily accessible, well established and representative, (combining common arable crops such as wheat and oilseed rape with recently introduced Belgian Poplar Clones). These are capable of high growth rates, (see Forestry Commission Research Information Note 181), and provide strong straight stems with minimum branching. Data on tree productivity is given in Table 6.3 to give an indication of the growth potential of these systems. Appendix 4 contains photographs of the Manor farm site.

Table 6.3. Site productivity data for Manor Farm, Wolverton, 1989-1992.

Height and DBH, (Diameter at Breast Height), measurements have been taken in each year. Figures presented are for the years 1989-1992 for both Boelare and Beaupre. There is no significant difference between varieties with respect to height and DBH.

| YEAR | VARIETY | HEIGHT (M) | DBH (CM) |
|---|---|---|---|
| 1989 | Beaupre | 4.4 | n/a |
| | Boelare | 4.3 | n/a |
| 1990 | Beaupre | 6.8 | 6.2 |
| | Boelare | 6.4 | 6.1 |
| 1991 | Beaupre | 8.8 | 9.3 |
| | Boelare | 8.9 | 9.5 |
| 1992 | Beaupre | 11.2 | 13.5 |
| | Boelare | 11.4 | 14.1 |

These growth rates can be compared with more traditional poplar varieties in yield class 14, (see Chapter 8 for definition of yield class), that in similar conditions would be about 8.9M tall with a DBH of 12.6 cm after 5 years growth. These dimensions were reached in only 3 years by the above poplar clones. The presence of the trees has an effect on the productivity of the main arable crop and this is demonstrated in Table 6.4, together with information on the arable rotation.

Table 6.4 The effects of the presence of the trees on the yield of the main crop in the years since the establishment of the silvoarable systems,

| Year | Crop | Variety | Yield $Tha^{-1}$ Control | Yield $Tha^{-1}$ Intercropped |
|---|---|---|---|---|
| 1988 | S. Wheat | Axona | 4.26 | 3.07 |
| 1989 | S. Wheat | Axona | 3.03 | 1.48 |
| 1990 | Fallow | - | - | - |
| 1991 | S. Wheat | Axona | n/a | n/a |
| 1992 | S. OSR | Forte | n/a | n/a |
| 1993 | S. Barley | Chariot | - | - |

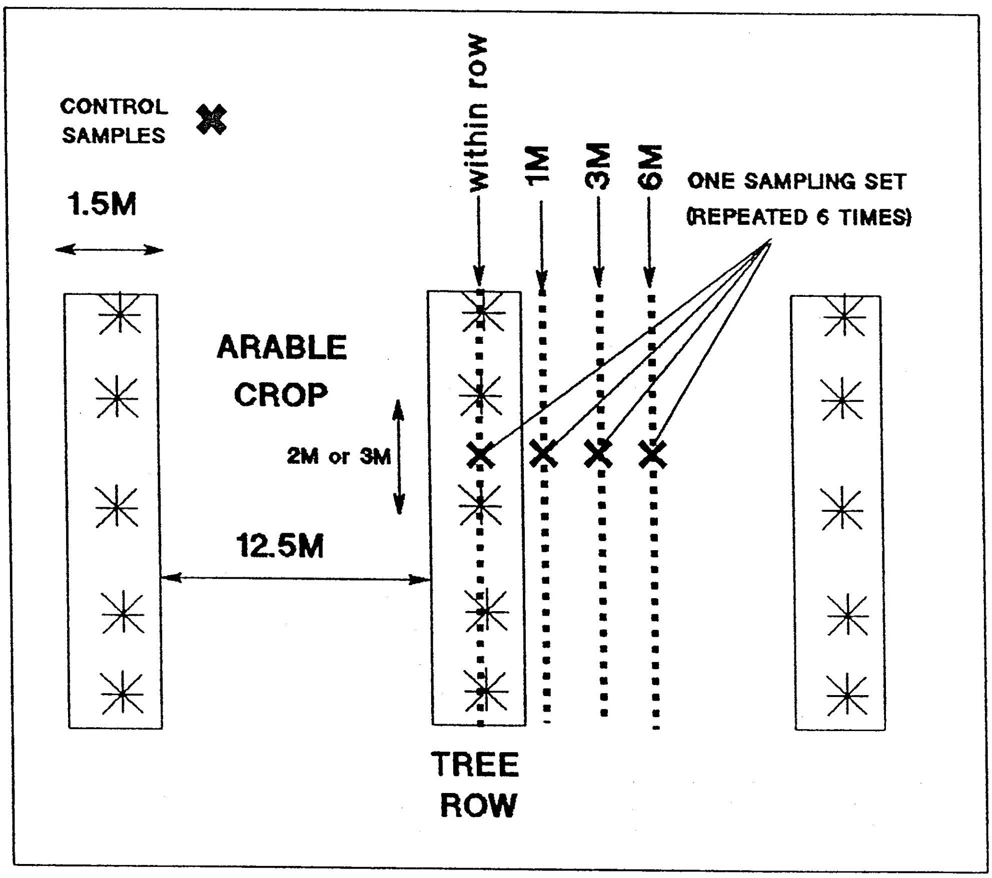
**6.7 THE WOLVERTON TRIAL AND THE SOIL SAMPLING,**

The site was planted in March 1988 with rows of Poplar, varieties Boelare and Beaupre, at a between row spacing of 14M. The trees were initially planted at 1M within row spacing, but were subsequently thinned to 2 and 3M spacing in the autumn of 1991. No attempt was made to differentiate between varietal effects or recent thinning effects on the soil system. The trees were planted as 1.5M rods into black polythene mulch to suppress weed competition, (to which poplar are particularly susceptible when young, Forestry Commission 1990, Bulletin 92). Trees have subsequently been brashed, (removal of lower branches to improve timber quality, allow easier access of machinery and to allow more light into the arable crop). Appendix 4 contains several photographs of the site taken in the spring of 1993 when the trees were about 5 years old.

Soil samples were taken from the silvoarable trial on the 8th June 1992 to investigate changes in the lateral and vertical distribution of both soil organic matter and soil invertebrates, (specifically arthropoda), due to the presence of trees. The soil on the 4 ha site is a clay loam series classified grade 3 and at the time of sampling was planted with a crop of spring Oil Seed Rape. Belgian Poplar Clones, (vars. Boelare and Beaupre,) are planted in rows at 14M intervals across the field.

The samples were collected from within the tree rows and at 1,3 and 6M from the centre of the tree rows with 6 samples being collected at each distance. Sample cores were taken at depths of 0-15cm and 15-30cm, control samples were taken from within the same field, (see Figure 6.6.)

Figure 6.6 Diagrammatic representation of the experimental samples



Soil animals were extracted using Tullgren funnels, (see Appendix 3 and Chapter 5). Extracted animals were identified, counted and measured and the results of these analysis used to produce bodylength spectra of animals within the phylum arthropoda between 0 and 6mm for each of the sampling distances and the control. Additionally, the soil organic matter content of the extracted samples was estimated using a standard titration technique. (British Standard 1377/1901). This is based on the oxidation of organic matter using chromic acid and determines the amount of organic carbon in the samples, which was subsequently multiplied by a correction factor of 1.724 to give the percentage organic matter. See Appendix 5 for details of methodology.

**6.8 EXPERIMENTAL RESULTS,**

Figures 6.7 to 6.16 illustrate bodysize spectra for the 10 regions sampled, expressed as number of invertebrates per $M^2$. Each of the distributions is positively skewed indicating that the majority of the arthropoda in the size range 0 to 6mm lie at the lower end of the distribution. A summary of the results of the analysis is provided in Table 6.5. As with the Rothamsted plots the table provides analysis of animals between 0 and 2mm, (see Section 5.5.3 for discussion).

Z-values are derived from Wilcoxson's Signed Rank Test and illustrate that only the within row sub-surface distributions and the two distributions taken 1M from the trees have significantly different distributions to the controls. The figures presented in Table 6.5 are summarized graphically in Figure 6.17 which shows bodysize attributes at each of sampling sites for the top 30cm, (i.e. surface + sub-surface). The highest number of soil invertebrates are also located in the immediate vicinity of the trees, (ie the within row and 1M sampling) these being 1.5 to 2.5 times greater than the control. Beyond the uncultivated strip, (into which the trees are planted), the difference in numbers of recorded invertebrates between the control samples and those taken between the tree rows is comparatively small. The highest figures for cumulative bodymass are found within the tree rows and at 1 and 3M from the base of the trees. Within the sub-surface samples the largest numbers of soil invertebrates were found within the tree rows. The samples taken 1M from the base of the trees contained more invertebrates than the control or those taken further from the trees. Both cumulative bodylength and mass per $M^2$ gradually declined as distance from the trees increased, the sub surface control containing about half the cumulative bodymass as the samples taken within the tree rows. This suggests that the influence of the trees extends some distance into the arable alleys.

No trends associated with individual bodysize are apparent, this being similar to the findings of the Rothamsted experiments described in Chapter 5. However, the invertebrates extracted from within the tree rows were generally smaller than those found elsewhere on the plots. Surface samples for the within row and those 1M from the base showed significantly higher levels of organic matter than those found in the surface control, see Table 6.6.

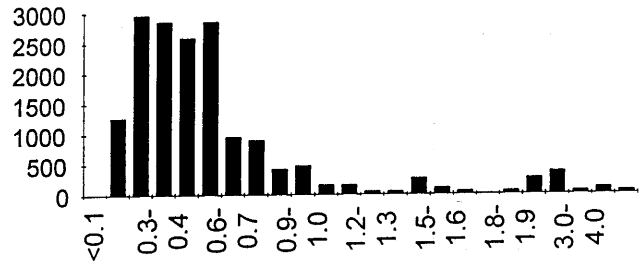



FIGURE 6.7: 1M FROM TREES (S)

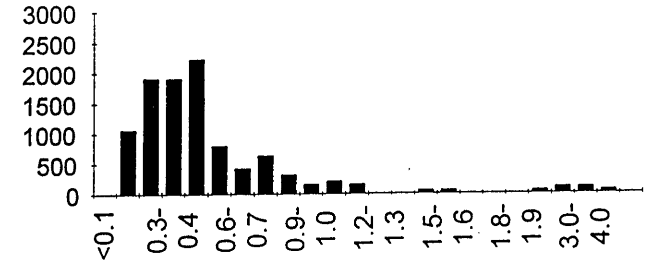



FIGURE 6.8: 1M FROM TREES(S-S)

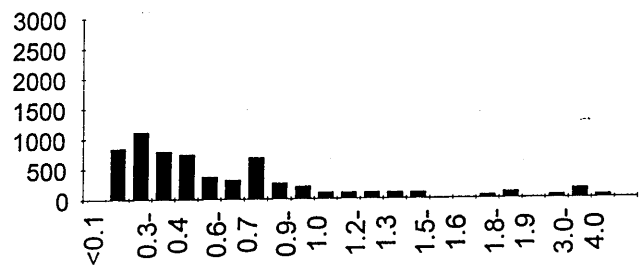



FIGURE 6.9 : 3M FROM TREES (S)

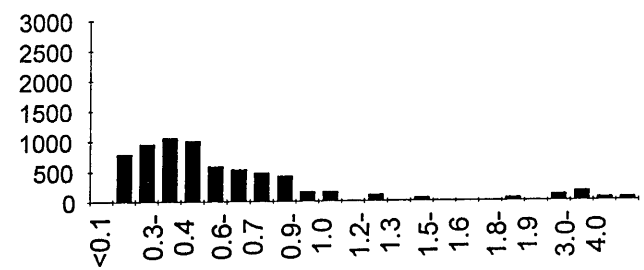



FIGURE 6.10 : 3M FROM TREES(SS)

HORIZONTAL AXIS: BODYLENGTH IN MM
VERTICAL AXIS: NUMBER OF ANIMALS/M2
S= SURFACE SS=SUB-SURFACE

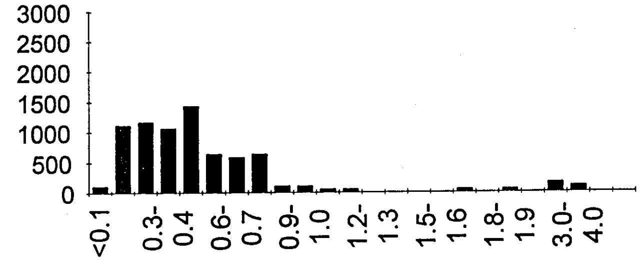


FIGURE 6.11: 6M FROM TREES (S)

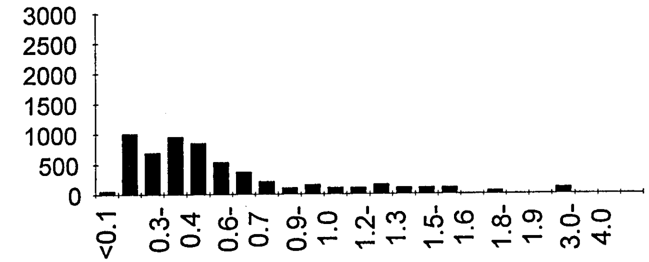


FIGURE 6.12: 6M FROM TREES (SS)

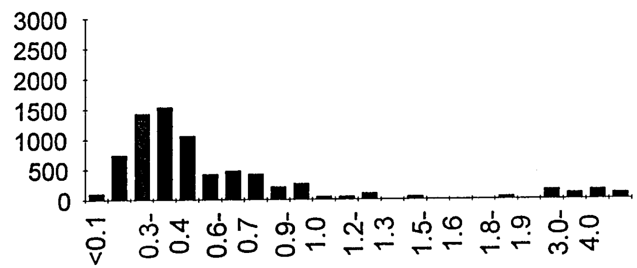


FIGURE 6.13: CONTROL (S)

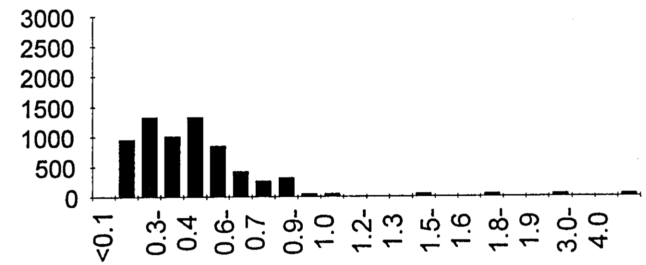


FIGURE 6.14: CONTROL (SS)

HORIZONTAL AXIS: BODYLENGTH IN MM
VERTICAL AXIS: NUMBER OF ANIMALS/M2
S= SURFACE SS=SUB-SURFACE

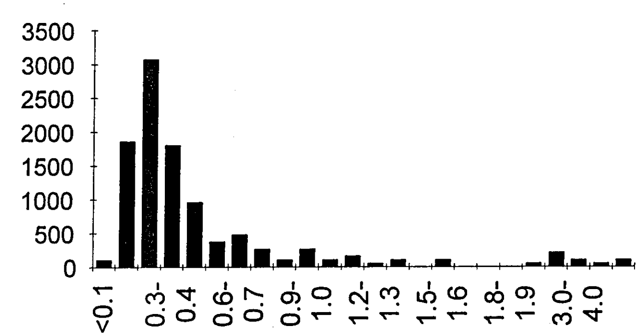



FIGURE 6.15 : WITHIN TREE ROWS (S)

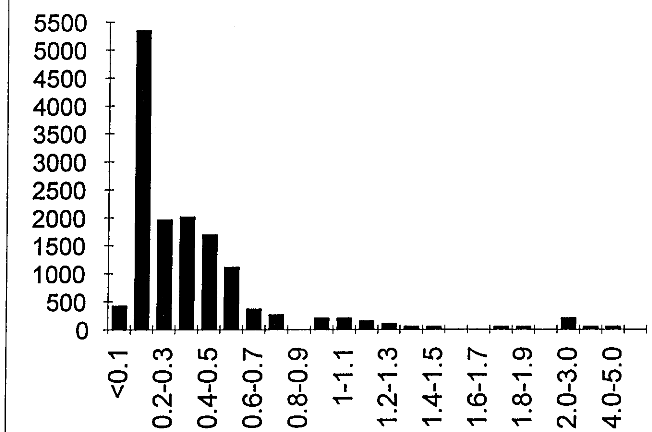



FIGURE 6.16 : WITHIN TREE ROWS (SS)

HORIZONTAL AXIS: BODYLENGTH IN MM
VERTICAL AXIS: NUMBER OF ANIMALS/M2
S= SURFACE SS=SUB-SURFACE

Table 6.5 : Number of animals, cumulative bodylength and bodymass per $M^2$ for each of the 10 regions sampled. Bodysize range of 0 to 2MM

A = Number of animals per $M^2$
B = Cumulative bodylength in MM per $M^2$
C = Average bodylength in MM
D = Bodymass of animals per $M^2$ in gms
E = Individual body mass in gms x $10^{-5}$

| | A | B | C | D | E | z | p | sign. |
|---|---|---|---|---|---|---|---|---|
| Within row (surface) | 9858 | 3943 | .39 | 0.098 | 1 | -0.7101 | .4777 | n/s |
| Within row (sub-surface) | 14098 | 5018 | .35 | 0.135 | .95 | -2.85 | .0043 | ** |
| Within row (surface+sub.) | 23956 | 8961 | .37 | 0.233 | .97 | | | |
| 1M from trees (surface) | 16483 | 9395 | .57 | 0.239 | 1.44 | -3.37 | .0007 | ** |
| 1M from trees (sub-surface) | 9964 | 4583 | .45 | 0.096 | .96 | -2.89 | .0038 | ** |
| 1M from trees (surface+sub.) | 26447 | 13978 | .52 | 0.335 | 1.26 | | | |
| 3M from trees (surface) | 6042 | 3383 | .56 | 0.096 | 1.58 | -1.04 | .2959 | n/s |
| 3M from trees (sub-surface) | 6320 | 3286 | .52 | 0.081 | 1.28 | -0.439 | .6803 | n/s |
| 3M from trees (surface+sub) | 12362 | 6669 | .53 | .177 | 1.43 | | | |
| 6M from trees (surface) | 7155 | 3276 | .46 | 0.069 | .96 | -0.156 | .8753 | n/s |
| 6M from trees (sub-surface) | 5671 | 2920 | .51 | 0.074 | 1.3 | -0.298 | .9826 | n/s |
| 6M from trees (surface+sub) | 12826 | 6196 | .48 | 0.143 | 1.11 | | | |
| Control (surface) | 6996 | 3281 | .46 | 0.088 | 1.25 | | | |
| Control (sub-surface) | 6678 | 2884 | .43 | 0.064 | .95 | | | |
| Control (surface+sub) | 13674 | 6165 | .45 | 0.152 | 1.11 | | | |
| **AVERAGE VALUES** | **8926** | **4196** | **.47** | **.104** | **1.16** | | | |

** Significance at the 99.9% level
Z VALUE DERIVED FROM WILCOXSON SIGNED RANK TEST

Figure 6.17: NUMBER OF ANIMALS AND BODYSIZE MEASURES AT EACH OF THE SAMPLING SITES

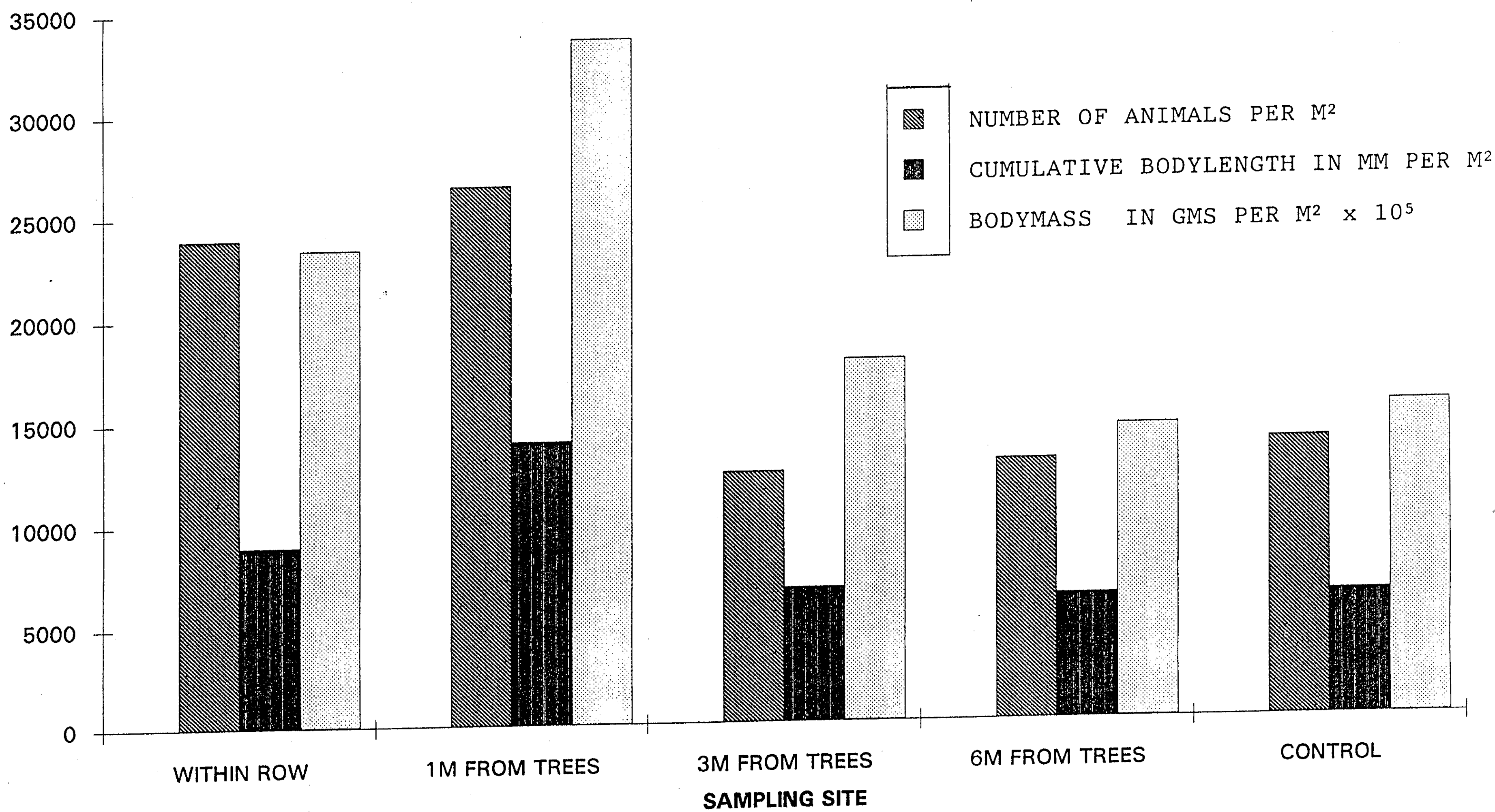


Table 6.6 Average soil organic matter estimates by titration,

| Distance from tree bases | Surface 15cm samples | t-value | significance |
|---|---|---|---|
| Within row | 6.52 | 2.436 | 0.05 |
| 1M | 6.54 | 2.597 | 0.05 |
| 3M | 5.76 | 0.436 | NS |
| 6M | 5.8 | 0.446 | NS |
| Control | 5.65 | | |
| | Surface 15cm samples | t-value | significance |
| Within row | 6.04 | 1.67 | NS |
| 1M | 6.07 | 2.14 | NS |
| 3M | 5.15 | 0.425 | NS |
| 6M | 5.63 | 0.843 | NS |
| Control | 5.36 | | |

The organic matter in the deeper sampling was generally lower than that on the surface and no significant differences were found between the sub-surface samples and the control. However, sub-surface samples taken from within the tree rows and 1M from the base of the trees were generally of higher organic content. The general magnitude of the figures for soil organic matter content is high for arable soils in England and Wales, (see Table 3.6). There does not appear to be a relationship between number of animals and depth. For instance within the tree rows many more individuals were found in the sub-surface samples. Similar results were found in the 3M sampling. The samples taken close to the trees have higher levels of soil organic matter, higher numbers of individuals and cumulative bodymass suggesting that trees can rapidly alter some of the processes within the soil.

### 6.8.1 Comparing the Rothamsted and Wolverton experiments,

There are generally less soil animals on the Wolverton plots in comparison to those at Rothamsted. The Rothamsted plot which best resembles the Wolverton site is the rotational plot receiving 96 kgs/ha of nitrogen. The former contained about 17000 animals per $M^2$, whereas the Wolverton plot samples range from 13000-23000 animals per $M^2$. At Wolverton the animals are on average smaller with respect to both length and mass. The generally higher cumulative mass per $M^2$ on the Rothamsted plots is due to several factors:

1. The higher average size of individual animals,

2. The higher number of animals per $M^2$,

3. The Rothamsted plots contained more Acarina relative to Collembola. The former weigh more heavily per unit length.

These differences within the soil community could be associated with the variation in soil type and other physical attributes of the 2 sites. The rotation at Wolverton has been based upon spring cropping in recent years, and has also included a fallow, (1990), both of which can effect soil communities. The differences in cropping regimes would also result in different chemical sprays being used, and these are known to effect soil populations, (see Edwards 1984). These differences suggest that caution should be exercised before making comparisons of results from different sites

## 6.9 DISCUSSION ARISING FROM THE EXPERIMENTS,

The purpose of these field experiments was to investigate the effects of a silvoarable system on the soil, using two simple measures that have been described in Chapters 4 and 5. Simple bodysize measurements of soil invertebrates and soil organic matter content have been used as proxy indicators of the biological processes and the functional diversity of the detritus community within the soil. Results suggest that since the establishment of the trials the presence of the poplar trees has effected the amount of soil organic matter, and this effect is found both in the surface and sub-surface profiles. Further, the experiments illustrate that the trees have an impact on the invertebrate measures, although many questions are raised by the results. The degree to which the trees effect the soil laterally into the arable alleys cannot be established from these experiments, although the samples taken at 1M from the trees, just within the arable soil, show significantly higher soil organic matter.

The mechanisms through which the trees effect both the soil invertebrates and the soil organic matter beyond the uncultivated mulch are complicated, being a combination of:

1. An increase in the annual return of organic matter to the surface through plant debris associated with the trees,

2. An increase in organic material return through root death and slothing,

3. Modification of the microclimate effecting detritus processes,

The lower numbers of soil animals in the control and those samples taken at 3 and 6M from the trees suggests that cultivation may have an overriding effect on invertebrate numbers. Earlier reviews of research on arable land, (Edwards 1984, Madge 1981), suggest that cultivation has a large impact on the invertebrate communities within arable soils, and both Chapters 4 and 5 demonstrate the importance of cultivation as a determinant in agroecosystem processes.

As the tree root system expands further it is possible that the "oasis" effect that has been observed in the immediate vicinity of the trees may expand. There appears to be a trade off between the lateral distance from the tree and the effect of continuous annual cultivation on the soil between the trees. The rate and degree to which trees will continue to increase their influence within the arable alleys cannot be determined from these experiments. Although the poplar trees roots probably meet between the rows their density and influence may not be large enough at these relatively wide row widths to modify the cultivated soil environment to the same degree as they can near to the trees themselves. This has important implications for the spatial planting pattern of trees within agroforestry systems. There will be trade offs between spatial planting pattern, shading and the use of machinery which may inhibit the use of narrower between row spacing, (i.e. 8M instead of 14M).

The use of bodysize measures of soil invertebrates as an indicator of physiology and functional diversity of the soil community needs to be further explored, possibly to formulate a range of biological indicators of soil health. These results and those of the experiments undertaken at Rothamsted raise doubts about the use of a simple measure of bodylength, instead of bodymass, which requires more accurate measurement. Energetically it is the total bodymass per $M^2$ and the mass at a given size which are important measures, (Cousins 1990). However, simple information about the effect of changes in agricultural practice on the general size and structure of the detritus community may help highlight innovations which are ecologically attractive as well as being economically and financially viable. As interest continues to increase in sustainable systems research, (Edwards et al 1991), the importance of the soil community in the cycling of nutrients, and the maintenance of physical, chemical and biological conditions for growth in the soil is likely to receive increased attention. Further implications and conclusions are offered in the context of the two research aims highlighted in section 6.1.

### 6.9.1. The general characteristics of agroforestry systems which suggest it is a cropping innovation that can contribute to the increased sustainability of land based production,

Earlier in the thesis, (Chapter 1 and 2), it was argued that increasing the sustainability of land based production would require the maintenance of or an increase in the interception of sunlight by plants, but in a manner that was conserving of plant nutrients, and other input resources. Extended discussion at the start of this chapter illustrated that agroforestry systems could fulfil these conditions by creating agroecosystems that have at least two tiers of photosynthetic material, and an extensive rooting system which is capable of exploiting or mopping up extra soil reserves. The presence of trees may ameliorate local climate conditions, helping to reduce erosion and possibly providing more favourable conditions for plant growth. Agroforestry systems increase both the temporal and spatial volume of structure within the agroecosystem and in doing so are likely to increase the biodiversity within that system by increasing niche space available. An example of this is the increased numbers of the rare Golden Orioles which nest in rows of poplar trees on the otherwise arable dominated fenlands, (Prater 1993). There is a need for research which investigates the wider implications of the presence of trees on temperate arable farmland, particularly with respect to spatial and temporal sunlight interception, shading, nutrient cycling, water availability and biodiversity.

The uptake of agroforestry systems on farms could be viewed as a step toward agricultural production that is empathetic with natural ecological cycles, rather than being antagonistic to them. The (re)introduction of perennial crops onto some farmland could have considerable benefits, i.e less open nutrient cycles, replenishment of soil fertility, structuration of the soil etc. Further, there may be benefits in terms of pest, disease and weed interactions. From this perspective they are likely to increase the degree of sustainability of land based production. However, as shall be discussed in the ensuing chapters, their uptake on farms is constrained considerably by their economic/financial viability and the inflexibility of the existing farm infrastructure.

The increase in overall productivity could be at the expense of a reduction in the quantity and quality of the normal arable crop. At present the non-woody crop is of higher value than products associated with the tree crop. Whether the overall increase in drymatter productivity is economically viable in the future will depend on the relative value of the two products. Interest is developing in high value oil and nut production from trees, (Newman et al 1991). This, or a shift in the relative value of wood products may provide impetus to commercial interest in these spatially mixed systems and ensure the financial productivity of these systems matches their potential drymatter yield.

### 6.9.2. The effects of a silvoarable system on the soil system,

The silvoarable system investigated has had an effect on the soil system in the 5 years since its establishment. However, the extent to which the perennial crop affects the soil system beyond the immediate vicinity of the trees requires further research. It is likely that the root systems of the trees has extended across the arable alleys, but these experiments suggest their effects as measured by soil organic matter and soil invertebrates is limited to a region of a 2 to 4M surrounding the trees.

Rooting patterns and associated interactions play a vital role in the biological processes associated with the soil system, yet by their nature roots are difficult to study. It is known that in good conditions poplar roots proliferate quickly and if they have met across the arable alleys these experiments suggest that any effects on the detritus community due to the presence of tree roots, at least in these initial years, is curtailed by the impact of annual cultivation. This raises questions about ideal planting widths, not only from the point of view of machinery access, but from the perspective of soil and agroecosystem processes. Further research which examines the distance over which the trees can influence soil properties such as organic matter content and the way in which these properties change over time could be usefully undertaken.

Figure 6.4 illustrated that the volume of habitat per hectare will be enhanced by tree planting, suggesting an immediate increase in biodiversity via more niche spaces. Further, the presence of trees may improve the cycling of nutrients and water on at least part of the field. However, a trade off will exist between the degree of benefit accrued in terms of better cycling of nutrients, increased habitat, and soil organic matter, and the degree of sacrifice that is acceptable in terms of ease of cultivation, general management and the loss in annual crop yield due to shading. The effect of the trees on the soil system will be partly dependent on the original state of the soil. At 14M spacing silvoarable systems could make a major contribution if established on soils that are in biologically poor condition. The organic content of the soil at the Wolverton site is high compared to many arable soils, (see Church and Skinner 1986), possibly reducing the impact of the trees. On soils of low organic content the effect of the trees could be more pronounced.

In conclusion it is unlikely that trees planted in these spatial patterns will have a negative effect ecologically with regard to the cycling of nutrients, conservation of habitat, and the health of the soil on normal arable land. Agronomically, a considerable amount of research already exists on pest and disease interactions in intercropping systems, much of it illustrating benefits from these spatially diverse systems. Less research evidence exists on the partition of nutrients between the woody and non-woody crop and this is an area requiring further research effort. On poor soils or those that have been over exploited the planting of tree/crop mixtures is likely to be beneficial to the physical, chemical and biological health of the soil, providing the systems are well managed. Theoretically annual/perennial combinations on arable land are promising, but research needs to be undertaken to further substantiate this experimental evidence that this form of agroforestry is a step toward the design of increasingly sustainable farming systems on temperate arable farmland.

## 6.10 LINKING PHYSICAL AND SOCIAL SYSTEMS: THE NEXT STEP

In Chapter 1 it was suggested that there is a need to assess cropping innovations from a longer-term ecological perspective as well as from a viewpoint of short term economic feasibility. In the previous 4 chapters this has led to the exploration of two research interfaces, linking the concept of sustainability to agroecosystem processes and then linking this to the methods and activities that the farmer uses to crop the land. This chapter introduces the use of silvoarable agroforestry as a research medium. It is assessed using principles discussed in Chapters 2 to 5 to see if it is the type of cropping practice that, if adopted by farmers, could be described as one which encourages development along increasingly sustainable pathways.

This chapter is viewed as the culmination and practical application of the research undertaken in the previous chapters. In the following chapters the emphasis of the research process changes from one of scientific exploration of farming systems to a social systems approach. This second part of the thesis recognises that change cannot be viewed or understood from a purely scientific perspective. Thus the ensuing chapters explore the third interface within the thesis which links policy and decision making to what the farmer actually does.

Chapter 7 investigates the wider farming environment and agenda into which managed change is necessarily introduced, before Chapters 8 and 9 return to the possibility and mechanisms of introducing silvoarable agroforestry systems as an increasingly sustainable cropping practice on UK farms.

# CHAPTER 7: AGRICULTURAL CHANGE: A COMPLICATED PROCESS,

*"If we want to know how or why a farmer acts in a certain way, we have to enquire why men act, and especially why men act as they do when they live in the sort of social environment and general circumstances in which farmers live," A W Ashby 1926,*

## 7.1 INTRODUCTION AND SUMMARY,

The possibility of undertaking ecological assessment of cropping innovations have been discussed in previous chapters. In this chapter the emphasis switches from the impacts of change on longer term ecological processes within the agroecosystem to consider the socio-economic environment in which change takes place. This initiates the exploration of the third interface within the thesis which links policy to what farmers actually do. A series of interviews is undertaken based on the premise that the process of change to increasingly sustainable agricultural systems cannot be successfully carried out purely on the basis of "scientific" understanding. This knowledge needs placing within a wider context, through the exploration of the wider system.

During this series of interviews farmers are encouraged to elicit the farming agenda as seen from their perspective. This provides a rich source of data and illustrates the wide variety within the farming agenda. Farmers discussed the long-term issues associated with farming, although for the majority the short term survival of the farm business in a turbulent policy environment was the most pressing issue. Information relating to farmer's motivations, job satisfaction, sources of information and thoughts about the future are utilized in a discussion about the process of change to differing farming systems.

## 7.2 UNDERSTANDING THE SYSTEM,

In the previous chapters the effects of agricultural activity on the agroecosystem have been assessed via their impacts on the soil system. In this and the ensuing chapters the process of introducing cropping innovations, (using silvoarable agroforestry as an example), is explored. Changes in agricultural practice are often suggested purely on the basis of simple financial calculations which take little account of the variety and complexity surrounding the decisions that need to be taken by individual farmers. Often knowledge of how a diverse range of farmers will react to a given change is assumed, rather than investigated.

The basis of this chapter is to explore what farmers actually do and how they perceive change using a series of interviews, the objectives of which were to gather information on the underlying system into which changes in cropping necessarily need to be introduced. This avoids attempts to predict behaviour on a narrow and often stereotyped knowledge base. As Gasson (1973) comments, economic theory assumes nothing about the personality of economic man except that his goal is profit maximization and that he is rational, which implies that when confronted with alternatives he selects that course yielding greatest profit.

A number of relevant studies have been undertaken in the past which demonstrate the strengths and weaknesses of various techniques. Gasson (1973) attempts to focus upon why decisions are made, rather than the way in which they are made. She suggests that a better understanding of motivation used in conjunction with other available material could provide a more adequate explanation and prediction of farmers behaviour. Several methods of information gathering were used in her study ranging from open ended discussions to forced choice questions. She considers the implications arising from the study are that farmers bring a strongly intrinsic orientation to work, instrumental values being rather less significant and social values least so. Smaller farmers in particular put emphasis on the intrinsic aspects of work, particularly independence.

More recent studies have focused on farmers and the environment, and in particular conservation. A recent study detailed in a paper by Carr and Tait (1991) attempts to explain an apparent anomaly between farmers attitudes and actions to conservation. Their study comprised of two stages: lengthy conversational interviews with both farmers and conservationists and a second questionnaire based survey. The interviews provided a rich source of information on the range of farmers and conservationists views on conversation, whilst the second stage provided numerical support or dissent. The results show broadly that farmers attitudes to wildlife and conservation are not necessarily a reliable guide to behaviour, although the authors consider this does not mean that successful conservation on farmland by voluntary means is hopeless...

*"much can be achieved by ensuring recommendations and incentives accord with farming interests and values."*

This is an important observation as it suggests that the instigators of change, (in the above case, those making conservation policy), have an incomplete understanding of the farming agenda. This is highlighted in a study undertaken by Potter and Gasson (1988), considering the farmer participation in land diversion schemes, (before the days of "compulsory" set-aside). Results of the survey suggested that the set-aside element could meet with the greatest resistance from those very farmers groups it is designed to help, i.e intermediate and social problem farmers. Their survey explored the participation of farmers in, what were then, hypothetical land diversion schemes. Farmers were asked for two pieces of information, firstly a "bid" equivalent to the minimum annual acreage payment he/she would require to encourage him/her to enrol land in such a scheme, and secondly the acreage he/she would be willing to enrol at that payment. They show that most farmers were prepared to give a bid but concluded somewhat sceptically that such voluntary schemes are only subsidizing land use changes that would have occurred anyway.

A more traditional structured questionnaire approach was undertaken in 1987/1988, (CAMS 1988), to study the attitudes of cereal farmers to

"Long-term prospects and policy reforms". A postal survey of 1200 farmers, ( with a response rate of about a third), concluded that the majority of [cereal] farmers surveyed felt that the problem of cereals over-production had been exaggerated. Of greater interest was the finding that farmers considered the most effective option for limiting production involved some mechanism for limiting the acreage planted. However, the study seems in danger of confusing attitude with behaviour. They suggest that because small and medium farmers thought that grants to leave land fallow would have greater effectiveness that such farmers would be much more likely to take up such grants. The research of Carr and Tait (1991) suggests that attitude is not always a good indicator of possible behaviour. Attitudinal research has been undertaken in America for many years although not without criticism. Although Lockeretz (1990) discussing agriculture and soil conservation comments,

*"technical developments in soil conservation have been supplemented, properly, by studies that go beyond what the farmer could do, to try to understand what they actually do."*

...he goes on to suggest [we] are far from achieving this understanding of what farmers actually do. He offers 3 reasons in explanation of this:

1. Statistical representations over-emphasize positive findings and underestimate that which is not learned,

2. Many studies operate through too a narrow set of preconditions or paradigm,

3.Variations in time and space is often inadequately explored,

**7.3 AIMS OF THE INTERVIEWS,**

Within the broad objective of understanding the systems to a greater degree to facilitate the process of change the interviews had two specific aims which attempt to avoid the criticisms voiced by Lockeretz (1990),

1. To demonstrate that farmers have a wider or different agenda than is often reported or assumed by those who seek to influence them,

2. To gather information on the process of change in agricultural systems.

**7.4 IDENTIFYING AN APPROPRIATE TECHNIQUE,**

To overcome the types of shortfalls outlined by Lockeretz an interview methodology was sought that would allow farmers to verbalize a range of agenda which could be used to highlight key areas and the linkages between them. Only then, as part of a multimethod approach can attempts be made to measure the changing state of those attributes and subsequently to predict possible behaviours. The need for the pursual of linkages between issues that are raised suggests that face to face interviews rather than postal questionnaires provide a more suitable approach. However, within the interview situation there is a danger of setting too tight an agenda for discussion, leaving the interviewer with no idea of the relative importance of the issues being discussed. This can be exacerbated because some respondents answer questions in a manner which they feel the interviewer would like them answered.

Initially it is not information in response to specific questions that should be sought but a much broader understanding of that persons "world view". Burgess et al (1988) suggests that sensitive interviewing with a minimum of structured questioning offered one way of allowing individuals and groups of respondents to reconstruct the environment in which they lived. This philosophy was used by Lemon (1991) to develop a pathways elicitation technique. He states,

*"...Unlike a structured questionnaire which has limited scope for the elaboration and linking of concepts and ideas, the pathways design was intended to encourage the respondent to be expansive and to pursue pathways beyond their immediate system of interest."*

The process of identifying these complex patterns can be described under the broad heading of cognitive mapping. The maps formed are a type of structural modelling which can shed considerable light on the potential links between systems elements. Through the elicitation of these maps the respondent is able to place a particular issue in the context of those factors that are felt to be impacting upon it, or affected by it. This avoids much of the criticism that can be levelled at more structured techniques which pre-empt the focus of the inquiry and can result in the interpretation of systems and agendas that are artificially simplified. Lockeretz (1990) suggests that there is little justification for devoting more attention to one component of a complex process before it can be confidently stated how strongly those components are linked. This is even less justifiable if not all the major components interacting within the process are known.

## 7.5 ELICITING THE AGRICULTURAL AGENDA,

A pathways approach to elicitation was developed which fits under the general heading of common sense elicitation techniques, (Lemon 1991). This was used to elaborate salient issues surrounding the present farming agenda, producing a wealth of information concerning specific issues, and in many cases linkages between them. During the interviews farmers were encouraged to place particular issues in the context of those factors that were felt to be impacting upon it, or affected by it. The exercise was designed to be as unrestricted as possible. This allowed for the introduction of elements that were not directly related to the core questions into a mapping format which increased the richness of information, frequently absent from more formal elicitation techniques.

The result is a number of pathways which have been pursued until it is felt that the information provided is adequate, the linkages have been exhausted or the farmer becomes unwilling to pursue a path further. The approach can be demanding on both interviewer and interviewee, and a working knowledge by the former of the farming industry was seen as a bonus in the enabling of continuity within the interviews, and the continued pursuit of "interesting" pathways.

## 7.6 THE INTERVIEWS: ORGANIZATION, TIMING AND DETAILS,

It was felt appropriate to interview about 25 farmers, although it was recognised that no sample would be characteristic of the entire farming community. The farmers interviewed needed to be representative of a range of farm sizes and variety of enterprises. Farmers were initially contacted from the yellow pages which proved to be quite a successful method of making appointments. Approximately 25% of those contacted were eventually interviewed. Of the rest about 25% said they were not interested in discussing their opinions on the "present situation with regard to agriculture". Another 25% were too busy but suggested the possibility of contacting them later, and the remainder were unsuitable either because they were now retired, had left farming, or were only smallholders.

The hours and nature of work undertaken by many farmers meant they were difficult to contact in the day, the best time for contact was later in the evening. Thus the majority of initial contacts were made between 7 and 9 at night. Often, where follow up calls were necessary, a useful time to get hold of farmers was "at breakfast". ie between 8 and 9.30 in the morning, although with some individuals great persistence was required before appointments could be made. Flexibility in the arrangement of interviews was also required, with many taking place in the evening, sometimes as late as 9.00pm. The timing of the interviews was considered to be critical to the response from farmers when asked if they were prepared to be interviewed. April, May and June are relatively quiet periods for arable farmers with periodic bursts of activity for spraying and fertilizing. For livestock farmers there is certainly a very busy period in May during silage time, and in 1992 this coincided with a spell of particularly settled weather in which no attempt was made to contact or arrange interviews. By the end of June it was envisaged that many farmers would be preoccupied with the harvest and that interviews between July and mid November would be best avoided. Within the overall framework of the research this was an important constraint.

The interviewing technique was piloted on two people who are knowledgeable of both farmers and farming issues and understanding of errors and offer positive criticism where necessary. The main interviewing was conducted on a informal basis. After a brief introduction about the research the interview was initiated with the question,

*" What do you feel are the main issues/problems facing you as a farmer at present."*

The responses to this initial question formed the basis for pathways of discussion to be developed into a multitude of issues. It is useful for the interviewer to have in the back of his mind the areas on which he requires information, and to aid the development of pathways which may elicit information on these themes. Once the pathways developed from the first question had been expanded then a second general question was asked,

*"What do you understand by the term "good farm practice?"*

This again allowed the development of several pathways arising from the initial question. In addition to the two broad initial questions which were used to develop the main part of the interview, four specific questions were "held in reserve". If, toward the end of the interview, an answer to these had been given during the previous discussion then this would often be reiterated or confirmed. If the answers to these questions had not been directly covered during the pathways elicitation then they were usually introduced toward the end of the interview , as *four short specific questions before we finish.* This let the farmer know the discussion was drawing to a close, and kept the answers to the questions brief. These 4 questions were:

*"What are your main sources of technical information?"*

*"Which element of your work provides you with the most satisfaction?"*

*"Are there any policies presently being implemented that you feel particularly strongly about?"*

*"What issues do you think are particularly important with regard to the longer-term future of the farming sector?"*

Depending on the interest in the issues and the complexity of the discussion the interviews lasted on average about 1 hour, with non being less than 40 minutes. Some of the interviews continued for over 90 minutes and in some cases included sessions looking at livestock etc.

## 7.7 DATA RECORDING AND INTERVIEW RESPONSES,

Some characteristics of each farm were recorded on a top sheet which was filled out following each interview. This was not actually produced in the interview, avoiding a degree of formality introduced by form filling at the start or end of an interview. A copy of this top sheet is provided in Figure 7.1 and a summary of the information about the farms visited is provided in Table 7.1, although this is not used for any formal statistical analysis. It demonstrates the variety of farms visited, and allows statements and maps used later in the chapter to be linked back to farm/farmer details if desired.

Interviews were recorded on paper using a simple box method, which allowed responses to be jotted in a box and then arrows drawn to show linkages as the pathway was elicited. This worked extremely well as a

Figure 7.1 : Example of the top sheet from one of the interviews, (farmer comments are in italics).

Respondent Number 2

Male/female, Tenant/owner/manager

Small holding/ family farm/ company/ estate/ other

Soil types *Mainly heavy clay based*

Enterprises carried *Arable, mainly wheat and OSR*

Training/background *Agricultural college, experience not from farming family*

**What do you feel are the main problems facing you with regard to your farming business?**

**What do you understand by the term, "good farming practice?"**

**What are your main sources of technical information?** *Industry publications, farming press, the Met. office. Local farmer's group plus other informal gatherings. ADAS only occasionally*

**Which element of your work provides you with the most satisfaction?** *Working in the countryside and feeling that I play an important role in looking after the countryside and providing food for the population.*

**Are there any policies presently being implemented that you feel strongly about?** *Not particularly although GATT and CAP reforms must be implemented fairly. A free market with respect to agriculture is a pipe dream.*

**What issues do you think are particularly important with regard to the longer-term future of the farming sector?** *Rural structure and food production. In reality the government cannot let all farmers go down the shoot, therefore future support will be important in one way or another.*

Table 7.1 : General information on farms/farmers interviewed

| A | B | C | D | E | F | G | H | I |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 2 | 2 | 2 | 1 | 3 | 99 | 700 (283) |
| 2 | 1 | 3 | 2 | 2 | 1 | 1 | 1 | 440 (178) |
| 3 | 1 | 3 | 2 | 2 | 4 | 3 | 99 | 500 (202) |
| 4 | 1 | 2 | 2 | 2 | 1 | 1 | 4 | 440 (178) |
| 5 | 1 | 3 | 1 | 2 | 1 | 3 | 4 | 360 (146) |
| 6 | 1 | 2 | 2 | 2 | 1 | 3 | 1 | 100 (40) |
| 7 | 1 | 4 | 1 | 2 | 1 | 3 | 4 | 70 (28) |
| 8 | 1 | 4 | 1 | 2 | 1 | 3 | 4 | 213 (86) |
| 9 | 1 | 3 | 2 | 2 | 4 | 1 | 99 | 500 (202) |
| 10 | 1 | 3 | 1 | 1 | 1 | 2 | 4 | 50 (20) |
| 11 | 1 | 2 | 2 | 1 | 1 | 1 | 4 | 70 (28) |
| 12 | 1 | 2 | 3 | 3 | 1 | 1 | 4 | 1000 (405) |
| 13 | 1 | 3 | 1 | 2 | 1 | 3 | 4 | 700 (283) |
| 14 | 1 | 3 | 1 | 2 | 2 | 2 | 4 | 120 (48) |
| 15 | 1 | 3 | 2 | 2 | 4 | 1 | 99 | 500 (202) |
| 16 | 1 | 1 | 2 | 2 | 4 | 3 | 2 | 600 (243) |
| 17 | 1 | 4 | 2 | 2 | 1 | 3 | 99 | 500 (202) |
| 18 | 1 | 3 | 2 | 2 | 2 | 1 | 4 | 2700 (1093) |
| 19 | 1 | 2 | 3 | 4 | 3 | 4 | 1 | 2000 (810) |
| 20 | 1 | 4 | 2 | 2 | 4 | 2 | 4 | 270 (109) |
| 21 | 1 | 3 | 2 | 2 | 1 | 3 | 4 | 200 (81) |
| 22 | 1 | 2 | 4 | 2&3 | 1 | 1 | 99 | 2700 (1093) |
| 23 | 1 | 3 | 1 | 1 | 1 | 1 | 4 | 150 (61) |
| 24 | 1 | 2 | 1 | 2 | 4 | 3 | 99 | 850 (344) |
| 25 | 1 | 2 | 2 | 2 | 4 | 1 | 4 | 500 (202) |

**CODING**

A=Questionnaire number
B=Sex 1=Male, 2=Female
C=Age 1= 20 to 30, 2= 30 to 45, 3 =45-60, 4=60+
D=Position in business 1=Tenant, 2=Owner, 3=Manager
E=Type of tenure 1=Small holding, 2=Family farm, 3=Company, 4=Estate, 5=Other
F=Soil type 1=Heavy, 2=Medium, 3=Light, 4=Mixed
G=Enterprises carried 1=Arable, 2=Livestock, 3=Mixed
H=Education 1=College, 2=University, 3=Day release, 4=Experiential
I=Farm size Acres (hectares)
99=No data available

recording techniques. Not all notes were recorded in this form and specific quotes were recorded in long hand on a separate piece of paper. An example of the data recording sheets from one of the interviews is provided in Appendix 6A.

The replies to the broad questions on issues/problems and good farming practice resulted in the noting of 79 extensive pathways maps. (46 on issues and problems and 33 on good farm practice). Figure 7.2 represents a single pathways map built up in response to the question of *"What do you understand by the term "good farm practice?"* From these maps, (see Section 7.6), and general discussion the Tables 7.2-7.7 were compiled. These give broadly categorised responses in from each of the specific questions asked. Table 7.8 provides a list of the responses to the question, *"What do you understand by the term "good farm practice"?* A full list of the statements in response to the other questions is provided in Appendix 6B together with cross reference to Table 7.1.

An overall report of the interviews was returned to those farmers concerned, (see Appendix 6C). This served several purposes. Firstly it responded to the interest by many about what the overall findings of the interviews had been. Secondly it allowed feedback on the interpretation of the data collected in the interviews, and finally it introduced the possibility of a follow up interview to talk more specifically about agroforestry systems. A response sheet was included, (see Appendix 6D), together with a photograph from the agroforestry systems at Milton Keynes to stimulate interest. Despite the inclusion of a prepaid envelope the rate of return of these forms was disappointing, (9 out of 25). However, these were without exception in broad agreement with the general interpretation of the interviews. Table 7.9 provides an example of one of the return sheets.

## 7.8 DISCUSSIONS ARISING FROM THE INTERVIEWS,

The interviews resulted in the collection of a rich source of data. This, combined with the relatively small sample, the variety of types of farmer, (with respect to their farming enterprises), and the way in which the information is used within the thesis meant that it was inappropriate to undertake quantitative statistical analysis on the data. There is recognition within the research community that it is inappropriate to necessarily treat data pertaining from social science in a manner more akin to traditional science, (see Meham and Wood 1975). However, three forms of analysis have been utilized in the presentation of the data. Firstly a series of pathways maps which draw broadly on cognitive mapping theory, (see Madu and Jacob 1991, Ackermann et al 1992), are used to demonstrate linkages highlighted by farmers. Secondly content analysis is used to record and tabulate key words or responses, (see Krippendorf 1980 and Tables 7.2 to 7.7). Finally key phrases/statements made by farmers are used in the text. These "results" are used to make inferences and to "trail" discussions rather than to make sweeping statistically fortified statements. Where maps and statements are used in the text these are linked to specific farm details through a questionnaire number which can be referred to in Table 7.1.

Figure 7.2 : Pathways map referring to good farm practice, (respomdent 1).

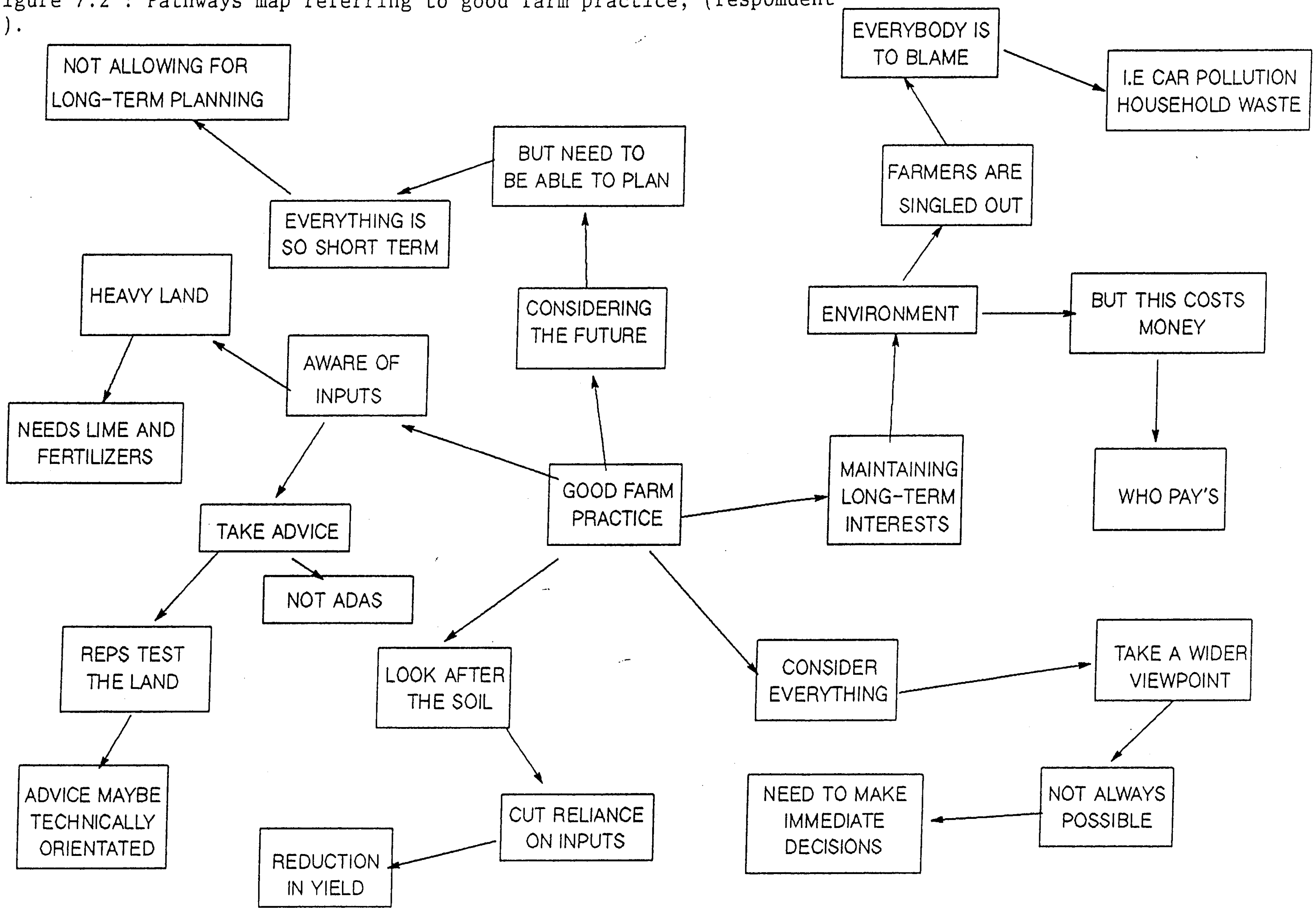


TABLE 7.2
RESPONSE TO GOOD FARM PRACTICE

| | |
|---|---|
| Environmental awareness | 22 |
| Soil quality | 17 |
| Good crop husbandry | 16 |
| Input/output control | 16 |
| Profitability | 11 |
| Business diversification | 10 |
| Animal husbandry | 7 |
| Public relations | 2 |
| Others | 4 |
| Total | 105 |

TABLE 7.3
PERCEIVED ISSUES AND PROBLEMS

| | |
|---|---|
| Financial issues | 31 |
| Policies, (CAP/GATT) | 20 |
| Uncertainty | 18 |
| Legislative restrictions | 17 |
| Marketing | 5 |
| Public relations | 4 |
| Individualism of farmers | 4 |
| Labour issues | 4 |
| Other | 11 |
| Total | 114 |

TABLE 7.4
SOURCES OF INFORMATION

| | |
|---|---|
| Farming press | 18 |
| Specialist advice | 17 |
| Sales representatives | 14 |
| Formal meetings | 13 |
| Technical publications | 6 |
| Informal chats | 6 |
| Trade rags | 2 |
| Met office | 2 |
| Total | 78 |

TABLE 7.5
SATISFACTION AT WORK

| | |
|---|---|
| Working in the countryside | 13 |
| Own boss | 10 |
| Efficienct/yield targets | 10 |
| Producing good food | 9 |
| Seeing the farming cycle | 8 |
| Variety in the work | 8 |
| Farming lifestyle | 6 |
| Working with animals | 6 |
| Working with machinery | 3 |
| Others | 10 |
| Total | 83 |

TABLE 7.6
POLICY CONCERNS

| | |
|---|---|
| Weight of legislation | 17 |
| Set-aside | 8 |
| Straw burning ban | 7 |
| Co-responsibility | 3 |
| No concerns | 3 |
| Quotas | 2 |
| Other | 6 |
| Total | 46 |

TABLE 7.7
FUTURE ISSUES IN FARMING

| | |
|---|---|
| Over-production, World food situation | 12 |
| Economic efficiency | 11 |
| Longer term objectives | 10 |
| Rural/public issues | 8 |
| Farm size, loss of farms | 8 |
| EC policies | 7 |
| Cyclic nature of farming | 7 |
| Renewables/carbon budgets | 5 |
| Co-operation | 5 |
| Need for flexibility | 4 |
| Other | 3 |
| Total | 80 |

Table 7.8 Summarized list of the responses to the question, " What do you understand by the term good farm practice?"

| Respondent number | Statement |
|---|---|
| 1 | Looking after the soil |
| 2 | Good rotation |
| 3 | Maximise profit |
| 4 | Awareness of general environment |
| 5 | Consideration for the environment |
| 6 | Keep livestock well, not too intensive |
| 7 | Improve land, better than when taken on |
| 8 | Attempt to maintain soil quality |
| 9 | Keep land in good heart |
| 10 | Diversification |
| 11 | Build up soil fertility |
| 12 | As much from as little |
| 13 | Diversification |
| 14 | In business, therefore, must make a profit |
| 15 | Good cropping, range to minimise pests |
| 16 | Balanced system, general compatibility |
| 17 | Restricted use of fertilizer/bagged silage |
| 18 | Good husbandry |
| 19 | Commercial survivability |
| 20 | Making land productive without massive inpu |
| 21 | Leave farm in better condition |
| 22 | What we're doing at the moment |
| 23 | Maximum yield from optimum inputs |
| 24 | Healthy and tidy farm in widest sense |
| 25 | Making best margins |
| 1 | Sustaining agriculture |
| 2 | Testing of soil regularly |
| 3 | Protect land for long term farming |
| 4 | Careful with inputs |
| 5 | Care about inputs |
| 6 | Control inputs, pollution |
| 7 | Rotate cropping |
| 8 | Good rotation |
| 9 | Limit fertilizers, rely on soil residuals |
| 10 | Care of land |
| 11 | Periodic reseeding |
| 12 | Aware of needs of future generation |
| 13 | Good crop husbandry |
| 14 | Reduced inputs and polluting outputs |
| 15 | Cropping, not to run-down fertility |
| 16 | Mixed enterprises, even if not profitable |
| 17 | Consider future capacity of the soil |
| 18 | Good business sense |
| 19 | Environmental and physical sustainability |
| 20 | Buy calves in April and May |
| 21 | Replace nutrients taken out |
| 22 | Awareness of inputs |
| 23 | Good husbandry |
| 24 | Longer term consideration |
| 25 | "Guess I'm supposed to mention the environ |
| 1 | Long as opposed to short term interest |

| Respondent number | Statement |
|---|---|
| 2 | Leave land in better condition than found it |
| 4 | Education of the young |
| 5 | Control over outputs , slurry |
| 6 | Spread eggs into many baskets |
| 7 | Not too much arable cropping |
| 8 | Reduce inputs (sprays, nitrogen etc) |
| 9 | Low input farming |
| 10 | Adequate fertilizer use |
| 11 | Obtain information-advice, attend meetings |
| 12 | Remember environment |
| 13 | Necessary but without environmental damage |
| 14 | Must not over exploit the land |
| 15 | Comply with legislation, expensive |
| 16 | Bring grass into arable rotation |
| 17 | Limit hedge cutting, plant trees |
| 18 | Knowledge of specific techniques |
| 19 | Landscape is maintained as a living entity |
| 20 | One beast per acre |
| 21 | Rotational cropping |
| 22 | Considerate of the environment |
| 23 | Balance between farming &economics |
| 24 | Financial view, must have good ROC |
| 25 | Farm without raping for future generations |
| 2 | Sheep enterprise |
| 4 | Public relations |
| 7 | Mixed farming with humus ploughed back |
| 8 | Sheep are good for fertility |
| 9 | Keep ground open |
| 10 | Tidy hedges and gates etc |
| 12 | Reduce inputs and waste, nitrogen |
| 13 | Peas and beans in rotation |
| 15 | Good looking farm, tidy |
| 16 | Wide management knowledge base |
| 17 | Animals necessary for countryside structure |
| 19 | Family/business continuity |
| 20 | Never have cattle on farm in the winter |
| 22 | Consideration of economics |
| 23 | Good clean crops |
| 24 | Combinable rotation |
| 25 | But must make a living first |
| 9 | Plant trees and general awareness of environment |
| 15 | Healtthy crops |
| 16 | Thought about the future |
| 17 | Putting goodness back into the soil |
| 20 | Planting trees |
| 22 | Planning |
| 23 | Keeping the nurient status high |
| 24 | With land stewardship, obligation to continuity |
| 25 | Tidy farm |
| 20 | Do not let grass go to seed |
| 22 | Timeliness |
| 23 | Putting money aside in the good times |
| 24 | Relations with public |
| 25 | Soil structure and tilth |

Table 7.9 : An example of one of the return sheets following the report being sent to farmers interviews, (respondent 12).

**It would be of great help if you could spend a couple of minutes answering the four questions below and putting the sheet in the post paid envelope, thanks again.**

1. Any general comments/critisms about the discussions, the report etc

IT highlights all the current problems faced by the farming community, also the need to unite small & big farms to become ~~of~~ a stronger body ~~to~~ The need to involve the general public, all key issues if we are to survive the next few years.

2. Given that the discussions set out to give an insight into the world as seen from the farmers viewpoint, how well do you think it does this from your own point of view?
(Please circle number on the sliding scale)

Very representative — A bad representation

1 (2) 3 4 5 6 7 8 9 10

3. Even if the report itself doesn't agree with your own viewpoint do you think it expresses more or less the views of the wider farming community?
(Any comments would be useful)

Yes. i.e SHARE FARMING Marketing Cooperatives
We should all be aware of maintaining the countryside to the best of our ability a view shared by a majority of farmers. But at no extra costs. to an individual.

4. I mentioned in the covering letter a specific interest in Agroforestry. I would be pleased to hear your views on such a cropping practice as well as outlining what I see as its pros and cons. Please circle with regard to me contacting you in November/December.

(YES) I maybe able to help you again,

NO Please don't contact me again,

### 7.8.1. Good practice: an environmental and economic balance

It is important to emphasise that what was claimed as good farming practice were not necessarily the most salient issues to the respondents. Indeed, it was these issues that were invariably cited as the driving force behind day to day decision making. If good practice was seen as the preservation and improvement of soil fertility for long term productivity it was often accompanied by a set of statements referring to the need for an on-going income from working the land. Similarly the desire for continuity through inter-generational farming was tempered by an awareness of the need to make ends meet in the short term. This discrepancy suggests that caution is exercised before equating good practice with actual behaviour, (see also Carr and Tait 1991).

Elements of good practice were seen collectively to establish a balanced farming system which combines ecological and physical sustainability with commercial survivability. This was generally considered to depend upon the ability to adopt a longer term approach to farming rather than one in which, as one respondent observed,

*"the driving force is short term and financial gain " (19)*

Paradoxically, the adoption of diverse ventures and farming practice, possibly resulting in short-term uncertainty, was accepted by some as necessary in order to limit uncertainty in the long-term. While such an approach inevitably restricts the capacity for profit maximization it was seen to broaden both the economic and physical bases for long term viability.

*"I am willing to keep some enterprise just ticking over as it is difficult to tell what will be profitable tomorrow",(16)*

The pressure to pursue increasingly intensive, non-diverse regimes was often felt to contrast with definitions of good farming practice. Therefore while good business was considered an appropriate bedfellow to good husbandry within an integrated farming process, the latter was often felt to be overrun by the demands of the former, (see Figure 7.2).

Central to this long term approach to farming was the desire to enable social and cultural continuity in agricultural areas. This was not restricted to a concern over the declining opportunities for employment on the land or for family based farming. It was also felt to be relevant to the maintenance of rural areas as "living entities" in which physical and socio-economic elements are inextricably linked.

*"When I first came here there were lots of tenancies. Now I'm the only real farmer left in the parish, with much of the land being farmed from a distance",(23)*

The intention to maintain or improve soil and land quality, as the basic resource of the farmer, was subject to considerable variation in the measures that were used to define quality. However three areas of farming behaviour were identified to support this broad objective.

1. The adoption of a diverse range of enterprises,

2. The optimisation of external inputs applied to the soil,

3. The use of rotational farming practices

The need for maintenance of soil fertility was expressed primarily through the appropriate usage of external inputs such as inorganic fertilizers and lime. Only a few farmers linked soil fertility to the maintenance of soil organic matter or humus. The current high profile of agricultural pollution has coincided with an increasing recognition of the relationship between inputs to and outputs from the soil, and in consequence between soil and water quality, Thompson (1992). Legislation to protect water quality i.e regarding nitrogen and slurry application was not always supported. Some were concerned about the expenditure required to comply with legislation, whilst others thought it unnecessary. For instance on the heavy clays of Bedfordshire the chances of leaching are minimal. However, some farmers felt extremely strongly about the over use of nitrogen fertilizers,

*"we need some form of nitrate limitation policy, it should be treated like alcohol, taxed and bonded, the world's drunk on it and its poisoning and pushing down prices."(3)*

The adoption of rotational cropping was considered alongside the need to optimise inputs as a means of maintaining soil fertility. Procedures for rotating crops were designed to control weed and disease build up, exploit any soil residuals and make the best use of work time during busy periods; i.e. trying to precede oil seed rape with a winter barley crop. Introducing grass into the rotation improved the fertility of the soil and increased the humus levels, (see Figure 7.3). Several farmers also exploited the residual benefits of leguminous crops which can leave considerable soil nitrogen residuals to be exploited by the following crop.

Where good practice extended to the mixing of "horn and corn" it was seen as one way of establishing the broad economic base that was felt necessary to limit long term uncertainty. While there was an awareness of the benefits of such cropping practice, some respondents had stopped keeping animals, (and therefore grew no grass), or had simplified rotations to increase timeliness and to keep labour and machinery costs to a minimum.

The perceived advantages of diversity in cropping practice were extended by some respondents to include diversification into areas outside the traditional farm remit. The fact that

*"farmers are having to step out of the realms of being a farmer"(12)*

was strongly opposed by those whose reasons for farming were associated primarily with working the land. This was not the prevailing view and over half of those spoken to had considered or started 'non-farming enterprises' ranging from stabling and eventing courses to bed and breakfast and road haulage. The concept of variety and diversity was not considered to be new, indeed it was felt to be a fundamental part of traditional farming expertise.

*"Diversification is good practice, it helps to spread labour demand and risk",(10)*

The inability of farmers, often due to economic constraints, to adapt to a changing environment was expressed as a source of concern alongside an acceptance that the knowledge base which supported many established practices was rapidly declining. Good practice in this context was seen as the willingness

1. To consider new innovations, both commercial and technical

2. To retain, develop and transmit a knowledge which has been developed over generations.

There was therefore, a general acceptance that a diversity of enterprises provided one of the most appropriate ways to deal with the long term uncertainty that was considered to be the major problem facing farming today.

**7.8.2 Issues and problems: uncertainty and short-termism**

The inability of existing policies to satisfy long-term objectives was perceived as having created additional uncertainty in the agricultural environment. There was a general acceptance of the continual variability of natural systems as inherent to the practice of farming. This tolerance was not extended to the unpredictability created by the perceived absence of a relevant long-term agricultural policy framework. Several current policies were seen to be insensitive to both the variation in local physical conditions and the social and commercial requirements of the farming community.

Uncertainty was considered to have arisen primarily out of the need to respond to various policy instruments, based upon political cycles, that did not take account of the longer natural cycles upon which farming decisions are traditionally based (Figure 7.4).

Additionally such policies were not felt to take sufficient account of their impact in creating an extremely complex and artificial market place. The delays and uncertainty in CAP and GATT processes were felt to have resulted in the inability of farmers to plan with confidence for the medium to long term. This was articulated in the resigned observation that it is possible to

*"farm against the weather but not against the politicians". (13)*

The issues and problems that were felt to underpin this uncertainty were primarily concerned with the need to meet short term economic goals. This concern was encapsulated by one or more elements of a

Figure 7.3 : Good farm practice and the soil (7)

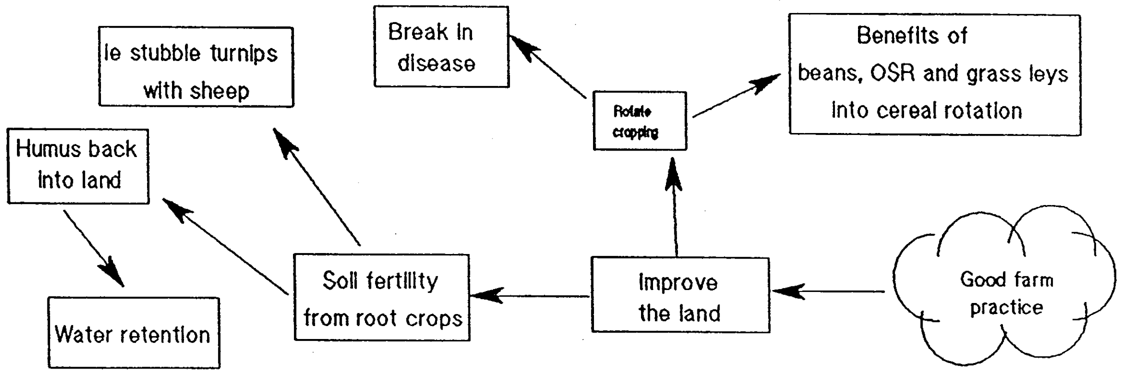
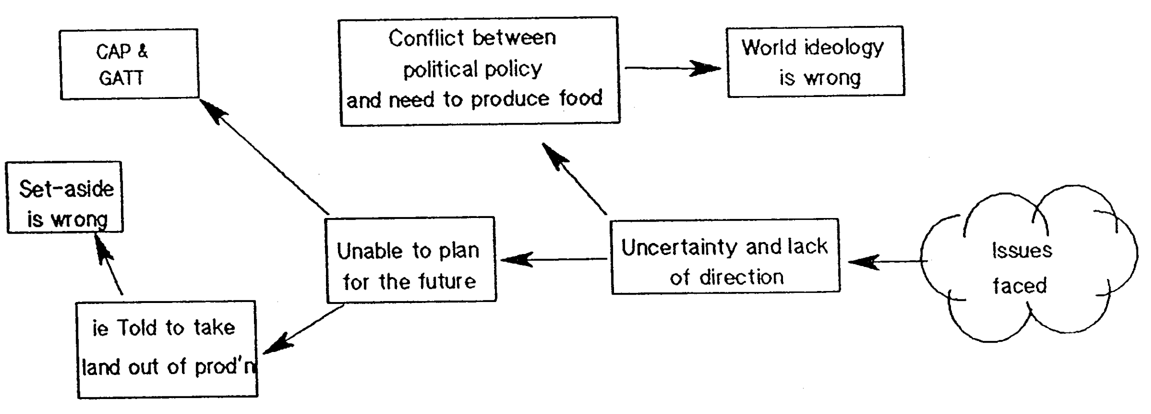



Figure 7.4 : The problem of uncertainty (19)



socio-economic cycle that has increasingly restricted the ability of farmers to feel in control of the farming process. The difficulty for some to step outside the cycle of high yields, increasing farm size, capitalization and the use of technology was felt to undermine the independence and control over decision making which enabled good farming practice. Ironically this desire for autonomy was perceived by some to have contributed to an underdeveloped cooperative sense within sections of the farming community. This was verbalised in terms of a cultural and structural distinction between UK farmers and many of their European counterparts, i.e. larger units, less family farms and more full time farmers. Similar issues have been highlighted by Marsh et al (1991).

The profit squeeze that was cited as a current problem by many of the respondents has also resulted in farms maximising yields per hectare or expanding to spread the burden of fixed costs.

*"Farmers are generally trying to reduce fixed costs and this seems to mean expansion. At present we can make a reasonable living out of our 700 acres, but in the future, who knows? We may need to expand to survive".(1)*

This scenario was seen to put tremendous pressure on the smaller farmer who is being "squeezed" still further by the current difficulty of raising additional capital or meeting the payments for that which has already been obtained. This has not been helped by the need to comply with increasing amounts of environmental, health and safety legislation which was seen by some to be responsible for tying up, or creating of "dead capital".

Previous studies have shown considerable public sympathy for the economic constraints within which the farmer has to operate, (Mori 1983 in Carr and Tait 1991). Where public support was less forthcoming it tended to highlight the lack of contact between the farming and wider community. The study found some traditional stereotyping of "townies" as uninformed about the practicalities of farming. Similarly there was not universal support for the idea of "opening farms up to the public". There was, however, a general acceptance of the need to improve the public image and to integrate the farming community more positively. This was already being done in a variety of ways both as conscious PR through open days and school liaison, and as part of a process of economic diversification with the return of farm shops and the introduction of bed and breakfast, farm holidays etc, see Figure 7.5.

Even though they belonged to a variety of representative groups (NFU, CLA and TFA), the majority of farmers who took part in the survey felt that they had little impact on the development of policy at the regional, national or international level. Several policies were cited to support the perceived lack of understanding about the farming agenda within the policy making process. This was particularly evident in the interpretation by policy makers of the complex relationship between farming and the environment.

*"Set-aside is bad for farmer's morale, the countryside and the CAP pocket", (19)*

Policies designed to control over production, such as set-aside were perceived as having a negative impact on the countryside i.e. spreading of weed seeds and the harbouring of plant disease. Further, the setting aside of badly managed wasteland was seen to "undermine the purpose of the farmer", and several questioned the ethics of setting land aside when there was a global food shortage. The final argument used against the system was that the very process of taking land out of production leads to a more intensive use of that which remains with the possibility that additional inputs will be used. The ban on straw burning following the 1992 harvest was seen as a topical example which highlights the complex and uncertain impacts of legislative policy. Issues such as "disease carry over", problems with establishment of the following crop, the need for more cultivation and the extra use of fossil fuels associated with this were all mentioned.

*"The ban on straw burning is ill thought out. It will cause problems on my heavy land, increasing costs and possibly reducing yields", (1)*

One farmer living on the urban fringe was particularly concerned about the fire risk that arose from the presence of large tracts of unburnt straw. Another estimated that burning stubble was worth up to £60 per hectare to him; this was based upon time, cultivation and spray savings. In addition to the obvious and intended benefit of reduced atmospheric pollution other positive effects of the ban were recognised. These included an improvement in soil workability due to increased humus levels and improved aeration. One farmer stated that now he was geared up for incorporation the process was as quick as burning. The variation in soil type was seen as fundamental to the continued success of incorporation. On some soils the maintenance of the facility to burn periodically within an incorporation regime would have been beneficial.

### 7.8.3 Present and future: Thoughts, motivations and information

Farmers receive a host of information on technical matters from specific advisers, sales representatives, and government sources. There are also specific broadcasting times for farming issues. The literature available to the farmer is immense, ranging from a host of free magazines which he receives through the post to others which he has to pay for such as the Farmer's Guardian and Farmer's Weekly. In addition to listing their sources of information, most made comments about certain sources of information. Trade advice was usually treated with some caution although some spoke of having good friends in the trade in whom they had complete confidence. This was particularly helpful in the selection of crop sprays and recommendations for their use, as the volume of literature and the rate at which changes take place makes it difficult for the farmer to keep well informed. ADAS, (Agricultural Development and Advisory Service), was frequently mentioned. The comments were both positive and negative. Some thought that ADAS was a source of good information and the services they provided worthwhile. Several of farmers paid regularly for their

Figure 7.5 : Economic diversification (24)

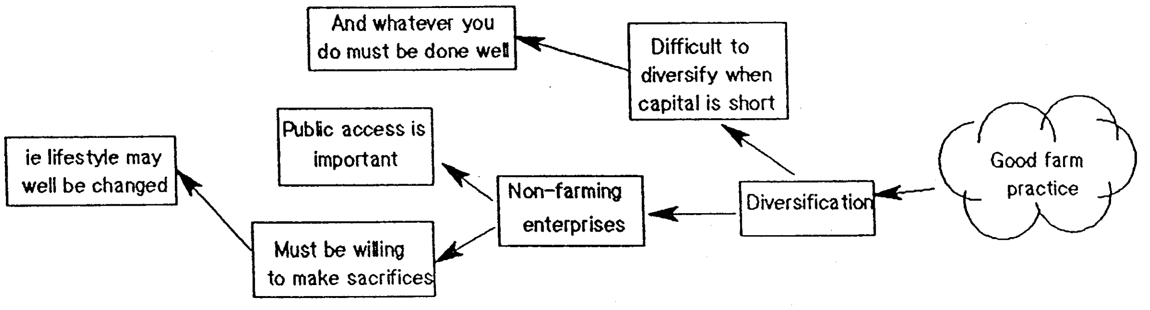
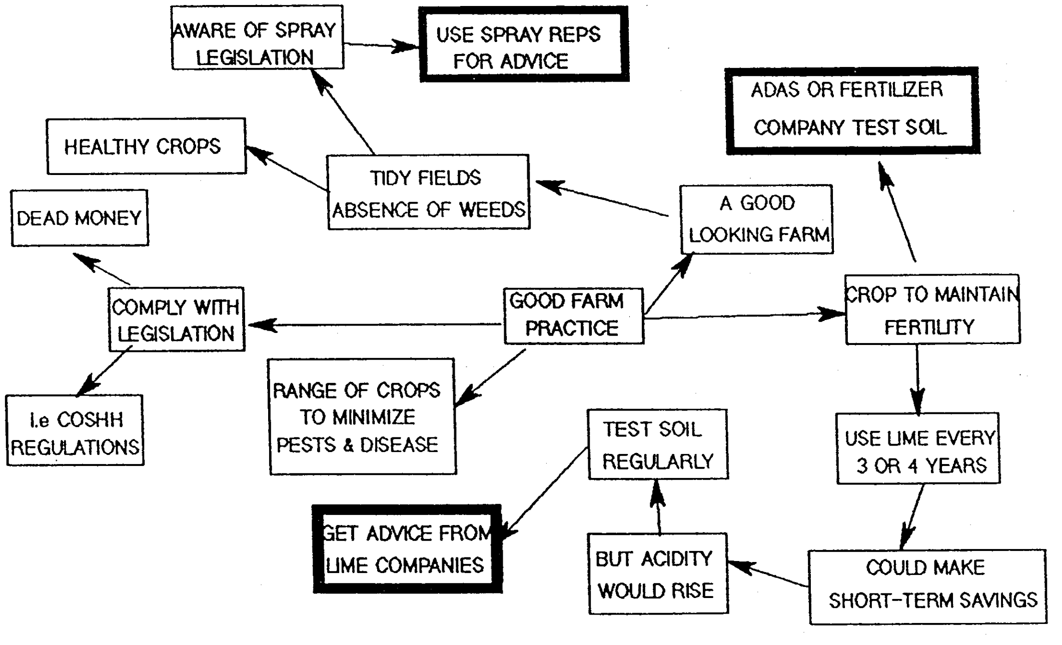



Figure 7.6 : Good farm practices and sources of information (13)



services on an acreage basis, whereas a greater number had occasional contact with ADAS. Conversely were those who had little time for ADAS, and felt that it was a service that farmers had been talked into using, was expensive and did more harm than good. Several of the arable farmers were using some form of agronomical advice either in the form of crop consultants, or by attending regular agronomy meetings. This was seen as keeping up to date with information and having somebody knowledgeable to bounce ideas off. Advice was interpreted by some within the wider context of good farm practice. The pathway map developed in Figure 7.6 shows how several of the areas classed as good farm practice are tied directly in with the farmer seeking information in different guises.

For many satisfaction at work is derived from being associated with the countryside, seeing the crops through from planting to harvesting and producing a good crop both in terms of quality and quantity. One farmer was wading through paperwork prior to the interview and was particularly scathing about the ever increasing amount of time he was having to spend in the office. There was a recognised need to make enough money for the farm to survive as an entity, but unlike many other businesses the farm is part of the family life.

*"Farming is a way of life as well as a business, but nowadays there seems to be little time to sit back and reflect,"(6)*

Whereas some could be very specific about the elements of their job that gives them satisfaction, such as working with stock or achieving high yields of corn, others were much less specific. Amongst these there was a general ethos of being involved in looking after the countryside and providing food for people which gave them satisfaction. The general absence of statements referring to money, suggesting that providing the farm was financially viable, making excess profits *per se* didn't provide a great deal motivation on a daily basis. However, many farmers felt overwhelmed by the increasing amount of paperwork associated with a myriad of rules, regulations and allowances.

This was partly responsible for the majority feeling there was a need for change within the agricultural industry. The important driving factors behind change were the political uncertainty within the UK and European Community, and associated with this, global food production and markets. This was coupled with a growing concern over the changing nature of the farming structure within the UK and the wider effects this was having.

*"Big farms swallow up little farms or they are squeezed out of business. This loss of farming families is very sad",(10)*

Over-production and world food supplies was topical at the time of the interviews with both the latest CAP reforms and the GATT negotiations making headline news. Many thought the next few years would be crucial for the survival of farms, and this would depend on the ability to keep a tight reign on fixed and variable costs. The small farmer and highly geared businesses were seen as those that would find the *weathering of the storm* most difficult.

*"I seem to be working harder and harder just to stand still", (25)*

The need to decide what was wanted in the longer term was discussed in connection with decisions being taken in Europe concerning food production, our role as food providers to the world population, and the type of countryside the public wanted to see. The potential of fuel crops was put forward by several as a means of stemming the increasing rise of redundant land. Other issues that were raised included the collective power of the agricultural industry, (or its lack of it), the education and training of the workforce, relations with the public and the possible productive potential within Eastern Europe.

## 7.9 CONCLUSIONS AND IMPLICATIONS ARISING FROM THE INTERVIEWS,

This first phase of interviews provides a rich source of data relating to the farming agenda in the UK. Additionally it provides background information on the possibility of uptake of innovative cropping practices. The interview methodology allowed the data collected to be placed in context, permitting some recognition of the overall importance of certain issues, i.e although having a set of modern up to date machinery was important to the farmers, many were having to make do with older machines because of the present financial situation. The recording of information during the interviews using pathways diagrams to portray discussion and lines of argument proved extremely useful. The data resulting from these interviews has been presented in three simple ways to "trail" an argument. This is only one form of presentation that may not be suitable for those seeking more focused results. Several computer packages are now available to deal with this type of data, i.e Cope, Nudist. These are particularly useful when more quantitative results are sought from larger data sets.

### 7.9.1 The farming agenda

The issues of straw burning and set-aside discussed in section 7.8.2 provide examples of the need for policy makers to obtain information about, and account for, the variety of

1. physical and spatial settings

2. socio-economic and cultural systems within the farming community.

This supports the development of policy instruments that are more appropriate to complex human and natural systems than the current tendency to legislate in a "blanket fashion". It is true that economic issues were of great concern to many, however the reasons for this concern and the way in which individuals respond were extremely diverse. Considerable emphasis was placed on the need to plan for the future, not only in economic and commercial terms, but with regard to the wider physical and cultural environment in which the farm operates.

Agriculture is an industry that has always accepted and attempted to minimize the uncertainty caused by uncontrollable natural factors. Furthermore, in a temperate climate some constraints can be placed on this uncertainty by taking decisions on the strength of acquired knowledge about local conditions. High levels of uncertainty are being experienced due to current policies. This has engendered a sense of frustration that control over decision making has been usurped by politicians and inaccessible political structures and procedures. This has created a situation in which many are *farming by the seat of their pants*, having to respond to short-term agendas which do not coincide with the longer term view that they would like to adopt.

As a result many farmers have become locked into a technological treadmill, needing to shed labour, increase mechanization and take on more land just to stand still. This has inevitably put increasing pressure on the smaller farmer and has led to the situation where farms are getting fewer and larger. From a purely economic point of view such units are able to exploit economies of scale but many recognize that farming is more than an industry, and forms the basis of the whole rural community. Although no specific source of job satisfaction could be specified it is clear that the majority of farmers interviewed were not motivated purely by money. The main source of satisfaction seemed to stem from an often intangible ethos surrounding working in the countryside.

The image of the farmer as a destructive influence on the countryside may often be exaggerated. Many have clear perceptions of what good farming practice is with regard to both the crops they grow and the animals they keep. Furthermore their knowledge of how such production systems affect the natural environment, and particularly the soil, seems to be underestimated. There may well be differences in what the farmer perceives as good farming practice and what policy makers, environmentalists and scientists understand by the term. While such practice is not necessarily good simply because the farmer perceives it to be so, improved information about the attitudes within the farming community towards certain practices should be obtained by the those who seek to influence them. The farmers themselves are not blameless regarding environmental problems and many recognize that individuals within the industry have not always acted benignly, (in some cases themselves). It appears that most farmers have given the question of the future of the industry some thought, although there is considerable variety in the importance individuals place on specific issues.

The need, although not always the desire for closer contact with the public was recognised and was seen by many to have advantages in terms of exposing the role played by the farmer in a changing countryside. While some have used this as a means of generating income through diversification and the direct marketing of products, the increasing burden of legislation applying to food quality, health and safety and land-use planning have been perceived as doing little to encourage such innovative practice. Although many representative bodies are trying hard to promote the farming image they seem to have had only limited success. Perhaps more importantly they are seen to be incapable of stemming the tide of restrictions and legislation that many farmers feel are being placed upon them.

The old ethos of passing on land in as good as, if not a better condition, than when it was taken over provided a strong theme, supported by generational continuity and thereby the transfer of knowledge about farming methods and local conditions. A policy framework which encourages long-termism and diversity and allows farmers to plan over longer timespans may well help both farming and the general countryside evolve in a direction which is more acceptable to the population as a whole. Policy makers need to be aware of the complexity of issues facing the farmer and the relative importance of these issues. This understanding will aid the formulation of policies based on a realistic set of long-term objectives.

### 7.9.2 The change process,

In the absence of clear achievable long-term objectives from both European Community and UK Agricultural Policy, the ability to respond to continually changing economic criteria will necessarily become a characteristic feature of those farms that survive. Whilst financial viability has, and will remain a primary assessment criteria of cropping systems, the present policy framework encourages highly capitalized specialist farming systems which are relatively inflexible to change. This makes it difficult for the farmer to explore the wider viability of cropping changes which do not fit within the general remit of his current system. For instance consider a farmer who buys a new harvester to cut 300ha of combinable crops. The need to keep this expensive machine working means that the farmer is less likely to convert some of his area to a non combinable crop such as sugar beet, potatoes or grass. New cropping systems not only have to be financially viable but need to fit into a given capital structure. Chapter 8 assesses the financial viability of one type of agroforestry system, using computer scenarios to analysis several case studies which test the suitability of these systems within existing farm infrastructures.

Associated with the increased specialism of farms is the reduction in diversity of "hands on" knowledge of the farmer himself. For instance the specialist cereal grower may have little or no experience of fattening sheep. This specialization adds another obstacle to the process of change and suggests that change will be more readily accepted if it requires the use of some existing knowledge base. Having to learn a new set of techniques and working methods is not only time consuming but can also be very expensive. As shall be discused further in Chapter 9, this may provide a barrier to the adoption of agroforestry systems.

Although not all farmers are facing financial hardship, all are faced with an uncertain operating environment. In such an environment favourability will be given to changes in cropping which involve low additional capital outlay, short pay back periods and assured markets. This stems from a perception that the whole agricultural policy framework appears to lack direction and in itself is unstable. Secondly even when financial encouragement is available in support of cropping changes, (i.e the current woodland planting schemes), uncertainty exists about the final markets for the product or the possibility that their adoption will be usurped by other policies.

Farmers are aware of the need to maintain soil fertility, although for some this is seen as a asset which can be supplied in the short-term out of a bag. Few farmers appeared concerned about long-term fertility issues, and only a couple mentioned the role of humus in soil fertility. The generally heavy land in the areas in which the survey took place may partly explain this lack of concern. Nevertheless it implies that many farmers in this area would not alter cropping practices purely on the basis of long-term soil issues. Therefore changes in cropping in response to soil associated issues may rely on the identification at a national level of those areas in which long-term soil productivity is questionable, and likewise the encouragement of alternative cropping practices which may benefit long-term soil conditions, (see Chapter 2). In the previous chapters the use of soil organic matter levels and soil invertebrates have been discussed and explored as two simple mechanisms for providing such information.

The overall implications for the process of change is that the likely uptake of cropping innovations at the farm level need to be assessed on several criteria:

1. Financial implications,

2. The way in which they fit into existing farming infrastructures,

3. The existing knowledge farmers have about that from of cropping,

4. The degree of security and assurance available to the farmer if he commits himself to a given form of cropping.

In the short term decision makers can influence the financial implications and to some degree the security the farmer feels in committing himself to a given cropping practice. However, the other two criteria, i.e. with respect to existing farm infrastructure and knowledge, are reliant upon significant changes in agricultural policy. This is discussed in more detail in the final chapter. In Chapters 8 and 9 the financial implications and the likelihood of uptake of silvoarable agroforestry systems are explored in greater detail.

# CHAPTER 8: THE ECONOMIC AND FINANCIAL IMPLICATIONS OF THE UPTAKE OF AGROFORESTRY,

*"Agroforestry is.... a radically different approach not only to land use and farming practice, but also to the assessment of the value and benefits of farming and its role in society",* (Carruthers 1990)

## 8.1 INTRODUCTION AND SUMMARY,

In Chapter 7 it was recognised that although the farming agenda is extremely varied, farmers are increasingly making cropping decisions purely on financial grounds. The aim of this chapter is to investigate the economic and financial implications associated with the uptake of silvoarable agroforestry systems on farms, thus extending the research within the third interface which links policy to what the farmer does.

Initially literature concerning the growing of trees on farmland is reviewed, concentrating on the increased interest in reafforestation of the UK. Agroforestry is seen as one possible mechanism for achieving this goal, possibly by gradually encouraging and introducing the growing of trees on farmland. The recent interest in poplar as a possible on farm tree crop is discussed from the agronomic point of view but also because of its value in producing a versatile end product. Its use is being explored for both short rotation coppice systems and for the production of mature timber. New varieties imported from Belgium make it possible to produce a mature stand in 20 to 25 years under good growing conditions.

Whereas Chapter 6 explored the effects of a silvoarable system on soil processes, this chapter extends the assessment of these poplar based systems to consider their economic and financial viability. The difficulties of undertaking national economic benefit calculations on agroforestry are discussed, and previous financial modelling of these systems is explored. This is mainly the bio-economic modelling that has been undertaken at the University of North Wales to study the economic implications of longer poplar rotations.

In contrast to the Bangor models a simple spreadsheet based financial model is described and utilized to demonstrate the on farm profitability of poplar silvoarable systems when cut on a short rotation. It is concluded that in some situations these systems appear to be financially viable, although it is recognised that this is not a particularly good indication of their potential uptake on farms. Chapter 9 explores the likelihood of uptake of these systems on farms via a second phase of interviews with farmers which addresses the issues, problems and benefits of tree/crop combinations on arable farmland.

## 8.2 GROWING TREES ON FARMLAND,

It has been predicted that by the year 2000 there will be 1-1.5 million hectares of land surplus to production requirements in the UK, (Carter 1990). In 1988 schemes were introduced throughout Europe to set-aside productive land, as a means of reducing agricultural surpluses, and by 1990 about 130,000ha had been set-aside within the UK. The 1992 CAP reforms introduced a new scheme in which farmers generally need to set-aside 15% of their arable area if they wish to obtain a area payments on the remaining land, (Nix 1993). It is estimated that about 750,000 ha of land has been set-aside in the 1992/93 season, (MAFF 1993, personal communication), although the final figure will not be known until the all of the Integrated Administration and Control Systems forms, (IACS), have been processed.

There is growing research interest in finding alternative uses for this land which has been set-aside, the planting of trees being one. This pressure will increase further during the 1993 harvest when schemes for non-rotational set-aside are released. Several arguments can be voiced in favour of growing trees. Firstly the UK is one of the least afforested countries in the developed world, see Table 8.1.

Table 8.1 Land use for forestry and agriculture, (after Alcock and Thomas 1987)

| | % Forest | % Agriculture |
|---|---|---|
| Great Britain | 10 | 77 |
| EEC | 22 | 62 |
| USA | 31 | 47 |
| (former) USSR | 41 | 28 |

Wide scale deforestation started with the Celts from about 400BC onwards, and by the time of the Norman invasion natural forest cover was probably down to about 15% of land area. Decline of the forests has continued since this time, accelerating during the First World War. Recently farming policy has encouraged the removal of small copses and hedgerow trees. By the mid 1980's about 18 million Elm trees had been felled due to Dutch Elm Disease resulting in the loss of a common hedge and parkland feature. These factors have led to several schemes to encourage tree planting for a national aesthetic or community value. The most ambitious of these is the Community Forest programme initiated by the Forestry Commission and Countryside Commission which aims to afforest 12 areas within the UK, each "forest" covering between 8000 and 20,000 hectares.

Secondly, the UK imports substantial quantities of timber and it would be possible to reduce these imports by ambitious tree planting programmes. It is estimated that in 1992 the UK imported between 80 and 90% of her timber requirement at a cost of between £6 and £7 billion . (This being the fourth largest category of imports). Large scale planting of coniferous forests has taken place on the relatively low value upland areas over the past decades. However, the return of capital from afforestation of lowland areas is low, accentuated if the trees are slower growing hardwoods. Conifers could be conceivably be harvested at 35 to 50 years on lowland sites, but this is still a very long rotation in comparison to traditional agricultural enterprises.

Thirdly, trees can provide a source of biomass for energy, ensuring useful output from land that would otherwise be unproductive. A variety of systems are being investigated although the systems receiving greatest interest are those centred on the growing of woody products on short rotation, (ETSU 1985, Newman and Wainwright 1988, Carter 1992, Ford-Robertson et al 1992). These systems are based mainly on cutting rotations of 3 to 5 years, to produce a product which can be utilized for energy production.

## 8.3 AGROFORESTRY AS AN ALTERNATIVE LAND-USE IN THE UK

Although commonplace in tropical and sub-tropical, climates the growing of trees and crops in close association is not common practice in the UK, (see Chapter 6). This does not make it a new science, but is in one sense applying old ideas to modern farming methods. In this sense it is still,

*".... at the stage of laying its conceptual and methodological foundations"*, (Carruthers 1990)

Agroforestry systems can involve both short and long-term growing rotations, cut regularly to produce a immature product, or left over a long time period to produce a mature timber crop. In this sense agroforestry is more specific to the spatial layout of the trees and some other crop, rather than the timeframe over which the trees are grown. In section 6.4 the possible benefits of utilizing agroforestry systems within the UK were discussed. Of these several apply to forestry in general, implying that for agroforestry to be successfully adopted it will need to have other advantages beside being a producer of wood, and a method of reducing agricultural surplus's. If these are the only benefits then it is likely that growers would be more inclined to opt for blocks of trees which are easier to manage.

With the exception of the larger landed estates, farming and forestry have not traditionally combined well in the UK. The techniques and skills required for success in either being quite different. Thus, the growing of trees on farms has been, at best, incidental or ancillary to main farm activities, (CEED 1986). The introduction onto the farm of managed agroforestry systems may provide an opportunity for a gradual introduction of commercial timber growing onto farms, without the farmer having to turn large blocks of land over to woodland. If, as seems likely, agroforestry becomes an option for non-rotational set-aside in 1993, the growing of trees on arable land could become an accepted alternative form of cropping.

## 8.4 AN APPROPRIATE AGROFORESTRY SYSTEM,

The implications drawn in Chapter 7 highlighted that farmers were only likely to consider changes in cropping which involved minimum capital outlay and a rapid payback on investment. It has been suggested by Newman et al (1991) that poplar silvo-arable systems can provide rapid payback if cut regularly. Table 8.2 provides payback calculations based on a silvo-arable system cut every five years,

Table 8.2 Payback period of a poplar silvo-arable system (after Newman et al 1991)

**Silvo-arable system, LER=1,**

| Item | Year 1 | 2 | 3 |
|---|---|---|---|
| Establishment cost | 562 | 0 | 0 |
| Income from wheat 12.5/14 | | | |
| Poor (a) | 223 | 223 | 223 |
| Average (b) | 371 | 371 | 371 |
| High (c) | 473 | 473 | 473 |
| Income from poplar 1.5/14 | 0 | 0 | 263 |
| Cashflow | | | |
| (a) | -339 | 223 | 486 |
| (b) | -191 | 371 | 634 |
| (c) | -89 | 473 | 736 |

| | (a) | (b) | (c) |
|---|---|---|---|
| Payback | year 3 | year 2 | year 2 |
| NPV | | | |
| 10% | 265 | 670 | 949 |
| 3% | 335 | 766 | 1064 |

Other agroforestry systems being researched involve a greater degree of change on behalf of the arable farmer, or have longer payback periods, i.e. Agrisilvopastoral systems are being suggested and financially investigated at Bangor, (Thomas et al 1992). Trees are under-cropped with normal arable crops for a period of time until the level of shade due to the trees becomes too high to achieve a reasonable yield from the understory crop. At this point the arable cropping is converted to pasture and this is used to provide grazing or a cut crop of grass. Eventually as the trees mature still further the grass can no longer tolerate the high degree of shading and the trees become the sole crop on the land.

At Leeds University silvoarable trials are being undertaken using more traditional hardwood trees such as Ash, Sycamore, Walnut and Wildcherry. The aim is to produce high returns from quality furniture timber, the timber being mature in 50 to 60 years, (Farmer's Weekly, 4th September 1992). It is not certain for how long an arable crop can be supported beneath the trees, although it is envisaged that at some point in the future the trials will have to switch to a grass understory.

## 8.5 POPLARS AS A BASIS FOR SILVOARABLE SYSTEMS,

The need of both the energy and timber markets for a fast growing, but relatively high quality product has refocused interest on the growing of poplar in the UK. This has been encouraged by advances in the quality of poplar growing stock, (Thomas et al 1992), particularly the clones "Primo" and "Ghoy", *(p.deltoides x nigra),* and "Beaupre" and "Boelare", *(p.trichocarpa x deltoides),* whose characteristics are described in greater detail in Forestry Commission note 181. Poplar is a traditional timber tree throughout much of Europe and was planted extensively in the UK during the 1950 and 60's as a source of match splints. Interest in poplars slumped following the withdrawal of Bryant and May from the growing of timber for matches in 1978, (Beaton 1987). However, a few specialist markets have remained in the UK, particularly for peeler logs for producing plywood and light packaging, (particularly vegetable crates). Poplar sawlogs can be used in furniture, joinery and housing and for pallets and crates. In the latter role it is useful because it is very tough for its weight and has the unusual attributes of bruising rather than splintering when subject to abrasion, (Savill 1991). It is widely used in the manufacture of medium density particle and fibreboard. Following a depressed market in the 1980's the demand for poplar appears to be increasing rapidly as its versatility is recognised. In a paper given at a recent conference entitled, "Poplar- a profitable farm and woodland crop", Irwin (1993) commented that as the owner of a poplar peeling plant he had a market to expand his operations but no sustained supply that could allow him to invest in expensive new peeling lathes.

Poplars are also attracting considerable attention for burning as a biomass product. In high technology boilers the chipped product makes a good fuel stock which burns to leave about 1% ash and negligible emissions, (C. Foster 1993, personal communication). It can be used in open household fires, although it probably requires a period of drying before use.

Traditionally poplars are planted at 8m x 8m spacing to produce plantations ready for felling at around 35 years of age, depending on growth conditions, (Forestry Commission 1988). The introduction of the hybrid poplar clones, which have a growth potential of approximately 8 yield classes higher than traditional varieties, has reduced this timespan to between 20 and 30 years for mature timber. (A yield class is based on the potential maximum mean annual volume increment measured to 7cm top diameters. Thus a yield class of 22 refers to a plantation with an annual growth increment of 22 cubic metres per hectare). This has made the growing of poplar appear highly attractive, as it allows the planting and felling of a stand well within a farmer's lifetime. Cultivated poplar varieties prefer fertile loamy soils, alluvial or fen soils which are well drained and aerated, although they will grow reasonably on most soils, with exception of acid soils or where there is stagnant water. Their preference for growing at wide spacing makes them particularly suited to agroforestry situations.

Establishment is best achieved in weed free non-shaded conditions, with plantations often being set from young cuttings or larger rods. Following establishment at wide spacing, regular pruning is necessary to ensure the timber doesn't become too knotty and to ensure a good quality product. The new Belgian clones can be ready for harvest for saw or peeler logs as early as 18 years old on good sites. Alternatively the trees can be cut at more frequent intervals, causing the development of a coppice stool, from which a crop can be taken every 3 to 5 years.

## 8.6 A MARKET FOR THE PRODUCT

Harvesting the trees on a short rotation is only financially feasible if there is a market for timber of this age. If the trees are grown through to maturity, producing a good quality butt log, current knowledge suggests that a ready market will be available for such products, (Irwin 1993). The Forestry Commission (1988) suggest that a plantation of poplar in yield class 14, (Belgian clones may reach yield classes of 22+), felled at 35 years would produce around $480M^3$/ha of logs with a top diameter under the bark of above 18cm. This would yield £12000 to £14500 /ha after the 35 year rotation. However, cutting at 4 or 5 years produces a much smaller log which is of no peeler value. Table 6.3 gives some indication of the size of timber produced by Beaupre and Boelare clones after 4 years of growth,

Initially the agroforestry plots at Wolverton were set up as a biomass for energy trial, and early economic comparisons with poplar monoculture for energy were favourable, (Newman and Wainwright 1988). However, their comparison assumes a ready market for the biomass product, similar to many of the calculations undertaken for more conventional coppice for biomass, (Ford-Robertson et al 1992). This highlights a "no win" situation where farmers do not want to commit themselves to growing energy crops before there is an established market, whereas nobody seems willing to set up centres for burning a coppiced product until a series of producers have a product. An attempt to alleviate this problem has been made via a Department of Trade and Industry initiative. *"The Farm Wood Fuel and Energy Project"* aims to break this 'no supply-no market, no market-no supply cycle through raised awareness of coppice growing, demonstration of economic feasibility and the development and supply of local markets. Recently the South-Western Electricity Board has shown a commitment to setting up a small wood burning power station and is in the process of agreeing contracts with growers.

Other outlets for timber produced on short rotations have been suggested. For instance, the use of poplar wood for on farm building, although poplar is not that durable as a fencing timber and its heartwood in particular is resistant to impregnation by preservative, (Savill 1991). This problem is somewhat exacerbated because many lowland arable farms have little demand for fencing material or the use of timber for animal housing. However, on farm use is desirable because it eliminates transport cost, and this has focused attention on the use of poplar as an on farm fuel source. Many farms already have wood and straw burners installed, mostly to provide space heating for the farmhouse. Wood from a frequently cut agroforestry systems could provide a regular supply for these installations. Local markets for firewood could possibly be developed in populated areas.

A possible future on farm use for wood is in the generation of electricity, or local combined heat and power, (CHP), units using Sterling engines. These small scale thermodynamic generation units are still in the developmental and evaluation stage but it is thought that with 5 years units will be available for on farm generation. A London based company, (esd Engines), has been involved in the development of small Sterling units and hopes to produce engines in the future with conversion efficiencies of greater than 40%, (esd Engines, Technical Report 1993)

## 8.7 ECONOMIC ASSESSMENT OF AGROFORESTRY,

Research work at the University of North Wales, (Thomas 1990, 1991, Thomas et al 1992), provides some of the most in depth financial and economic analysis of agroforestry systems within the UK. Thomas (1990) outlines some of the problems and pitfalls of undertaking economic and financial research in agroforestry. Firstly he highlights the difference between financial and economic studies, and the difficulty involved with each. Financial analysis can be viewed as taking place from the perspective of the entrepreneur whereas the economic analysis is done from the perspective of the good to society as a whole.

One of the major problems associated with appraisal at the national level, for instance Cost Benefit Analysis, (CBA), is the isolation of one derivative of agroforestry and to compare it to a certain "conventional system". Although national CBA of agroforestry has been carried out in New Zealand, (Arthur-Worsop 1985), this was in a situation where the comparisons of agroforestry were against specific sheep based pastoral systems. In the UK analysis is dogged by the variety in the number of possible agroforestry systems that could be adopted and similar variety in the systems they could replace, (Carruthers 1992 personal communication). The issue of national benefit raises questions of the value of environmental benefits. A value for environmental benefits is often not included in economic analysis which may make investment decisions in agroforestry look unfavourable. Similarly at the farm level there may be benefits or disbenefits to the farmer which cannot be easily accounted for.

The results of national economic appraisal may influence greatly the degree of intervention that government is willing to undertake in making it a financially desirable alternative to the farmer. The addition of down stream benefits, for instance a reduction in erosion, can be large. In Nigeria the inclusion of environmental benefits of rural afforestation changed the prospective economic returns considerably, (Thomas 1990). The increased rotation length associated with the woody component of agroforestry systems raises issues concerning investment appraisals when compared to normal annual cropping. In the UK for instance, if the woody component consists of poplar trees maturing at 25 years, the value of return after that period needs to be assessed now. This usually involves net present value, (NPV), calculations or some other form of project evaluation, normally involving discount rates. NPV relies on expressing the future receipts from a project in terms of present values. Given a time preference rate, each years net cash flow can be reduced to a present value by multiplying it by $1/(1+r)^n$, a process known as discounting, (Warren 1982). This raises questions about the appropriate discounting rate to apply to agroforestry investment. Doyle et al (1986) note the difficulty of knowing what discount rates to use as well as problems in approximating the future value of timber. They see uneven cashflow as a problem associated with the financial aspects of agroforestry, especially where trees are taken through to maturity at older ages between 20 and 40 years.

Formal economic appraisal of agroforestry in the UK has yet to be undertaken, (Thomas 1990), or is too vague a concept. However, attempts to undertake an assessment on a crude basis, demonstrated that, when using a 5% discount rate, agroforestry could compete favourably with forestry or agriculture in hills and uplands and on the lowlands, particularly with low input agriculture, (Adcock and Thomas 1987), see Table 8.3. As no time frame is mentioned in the table it is assumed that it relates to one tree rotation.

Table 8.3, Net present value of forestry, agriculture and agroforestry £/ha at 5% discount rate,
(After Adcock and Thomas 1987)

| | Hill | Upland | Lowland No N | Lowland 300kg/ha of N |
|---|---|---|---|---|
| SOLE USE | | | | |
| Forestry | 1129 | - | - | - |
| Agriculture | 555 | 4234 | 1493 | 8585 |
| AGROFORESTRY | | | | |
| 100 stems/ha | 793 | 4273 | 3051 | 8314 |
| 400 stems/ha | 1071 | 3942 | - | - |

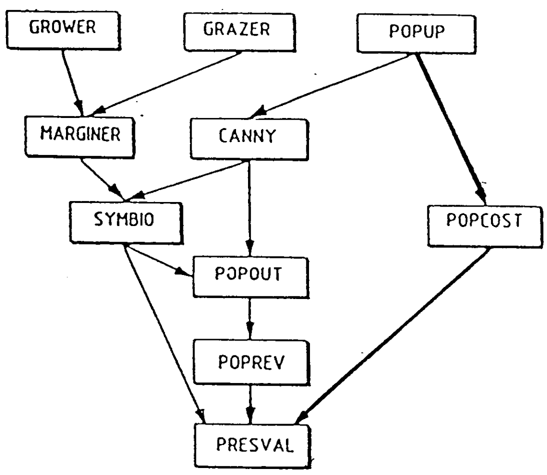
Several financial studies have been conducted to demonstrate the implication to the farmer of a undertaking a variety of agroforestry systems, (Thomas et al 1992, Newman et al 1990). This research has necessarily incorporated the use of models to simulate the growth of timber and expected returns at maturity to aid farmers and advisers in making decisions about investment in agroforestry projects.

## 8.8 FINANCIAL ASPECTS: ON FARM PROFITABILITY,

A problematic issue concerning modelling is the diverse range of cropping systems that come under the heading agroforestry and the ability of a model to simulate a range of these with any accuracy. Financial calculations based on the silvo-arable site at Wolverton suggest this type of agroforestry compares well with traditional coppice, (Newman et al 1991). However, this calculation is somewhat unrealistic as most farms do not grow coppice as a crop. The arable farmer will be concerned about the effect the planting of trees will have on his arable yields, and subsequent effect on margins. To demonstrate the economic evaluation of systems of multiple land-use in which agricultural and forestry enterprises are undertaken on the same area of land, sophisticated technical and economic models have been developed, (Thomas 1991, Thomas et al 1992), see Figure 8.1,

The "POPEYE" spreadsheet model has been developed further over the last couple of years, the latest version being called "Pop -mod",

Figure 8.1 A diagram of the POPEYE model developed at Bangor, (after Thomas 1991),




| | |
|---|---|
| GROWER | Estimates yield on the basis of site characteristics. |
| GRAZER | Identifies sward. Calculates stocking rates. Estimates performance level. |
| POPUP | Estimates Stem Diameter and height from spacing and age. |
| POPCOST | Details inputs and factor prices required for all planting Silvicultural and harvesting operations. Calculates timber costs per ha. per year for any specified planting regime. |
| MARGINER | Converts Grower and Grazer to equivalent Gross Margins ( £ /ha ). |
| CANNY | Estimates crown diameter from stem diameter and crown depth from POPUP for any specified pruning rigime. |
| SYMBIO | Reduces agricultural gross margins per ha. with increasing crown development. Alters annual basal area increment as required. |
| POPOUT | Estimates timber volume on the basis of Buttlog Volume and Toplog volume per ha. |
| POPREV | Includes grants , all product prices and calculates revenues per ha. per year of rotation for any specified planting. |
| PRESVAL | Calculates net cash flows per annum and uses these to give Net Present Values ( NPV ) per ha. for a range of real discount rates ' All Agricultural', ' All Forestry and Agroforestry' options are compared . |
| Notes | All input and outputs are included as variables in both physical and financial forms . This changes in technical input/output coefficients, factor and product prices can be examined in terms of impact on NPV. |

which broadens the scope of the original model particularly to include the uptake of agroforestry on better quality land. The model has been developed to consider the economics of growing single stem poplar through to a given log diameter, (Thomas 1991) or through to a size which maximizes NPV, (Thomas et al 1992). The model can be classed as being bio-economic because it includes growth components for individual tree volumes and takes into account interactions between trees and non-woody components. The model is based on 1 hectare cells of land, rather than a farm, which "avoids some of problems associated with cashflows and capital items". In the later POP-MOD model agricultural production is expressed in net margin terms which make allowance for the allocation of fixed costs to agricultural enterprises, (usually agricultural output is expressed as a gross margin which ignores fixed costs). The range of system characteristics that can be investigated by the model are extensive. A typical agrisilvopastoral rotation lasting about 20 years would be,

| | | |
|---|---|---|
| 0 - 7 | years | Normal arable rotation, |
| 7 - 15 | years | Grassland supporting sheep |
| 15- 17/25 | years | No understory crop |

Using discount rates of 5% Thomas et al (1992) demonstrate that under certain conditions the growing of poplar on these types of agrisilvopastoral systems compares well with conventional agriculture on good quality arable land. Figures in Table 8.4 are for the Belgian clone *"Beaupre"* using figures for yield classes of 22 which are achievable on good quality land, and 28 which could be hypothetically achievable in the future. Figures assume proportional planting grant currently available for agroforestry. Three cases are used:

Case 1: Agricultural returns are described in gross margin terms, and all prices are held at their current levels. Agricultural output is often quoted in gross margin terms because of the difficulty of assigning fixed costs to various enterprises. This is in contrast to forest output which is usually quoted in net margin terms. This tends to give conventional agriculture an apparent financial advantage over agroforestry if margins are calculated on this basis.

Case 2: 20% reduction in agricultural prices anticipated under the CAP reforms. Although product price may well fall following the CAP reforms, farm income is likely to be maintained under the area payments scheme. These payments appear very favourable at present following the devaluation of the pound on "Black Wednesday" after Britain's exit from the ERM. A 20% fall in farm incomes may therefore be pessimistic. Additionally the poor harvest in 1992, led to shortage and very high prices, especially for wheat, demonstrating the general volatility of some agricultural product prices.

Case 3: Agricultural output is described in net rather than gross margin terms. This is a more realistic scenario as both the trees and the arable costs are calculated at the net level.

Table 8.4: Selected output from POP-MOD calculated on a Net Present Value basis, (adapted from Thomas et al 1992)

| | | CASE 1 | CASE 2 | CASE3 |
|---|---|---|---|---|
| Net benefit Agroforestry £/ha | Beaupre 22 | -1794 | 213 | 2121 |
| | Beaupre 28 | 440 | 2500 | 4493 |
| Rotation Length (years) | Beaupre 22 | 18 | 19 | 20 |
| | Beaupre 28 | 18 | 19 | 20 |

Although yield classes of 28 are somewhat speculative, (comment by Arnold Beaton at recent poplar conference), case 2 demonstrates that over a 19 year rotation, under present grant conditions there is a small net benefit to agroforestry of £213/ha when yield class 22 is assumed.

It was strongly emphasised at a recent poplar conference that growers need to aim for quality wood if growing through to maturity, achieved mainly through appropriate pruning or brashing to produce a knot free timber. At the same meeting it was suggested that the exploration of the uses of poplar will provide new markets with the prospect of greater added value, increasing the value of the standing crop. For those producers who wish to commit themselves to longer production systems this may provide a viable alternative. However, a realistic viewpoint is given by Beaton (1993), commenting on the results of his derived cashflow models,

*" ...... growing poplar [to maturity] is not an alternative to normal farming since even with full grants and payments the cash received throughout the rotation is not exciting. The real advantage lies in the opportunity for farmers and land owners to build up capital well within a working lifetime to an extent that puts all other forestry in the shade."*

These sentiments suggest that the planting of poplar for mature stands will continue to be limited to those who have the capacity to relinquish short term gain for longer-term investment, probably in small areas. The interviews with farmers in Chapters 7 and 9 suggest that those farmers who can afford or are inclined to take land out of production for long periods often plant trees to enhance the landscape, environment or general amenity or to act as shelterbelts, rather than for any financial value they may accrue. These interviews revealed that farmers were concerned about short-term financial survival. In this atmosphere it is suggested that poplar systems based on short term rotations will be a favourable option if they can be proven to be financially viable.

In the next section the development of a financial model is described which investigates the possibility of growing poplar in a silvoarable situation, (see Chapter 6), where the trees are cut every five years and allowed to regenerate. The model was developed partly to be used as an interactive tool during a second phase of interviews with farmers, (see Chapter 9). In contrast to the Bangor model it aims to represent individual farms, rather than one hectare blocks, and is simpler in its construction.

## 8.9 THE DEVELOPMENT OF A SIMPLE FINANCIAL MODEL FOR SHORT ROTATION POPLAR SILVOARABLE SYSTEMS

The financial model, (ROWMOD), assumes that poplar trees are planted in rows on arable farmland, the trees being harvested every five years. The model is based loosely on the silvoarable system at Wolverton, described in Chapter 6. The model runs over three tree rotations, i.e. 15 years. This time period was selected as it is long enough to allow benefits to be accrued from the regrowth of the stools over several rotations. In the first five years the trees grow as single stems, although after cutting for the first time they can either be left to coppice or encouraged to regrow as a single stem. It is assumed that whichever regrowth strategy is allowed the volume of timber produced will be similar. A schematic for the model is provided in Figure 8.2, and the formulae used in the model can be found in Appendix 7.

The model has been constructed using the Excel spreadsheet package and is designed to be used in two situations. Firstly, to carry out a desk top study of a range of scenarios and secondly for use on individual farms during a second phase of interviews, (see Chapter 9). The model requires the selection of a preferred growing width for the alleys, and needs decisions to be made about growth conditions and local markets for the woody product. When the model is used interactivily the farmer is encouraged to impute figures for present gross margins within his/her rotation and to estimate overall fixed costs on his/her farm. The model allows the exploration of future scenarios via changes in agricultural prices, interest rates etc and can examine various policy incentives that may make this form of agroforestry a viable option on farms.

### 8.9.1 Structure of the model

*Arable crop net margin:* The arable rotation of the farm is imputed and the average crop gross margins per hectare recorded. An average figure for fixed cost per hectare is used to calculate a net margin per hectare. There are always problems associated with the allocation of fixed costs to differing farm enterprises. Enterprise fixed costs will varying considerably from farm to farm, and are extremely difficult to measure on farm without careful recording of labour and machinery use for various enterprises. Approximated fixed costs per hectare must therefore be accepted as a weakness within the model. The net margin in each year is used to calculate a discounted cashflow for *conventional* arable cropping over 15 years. The discount rate and agricultural prices can be changed on a yearly basis to investigate a variety of scenarios. The arable net margin is also used in the calculation of a net margin under agroforestry.

Figure 8.2 A schematic of the main compartments within ROWMOD.

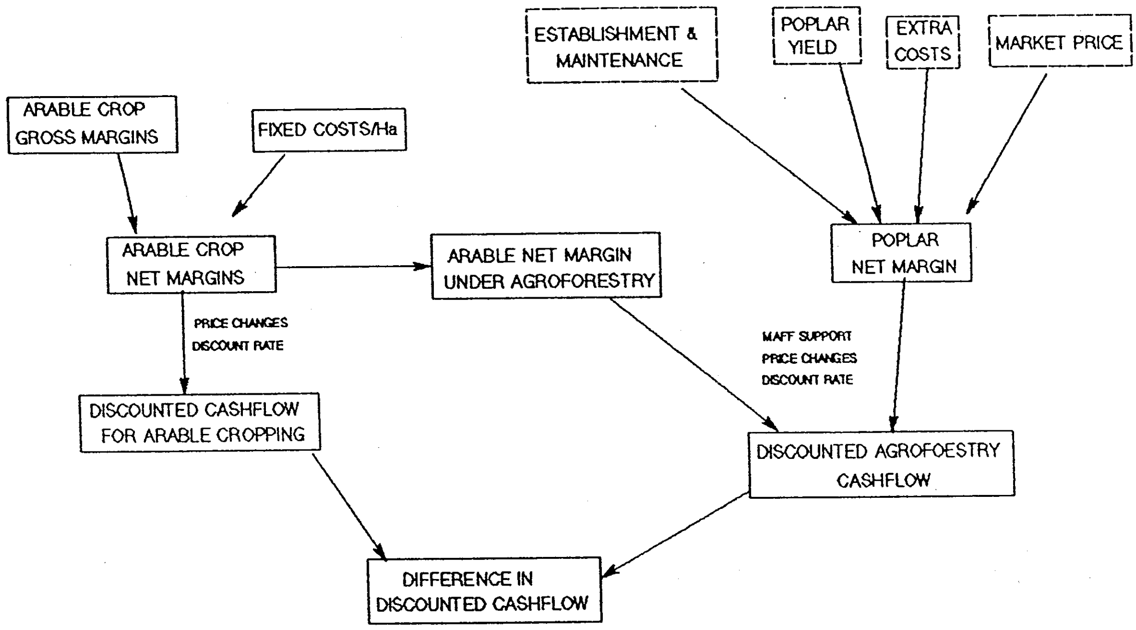
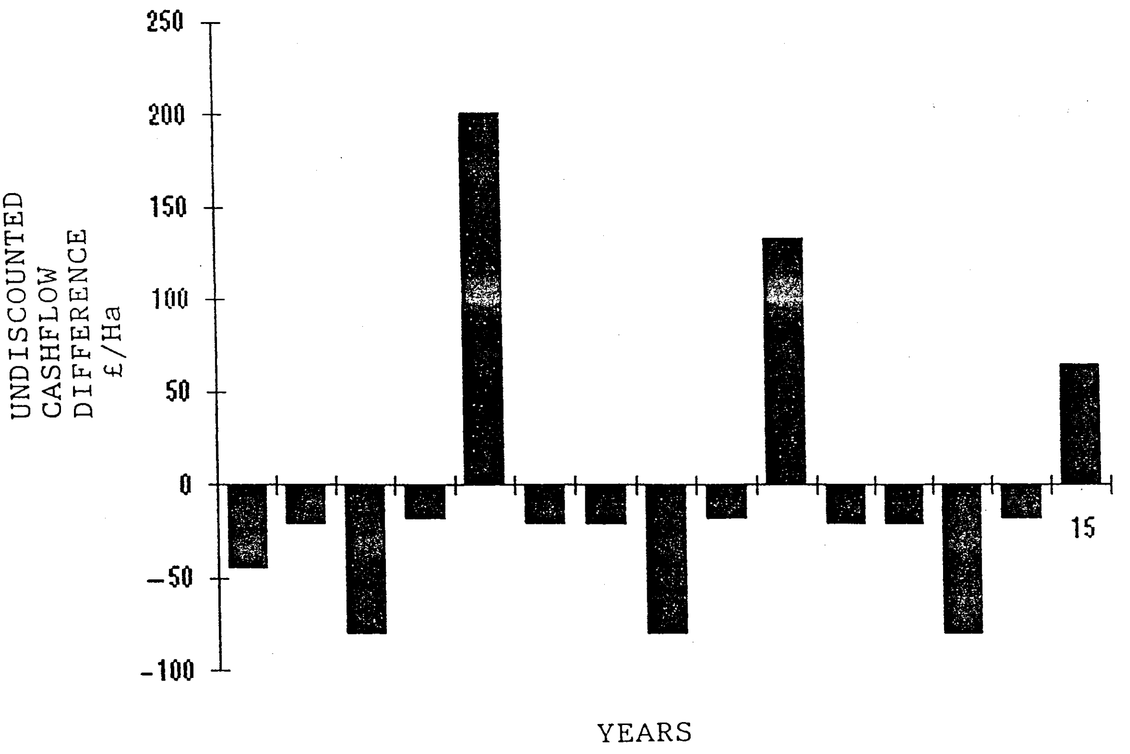



Figure 8.3: Cashflow difference between conventional cropping and agroforestry.



*Net margin under agroforestry*: In the first two years of tree growth there is assumed to be no effect on the arable crop yield apart from the reduction in area grown, i.e. due to the 1.5M mulched strip into which the trees are planted. In the ensuing 3 years it is assumed that shading by the trees will effect the yield of the arable crop. This is dependant on whether it is the third, fourth or fifth year of the woody rotation and on the spacing between rows, (see Table 8.5).

Table 8.5: The percentage reduction in net margin per hectare of the arable crop due to the presence of trees,

| | Year | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| Row width | | | | | |
| 8M | 19 | 19 | 34 | 39 | 44 |
| 14M | 11 | 11 | 20 | 24 | 27 |

This analysis may treat agroforestry systems unfavourably as some research has shown a positive yield effect due to the presence of trees, (Newman 1986). However, such analysis rely on drymatter yields and not necessarily the quantity and quality of harvestible grain, (see section 6.5.1).

*Poplar yield per hectare:* Is a function of three parameters: number of trees planted per hectare: the yield potential of each individual tree after 5 years, and the actual growth conditions of the site. It is assumed that trees are planted at 1M spacing within rows allowing the number of trees per hectare to be easily calculated. For instance at 1 x 14M spacing the average number of trees per hectare is 714. The yield potential of each tree in ideal growing conditions is harder to estimate. Beaton (1993) assuming a yield class of 20 for the new Belgian Clones suggested that at 3 x 3M spacing the volume of each individual tree would be $0.048M^3$ after 5 years. Similarly, on wider spacing of 8 x 8M he suggests the volume of each individual tree would be $0.076M^3$. Calculations based on the average height and diameter of the Boelare and Beaupre clones at the Wolverton site suggest each individual tree has an average volume of $0.065M^3$ after 4.5 years of growth. However, this calculation is inaccurate because the stand was thinned, (at 3.5 years), from the original 1M within row spacing leaving trees spaced at 2 and 3M. This thinning will have enhanced the growth rate of the remaining trees.

Based on the above information the model assumes an average figure for individual tree volume after 5 years of $0.05M^3$ under good poplar growth conditions. The model allows for medium and poor poplar growing conditions by assuming yields of 80 and 60% respectively of those achieved under good conditions.

*Market price:* The market price can be set at whatever figure seems appropriate, and is a function of the market situation. A base figure of £11 /$M^3$ has been used to represent average value of cut timber of this size in the farmyard. This is well below the present price for peeler logs of about £40/$M^3$ delivered in, or that for sawlogs at £30/$M^3$ delivered in, (Irwin 1993). The price of £11/*M3* is based on the value of poplar wood as an energy product, although this smaller timber may have a value for on farm building, or a local log market, which may attract a premium. Newman and Wainwright (1988) assume a price of £35 per oven dried tonne, (ODT), but include no harvest or transport costs. Carter (1992) assumes a price of £38 per oven dried tonne for chipped coppice, all costs included. It has been assumed that fresh cut poplar contains 40% moisture and has a density of 700 kgs/$M^3$. On this basis 2.35$M^3$ of fresh poplar is equivalent to an oven dry tonne, suggesting a value as an energy product of £11/$M^3$ for fresh poplar based on a standing price of £25/ODT.

*Establishment and Maintenance:* Grant schemes are available for the establishment of trees on farmland. However, at present it is not possible to plant trees on set-aside land and claim the area payments. It is possible that this situation may change after the 1993 harvest. Planting under an agroforestry regime attracts a proportion of the full grant depending on the number of trees which are planted per hectare. However, the amount of grant paid under an alley planting system appears to depend largely on the discretion of the local Woodland Officer, (Forestry Authority 1992 personal communication). The Woodland Grant Scheme, (WGS), allows full payment under a planting of 1100 stems per hectare, with a "better land" supplement of £600 per hectare at the same planting density. The Woodland Grant varies depending on the area planted. Table 8.6 illustrates the variation in the grant depending on area planted and density of trees,

Table 8.6 Current rates of Forestry Commission Grant for Broadleaved plantings,

| Woodland Grant Scheme | £/ha | | |
|---|---|---|---|
| | 1100 stems/ha | 714 stems/ha | 175 stems/ha |
| < 1ha | 1575 | 1022 | 250.56 |
| 1.0 - 2.9 ha | 1375 | 892 | 218.75 |
| 3.0 - 9.9 ha | 1175 | 762 | 186 |
| > 10 ha | 975 | 632 | 155 |
| Better land Supplement | 600 | 389 | 95 |

The model allows an appropriate figure for grant aid to be imputed. The WGS gives 70% of full payment in the first year followed by two subsequent payment of 20 and 10% at years 5 and 10 respectively. Table 8.7 illustrates possible grant payment under the WGS for a 1 x 14M planting of 714 trees/ha depending whether the grant were paid in full, at two thirds rate, or at a third of the rate.

Table 8.7: A range of possible grant scenarios for agroforestry, Proportional WGS grant + Better land supp.

| Area | 33% | 66% | 100% |
|---|---|---|---|
| <1ha | 470.3 | 940.6 | 1411 |
| 1 - 2.9ha | 427 | 854 | 1281 |
| 3 - 9.9ha | 383.6 | 767.3 | 1151 |
| >10ha | 341 | 681 | 1021 |

Establishment costs per hectare are calculated on an individual tree basis depending on the number of trees per hectare that are established. The trees are assumed to be planted as 1.5M rods into a polythene mulch, individually guarded. Costs assumed are illustrated in Table 8.8.

Table 8.8: Marginal costs of establishing a 1ha block of poplar agroforestry system at 1x 14M spacing assuming 714 trees per hectare, (adapted from Newman et al 1991),

| | Cost £ | Source of information |
|---|---|---|
| Individual tree guards | 143 | UK suppliers |
| 500 Gauge mulch 27p/M | 193 | UK suppliers |
| 1.5 M rods @ 17.7 p | 126 | Forestry Commission |
| Planting costs, labour | 100 | Nix (1992), |
| Cost per hectare | £562 | |
| Cost per tree | £0.78 | |

The model uses two costs dependant on the hectarage grown. If more than 10ha are grown it is assumed each individual tree costs £0.70 to plant, and if less than 10 ha is planted the cost of establishment is slightly higher at £0.80 per tree.

*Extra costs incurred:* Depending on the individual farm situation the farmer estimates the likely additional costs incurred in the growing of the trees. Although fixed costs arising from the arable production may in theory fall due to the reduced hectarage this may not be a realistic assumption unless need is reduced by a whole unit, (i.e a whole tractor or a whole man). Extra costs may be incurred at pruning and felling. The scale of these costs will be dependant on the farmer having existing equipment and regular labour on farm to undertake these operations.

*Other variables:* The cashflows are discounted into the future using a value based on the current bank-rate. Although investment in forestry usually commands a low discount rate, (3-5%), this is unrealistic for the farmer considering relatively short-term projects. The model can investigate the effects of changes in costs and prices of both the agricultural and the poplar products.

*Output from the model:* The final output from the model is a comparison of the discounted cashflow for agroforestry and the conventional arable crop rotation undertaken on the farm. This is represented as a single figure, (i.e net benefit in term of NPV from adopting agroforestry). Additionally graphs are generated which demonstrate cashflow over the 15 years represented by the model.

### 8.9.2 Application of the model,

The example of Hall Farm, (fictional), is used to represent an average arable unit situated in Mid/ Eastern England. The farm size is 250 ha and the farmer is assumed to be prepared to commit 5% of his land area to this form of agroforestry, (i.e. 12.5ha). Details of the rotation, gross margins, and other assumptions are given in Table 8.9. Figures for gross margins and fixed costs are taken from Nix (1993),

Table 8.9 Details of the rotation at Hall farm,

| | Crop | Gross Margin £/ha/yr |
|---|---|---|
| Year 1 | Winter wheat | 545 |
| Year 2 | Winter wheat | 545 |
| Year 3 | Winter beans | 495 |
| Year 4 | Winter barley | 425 |
| Year 5 | OSR | 530 |

| | |
|---|---|
| Area planted to agroforestry | 12.5 ha |
| Fixed costs per hectare/year | £345 |
| Tree row width | 14M |
| Change in prices/year | 0 |
| Growth conditions for poplar | Medium, (0.8) |
| Poplar price | £11/$M^3$ |
| Assumed grant | £681/ha |
| (This two thirds of the full proportional grant), | |
| No market opportunity | |
| Extra costs | £200/ha each tree harvest, £50/ha pruning in year 3, |
| Interest rate | 7% |

Results from the run are presented in Table 8.10, and show that under the conditions stipulated there is no financial benefit, as measured in Net Present Value, of undertaking agroforestry, (Difference in NPV between conventional as opposed to agroforestry is -51). Figure 8.3 illustrates the undiscounted cashflow difference between agroforestry and conventional cropping. This shows a disparity in the 4 years following planting, until the first harvest, where the timber harvest provides a boost in income, supplemented by the second instalment of the WGS. Re-planting costs are not incurred in the following rotations, although there is a small disbenefit to agroforestry in the following years leading to the second wood harvest.

### 8.9.3 Sensitivity analysis,

The analysis concentrates on the variables whose exact value is hard to establish or those which are likely to change in future years.

Table 8.10 : Fictional model run illustrating that agroforestry systems can be shown produce similar discounted cahflows as more conventional systems.

| yr | crop | farm area agfor ha | growth conds. 1=high, .8=med .6=low | farm crop gm's | % cha. ag prix | farm size | labour fuel repairs total | agfor row width | % cha. pop. price | price poplar £/M3 | market oppor 1 , 1.5 | extra fixed costs | Int.. rate | FC or MAFF supp total 681 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | WW | 13 | 0.8 | 545 | 0 | 250 | 86250 | 14 | 0 | 11 | 1 | 0 | 7 | 476.7 |
| 2 | WW | 13 | 0.8 | 545 | 0 | 250 | 86250 | 14 | 0 | 11 | 1 | 0 | 7 | 0 |
| 3 | WBE | 13 | 0.8 | 495 | 0 | 250 | 86250 | 14 | 0 | 11 | 1 | 50 | 7 | 0 |
| 4 | WBA | 13 | 0.8 | 425 | 0 | 250 | 86250 | 14 | 0 | 11 | 1 | 0 | 7 | 0 |
| 5 | OSR | 13 | 0.8 | 530 | 0 | 250 | 86250 | 14 | 0 | 11 | 1 | 200 | 7 | 136.2 |
| 6 | WW | 13 | 0.8 | 545 | 0 | 250 | 86250 | 14 | 0 | 11 | 1 | 0 | 7 | 0 |
| 7 | WW | 13 | 0.8 | 545 | 0 | 250 | 86250 | 14 | 0 | 11 | 1 | 0 | 7 | 0 |
| 8 | WBE | 13 | 0.8 | 495 | 0 | 250 | 86250 | 14 | 0 | 11 | 1 | 50 | 7 | 0 |
| 9 | WBA | 13 | 0.8 | 425 | 0 | 250 | 86250 | 14 | 0 | 11 | 1 | 0 | 7 | 0 |
| 10 | OSR | 13 | 0.8 | 530 | 0 | 250 | 86250 | 14 | 0 | 11 | 1 | 200 | 7 | 68.1 |
| 11 | WW | 13 | 0.8 | 545 | 0 | 250 | 86250 | 14 | 0 | 11 | 1 | 0 | 7 | 0 |
| 12 | WW | 13 | 0.8 | 545 | 0 | 250 | 86250 | 14 | 0 | 11 | 1 | 0 | 7 | 0 |
| 13 | WBE | 13 | 0.8 | 495 | 0 | 250 | 86250 | 14 | 0 | 11 | 1 | 50 | 7 | 0 |
| 14 | WBA | 13 | 0.8 | 425 | 0 | 250 | 86250 | 14 | 0 | 11 | 1 | 0 | 7 | 0 |
| 15 | OSR | 13 | 0.8 | 530 | 0 | 250 | 86250 | 14 | 0 | 11 | 1 | 200 | 7 | 0 |

| | |
|---|---|
| COST OF ESTABLISHMENT/HA | 500 |
| ASSUMED GRANT PER HECTARE | 681 |
| NPV OF AGROFORESTRY | 1405.5262 |
| NPV OF CONVENTIONAL CROPPING | 1456.4125 |
| BENEFIT OF AGROFORESTRY | -50.8863 |

Figures presented in Table 8.9 are used for the base run of the model and the results are discussed and presented graphically below. *(ACFB in the graphs stands for agroforestry cashflow benefit).*

*Growth conditions for poplar:* The growth conditions for poplar have a significant effect on the NPV. Poor growth conditions, (low pH, poorly drained exposed sites), compare unfavourably with better sites such as those at Wolverton. Under the latter conditions agroforestry compares well with conventional cropping, (see Figure 8.4)

*Change in agricultural prices:* There has been speculation about a 20% drop in cereal prices following the recent CAP reforms. However, the 1992 harvest saw wheat prices in particular increasing sharply due to a poor harvest and a devalued pound. The model suggests that if prices do fall by 20% then agroforestry is likely to become favourable even under average conditions. However, if prices remain stable or even continue their upward movement then this form of agroforestry is likely to become less favoured, (see Figure 8.5).

*Annual percentage change in poplar price:* Demand for good quality poplar is outstripping supply at present which suggests that at least for large timber the price is likely to rise. This will not necessarily be reflected in the price attained for smaller timber. However, if recent incentives to encourage energy forestry are successful, the promise of a regular market may stimulate a gradual increase in price. The analysis investigates a maximum of a 3% increase or decrease in price per annum over a 15 year run. An annual rise in price of just over 2% would put agroforestry at breakeven point over the 15 years, ( see Figure 8.6).

*Change in assumed base poplar price:* The model uses a base of £11/$M^3$ for cut wood in the farmyard, based on its approximate value as an energy product. Nix (1993) gives a value for first thinnings wood of £3-£12/$M^3$ for a size <0.13 $M^3$/tree. This suggests that if no energy market is available the profitability of short rotation agroforestry will be further diminished. However, it would only take an increase of £2/$M^3$ to make the base run comparable with a conventional arable rotation, ( see Figure 8.7).

*Market opportunity*: The model can investigate the exploitation of premium markets allowing upto 50% on top of the base price. For instance, use in market gardens or for fencing stakes may attract a premium. A premium of slightly less than 20% for the poplar gives a breakeven with the conventional rotation. The results of allowing a market premium are similar for increasing the base poplar price, (see Figure 8.7).

*Extra cost:* This is the hardest variable to estimate on a general basis. Normally trees being grown on short rotation would not be pruned. However, the need for access of machinery between the rows of trees means that pruning is an advantage. This was carried out in year three on the Wolverton plots. Due to the ease of access it is estimated that two men could prune a hectare in a day at a cost of £100. However, some of this labour is time saved in not having to

Figure 8.4: Effect of poplar growth conditions on NPV,

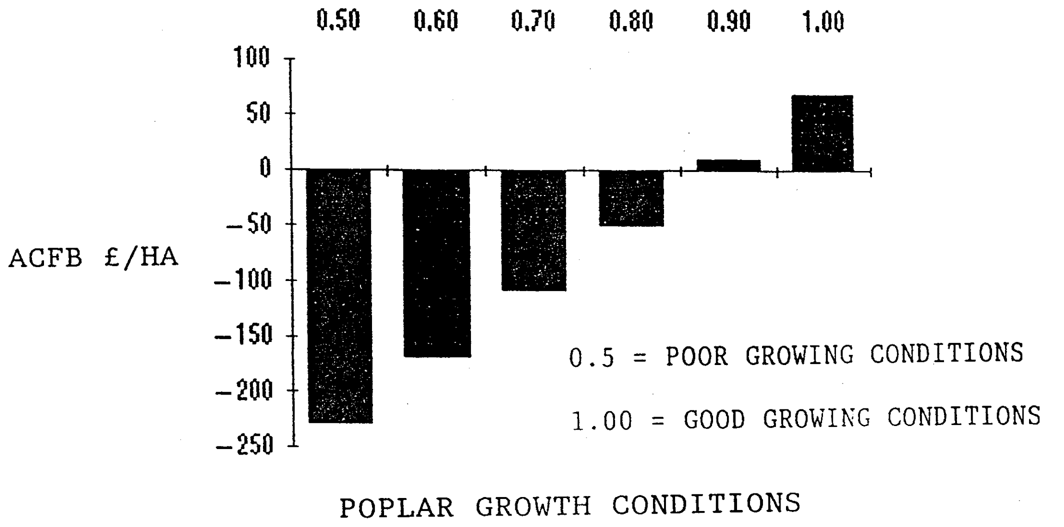



Figure 8.5: Effect of % change in agricultural prices on NPV

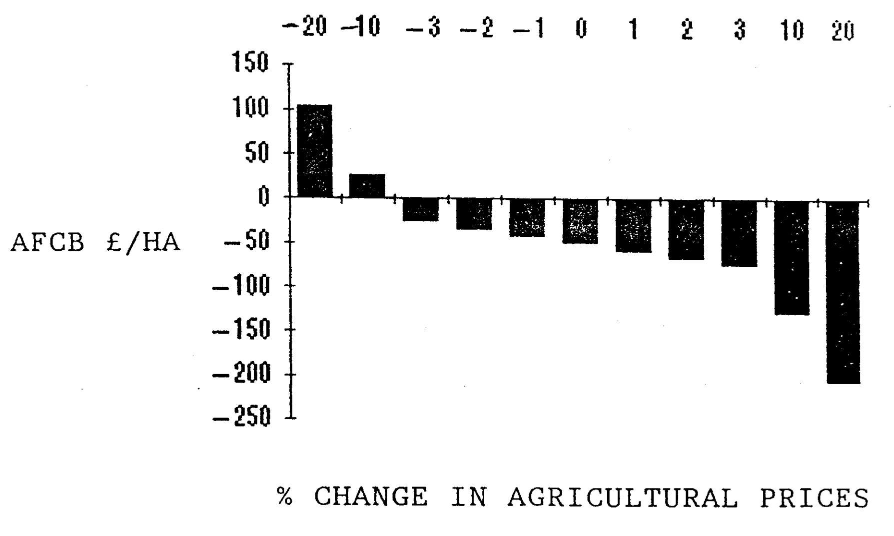


Figure 8.6: The effect of changes in poplar price on NPV,

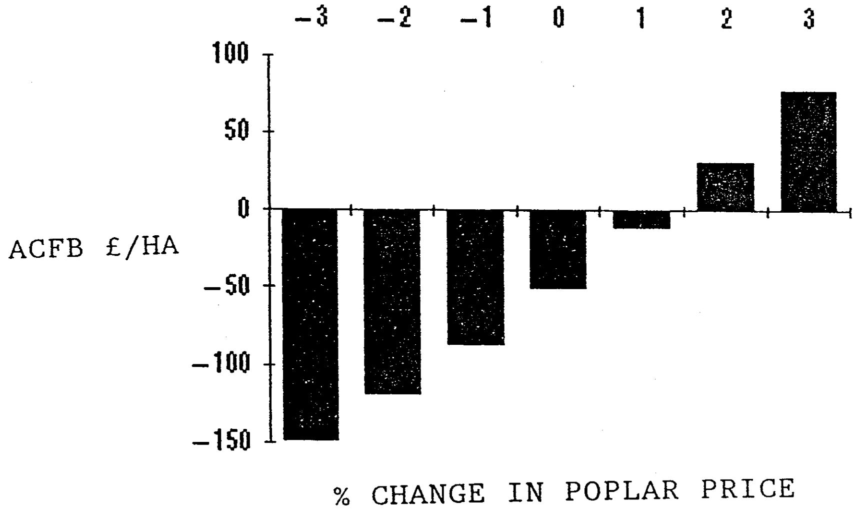
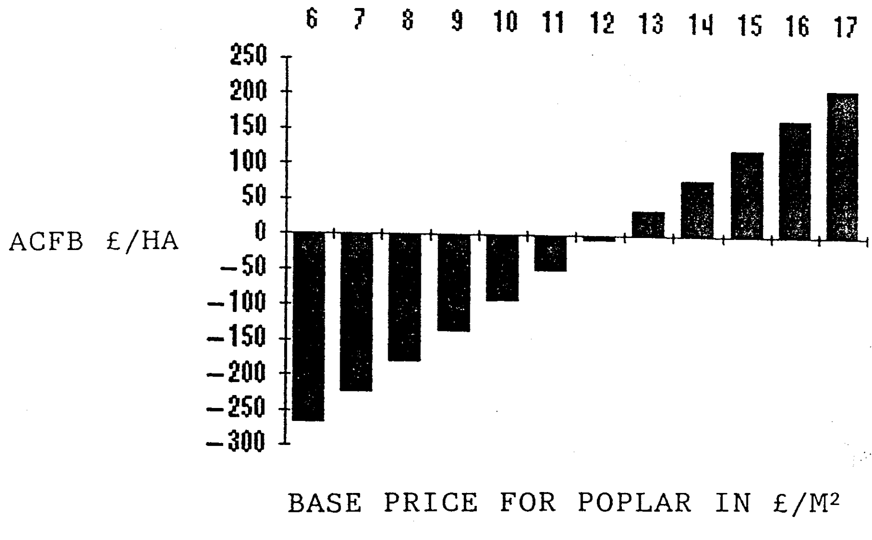



Figure 8.7: Effect of changes in the base price of poplar on NPV,



cultivate the 1.5M strip that would normally be part of the arable rotation. Thus the base run assumes only £50 extra costs in the third year. Similarly, it is extremely difficult to estimate harvesting costs every five years. A value of £200/ha has been allowed for this, although it will depend on the experience of the on farm labour, the time available, and the availability of appropriate machinery. However this is an important variable in the calculation of the financial viability of agroforestry. Figure 8.8 illustrates the sensitivity of NPV to changes in extra fixed costs.

*Discount rate:* Application of discount rates between 2 and 13% had little effect on the difference between the NPV's of agroforestry compared to conventional cropping. Traditional forestry investment has always suffered because of long payback periods, usually adopting low discount rates of between 1 and 5%. The model suggests that discount rates used in this type of agroforestry have little bearing on the amount of difference between the discounted cashflows of it or a conventional rotation. This is because even within the agroforestry option the majority of the income is still derived from the arable crops and the trees are harvested regularly ensuring a reasonable discounted income.

*Establishment grant:* The amount of support available, either from MAFF or the Forestry Authority has a large impact on the discounted cashflow from agroforestry. The exact level of grant that this form of agroforestry attracts appears to depend on individual woodland officers. The base run errs on the safe side allowing two thirds of the full proportional grant. However, if the full proportional grant of £1022/ha can be claimed the agroforestry option appears increasingly favourable. The possibility of obtaining set-aside payments on the wooded strips would enhance the profitability of agroforestry still further. This may be a possibility following the introduction of non-rotational set-aside after the 1993 harvest.

*Change in fixed costs:* The agricultural industry as a whole is at present facing a price squeeze, resulting in a push to reduce fixed costs. As fixed costs fall the agroforestry option becomes less favourable suggesting that current policy on the majority of farms is actually making the take up of agroforestry less financially viable, (see Figure 8.9).

*Change in the yield of arable crop due to the presence of trees:* The model base run assumes that in years 3,4 and 5 of the tree rotation the yield of the arable crop is reduced by 20, 24,and 27% respectively due to the shading effects of the trees. This will obviously vary considerably from farm to farm dependant upon a host of variables. The results of increasing or decreasing the percentage effect the trees have on the arable crop is shown in Figure 8.10.

## 8.10 EXPLORING THE FINANCIAL VIABILITY OF SILVOARABLE SYSTEMS,

It would be impossible to explore all configurations of variables within the model. This section utilizes the information from the

Figure 8.8: The effects of changes in extra fixed costs on NPV,

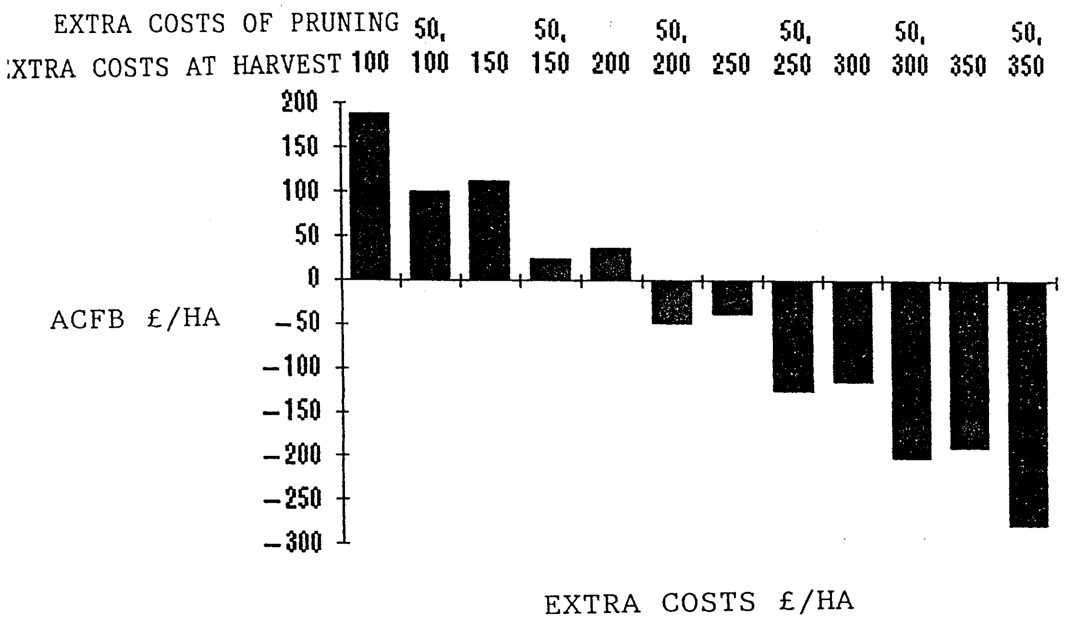



Figure 8.9: The effects of changing the farms fixed costs on the NPV.

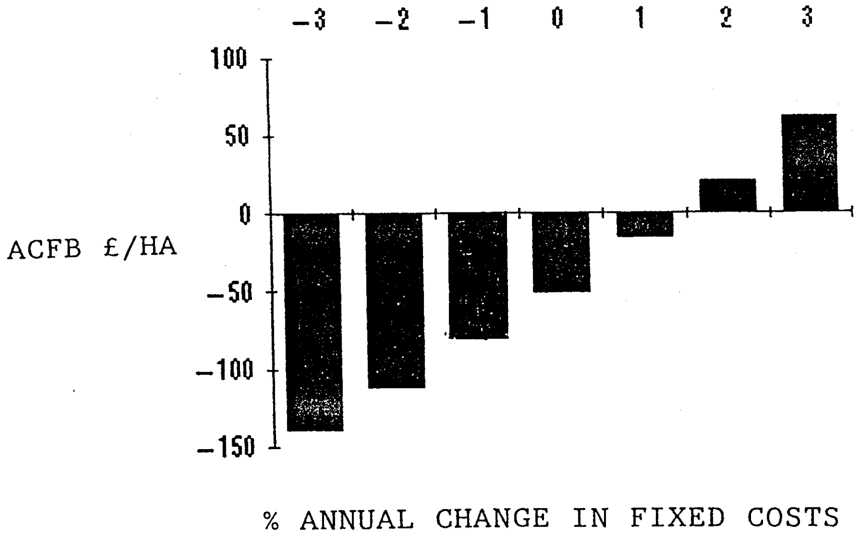
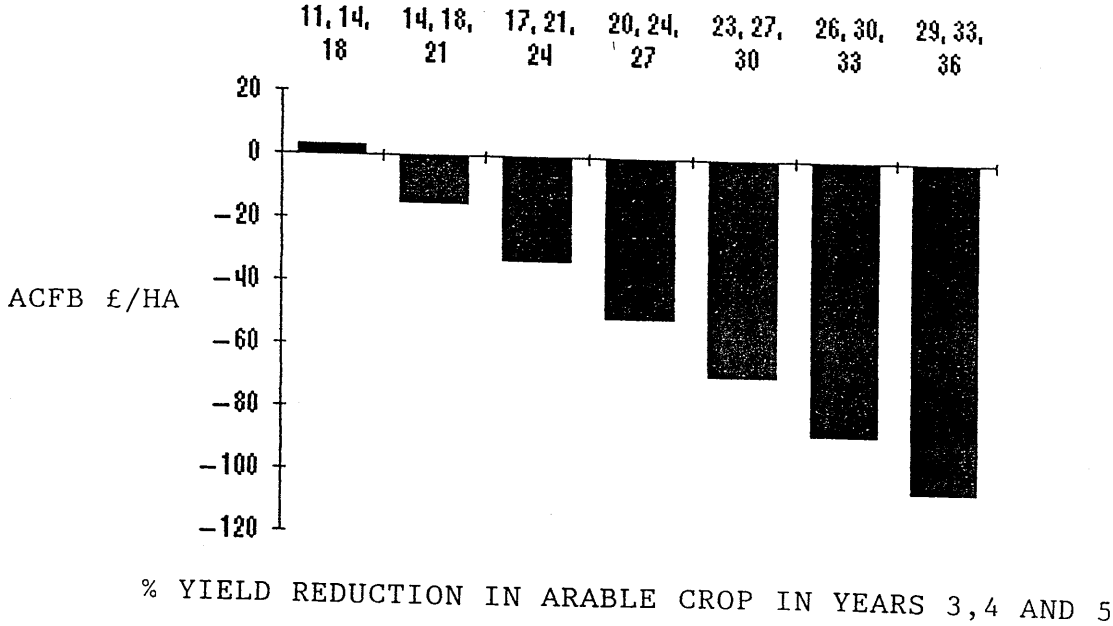


Figure 8.10: The effect of the tree/crop interaction on NPV.



sensitivity analysis to consider financial aspects of silvoarable systems under very favourable conditions and unfavourable conditions.

### 8.10.1 Financial viability under favourable conditions,

The parameters in Table 8.11 are used to explore the agroforestry option under favourable conditions,

Table 8.11 Conditions favourable to agroforestry,

| | Crop | Gross Margin £/ha |
|---|---|---|
| Year 1 | Winter wheat | 545 |
| Year 2 | Winter wheat | 545 |
| Year 3 | Winter beans | 495 |
| Year 4 | Winter barley | 425 |
| Year 5 | OSR | 530 |

| | |
|---|---|
| Area planted to agroforestry | 8 ha |
| Fixed costs per hectare | £345 |
| Tree row width | 14M |
| Change in fixed costs | +1%/yr |
| Change in poplar price | +2%/yr |
| Change in agricultural prices | -10% |
| Growth conditions for poplar | High (1) |
| Poplar price | £11/$M^3$ |
| Assumed grant | £1151/ha |
| Market opportunity | 1.25 |
| Extra costs | £150/ha each tree harvest, |
| Interest rate | 7% |

Gross margins for the arable crops and farm fixed costs are the same as in the base run, although the latter are rising at 1% per year. The area planted to agroforestry has been reduced to attract a larger grant, and the full proportional grant has been allowed, (£1151/ha). Agricultural prices are reduced by 10%, although the price of poplar is slowly rising at 2% /year. The farm is assumed to have ideal poplar growth conditions and is in a situation where a 25% premium can be obtained for the five year old timber. Extra costs are reduced to a minimum because the growing of trees fits in well with existing farm enterprises, machinery and labour schedules. The results of the model run are given in Table 8.12.

This model run demonstrates the circumstances in which silvoarable systems are most favoured. Whereas some of the assumptions made in this model run are realistic, i.e fall in agricultural prices, good growth conditions on certain farms, others such as full proportional grant, exploitation of premium market and rising fixed costs per hectare are optimistic.

Table 8.12 : Results of a favourable model run

| crop | farm area agfor ha | growth conds. 1=high, .8=med .6=low | farm crop gm's | % cha. ag prix | farm size | labour fuel repairs total | agfor row width | % cha. pop. price | price poplar £/M3 | market oppor 1 , 1.5 | extra fixed costs | Int.. rate | FC or MAFF supp total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | 1151.00 |
| WW | 8.00 | 1.00 | 545.00 | -10.00 | 250.00 | 86250.00 | 14.00 | 2.00 | 11.00 | 1.25 | 0.00 | 7.00 | 805.70 |
| WW | 8.00 | 1.00 | 545.00 | -10.00 | 250.00 | 87112.50 | 14.00 | 2.00 | 11.22 | 1.25 | 0.00 | 7.00 | 0.00 |
| WBE | 8.00 | 1.00 | 495.00 | -10.00 | 250.00 | 87983.63 | 14.00 | 2.00 | 11.44 | 1.25 | 0.00 | 7.00 | 0.00 |
| WBA | 8.00 | 1.00 | 425.00 | -10.00 | 250.00 | 88863.46 | 14.00 | 2.00 | 11.67 | 1.25 | 0.00 | 7.00 | 0.00 |
| OSR | 8.00 | 1.00 | 530.00 | -10.00 | 250.00 | 89752.10 | 14.00 | 2.00 | 11.91 | 1.25 | 150.00 | 7.00 | 230.20 |
| WW | 8.00 | 1.00 | 545.00 | -10.00 | 250.00 | 90649.62 | 14.00 | 2.00 | 12.14 | 1.25 | 0.00 | 7.00 | 0.00 |
| WW | 8.00 | 1.00 | 545.00 | -10.00 | 250.00 | 91556.11 | 14.00 | 2.00 | 12.39 | 1.25 | 0.00 | 7.00 | 0.00 |
| WBE | 8.00 | 1.00 | 495.00 | -10.00 | 250.00 | 92471.67 | 14.00 | 2.00 | 12.64 | 1.25 | 0.00 | 7.00 | 0.00 |
| WBA | 8.00 | 1.00 | 425.00 | -10.00 | 250.00 | 93396.39 | 14.00 | 2.00 | 12.89 | 1.25 | 0.00 | 7.00 | 0.00 |
| OSR | 8.00 | 1.00 | 530.00 | -10.00 | 250.00 | 94330.35 | 14.00 | 2.00 | 13.15 | 1.25 | 150.00 | 7.00 | 115.10 |
| WW | 8.00 | 1.00 | 545.00 | -10.00 | 250.00 | 95273.66 | 14.00 | 2.00 | 13.41 | 1.25 | 0.00 | 7.00 | 0.00 |
| WW | 8.00 | 1.00 | 545.00 | -10.00 | 250.00 | 96226.39 | 14.00 | 2.00 | 13.68 | 1.25 | 0.00 | 7.00 | 0.00 |
| WBE | 8.00 | 1.00 | 495.00 | -10.00 | 250.00 | 97188.66 | 14.00 | 2.00 | 13.95 | 1.25 | 0.00 | 7.00 | 0.00 |
| WBA | 8.00 | 1.00 | 425.00 | -10.00 | 250.00 | 98160.55 | 14.00 | 2.00 | 14.23 | 1.25 | 0.00 | 7.00 | 0.00 |
| OSR | 8.00 | 1.00 | 530.00 | -10.00 | 250.00 | 99142.15 | 14.00 | 2.00 | 14.51 | 1.25 | 150.00 | 7.00 | 0.00 |

| | |
|---|---|
| COST OF ESTABLISHMENT/HA | 571.43 |
| ASSUMED GRANT PER HECTARE | 1151.00 |
| NPV OF AGROFORESTRY | 1775.87 |
| NPV OF CONVENTIONAL CROPPING | 827.42 |
| BENEFIT OF AGROFORESTRY | 948.46 |

### 8.10.2. Financial viability under unfavourable conditions,

The parameters in Table 8.13 were used to explore the agroforestry option under unfavourable conditions,

Table 8.13 Conditions unfavourable to agroforestry,

| | Crop | Gross Margin £/ha |
|---|---|---|
| Year 1 | Winter wheat | 660 |
| Year 2 | Winter wheat | 660 |
| Year 3 | Winter beans | 550 |
| Year 4 | Winter barley | 530 |
| Year 5 | OSR | 615 |

| | |
|---|---|
| Area planted to agroforestry | 12.5 ha |
| Fixed costs per hectare | £300 |
| Tree row width | 14M |
| Change in fixed costs | -1%/yr |
| Change in poplar price | 0 |
| Change in agricultural prices | +10% |
| Growth conditions for poplar | Medium (0.8) |
| Poplar price | £7/$M^3$ |
| Assumed grant | £681/ha |
| Market opportunity | 1 |
| Extra costs | £250/ha each tree harvest, £50/ha pruning in year 3 |
| Interest rate | 7% |

Figures for gross margins are taken from premium farms in Nix (1993). Fixed costs have been reduced to £300 per hectare and are further reduced at 1% per annum to reflect a downward trend. Agricultural prices are assumed to rise by 10% whilst a lower base price for poplar is assumed. There is no premium market that can be exploited and poplar price remains stable. The results of the model run are presented in Table 8.14. The higher gross margins of the arable crops results in a higher NPV for both the conventional arable cropping and the agroforestry regime. However, it means that the opportunity cost of taking land out of arable production is high, making the silvoarable option less attractive.

## 8.11 DISCUSSION ON FINANCIAL AND ECONOMIC VIABILITY,

The two examples in the section above illustrate the wide range of financial possibilities and outcomes following the adoption of a short rotation silvoarable system on farmland. The "favourable" model run supports the findings of other economic modelling of poplar based agroforestry systems, particularly that undertaken at Bangor, (Thomas 1991). This has demonstrated that careful management of the trees in association with arable and grassland cropping can result in agroforestry systems which are economically viable over a time period

Table 8.14 : Results of an unfavourable model run

| crop | farm area agfor ha | growth conds. 1=high, .8=med .6=low | farm crop gm's | % cha. ag prix | farm size | labour fuel repairs total | agfor row width | % cha. pop. price | price poplar £/M3 | market oppor 1 , 1.5 | extra fixed costs | Int.. rate | FC or MAFF supp total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | 681.00 |
| WW | 13.00 | 0.80 | 660.00 | 10.00 | 250.00 | 75000.00 | 14.00 | 0.00 | 7.00 | 1.00 | 0.00 | 7.00 | 476.70 |
| WW | 13.00 | 0.80 | 660.00 | 10.00 | 250.00 | 74250.00 | 14.00 | 0.00 | 7.00 | 1.00 | 0.00 | 7.00 | 0.00 |
| WBE | 13.00 | 0.80 | 550.00 | 10.00 | 250.00 | 73507.50 | 14.00 | 0.00 | 7.00 | 1.00 | 50.00 | 7.00 | 0.00 |
| WBA | 13.00 | 0.80 | 530.00 | 10.00 | 250.00 | 72772.43 | 14.00 | 0.00 | 7.00 | 1.00 | 0.00 | 7.00 | 0.00 |
| OSR | 13.00 | 0.80 | 615.00 | 10.00 | 250.00 | 72044.70 | 14.00 | 0.00 | 7.00 | 1.00 | 250.00 | 7.00 | 136.20 |
| WW | 13.00 | 0.80 | 660.00 | 10.00 | 250.00 | 71324.25 | 14.00 | 0.00 | 7.00 | 1.00 | 0.00 | 7.00 | 0.00 |
| WW | 13.00 | 0.80 | 660.00 | 10.00 | 250.00 | 70611.01 | 14.00 | 0.00 | 7.00 | 1.00 | 0.00 | 7.00 | 0.00 |
| WBE | 13.00 | 0.80 | 550.00 | 10.00 | 250.00 | 69904.90 | 14.00 | 0.00 | 7.00 | 1.00 | 50.00 | 7.00 | 0.00 |
| WBA | 13.00 | 0.80 | 530.00 | 10.00 | 250.00 | 69205.85 | 14.00 | 0.00 | 7.00 | 1.00 | 0.00 | 7.00 | 0.00 |
| OSR | 13.00 | 0.80 | 615.00 | 10.00 | 250.00 | 68513.79 | 14.00 | 0.00 | 7.00 | 1.00 | 250.00 | 7.00 | 68.10 |
| WW | 13.00 | 0.80 | 660.00 | 10.00 | 250.00 | 67828.66 | 14.00 | 0.00 | 7.00 | 1.00 | 0.00 | 7.00 | 0.00 |
| WW | 13.00 | 0.80 | 660.00 | 10.00 | 250.00 | 67150.37 | 14.00 | 0.00 | 7.00 | 1.00 | 0.00 | 7.00 | 0.00 |
| WBE | 13.00 | 0.80 | 550.00 | 10.00 | 250.00 | 66478.87 | 14.00 | 0.00 | 7.00 | 1.00 | 50.00 | 7.00 | 0.00 |
| WBA | 13.00 | 0.80 | 530.00 | 10.00 | 250.00 | 65814.08 | 14.00 | 0.00 | 7.00 | 1.00 | 0.00 | 7.00 | 0.00 |
| OSR | 13.00 | 0.80 | 615.00 | 10.00 | 250.00 | 65155.94 | 14.00 | 0.00 | 7.00 | 1.00 | 250.00 | 7.00 | 0.00 |

| | |
|---|---|
| COST OF ESTABLISHMENT/HA | 500.00 |
| ASSUMED GRANT PER HECTARE | 681.00 |
| NPV OF AGROFORESTRY | 2745.26 |
| NPV OF CONVENTIONAL CROPPING | 3377.99 |
| BENEFIT OF AGROFORESTRY | -632.73 |

of 17 to 25 years. These systems could provide a useful method of timber growing for those farmers who are dedicated to growing mature trees, and who are willing and able to commit land and capital to longer rotations.

A possible alternative for those who require shorter rotations, and faster payback, is to grow poplar for cutting every five years, aiming for a general purpose product, which can be used for burning, building or possibly pulping. The interviews described in Chapter 7 suggested that farmers in general were not keen to commit themselves to longer-term projects because of the uncertainty surrounding current policy. ROWMOD illustrates that under certain conditions these short rotations can compete favourably with a conventional arable cropping system. Sensitivity analysis suggests the viability of such systems is governed particularly by the grants available, the final price realized for the wood product, the on farm growth conditions for poplar and the values that are assumed for extra farm costs associated with the systems. This emphasises that financial assessment needs to be carried out at the farm level, as the profitability of these systems varies considerably from farm to farm.

One of the problems of cutting at an early age is the identification of a suitable market, and the placing of a realistic monetary value on the end product. Values assumed in ROWMOD are somewhat speculative. However, considerable interest is developing in poplar coppice and a market for young timber for energy production is likely to be established in the near future.

Whether or not silvoarable systems attract financial support at a national level is dependant on convincing decision makers that it is worth encouraging. In the present highly interventionist agricultural markets silvoarable systems seem unlikely to receive any attention from farmers without such support. The problems associated with carrying out a realistic economic analysis of agroforestry in the UK were discussed at the start of the chapter. Agroforestry systems are attributed with a wide range of benefits many of which are difficult to quantify realistically in monetary terms. For instance, in Chapter 6 the effects of a silvoarable system on the soil were investigated, and this revealed changes in soil organic status and soil invertebrate populations attributable to the presence of trees on arable land. These changes, suggesting that the uptake of silvoarable systems could benefit the soil in some circumstances, would be difficult to represent in terms of national benefit, and almost impossible to value economically.

The use of land for the growing of trees is gaining support due to a national deficit in timber, a low level of afforestation and from a environmental viewpoint. This has lead to increased interest in the growing of trees on surplus farmland, presently redundant under set-aside schemes. However, the returns to the farmer for planting trees for commercial purposes are generally low and this continues to provide a stumbling block for such schemes. The recently introduced Belgian poplar clones have reduced the rotation to about 20 years on good growing land and this increases the favourability of tree growing on farmland. Nevertheless, returns from growing pure stands of poplar for timber are still unfavourable financially compared with normal arable cropping, (Beaton 1993).

The growing of trees on farmland is often viewed as incidental or ancillary to main farm activities, (CEED 1986). Agroforestry may provide one mechanism for the farmer to gain knowledge and experience in tree growing without having to commit large tracts of land to woodland. The analysis undertaken in this chapter suggests that on some farms these systems could be financially viable. A final series of interviews discussed in the following chapter completes the link between policy and decision making and what the farmer actually does. The activities undertaken as part of this third interface can be summarized:

1. A series of interviews to ascertain the broader farming agenda and to investigate attitudes of farmers to change in general, (Chapter 7),

2. Financial and economic assessment to study the potential use of poplar silvoarable systems on farms from a commercial viewpoint, (Chapter 8),

3. A second series of interviews to discuss the actual uptake of agroforestry on farms and the mechanisms which may encourage farmers to use these systems.

The information obtained during the first series of interviews suggests that despite the possibility of agroforestry systems being a financially viable proposition on some farms, the process of actually encouraging their uptake is likely to be more complicated.

# CHAPTER 9: SILVOARABLE AGROFORESTRY IN THE UK: A REALISTIC OPTION FOR FARMERS?

*"The walnut delights in a dry sound and rich land;..in cornfields. ...Burgundy abounds with them, where they stand in the middle of goodly wheat lands, at sixty and hundred foot distance; and it is so far from hurting the crop, that they look on them as the great preserver, by keeping the grounds warm, nor do they hinder the plough", (Evelyn 1679).*

## 9.1 INTRODUCTION AND SUMMARY,

The research discussed and undertaken within this chapter provides the final part of the exploration of the third interface within the thesis. Chapter 8 demonstrated that silvoarable agroforestry systems can be a financially viable proposition in some circumstances. In the first phase of interviews financial viability was found to be only one of many issues surrounding the uptake of cropping practices on farms, although the most important. In this chapter the possible adoption of silvoarable agroforestry systems on arable farms is investigated further via a second series of interviews. A number of the farmers interviewed in phase 1 agreed to a second meeting to explore the issues surrounding the growing of trees on arable land. This provided a rich source of information on the general attitude of those interviewed to timber production as well as specific views on the spatial mixing of trees and arable crops in silvoarable systems. Additionally the model, (ROWMOD), described in the previous chapter was used interactively with some of the farmers to give a realistic financial assessment of the likely adoption of agroforestry systems on their farms.

The research in this chapter is undertaken with the recognition that alternative cropping systems will not necessarily be adopted simply because they appear favourable to agroecosystem processes or because they are financially viable. It is suggested that silvoarable systems do not fit well within existing farming ideology in the UK. It is argued that their wide scale adoption would rely on specific support for this type of cropping. Support for tree establishment is likely to encourage the planting of woodland in blocks rather than in these spatially diverse systems. The existing farm infrastructure, high levels of mechanisation and lack of knowledge of intercropping systems all provide a degree of inertia. In the short term, without appropriately directed support this type of agroforestry may be limited to specialist applications, but continued research and development will gradually raise the profile of these types of farming system. The chapter concludes by refocussing on the intellectual thrust of the thesis, i.e. the provision of policy relevant information. It is suggested on the basis of exploration undertaken within this thesis that policy instruments can aid the introduction of agroforestry at three levels. By:

1. increasing awareness,

2. providing support within the existing policy framework,

3. encouraging a gradual change in underlying farming ideology.

## 9.2 FROM RESEARCH TO COMMERCIAL VIABILITY

In previous chapters benefits accruing from agroforestry systems have been discussed. This culminated with an expression of financial viability under some conditions. The series of interviews described in Chapter 7 suggested that although financial aspects of production were extremely important to farmers, their choice of farming system was subject to a range of physical, social and environmental conditions. In the earlier chapters of this thesis it was argued that some form of longer term ecological assessment of cropping innovations was needed in addition to purely economic or financial assessment. This series of interviews highlights a further problem with using financial viability as an indicator of potential uptake of innovative cropping systems, illustrating that financial viability is not a good indicator of potential uptake. This is important because although there is an increasing amount of research interest in agroforestry systems, (see Chapters 6 and 8), very few commercial systems exist in the UK. This second phase of interviews explores the issues surrounding the move from experimental systems to commercial uptake. The interviews had several specific aims:

1. To discuss the issues surrounding the uptake of silvoarable agroforestry on individual farms,

2. To evaluate the range of markets, financial aspects and uses as seen by the farmer,

3. To explore the financial viability of silvoarable agroforestry on individual farms through the use of ROWMOD,

4. To examine the types of policy incentives which could make agroforestry a more attractive alternative to farmers.

An earlier pilot survey, (see Appendix 8), had suggested the term "agroforestry" was not commonly understood by farmers, and it was envisaged that a brief description of the systems would be needed at the start of each interview. The same survey suggested that some farmers may be willing to grow trees as a commercial crop and had given some thought to the on farm production of energy. This pilot provided useful guide-lines in the design of the phase 2 interviews.

## 9.3 DESCRIPTION OF THE PHASE 2 INTERVIEWS,

Although this series of interviews was conducted in similar conditions to those described in Chapter 7, they were more focussed. A review of "interviews as conversations" is provided by Burgess (1984) who comments that,

*"The unstructured interview is rarely conducted in isolation; it is often part of a broader programme of research and draws on the knowledge the researcher has of a social situation."*

Following the successful completion of the interviews described in Chapter 7, this second phase of interviews used a similar technique which encouraged farmers to develop their answers outside a structured format. The farmers interviewed were selected from those visited in Chapter 7. Only arable farmers were approached in this second phase and this resulted in 11 interviews being arranged. It is recognised that this is a small interview sample. However, it has been demonstrated in other studies that expanding the number of respondents above 10 to 12 results in only small increases in the numbers of issues elicited. For instance, Coburn (1991) recognises that with qualitative research the best indication of when one has enough information is the point at which additional information is largely redundant. Figure 9.1 is a graphical illustration of this phenomena derived from this series of interviews. On the horizontal axis the individual respondents are listed in the order in which they were interviewed. The vertical axis corresponds to the number of new issues raised by successive respondents under the general heading *planting and agronomic factors.*

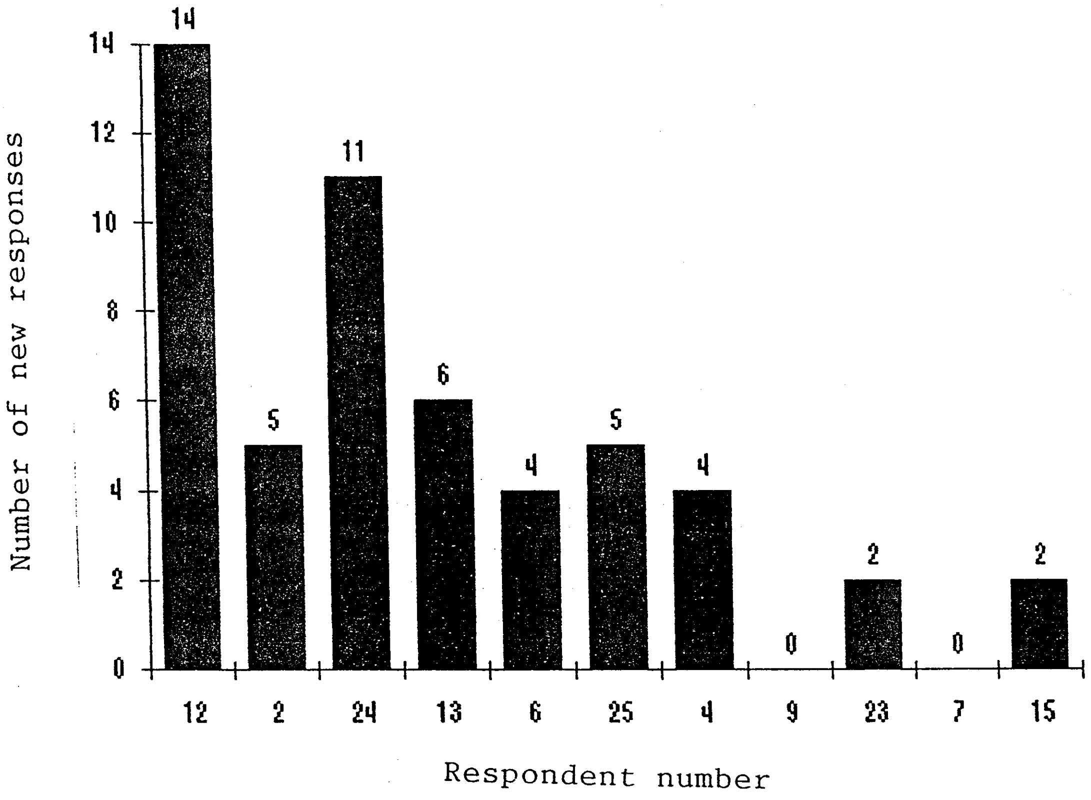
The length of the interviews varied considerably, the shortest being just under an hour, several of the longest lasting for about three hours. The interviews took place over a period of four months during late 1992 and early 1993, this being a generally quiet time for arable farmers. The atmosphere at the majority of the interviews was relaxed, without the need for formal introductions. Interviewing the same respondents for a second time was viewed as a benefit as it allowed cross reference to the responses received during the first series of interviews. Various examples of this cross referencing are provided in the ensuing text.

## 9.4 THE USE OF ROWMOD AS AN INTERACTIVE TOOL,

The financial model described in the previous chapter was used in conjunction with a lap top computer in some interviews as an interactive tool for demonstrating financial viability of the short rotation agroforestry systems on individual farms. It also acted as a useful tool purely as a means of focusing discussion. Attributes of individual farms were used in the model, and the farmers were required to select values for various parameters. Output was displayed graphically and figures calculated for the NPV of conventional cropping and agroforestry for the "present situation", (see Chapter 8). Following this initial run it was envisaged that the model could be used to explore various policy incentives, by using various instruments such as guarantied prices, annual MAFF support etc. However, there were several issues and problems associated with the use of the model;

1. Whereas farmers were willing to discuss issues surrounding agroforestry, several did not want to examine the financial aspects in detail, possibly because they did not want to expose present margins etc.

Figure 9.1: Additional issues elicited with increasing number of respondents



2. Not all farmers had financial details of gross margins and average fixed costs to hand. This problem was envisaged before the interviews and the possibility of asking farmers to prepare certain financial figures was considered. However, this was dismissed as a further infringement on those who had been already been good enough to agree to be interviewed twice.

3. Those farmers who showed greatest interest in the output of the model were also concerned about the calculating process, and the validity of the output from the model. Although key variables in the model were discussed, a full explanation of the structure of the model would have been extremely time consuming.

The data resulting from the use of the model is presented in greater detail in Section 9.8. Additional information and statements gathered as a result of model use appears as comments in the ensuing text.

**9.5 DETAILS OF THE INTERVIEWS,**

Interviews were initiated with general discussion concerning either the farmers work or the progression of this research project. The autumn of 1992 had been an extremely wet period, creating difficult conditions for those farming on heavy Bedfordshire soils. In many cases this topic provided a focus of initial conversation. Some of the farmers interviewed had managed to plant very little in the autumn and were either going to or had started spring drilling for the first time in many years.

Discussions were focused on silvoarable agroforestry using a series of photographs of the arable-poplar system at Wolverton, (see examples of photographs in Appendix 4). These gave an impression of the growing of widely spaced trees on arable land, and indicated the rate of growth that can be expected from the Belgian poplar clones in good conditions. A brief overview of the theory behind the systems was provided, concentrating particularly on nutrient cycling, light utilization and the diversification of production. Following this introduction the discussions were centred on several themes designed to provide information concerning the stated aims:

*General issues and first impressions,*
*Planting and agronomic factors,*
*Harvesting of the trees,*
*Markets, uses and financial aspects,*
*Policy incentives,*
*Public image and the environment*

The discussions were recorded by hand and statements transferred onto computer directly after each interview. The attributes associated with the farmers interviewed can be identified in Table 7.1 by the numbers *2, 4, 6, 7, 9, 12, 13,15, 23, 24, and 25.* Respondents were given the same identification number as those used in Chapter 7. Results are discussed using quotes where appropriate and the development of lines of discussion using respondent number as identification for cross reference. The interviews are used to develop themes and not to predict behaviour. They aim to demonstrate the extent to which this type of interviewing can provide insights for those researchers seeking to link theoretical and experimental information with commercial viability. A full list of the statements from all of the interviews is provided in Appendix 9.

## 9.6 THE ISSUES SURROUNDING THE UPTAKE OF AGROFORESTRY ON INDIVIDUAL FARMS, (AIM 1)

Of overriding importance, and often the first questions asked about the systems was whether they were economic. There was a general feeling that *"trees have no place as a short-term revenue crop on the farm"(23)*. Although trees had been planted regularly on all but a few farms this was usually undertaken for non-commercial reasons, i.e for game cover, windbreaks, to replace dead Elm or for aesthetic purposes within the countryside, *(4,6,7,12,15,23,24,25)*. Some farmers had planted and made a limited amount of money from Christmas trees, *(23,24,25)*. Several of the farmers were in the process of planting, or applying for grants to plant small blocks of trees, *(2,6,24)*, whereas others had established plantations which were now ready for thinning, *(4,25)*. Despite an initial rejection of the growing of trees as a commercial crop all of the farmers were interested enough to study the photographs of the silvoarable trial and to give the suggested systems further thought. Table 9.1 gives an indication of the number of statements recorded and the category into which they fell.

Table 9.1 Number and categorisation of the comments received from all 11 interviews.

| | |
|---|---|
| General comments | 27 |
| First impressions | 78 |
| Planting and agronomic | 136 |
| Harvesting | 52 |
| Markets | 89 |
| Public and environment | 26 |
| Policy | 48 |
| Total | 456 |

Both long and short rotations were discussed, i.e the longer rotations suggested by Thomas et al (1992) and the shorter rotations investigated in ROWMOD. Several farmers were very interested in the logistics of the longer-term systems, *(2,12,13,)* although there were concerns, *i.e. committing oneself to long-term systems is not a good idea in todays economic climate,"(12) and "maintaining the flexibility of systems is very important," (2,23)*. Both of these principles were discussed during phase 1 of the interviews and it is interesting to note that the policy environment that stops farmers committing themselves to long-term systems may also be reducing the amount of flexibility in farming systems by committing farmers to bigger, more specialized farms. Planting trees on arable land could thus be interpreted as committing farmers to already inflexible systems.

One farmer suggested these longer rotations could be used to aid the establishment of community forests, *(25)*. The concept of the longer rotation systems which relied on grazing by stock did not fit well within present all arable systems, *(2,7,12,15,25)*, and there was concern about stock damaging the growing trees, *(23,25)*. The planting of trees in these longer rotation systems were *"a useful generational/ inheritance option"*, *(13)*, although there were, *"nagging doubts about the growing of trees on land which is suitable for food production"*, *(12)*. Similar doubts were raised in Chapter 7 about global food shortages, i.e *"There is a mis match somewhere, British farmers have the ability to produce the food, yet people are starving"*, *(21)*

From a financial perspective the short rotation systems appeared to be a favourable option, provided uses and markets for the smaller timber could be found, *(24)*. However, there were concerns about lack of experience of managing these systems, *(9,12,13,23)*, *"I am an arable manager and sceptical about diversifying to far from this base"*, *(12)*. This exemplifies the thinking of many that the arable and wooded areas should be kept separate, with the trees preferably grown in blocks, *(4,6,15,23,25)*. This would arguably allow easier management, but also ensure that any problems or mistakes associated with the trees, would not effect the smooth running of the relatively profitable arable operations.

### 9.6.1 Planting and agronomic factors

The farmers were concerned about the impact of the trees on their ability to grow and farm the regular arable crop. Whereas some of the comments concerning planting and agronomic factors were predictable, the variety of responses demonstrated specific farms would be more suited to agroforestry than others. Shading by the trees was seen as a major problem *(4,6,7,9,12,13,23,24,25)*. However, the effects of this was not necessarily interpreted as a loss of yield of the arable crop but a reduction in the ability of the soil to dry out following wet weather *(4,6,9,12,24,25)*. Wet fields were probably at the fore of farmers memories following the extremely wet autumn in 1992, (One farmer commented that he only had time to be sat talking because he was waiting for his fields to dry out!). The generally heavy clay soils of Bedfordshire will not travel when wet, and the farmers rely on good drying conditions to ensure a maximum cultivation window. This was evident in the first phase of interviews, where timeliness of operations was a major theme associated with good farm practice.

Shading by the trees would effect both yield and quality of arable crops, *(7,9)*. One farmer commented that he thought the 5 year old trees in the photographs would reduce yields by 50%, *(25)*. Another was particularly concerned about the quality of Brussel Sprouts and Strawberries which he knew from experience did not reach marketable size if shaded, *(23)*. The same farmer in phase 1 mentioned the satisfaction he got from harvesting a good yield of healthy crop. The reduction in wind speed combined with shading would impinge on the speed and evenness of drying of the arable crop at harvest time, *(6)*. The reduction in wind speed could be seen as a benefit in the east of the country to stop the blowing soils, *(4,25)* and two farmers commented that the reduction in wind speed may allow them to spray the arable crop when normally they wouldn't be able to, *(6,15)*. However, the alteration in microclimate was of concern, *(4,13,15,25)*, one farmer commenting that *"the humidity between the trees could lead to fungal diseases", (25)*. The planting orientation of the trees would have considerable impact on shading and wind speed, *(6,9,24)*, although it could be governed by the topography of the ground, *(24)*.

Larger pests, i.e. pigeons and rabbits would thrive in agroforestry systems,*(7,12,13,23,25)* and the trees may provide overwinter accommodation for aphids,*(6)*. However, it was thought that there could be possible beneficial pest interactions due to the trees,*(4,24,)* and that trees would provide excellent cover for shooting, *(4,23,24)*. Several farmers were sceptical about any ecological benefits pertaining from agroforestry systems, *(4,23)*.

The water regime associated with poplar was discussed, *(2,6,7,12,24,25)*. Worries about the trees lowering the water table in dry years, *(6,24)* were counter balanced by one farmer who thought the poplars might help to dry out previously soggy ground, *(12)*. However, several farmers were worried about the aggressive nature of poplar roots on their existing field drains, *(12,15,24,25)*. One farmer commented, *"the roots will damage the tile drains...there isn't 10 acres on the whole farm that isn't underdrained", (25)*. While interviewing one farmer a gas board engineer arrived, and in discussion commented that it was not possible to plant willow or poplar within 10M of a gas main. At a recent poplar conference the chairman, *(D. Davenport)*, commented that he had once traced a poplar root 70 feet through a tile drain, *("Poplar- a profitable farm and woodland crop" RASE 1993)*

Cultivation provided another major area of concern, *(2,4,6,7,13,24,25)*. One farmer commented, *" I've enough cultivation problems without planting trees in the middle of my fields",(13)*. Rows of trees obviously place some restrictions on the cultivation regimes that can be adopted. Being forced to cultivate in one direction was problematic, *(4,13,24)*, although one farmer practicing minimum cultivation didn't see this as a obstacle, *(25)*. Several farmers preferred to cross cultivate to ensure good burial of straw following the burning ban, and to reduce ridging of soil. The previous series of interviews highlighted that farmers were still experimenting with methods of incorporating straw, made more difficult on many of the farms because of the heavy soils. The width of the tree rows would require accurate working and tramlining between the rows, *(7,13)*, and there was the danger of damaging expensive tackle especially on undulating ground, *(24)*. Spraying and fertilizing were seen as two problem areas, *(4,6,13,24,25)*. One farmer tramlined spraying and fertilizing at 24M, making it sensible to double the tree row width, *(24)*. The same farmer commented on the need for full width fertilizer spreaders between the tree rows, not those which rely on the overlap of spreading pattern. This may incur extra fixed costs.

The effects of arable sprays on the trees was of concern, *(4,15,24,)* whereas others were worried about the need to spray the mulched area to stop the ingression of weeds, *(13)*. The nutrient interactions between the arable crop and the trees were debated, *(2,7,24,25)* and two farmer's commented on the loss of nutrients in harvested wood, *(7,25)*, *"If you remove a timber crop every five years then what about the loss of phosphate and potash? (25)*. The idea of trees searching out untapped sources of nutrients in the soil was treated with some scepticism, *(2,25)*, and it was thought that the fall of leaves onto the surface of the ground could limit germination, *(12,25)*. One farmer had observed that on land adjacent to the numerous blocks of trees on his estate, *"leaves tend to accumulate in still years and reduced the germination of the autumn sown crop", (12)*. The large leaves of the poplar in the photographs could accentuate this problem, *(25)*, leading to the suggestion that other species should be considered. There was also concern about the lack of knowledge relating to the diseases of poplar, *(7)*.

Nearly all of the farmers had some experience of tree establishment and did not see the physical task of planting as a problem. One farmer on very heavy land was worried about access for planting during the winter, *(13)*, as they preferred to keep off the land completely during this period. The maintenance of the trees could be carried out at quiet times of the year, *(12)* although some said they could do without the hassle, *(13)*. The majority of farmers commented that if they were going to grow trees they would prefer to plant and manage them in small blocks. Few could see any benefit from spreading the trees across their valuable arable land. This was seen as having a negative effect on arable yield and making the cultivation of the land more difficult. These difficulties appeared to far outweigh any benefits that could accrue from tighter nutrient cycles or positive interactions between the woody and non-woody crop.

9.6.2 Harvesting the trees,

All of the farmers had some experience of cutting trees down, and owned a chainsaw. Dead Elm had provided a huge amount of wood over the last 20 years, encouraging the purchase of wood burners, *(9,12,23,24,)*. One farmer had cut substantial quantities of timber 10 years ago to heat his house and was still using this supply, *(24)*. Several had been on training courses associated with the use of chainsaws, *(4,12)*, and were considering thinning existing woodlands on their farms. The ban on straw burning had encouraged one arable farmer to consider the purchase of a burner in which he hoped to burn both wood and straw, *(15)*.

Operations associated with timber harvesting were often seen as time consuming, costly and generally hard work, *(4,13,23)*. Some farmers would sooner leave the harvesting of the trees to others, *(13,23)*. *"Wood harvesting is hard work and very time consuming if not set-up properly", (4)*. However, tree work could be used at quiet times which generally occur during the winter on arable farms, *(2,4,9,12,)*, although there were concerns that the timber harvest was bound to result in a labour clash at busy times, *(7)*. Any possibility of mechanising the harvest would be a bonus, *(25)*.

The actual harvesting of trees raised issues about the condition of the land in the late autumn and winter, *(2,9,24,)*. There was a feeling that the land would need to be bare for the tree harvest, thus making autumn the ideal time, probably on the stubble. Several suggested that spring crops could be planted in the year of tree harvest, *(2,12,15,24)* and that arable rotations could be designed around the tree cutting, *"Could fit the tree work into the slacker periods when the demand for labour is less, and in the year of the tree harvest then could possibly plant a spring crop", (12)*. The whole rotation could possibly get very complicated if both the trees and arable crops were grown in a 5 year rotation to ensure a continual supply of wood, *(24)*.

Cut stools or stumps were seen both beneficially and as a complication. Although the regrowth from the stool is a cheap way of re-establishment of the woody crop, *(23)*, the stools themselves were viewed as an obstacle to the short-term reversibility of the systems, *(12,23)*. Overall, farmer's opinions on harvesting could be divided into two categories: those who did not want anything to do with the harvesting of trees, and those who were happy to harvest trees but were concerned about how it would impinge on their normal arable rotation, i.e. *"Damage to the main crop should be avoided....the arable rotation would need to be planned carefully around the tree harvest,"(2)*.

**9.6.3 Public image and environment,**

It was thought that the public would think that any trees were better than no trees *(12,15)*, *"Public would like to see trees growing in the broad plains of Bedfordshire", (2)*. Tree planting may alleviate some of the public criticism over set-aside, *(13,24)*. However, several farmers commented that small clumps of trees could be more aesthetically pleasing, *(4,24)* and are likely to be better for wildlife, *(2,4,)*. The phase 1 interviews illustrated a range of opinions on the need to appease public opinion. This was reflected in these interviews, with some farmers keen to improve public relations, *(4,7,24, 25)*, whilst others were not too worried, *"the public might like such a system but I don't really care about that."(23)*

Another farmer who is very interested in public relations was not sure what the wider reaction to agroforestry systems would be, commenting, *"the public may not like rows of foreign trees compared to native plantings",(24)*. Noise abatement associated with rows of trees could be an advantage following the construction of new roads, *(12)*, as was the windbreak effects of shelterbelts near new buildings, *(25)*. There were also thought to be wider benefits from planting trees, i.e. *"The trees will clean the atmosphere by removing the carbon dioxide",(7)*. The possible advantages of rows of trees with alleys in between was raised in connection with shooting, *(4,12,23,24)*. Game birds would thrive on a mixture of good cover and accessible food source. Access down the allies would be good for the guns, and could be planted with specialist game cover, i.e artichokes, *(24)*.

## 9.7 MARKETS, FINANCIAL ASPECTS AND USES AS SEEN BY THE FARMER, (AIM 2)

Farmers were sceptical as to the market for timber cut at an early age. Whereas current knowledge suggests that a market for mature timber may exist in 20-25 years, the market for smaller timber in 5 years time is uncertain. This timber could either be used on or off farm for a variety of purposes. The use or market for the timber produced could be classified into on farm and off farm. Some of the farms had an existing need for timber to fuel woodburners and open fires, *(4,6,9,15,23,24)*. This did not necessarily mean the farmers were keen to grow their own wood, i.e. *"Better off retailing wood rather than growing it"*, *(23)*. One farmer used reject pallets to heat his house and swimming pool, *(9)*, whereas another was happy to clear windblown trees from the local neighbourhood, *(23)*. Despite having reasonable supplies of timber one farmer considered the time and effort needed to collect, harvest and transport the wood made it more economic to buy firewood in, *(4)*. Similar views had led an estate manager to rip out the woodburner altogether and replace it with oil fired central heating, *(12)*. There was the possibility of drying grain using the wood, *(13)*, although annual demand for drying facilities was spasmodic. A continuous wood supply could be used for greenhouse heating, *(25)*, although none of the farms visited were undertaking commercial growing under glass.

Those who would consider burning poplar were very interested in its drying and burning abilities, *(2,9,24,25)*. *"I am in favour of growing some timber but I am worried about its [the poplar's] burning abilities, particularly tar production in the boiler"*, *(9)*. One farmer was interested in loss of weight following harvest and whether poplar was prone to spit on an open fire, *(24)*. Although poplar is not recognised for its exterior durability it has been used as a building material in the past. However, there was only limited scope for its use in this context because few of the farms had a demand for fences, posts or animal shelters, *(9,12,13,25)*. Even where posts were purchased, (about 200 a year), the farmer felt it would probably make sense to buy good quality posts in, *(24)*. The possibility of using the poplars to make lapboard fencing was discussed, *(15)*, the same farmer considering general interest in the systems would be boosted as the price of oil rose, making home grown energy a more attractive proposition.

A small farm that was run in conjunction with a livery enterprise had a demand for chippings for an all weather arena. They presently bought in about 100M³ of wood chip each year. Despite this use on the doorstep the farmer was still sceptical about growing his own timber, *(6)*. He was concerned that the poplar wood may have a high resin content, causing it to stick to the horses hooves. During the previous series of interviews he had expressed an interest in growing trees for an aesthetic point of view to make the horse rides more scenic, although he appeared to favour the more random planting of traditional broadleaves.

Finding a market for the off-farm use of the timber cut on short rotation could be problematic, *(4,7,13,24,25)*. However local markets were thought to exist for firewood, *(2,13,25)*, especially for those who farmed close to population centres. The advantages of living next to a population centre was highlighted in the phase 1 interviews, where several farmers were keen to develop enterprises to exploit these potential markets, *(4,6,15,23,24)*. However, the financial return from firewood enterprises was thought to be limited, *(23)*, and the market would soon become saturated if it became profitable, i.e. neighbouring farms would flood the market,*(2)*. Transportation was recognised as being a crucial element of overall costs, *(12)*, and could govern the profitability of growing wood for local Combined Heat and Power project, (CHP), *(25)*. One farmer had undertaken detailed costings to supply wood chip to a local hall, (used as a school for the blind), whose heating boiler was in need of replacement, *(24)*. Despite the farm being in a ring fence around the hall the scheme was not viable. Problems were compounded by the time-lag needed to establish a productive short rotation wood supply, (at least 3 years). In the first round of interviews this farmer expressed an interest in alternative ideas, and had already set up an eventing course, fishing ponds, and caravan storage. *(The author was later invited to a diversification/conservation day which he arranged to aid public relations, which was a big success.)*

Other possible outlets included supply to market gardens, either as wood chip as a mulch for bare land, *(2,4)* for trestle making or basket making, *(4)*. Despite there being general discussion on the use of woodchips in centralized generating plant, nobody was aware of local proposals to set-up such a scheme, *(2,7,9,25)*, which would be necessary to keep costs down. *"I doubt if it would be economic to move wood more than about a 10 mile radius of the farm", (25)*

Profit was thought to lie in the value added to the timber, *(23,24)*, as one farmer commented about growing mature timber, *"the lumber yard could make as much in 6 months as the farmer makes in 25 years of growing the wood", (24)*. However, farmers could visualise a market for mature timber, whereas the market for the wood grown on short rotation was more speculative. Farmers noted in the first phase of interviews that product marketing was not one of the industries strong points and many farmers, despite being aware of the need for good marketing were more interested in the growing of the product. If a reliable market could be established for the smaller product the system would offer farmers a rapid payback and could provide one method for utilizing set-aside land.

## 9.8 EXPLORING THE FINANCIAL VIABILITY OF AGROFORESTRY ON INDIVIDUAL FARMS THROUGH THE USE OF ROWMOD, (AIM 3)

It was anticipated that farmers may have used interactive financial models on lap top computers with sales representatives and advisers. However, this was found not to be the case. As with the base runs and sensitivity analysis described in the previous chapter many of the initial runs on the farms showed conventional rotations to give a slightly better NPV than the agroforestry systems. The exception was one farmer who tramlined at 24M and chose to plant trees at a wider spacing, see Table 9.2,

Table 9.2 : Example of ROWMOD output from 4 farms on which it was used interactivily.

| | | | | |
|---|---|---|---|---|
| Farm number | 2 | 12 | 24 | 25 |
| Crop rotation | Winter wheat | Winter wheat (milling) | Winter wheat | Winter wheat |
| | Winter wheat | Oilssed rape | Oilssed rape | Winter wheat |
| | Winter wheat | Winter wheat, (feed) | Winter barley | Winter wheat |
| | Winter wheat | Winter beans | Winter wheat | Winter wheat |
| | Winter wheat | Winter wheat (milling) | Winter wheat | Winter wheat |
| Gross margins | 500 | 632 | 545 | 550 |
| £/ha | 500 | 598 | 495 | 550 |
| | 500 | 673 | 545 | 550 |
| | 500 | 442 | 530 | 550 |
| | 500 | 632 | 545 | 550 |
| Agroforestry area (ha) | 4 | 3 | 4 | 4 |
| Poplar growth conditions | 0.8 | 0.8 | 0.8 | 0.9 |
| % change in agricultural prices | 0 | 2 | 0 | 0 |
| Farm size (ha) | 180 | 350 | 225 | 200 |
| %change in fixed costs | 0 | 0 | 0 | 0 |
| Fixed costs per hectare | 200 | 300 | 300 | 300 |
| Row width (M) | 14 | 14 | 28 | 14 |
| %change in poplar price | 1 | 2 | 0 | 0 |
| Poplar price (£/M3) | 11 | 11 | 11 | 11 |
| Market opportunity | 1.25 | 1 | 1.2 | 1 |
| Extra fixed costs(£'s) | 250 every 5yrs | 250 every 5yrs | 250 every 5yrs | 250 every 5yrs |
| Interest rate (%) | 7 | 7 | 10 | 7 |
| Establishment grant (£) | 767 | 767 | 767 | 767 |
| NPV agroforestry(£) | 2552 | 2528 | 1777 | 2081 |
| NPV conventional cropping(£) | 2644 | 2712 | 1653 | 2203 |
| Benefit to agroforestry (£) | -91 | -184 | 123 | -122 |

Farm 2 was a mainly continuous wheat grower, with low fixed costs related to minimum cultivation and relatively low variable costs. However, the recent ban on straw burning had forced him to start ploughing again. He foresaw a possible local market for wood grown on short rotation in Milton Keynes, and of all the farmers interviewed during phase 2 he was probably the most likely candidate for trying out such a system. Farm 12 appeared to be one of the most appropriate farms on which to establish silvoarable systems. The farm is an estate with an established shoot, a reasonable demand for wood for burning in all of the estate houses and is reasonably close to population centres. However, the manager is a very competent arable farmer, achieving good margins and sceptical about the growing of trees on arable land. The high arable margins means that the opportunity cost of establishing agroforestry systems is high, making their establishment financially unfavourable.

Farmer 24 based his calculations on 24M tramlines because all of his fertilizing and spray equipment was set up to work at these widths. This, combined with relatively low gross margins, and a possible local market made the agroforestry option look more favourable on his farm. Farm 25 was also based on continuous wheat, although margins were slightly higher than farm 2. This combined with no perceived market opportunity made agroforestry less attractive. This was despite more favourable growing conditions for poplar than on any of the other farms on which the farmers had agreed to explore the financial implications using ROWMOD.

Overall differences in NPV between conventional and agroforestry systems were not considered to be particularly significant by the farmers, as they showed that provided the assumptions in the model were correct, agroforestry was in the same "ballpark" financially as conventional systems. There was general recognition by the farmers that the figures needed to be treated with caution because of their limited exposure to the calculating process within the model, *(12,24)*. Whereas farmers were able to make assumptions about change in agricultural prices, they were unable to make realistic estimates, or informed guesses concerning premium markets for wood in the area in which they farmed or the extra fixed costs that may be incurred on their farms due to the adoption of agroforestry. This provided a limitation when trying to adapt the model to individual farm situations, particularly as these variables had been shown to be important in the sensitivity analysis, (see Chapter 8).

It was possible to alter variables to make agroforestry look financially more attractive than conventional arable cropping. However, this possibility was met with some scepticism by farmers for two reasons,

1. A variety of problems associated with the systems had already been discussed, and the systems were generally viewed by the farmers as being complex, risky and inflexible.

2. The market for the timber cut at 5 years was not established and any value imputed into the model was seen as hypothetical. For

instance, it would have been beneficial if there was a buyer of woodchips in the area offering £11 /M³. This would have provide a tangible starting point.

The heavy nature of much of the land farmed meant that all the farmers chose the average growth conditions and most would be only willing to grow a few hectares of agroforestry in the first instance,*(2,12,24,)*. Two of the farms had higher than average gross margins and this reduced the favourability of agroforestry. The cashflows calculated from the model demonstrated the possibilities for manipulating the arable rotation and tree harvests to smooth out cashflows. The next section examines the output from the model and the possibility of manipulating the rotation to provide a more balanced cashflow.

**9.8.1 A worked example,**

The farm used as an example is a 350 ha managed estate, where the present manager has been in charge for the last 14 years, (given the hypothetical name of Home farm). The farm is all arable. The estate has an established shoot, several areas of old woodland and has recently established 6 x1 ha copses which are maintained by regular farm staff. The soil is heavy Hanslope clay series, mainly grade 3(a) with patches of grade 2. The farm is split into mainly large fields averaging 40 to 50 acres, (16-20 ha).

The farm achieves higher than average gross margins for its arable crops, with about average fixed costs per hectare. The established woodland and apparent open mindedness of its manager suggest it is the type of farm which could most easily adopt agroforestry systems. Table 9.2 provides details of parameters used in the initial model run, (see farm 12). The results of this initial run showed a NPV over the 15 years of £2712/ha for conventional cropping and £2528/ha for agroforestry, a difference of £184 in favour of the conventional cropping. The cashflows from the two system are presented in Figure 9.2.

The possibility exists to design the silvoarable system to produce a cashflow of increased uniformity, recollecting that farmers commented on the possibility of planting a spring crop in the year of timber harvest. Using the above farm as an example the arable rotation was extended to 5 years to fit in with the tree rotation:-

| | | |
|---|---|---|
| Year 1 | Milling wheat | £632/ha |
| Year 2 | Winter Barley | £520/ha(from Nix 1993) |
| Year 3 | OSR | £598/ha |
| Year 4 | Feed wheat | £673/ha |
| Year 5 | Spring beans | £420/ha(from Nix 1993) |

This hypothetical rotation reduced the deficit for agroforestry down to -£140 and evened out the fluctuation in cashflow, see Figure 9.3.

The model was further used to demonstrate the degree of change needed in any one parameter before agroforestry became financially advantageous. These are:

Figure 9.2 Cashflows associated with conventional and agroforestry cropping systems,

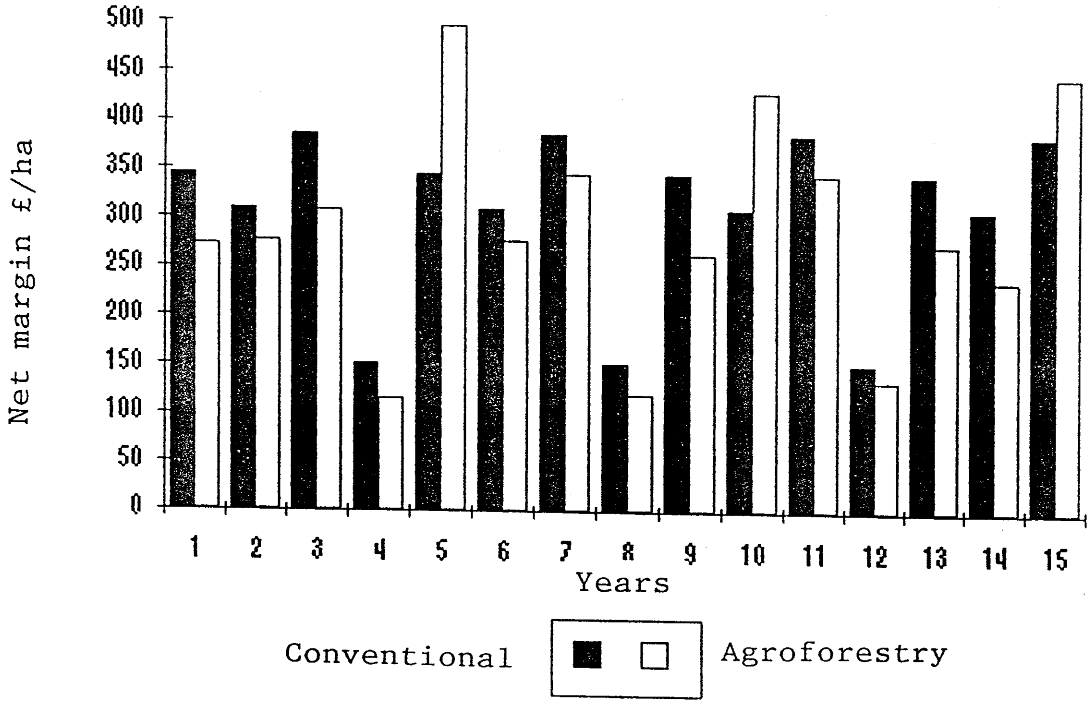
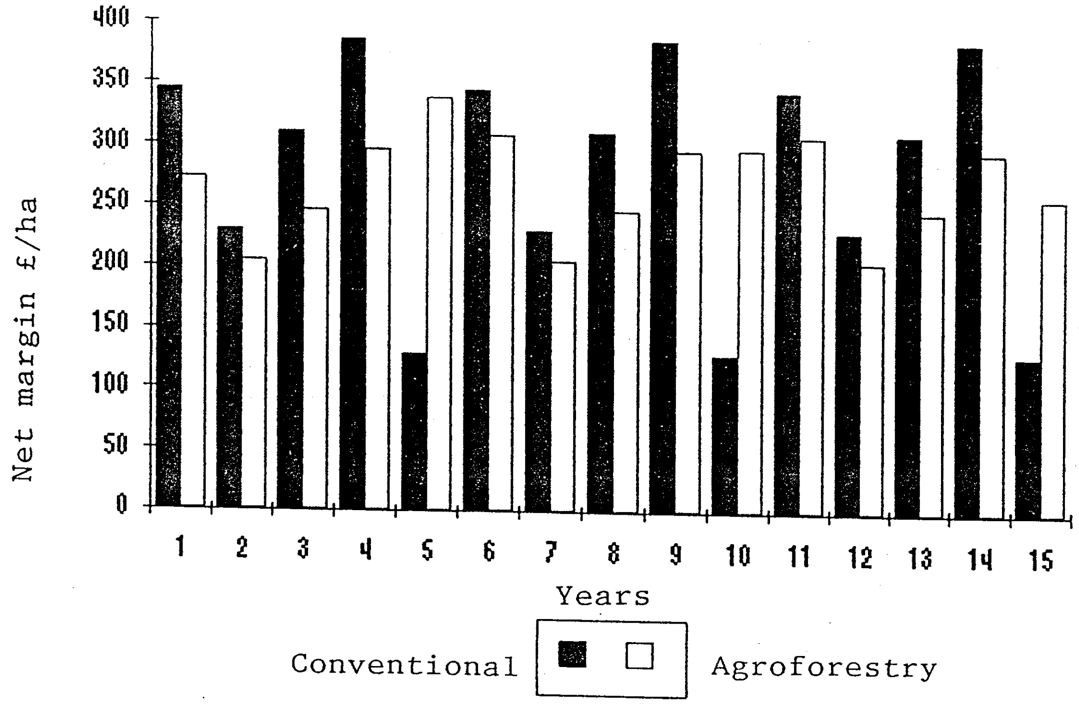



Figure 9.3 : Designing rotations to reduce fluctuations in cashflow



A 18% fall in agricultural prices in year 1,

A 40% rise in fixed costs in year 1,

A 5.1% annual increase in fixed costs over 15 years,

A 5.5% annual increase in poplar prices

A 31% rise in price for poplar wood in year 1,

A 50% fall in extra fixed costs associated with agroforestry,

A 28% increase in establishment grant,

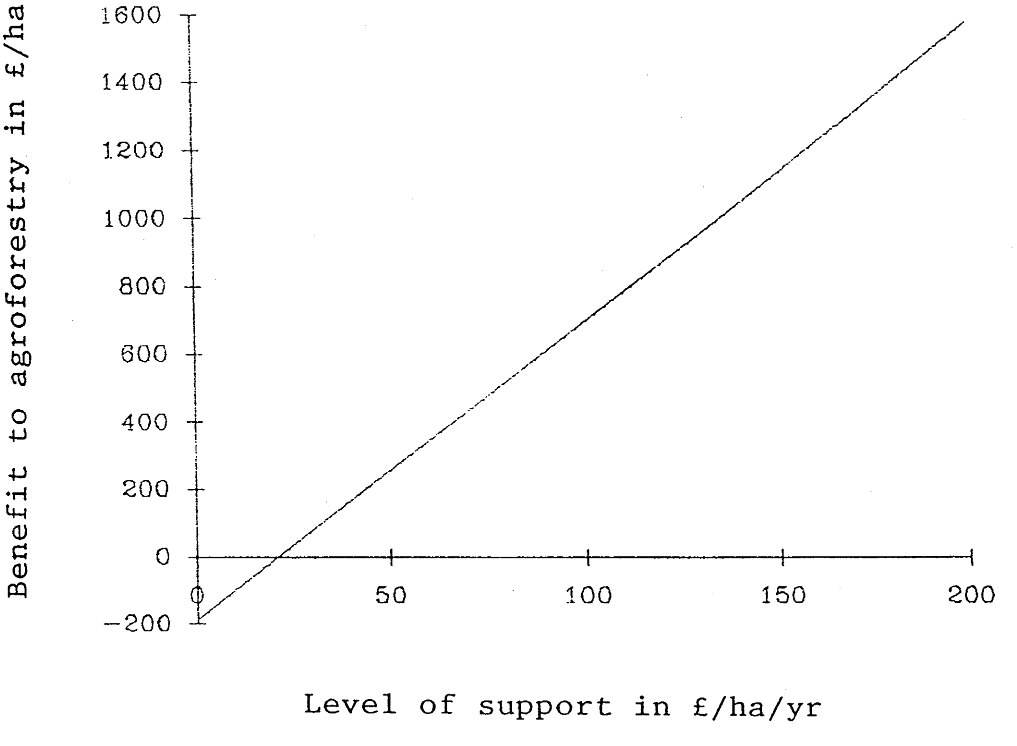
It is impossible to predict how the above parameters are likely to change in the future. However, major changes are expected in what is allowable under set-aside after the next harvest. If agroforestry systems could be established as part of non-rotational set-aside, assuming the 1.5M strips into which the trees are planted are arable land taken out of production, then financially the systems could look extremely favourable. The disadvantage is that farmers may have to remove more than 15% of their land from arable production if they wish to enter these non-rotational schemes. The level of financial support provided under these schemes has not been released but it is presently about £208/ha/yr for rotational set-aside. Table 9.4 gives the results of 4 model runs using the base parameters for Home farm assuming non-rotational set-aside is allowable for agroforestry systems at 4 possible rates, 50,100,150, and 200 £/ha/year.

Table 9.4 Results of set-aside analysis, presented as NPV for 15 year model run.

| Set-aside payment £/ha/yr | 0 | 50 | 100 | 150 | 200 |
|---|---|---|---|---|---|
| NPV of agroforestry (£/ha) | 2527 | 2968 | 3408 | 3849 | 4289 |
| NPV of conventional (£/ha) | 2712 | 2712 | 2712 | 2712 | 2712 |
| Benefit of agroforestry (£/ha) | -185 | 255 | 696 | 1136 | 1577 |

The results of this analysis demonstrate that even a small annual set-aside payment would make the agroforestry option look favourable. Figure 9.4 provides a breakeven graph suggesting that at a support level as low as £25/ha/year, agroforestry would be a financially viable proposition. At higher rates of set-aside payment the financial benefits of agroforestry could be substantial. However, the feedback from farmers suggests that blanket set-aside payments for trees would not necessarily encourage farmers to adopt silvoarable systems. Unless policy differentiated in favour of these types of system, farmers would be inclined to plant trees in clumps or blocks.

Figure 9.4 : Breakeven graph indicating the effects of the level of annual support payments on the benefit to agroforestry under conditions at Home farm



## 9.9 THE TYPES OF POLICY INCENTIVES WHICH COULD MAKE AGROFORESTRY A MORE ATTRACTIVE ALTERNATIVE TO FARMERS, (AIM 4),

Discussion on the policy incentives centred on two themes, the growing of wood on arable farmland in general and adoption of silvoarable agroforestry systems. Growing of timber to maturity even at 20-30 years was not seen as a viable commercial replacement for arable cropping. However, farmers had still established areas of woodland, and many were considering doing so in the near future as part of the overall farm strategy. The possibility of establishing trees on set-aside was greeted with caution, *(2,7,12,15,25)*. This caution was based on an assumption that set-aside could be withdrawn as fast as it was introduced, leaving farmers with a low income crop growing on 15% of their land. *"Not enough stability in agriculture to commit oneself to trees", (25)*. This situation was evident during the previous phase of interviews, suggesting little had changed over the intervening time period. Uncertainty about the future arising from an ever changing policy environment remained a key issue.

Set aside could be used as a carrot, i.e. *"Plant 10% of your land area with trees and be excused the other 5%", (2)*, or there could be guaranteed set-aside over long time periods, say 20 years, which would increase stability, *(25)*. Some form of *"financial protection is needed which demonstrates long-term commitment", (2)*, [from the government]. In the 8 months to a year since the first phase of interviews the CAP reforms had linked set-aside to arable area payments, making it financially wise for larger farmers to set some land aside. Thus, although many of the farmers were still highly critical of set-aside there was an element of being resigned to the reformed system, *"Rotational set-aside is not turning out too badly for us, we just treat it as a traditional fallow", (15)*. The possibility of a non-rotational set-aside option after the 1993 harvest may offer a longer term commitment, *(7)*. One farmer explained the government could demonstrate its commitment to timber production by buying up land as it came on the market to be used for tree planting, *(23)*. A guaranteed price for the end product could help, *(2)*, as one farmer commented, *"whenever I attempt to sell mature timber the merchants reckon the market is depressed",(24)*

National schemes like the community forests were discussed with some scepticism, *(25)*, although the information and expertise provided within these programmes could be beneficial, *(2)*. One small farmer was concerned that agricultural prices could be reduced still further to make forestry financially appealing, *(23)*. If this was the case he said he would have to quit farming. During the first phase of interviews several farmers expressed concerns about being squeezed out of business, i.e. falling or fixed price for products with ever increasing input costs.

Incentives to encourage agroforestry needed to be slightly different to those for conventional timber. Whereas a block of trees impinged little on the conventional arable systems, the establishment of trees within arable fields, not only reduced the amount of arable land available but afforded an actual physical interaction with the arable crop. Although the possible ecological and agronomic benefits of the systems were discussed these were generally out weighed by the increased complexity and loss of flexibility associated with agroforestry. Short-term systems were not favoured because of the difficulty in identifying a market for the product and the long-term agroforestry systems required a radical change to pastoral based systems after only a few years. During the first phase of interviews many farmers recognised that marketing of products was a general weakness within the farming community. The comments made during this second phase generally supported these statements, with farmers generally preferring somebody to "offer" them a market, rather than having to go out and find or create a market.

One of the incentives the government could provide would be to aid in the development and setting up of markets, i.e. short-rotation forestry would benefit from the setting up of generating plant which could use locally grown wood, *(4,24)*. This would demonstrate a wider commitment to growing wood for fuel. The competition from cheap gas and oil provides a major stumbling block for the general development of wood fuel, *(9)*. It was thought increases in the price of energy would make wood based systems more favourable, *(23)*. However, *"how can they [the government] subsidise farm energy when they are letting coal mines close down?" (13)*. The setting up of marketing groups needed encouragement to investigate markets for products, *(2,12,)*, although the general problems of co-operation amongst British farmers were highlighted in the first phase of interviews. The novel nature of agroforestry system meant that farmers would "*need more information about the total concept*", *(2)*, as well as details on establishment, maintenance and diseases, *(2,9,24)*. A possible incentive would be the provision of free advice and training courses to those farmers who were interested.

To stimulate the establishment of agroforestry systems, policy incentives need to go further than just encouraging the production of wood *per se*, and need to be system specific. *"Unless systems became very financially viable I would rather plant trees in clumps", (24)* One farmer thought that these systems may be tried by those farming larger areas of land, who could perhaps afford a few mistakes. However he comments, *"as a small farmer I haven't the time or the land to invest in dodgy enterprises", (23)*. It is interesting to note how individual farmers perceive the size of their farming operations, *"As a small 450 acre tenanted farm we are less likely to try out these alternative systems", (15)*, (see also Appendix 8). A farm manager commented he would watch others try out the systems before he would commit land to such systems, *(12)*. This need to acquire knowledge was seen as one mechanism through which these systems could be encouraged via the use of training days and meetings, *(12)*.

One farmer commented about the uptake of these systems, *"New systems like these need to be financially sound plus a big bit more", (25)*. This illustrates that purely undertaking financial breakeven analysis is of little use to the farmer. Depending on their individual situation they will require a new system like agroforestry to be able to demonstrate benefit over and above what can be produced from their normal arable rotation. This extra will be needed to overcome market uncertainty, lack of knowledge about the growing systems and the need to commit land to longer growing cycles. The amount of benefit that needs to be offered will depend upon the individual farm situation. This piece of research has not attempted to acquire this information and this is clearly an area requiring further research if the adoption of these systems is to be encouraged at a policy level.

## 9.10 CONCLUDING COMMENTS AND IMPLICATIONS ARISING FROM THE INTERVIEWS

Following interviews conducted with arable farmers it has been established that a considerable number of problems and issues surround the uptake of silvoarable systems on farms. The philosophy of conducting interviews as conversations as detailed by Burgess (1984) proved a useful method of information gathering. The presentation of the soft data arising from these interviews is somewhat problematic, although its use in this research is perhaps somewhat easier because it fits into a wider research framework. The use of a small photograph album at the start of the interviews was an extremely useful method for focusing attention on the particular silvoarable systems being investigated. However, the use of ROWMOD as an interactive tool proved less successful than expected, (reasons for this are discussed in section 9.4.). In subsequent research work it may be possible to involve farmers in the construction of the model itself. This may require time to be forfeited by individual farmers. In a study of this nature it would be unrealistic to rely on this type of interaction. However, larger studies in the future could perhaps allocate several days monetary allowance in their budgets to permit realistic interaction of interested farmers in the process of model construction.

Growing of trees commercially is seen to conflict with the need to maintain flexibility in cropping, enabling adaption to an ever changing policy environment. Planting trees down the middle of fields is generally seen as a considerable reduction in this flexibility. Farming in the UK is a highly technological industry, relying upon tight schedules and accurate applications of fertilizers and sprays. Growing trees in fields is seen as making it increasingly difficult to keep to these schedules, reducing the effectiveness of expensive inputs, resulting in more complex farming systems. This is in contrast to an industry which is presently being forced to reduce fixed costs, often resulting in the simplification of cropping systems. There were further worries that agroforestry would reduce the effectiveness of existing capital infrastructure such as field drains and machinery. The first phase of interviews indicated that some farmers were already having to experiment with different cultivation systems following the post harvest ban on straw burning in 1992, and worries about further cultivation restrictions or changes imposed by the presence of rows of trees were evident in this series of interviews.

Agronomic disbenefits perceived by the farmers appeared to outweigh any advantages expressed in terms of nutrient cycling and general soil condition. Farmers were generally dismissive of the possibility of tighter nutrient cycling or improved soil condition under silvoarable systems. It is suggested whilst nutrients can be supplied relatively cheaply from a bag and the soil productivity can be easily maintained these aspects are unlikely to attract much attention from farmers.

Income arising from trees is generally perceived as a bonus and not generally a part of the financial planning on the farm. Those who had considered commercial planting were interested in shorter term energy coppice. In these circumstances management was thought to be considerably easier if the trees were grown in blocks separate from the arable crops. The uncertainty surrounding the market for wood grown on short rotation, whether as an energy product or a timber product for specialist use on or off farm added to the cynicism surrounding these systems. In contrast a market for mature timber could be envisaged, but the long growing rotation limited the amount of land that farmers were willing to commit to these systems. The longer term poplar agrisilvopastoral systems proposed at Bangor, (see Thomas et al 1992), would rely on many of the arable farms re-establishing animal enterprises to utilize the grass grown under such systems. Not only did farmers see this as financially difficult, but some had little experience in animal systems and preferred to just grow crops.

The results of using ROWMOD illustrated that silvoarable systems could be financially viable on some farms, or at least produce returns similar to more conventional arable systems. However, this did not encourage farmers to view these systems as a potential form of cropping on their farms because of the agronomic problems they perceived to be associated with the systems. The lack of a market for the product and the possibility that the trees could upset the growing of the arable crop provided major stumbling blocks. The development of markets for energy from wood could help to establish trees as a viable on farm crop. This would be re-enforced if a policy framework were in place which reduced the risk and uncertainty associated with the committing of land to a woody crop with a longer growth cycle. However, even if these objectives were met, silvoarable agroforestry would be a distant second choice to farmers who would rather manage the woody crop in separate blocks rather than mixed in with their established arable cropping. This suggests that for silvoarable systems to become a realistic option on a wider basis, policy will need to differentiate specifically in their favour. If this does not occur then its uptake in the near future may be limited to specialist circumstances, examples of which are listed below:

1. The establishment of a conventional poplar stand at wide spacing where additional income could be gained in the first few years by planting an arable understory crop,

2. For cover on estates with large game shoots,

3. In areas where soil degradation is perceived as a particular problem,

4. In areas where wind blow is severe,

5. For drying out or shading of soils or providing a specialist microclimate for a specific understory crop.

## 9.11 INFORMING THE DECISION MAKING PROCESS

It has been suggested earlier in this thesis, (see Chapters 6 and 8), that agroforestry could be both desirable within a sustainable systems framework and viable from a financial point of view. However discussion in the previous section suggests its uptake on farms is likely to be limited unless policy incentives are directed specifically in its favour. Alternatively, fundamental change in the policy framework could make these types of system appear more favourable. However, if these systems are to be encouraged there is a need to raise the profile of this type of mixed cropping, especially the benefits associated with the exploitation of the interaction between the woody and non-woody crop. Thus this research provides information to decision makers which identifies three levels through which agroforestry systems, and in a wider context, increasingly sustainable pathways, can be encouraged:

1. By increasing the awareness of intercropping systems, and other alternative cropping practices, particularly the beneficial interactions associated with crop mixtures and mixed enterprises,

2. By positively supporting agroforestry within the existing policy framework, via existing policy instruments

3. By introducing new policy instruments as part of a longer term change in farming ideology.

### 9.11.1 Increasing awareness,

The pilot study at Banbury market suggested a general lack of knowledge about agroforestry systems within the farming community. In the interviews described in this chapter farmers rarely discussed perceived advantages of agroforestry systems, suggesting a general lack of familiarity surrounding beneficial interactions associated with this form of intercropping.

Although research into agroforestry is well networked, its exposure in the wider farming press has been limited, although several articles are starting to appear, (see Farmer's Weekly 4th September 1992). Conferences and local farmers meetings provide a mechanism through which information can be disseminated and agroforestry has recently appeared on the agenda of several conferences. However, many of these meetings are associated with the growing of pure stands of trees either for mature timber or as arable coppice. Thus discussion on aspects of crop interactions and agronomic aspects of production often do not occur. Funding to set up a series of meetings, seminars or training days about intercropping systems in general could help to raise the awareness of these system. These could be run through the local agricultural colleges, encouraging the involvement of new entrants into the industry.

MAFF has recently provided funding for the setting up of 4 silvoarable sites throughout the UK, and several silvopastoral sites, referred to as the National Network Sites, are funded with help from AFRC, (see Chapter 6). The appropriate management and use of these sites should increase awareness of intercropping systems. Similarly the encouragement of on farm trials, particularly in conspicuous situations, (i.e. next to main trunk roads), could help to increase the exposure of these systems to a wider number of both farmers and public.

## 9.11.2 Supporting agroforestry using existing policy instruments.

There is no reason why agroforestry should not receive encouragement via existing support mechanisms under the CAP reforms. In one sense it is the requirement for farmers to set-aside land which has stimulated increased interest in a host of alternative land use systems since the mid 1980's. Unfortunately the present rotational set-aside scheme means that land planted to trees cannot be included in the area payments scheme. However, the introduction of a non-rotational set-aside option following the 1993 harvest may encourage the planting of trees. Whether the spatial planting patterns associated with agroforestry systems will be included as an option is unknown. Even if they are, unless they attract extra support the interviews undertaken in this chapter suggest that those growing trees are likely to grow them in blocks rather than in these spatially diverse systems.

The provision of extra support could be provided under the existing Farm Woodland Grant Scheme or other schemes introduced via the Forestry Authority. Such schemes could be used to further reduce establishment costs and provide regular payments into the future. Other methods of support could include guaranteed minimum prices for a set period into the future to allow farmers to carry out realistic cashflow budgets and payback calculations. Alternatively a premium could be paid for certain types and sizes of timber. However, one of the aims of current CAP reform is to cut the cost of agricultural support and thus direct support for agroforestry may be difficult to justify. Without this support it is unlikely that agroforestry will become a major cropping system in the UK in the near future.

Carruthers (1990) suggests that the prospects of agroforestry at the farm level can be viewed from two perspectives; firstly the extent to which it becomes a part of agricultural change along with ideologies and technology trends, and secondly the degree to which it fits in with the immediate needs of farming and becomes an established practice through this means. Overall this piece of research suggests that silvoarable agroforestry is unlikely to fit in with existing needs in farming and its adoption as a viable alternative within the current farming paradigm is doubtful. This means that the adoption of silvoarable systems relies on it being accepted as part of a more fundamental change in farming ideology within the UK which is based on long-term ecological sustainability as well as short term economic viability.

### 9.11.3 A change in farming ideology,

Financial analysis undertaken in this chapter and in Chapter 8 illustrates that silvoarable agroforestry could be a viable proposition on some farms without any additional support. Yet many other issues associated with its uptake on farms make it an unfavourable option. However, a critical factor associated with its adoption is the underlying feeling within the industry that the existing policy framework is volatile and lacks direction. This engenders a feeling of general uncertainty about the future, which means that many farmers are unwilling to commit themselves to cropping systems with production cycles of longer than a year. This is in an attempt to maintain flexibility because they have no long-term confidence in the current policy framework. However this flexibility is constrained. For instance to allow change from field beans to OSR or Linseed in response to prevailing support mechanisms.

To overcome this policy uncertainty and to instil a degree of stability into the decision making environment itself is a considerable task. Help via the development of markets and marketing groups demonstrates a longer term commitment to the growing of wood. The Department of Trade and Industry is already trying to do this via the Farm Energy Project. However the government is not demonstrating a similar level of commitment with respect to other alternative biofuels, with the last budget failing to exempt fuel derived from rape, (RME), from fuel duty. Thus, even within the area of biomass for energy, the signals about future direction of policy are often confusing and contradictory. This causes a sense of frustration at the farm level as demonstrated in the interviews in Chapter 7, in which many farmer's cannot see any realistic long-term goals. Where goals are set at government or EC level they are often restrictive. For instance the increased move towards production quotas only makes it more difficult for individual producers to change or expand the range of enterprises they carry. This in effect reduces the adaptability of individual producers.

This research suggests that the types of farming systems which are likely to follow increasingly sustainable pathways could be being actively discouraged by present policy mechanisms. In placing an ever increasing amount of regulation and constraint on the agricultural sector in order to try and stabilise production in what is effectively the short term, policy is reducing the ability of the producer to demonstrate adaptive behaviour. To enable land based production to pursue increasingly sustainable pathways policy should be allowing individual producers to maintain adaptive capacity. This may mean that producers should be encouraged to carry a wider range of enterprises, via established mixed cropping systems or more innovative intercropping systems.

A logical next step arising from this research project would be to try and assess the costs and risks associated with the process of change to increasing sustainable farming systems, together with the types of policy mechanisms and instruments that can aid the maintenance of adaptive behaviour within farming systems.

# CHAPTER 10: CONCLUSIONS, CONTRIBUTION AND IMPLICATIONS

*"The main message is not that thinking about the future is important- we surely all accept that- but that it is a task that should be taken seriously, as a professional activity", Spedding (1991).*

## 10.1 INTRODUCTION AND SUMMARY,

In this chapter the research project is discussed in the light of the original research framework. A research map is presented which illustrates how the research activities link together and this is discussed in the context of the overall research process. Conclusions arising from the specific research activities are summarised. The use of several research techniques within a integrative research approach offers an innovative method of working, whilst contributions are made by the individual techniques to specific disciplines. The assessment of silvoarable agroforestry as one possible future farming system allows conclusions to be drawn about this specific cropping practice, as well as providing insights into the assessment of other farming practices within a sustainable systems framework.

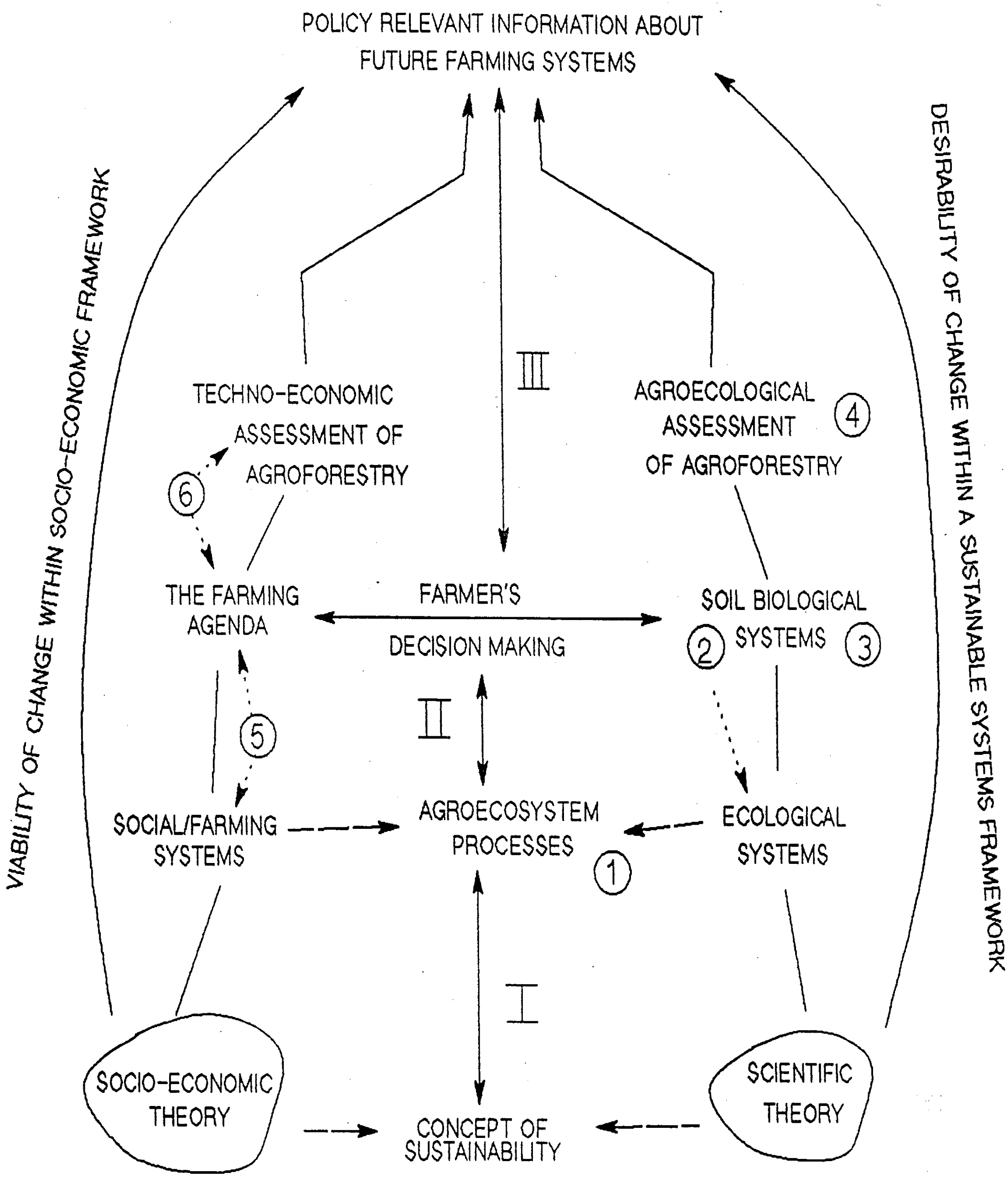
The overall output from the research is seen as the use of an integrative research approach to provide policy relevant information about future farming systems. This debate is widened to discuss pathways of change, the broader science policy agenda and the concept of sustainability. The chapter concludes by discussing the future sustainability of land based production

## 10.2 DISCUSSION AND CONCLUSIONS RELATING TO THE RESEARCH PROCESS,

This research project is embedded within a sustainable systems framework which links scientific and socio-economic theory, interpreting the resulting information in a manner which is accessible to the policy formulation and decision making process. Figure 10.1 provides an overview of the thesis and outlines the "linkages" and interfaces constructed and explored within the research and is a development of the conceptual model illustrated in Figure 1.5.

The map illustrates two broad research themes which are apparent in the chapter layout in Figure 1.7, i.e. the desirability of change within a sustainable systems framework and the viability of change within a socio-economic framework. A central argument in the thesis is that agricultural change toward increasingly sustainable systems cannot be assessed purely from a basis of socio-economic or scientific theory. This inevitably raises questions about the way in which research should be designed so that information from both the physical/ natural systems and the social, economic and cultural systems can be combined. Figure 10.1 illustrates an approach which enables the integration of this information. The research activities are mapped onto Figure 10.1 demonstrating research into both physical and social systems. However it is not simply the undertaking of a number of research activities that is of importance, but the manner in which they relate to one another and the relevance of the information provided by them.

Figure 10.1 Thesis overview: Mapping the linkages,




RESEARCH ACTIVITIES

1. The development of an (agro)ecosystem perspective within a sustainable systems framework
2. Modelling the effects of agricultural activity on carbon/organic matter flows and structure as an indicator of change within the agroecosystem
3. The investigation and use of simple invertebrate bodysize analysis as a representative measure of agroecosystem well being
4. Assessing the impact of silvoarable agroforestry systems on agroecosystem processes
5. Gaining a realistic interpretation of the current farming agenda
6. The economic, social and technical evaluation of issues surrounding the uptake of agroforestry on UK farms

RESEARCH INTERFACES

I CONCEPT OF SUSTAINABILITY AND AGROECOSYSTEM PROCESSES

II AGROECOSYSTEM PROCESSES AND FARMERS DECISION MAKING

III FARMERS DECISION MAKING AND POLICY RELEVANT INFORMATION

It is argued that economically viable change often steers a system along pathways which are not conducive with longer term ecological sustainability. A fundamental problem associated with agricultural change that has occurred in recent history is that it takes little account of the effect of that change on the long-term ecological sustainability of the systems into which it is being introduced. The ecological and economic systems cannot be treated in isolation but should be explored to discover how the wider farming agenda relates to fundamental agroecosystem processes. In encompassing research across a range of levels this thesis has raised a number of spatial and temporal issues. Processes occurring at different spatial levels operate at distinct rates, and in many cases current policy mechanisms are unable to recognise these spatial and temporal incongruities. For instance policy makes no attempt to differentiate as to soil type or condition, even though this is a fundamental resource within agricultural systems. This is partly because the interpretation of research at the scientific/ technological level makes it difficult and complicated for direct links to be made between the concept of sustainability and policy mechanisms. In Chapter 1 it was suggested that these links would be facilitated by a series of interfaces which have been referred to throughout the thesis. These interfaces are represented by roman numerals in Figure 10.1.

The specific interfaces that have been developed in this thesis are:-

*I. The interpretation of the concept of sustainability at an agroecosystem level.*

The soil system is argued to be a fundamental prerequisite for continued land based production. The large losses of organic structure due to the degree of human intervention in some agroecosystems is interpreted as an increase in vulnerability of those systems. Soil survey data was used in combination with a GIS to show that some arable dominated agroecosystems in the UK are potentially vulnerable to the continued use of inappropriate farming systems.

*II. The linking of agroecosystem processes to farmer's decision making.*

This interface was explored via two simple agroecosystem measures. Firstly, MOVEMOD illustrates a method of linking what the farmer does, to the amount of organic matter in the soil, which is argued to provide a long-term indicator of well-being within the agroecosystem. Secondly, soil invertebrate populations are explored as a more responsive agroecosystem measure that allows changes in cropping to be related to energy flows and functional diversity within that system. Although both measures have their weaknesses they contribute an understanding of how changes in the farmer's decisions about cropping practice can affect soil processes which are of fundamental importance within the productive agroecosystem.

*III. Linking decision making by the farmers and their perception of change to policy issues*

Understanding the economic and cultural system into which cropping innovations are to be introduced is of fundamental importance in the process of change. A study of the farming agenda illustrated that although financial implications of change are of primary importance to farmers, there are many other social, technical and cultural issues which aid or hamper the introduction of innovative cropping practices. Thus simply carrying out sophisticated financial analysis is unlikely to give the best indication of the potential response to a change in policy. A second phase of interviews suggested that the introduction of cropping systems which are seen to be outside the current farming ideology face considerable inertia. However, this is partly because the agricultural policy framework itself is perceived as being based on short-term agendas which appear to be continually changing.

## 10.3 A SUMMARY OF THE CONCLUSIONS ARISING FROM EACH OF THE SPECIFIC RESEARCH ACTIVITIES,

This section provides a summary of conclusions arising from individual research activities. These research activities are mapped numerically onto Figure 10.1.

### 10.3.1. The development of an (agro)ecosystem perspective within a sustainable systems framework

Increasingly sustainable agroecosystems are interpreted as those which can intercept as much if not more sunlight per unit area, whilst economizing the amounts of "external" nutrients used in the conversion of sunlight to a product useful to humans. The maintenance of agroecosystem structure is seen as a fundamental prerequisite in this process. However, many agricultural systems are poorly structured, both temporally and spatially, relying on a constant flow of external inputs to replace the connectiveness associated with natural systems. In some cases agricultural activity is impacting on the biophysical capital, (or structure), to such a degree that its maintenance as a productive resource is no longer guaranteed. The severity of the problem can be judged by the degree to which natural processes within a system have been altered by economically driven criteria. In many cases the latter leads to a reduction in the ability of a system to adapt to change, i.e a loss of options. The maintenance of options into the future is closely linked with increasingly sustainable pathways. The development of this (agro)ecosystem perspective, interpreting the effects of agricultural activity as a change in flows across a carbon or organic structure, provides a useful conceptualization within a sustainable systems framework.

### 10.3.2. Modelling the effects of agricultural activity on carbon\organic matter flows and structure as an indicator of change within the agroecosystem

To make progress along desirable pathways which maintain or increase future options there is a need to be able to monitor the effects of a multitude of changes in land use. This is problematic, and many of the current measures of the state of agroecosystems inform the scientific/technology agenda rather than provide information which is relevant to policy making. A modelling approach is used to highlight the difficulty of increasing soil organic matter within the constraints of current farming practice. Although organic matter provides a useful indicator of the present state of an agroecosystem its use as an indicator of change is limited because of the slow rates of change of this soil component on established arable farmland. Whereas only a small percentage of the soils of England and Wales contain very low levels of organic matter, Chapter 2 indicates that several regions could be vulnerable to soil organic matter depletion. In these areas it is appropriate to be aware of soil organic matter dynamics and to maintain this asset, at least at its current level. Appropriate agroecosystem management will involve closer consideration of cultivation regimes, the quantity and quality of organic material returned to the soil, and the rooting capabilities of crops in relation to the organic matter status of the soil. The model demonstrates that, once depleted, organic matter is a resource that is replaced slowly. If its depletion leads to the loss of the soil itself, it is unlikely that the land will remain productive into the future.

### 10.3.3. The investigation and use of simple invertebrate bodysize analysis as a representative measure of agroecosystem well-being

In tandem with the study of soil organic matter and the construction of MOVEMOD, investigations were being undertaken into the use of soil invertebrates as indicators of agroecosystem change. The hypotheses that bodysize measures can be used in wider scale monitoring is supported by the bodysize experiments conducted at Rothamsted and on a silvoarable site near Milton Keynes, and supplementary information is potentially available from their use. In combination with measures of total organic content and other physical and chemical parameters, bodysize measures could provide a tool to assess changes in condition of UK soils. Assessing change in soil condition under innovative cropping at both the local and national level is fundamental in the monitoring of change to increasingly sustainable systems.

### 10.3.4. Assessing the impact of silvoarable agroforestry systems on agroecosystem processes

From a review of the literature it is concluded that agroforestry has several benefits with respect to the attributes of increasingly sustainable systems, i.e increased interception of incoming radiation, conserving of soil resources. It has benefits in terms of agroecosystem structure, by mixing annual and perennial crops, increasing the volume of habitat and organic structure. The additional return of plant debris through the roots and leaf fall suggests that these mixed systems could also contribute to the soil organic matter in situations where it is depleted.

The two indicators of agroecosystem processes investigated in Chapters 4 and 5, (i.e. soil organic matter and invertebrate bodysize), are used to assess changes within the soil system on an arable field in which a silvoarable agroforestry trial had been initiated in March 1988. At the time of sampling the system had been established for just over four years. The results of these experiments demonstrated that in the short period since their establishment the silvoarable system has had an effect on the soil processes.

### 10.3.5. Gaining a realistic interpretation of the current farming agenda

In Chapter 7 the research process changes from an agroecosystem approach to an assessment of the viability of change within a socio economic framework. It is argued that the implementation of change in agricultural systems is a complicated process which would be facilitated if a better understanding of the system into which change is being introduced is obtained. Further, access to ecologically sustainable options is dependent on their acceptability and viability to farmers. The elicitation technique adopted for interviewing farmers provided a useful insight into the farming agenda, and one which is not pre-empted by restrictive questioning. This supplied a rich source of material to develop themes within the research. This elicitation technique is most appropriately used within a wider research framework which provides quantitative information about changes within the natural system, i.e the soil, as well as qualitative information about farmer's decision making.

### 10.3.6. The economic, social and technical evaluation of issues surrounding the uptake of agroforestry on UK farms

An economic, social and technical evaluation of silvoarable agroforestry was undertaken using a financial model and a second series of interviews. Although these systems can be shown to financially viable, the interviews with farmers questioned their potential uptake. Technical problems associated with machinery use and cultivation were numerous, and the lack of knowledge associated with agronomic issues, for instance to do with nutrients and sprays, raised concern. It can be concluded that this type of agroforestry does not fit in well with current arable farming systems in the UK, and although farmers in general were interested in alternative production systems they did not see silvoarable systems as a viable alternative to conventional cropping. It is concluded that unless a radical change in agricultural policy intervention takes place, silvoarable agroforestry will be confined to specialist uses.

## 10.4 THE RESEARCH APPROACH,

Technology and agricultural production have made huge leaps since the last world war, bringing us greater food security as an island nation than at any time in the recent past. This thesis did not set out to be highly critical of these advances, only to question how the most suitable pathways into the future may be identified, not only for our own generation but for those that follow. It is recognised from the outset that the future is inherently uncertain, although in the words of Spedding (1991),

*"Our inability to predict the future does not release us of our responsibility for thinking about it."*

This thinking about the future is embedded within the concept of sustainability. No attempt has been made to place a rigourous definition upon what is or is not "the sustainable system", nor is a "sustainable endstate" envisaged. However, it is not enough to simply state that which is unsustainable and it has been recognised that to make any research progress boundaries and broad goals need to be adopted. Therefore broad attributes towards which it would be desirable for farming systems to progress have been outlined. The need to increase or at least maintain the interception of solar radiation for the procurement of food, energy and fibre is seen as one such desirable attribute. Another recognises that in undertaking this interception of the sun's radiation agricultural production needs to be as resource conserving as possible, both in terms of imported nutrients and energy but also with respect to the soil itself.

Research concerning sustainable agriculture is often linked to a multidisciplinary approach, (Lockeretz 1991), and this piece of research has necessarily tried to emulate this type of methodology. For the individual this inevitably leads to problems. The need for breadth within the research compromises its depth in certain disciplines. This not only leaves a feeling that it would have been interesting to pursue various activities further, but exposes the individual to criticism from the disciplinary specialist. Daly and Cobb (1989) express the difficulty of pursuing this type of research effectively where the departmental organization of the university is determinative and where one's status depends on one's contribution to a particular discipline.

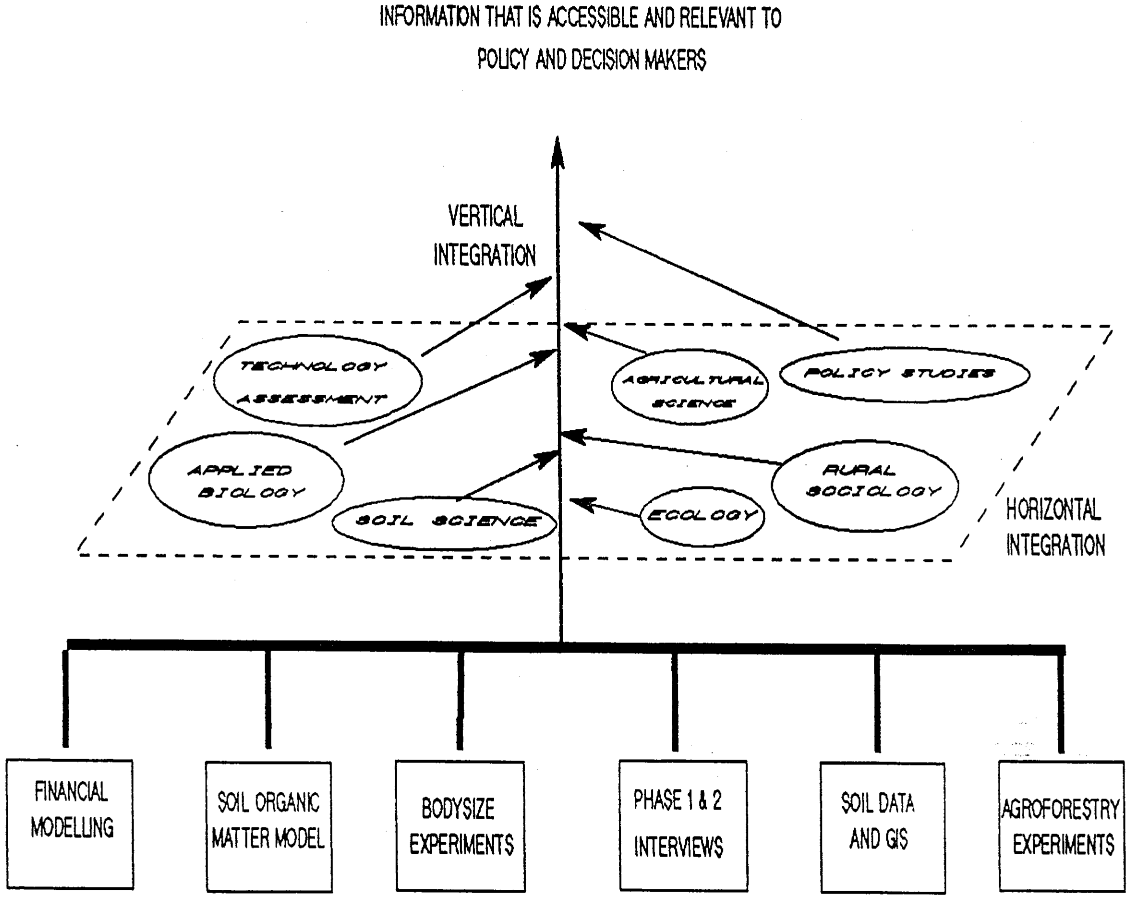
In addition to what is referred to here as a "horizontal integration" of differing disciplines, research in a sustainable systems framework requires a "vertical integration" to enable the presentation and interpretation of information derived from scientific or fieldwork at various decision making levels. Figure 10.2 provides a simple conceptualization of this vertical and horizontal structure.

The integrative research approach adopted in this thesis offers a single configuration of research activities that demonstrates linkages between several disciplines, (horizontal integration) and provides the vertical integration between science in its broadest sense and policy. The disciplines that form the basis for this integrated research approach are only one combination which demonstrate a methodology for linking the concept of sustainability to the need for policy relevant information. Lockeretz (1991) provides an excellent debate on the use of multidisciplinary research in sustainable agriculture, and suggests that,

*" An overly narrow range of disciplines is easier to change than an overly narrow scientific imagination."*

This suggests that it is the ability to conceptualize and synthesis new viewpoints that is as important, if not more so, than the range or mix of disciplines that are associated with a research project. In this thesis the disciplines with which the research process is

Figure 10.2 Conceptualization of the integrative research approach,



associated have not been "chosen" because they are seen as necessary for research within a sustainable systems framework, but because their integration was thought to enable the demonstration of the interfaces discussed earlier.

Larger research projects are exploring similar approaches. For instance the Archaeomedes research project being undertaken at the International Ecotechnology Research Centre, Cranfield concerns the threat to the sustainability of fragile ecosystems, and has the stated aim,

*" to produce policy -relevant methods of diagnosis and analysis of imminent and potential threats to the environment, involving loss of sustainability through land degradation and desertification."*

Overall this study suggests that the use of an integrative approach to assess changes in agricultural systems needs to embody at least four aspects,

1. An understanding of the physical system,

2. An understanding of the socio-economic system,

3. Measurement of the effects of change on the agroecosystem,

4. The financial, economic and social implications of change.

This methodological approach to the assessment of change may apply equally as well to a wide variety of socially necessary production systems that interact with or use part of natural systems, i.e. energy production, water utilization etc. Thus it is no longer good enough to assess innovations purely on their economic or financial viability. This is particularly true within the highly interventionist agricultural systems that are common place within the developed world. Although the future is uncertain, decisions necessarily need taking based on the most appropriate information available. This should include information on the effects of change on physical, social and economic systems.

Unfortunately the presentation of data from multiple sources in both qualitative and quantitative form is unlikely to make the task of the actual decision maker any easier, although it will hopefully mean the decision making process is better informed. However, as with the design of a thesis, little progress can be made unless objectives are clearly defined. Agricultural policy appears to lack any long-term positive goals for the industry to aim for. Constant change and uncertainty is forcing farming to follow the ebb and flow of political and economic wrangling rather than to fit in with social and physical systems in which it operates. This has meant that farming systems have become aligned with an economic agenda in which many farms have become highly specialized and capitalized units which are becoming increasingly inflexible to change.

From the above discussion three particular areas of importance arise:

1. The setting of some form of broad longer term attributes, (as opposed to narrowly defined states), toward which it would be desirable for (agricultural) systems to evolve,

2. The need to broaden the width of research assessment so that more information can be filtered into the decision making process,

3. The maintenance of flexibility and adaptability and the types of policy that may enable increased options in the future.

## 10.5 BROAD LONG TERM OBJECTIVES, A PATHWAYS APPROACH

In Chapters 1 and 2 the idea of the sustainable system was rejected in favour of what has been referred to as pathways of development that increase the degree of sustainability of a system. Figure 1.4 conceptualises these pathways but recognises that broad desirable attributes need to be envisaged toward which systems can evolve.

In many managed systems these broad attributes, or what could be referred to as a vision for the future appear to be lacking. In agricultural systems many of the aims of current policy appear contradictory and confusing not only to farmers but for those involved in the development of the industry, i.e. researchers, consultants and decision makers. This has lead to debates elsewhere about the need for long-term objectives or strategies to be set. These objectives could form part of a wider National Land Use Strategy, (see Green 1993). Unfortunately this is in contrast to the current political philosophy, but Green argues that because of the likelihood that agriculture will need continued support, and the need to equate ecological and environmental management with economic efficiency may conspire to favour such objectives.

If such objectives are to be set these should be based upon desirable attributes and not desired states. These attributes should be related to long-term resource efficiency, particularly the rates of use of non-renewables, and not purely related to economic efficiency. However, research initially needs reorientating from an approach which assumes what a desirable pathway is and concentrates research around it, to a research approach which identifies what the possible pathways are. These pathways are linked to a desire to maintain options into the future so that a given system can remain responsive to change. In the words of Fresco and Kroonenburg (1992),

*"... in order to be sustainable, land use must display a dynamic response to changing ecological and socioeconomic conditions"*

The possibility exists that policy itself has to qualitatively change from attempts to achieve certain states, towards goals which are related to attributes and abilities of technological and natural/human activities that can facilitate increasingly sustainable systems. This raises questions about how suitable pathways can be identified and how information from a diverse range of sources can be used in both the identification of desirable pathways, but also in the recording and monitoring of the change process.

## 10.6 INFORMATION AND DECISION MAKING, THE SCIENCE POLICY AGENDA

The filtering of information into the decision making process means that methodologies for synthesizing research and data from a range of disciplines are required. This thesis offers one example of an individual's interpretation of how this information can be synthesized. No attempt is made to suggest that this is the only method of carrying out research within a sustainable systems framework, or the specific disciplines that are required. However, it is necessary to have a person or a team that are capable of conceptualizing linkages and interfaces in addition to those who prefer to work within disciplinary specialisms. Bonnen (1986) comments on the lessons for science policy with respect to American agriculture. He is critical of many colleges that have become collections of disciplinary researchers who are unable to address the problems of future agriculture effectively. He sees part of the role of social science research as providing an integrated focus upon the agenda of science and that of the problems in agriculture. This supports the arguments of Newby (1992) that social science is integral and not merely marginal in the understanding of how scientific excellence and technological innovation may lead to economic and social well being.

Often when attempts are made to locate scientific research, (and thus the data and output from it), into a wider social, economic and cultural framework, the latter is seen as a "bolt on" part of the research design rather than an integral part of it. Therefore the primary aim of a considerable amount of scientifically orientated research is not in the presentation of policy relevant information. Other agendas for this research, (i.e testing theories etc), provide the main driving force which means that even if results do have relevance to policy, it is not presented or communicated in a useful manner. Paradoxically many scientific research projects are now having to pay more attention to their policy relevance to acquire funding, although this provides no guarantee that results and information pertaining from this research can be filtered into a broader policy relevant research framework.

A question arising from this particular research project, which has a broadly scientific base, is whether the overall research design and its operationalization provides information that is policy relevant. It is argued that it does. It not only illustrates mechanisms through which information about the effects of changes in cropping induced by the farmer can effect the ecological sustainability of the system, but also comments on the mechanisms associated with desired change. Consequently it provides relevant information on the desirability of change to agroforestry systems, the viability of change, and begins to question the actual transition process.

## 10.7 OPTION RETENTION AND FLEXIBILITY, THE CONCEPT OF SUSTAINABILITY,

In the previous sections the notion of desirable pathways of change has been discussed. This relies on the monitoring of the change process such that it is possible to question whether it is increasing or decreasing the degree of sustainability within that system. This closely relates to the notions of adaptability and flexibility within a system, challenging research across a variety of disciplines to illustrate how these systems attributes can be assessed at a variety of levels. This thesis has argued that it is the methods through which the information pertaining from a number of research activities is integrated and used to inform the decision making process that is of importance. However, the overall picture produced from this approach may actually complicate the decision making process.

For instance the experimental work and theoretical analysis of silvoarable agroforestry suggested that it could increase the ecological diversity, and maintain options into the future with respect to soil productivity and energy interception. However, at the farm level the farmers themselves thought these systems could actually reduce flexibility because of the longer term production cycles associated with the trees, making it difficult for them to adapt to an ever changing policy environment. This scepticism was not voiced simply because the farmers thought planning over the long-term was inherently wrong, only that the current policy regime, based on short-term economic criteria and a very volatile support framework made any long-term commitment extremely risky.

Thus it could be argued that current agricultural policy is actually at odds with a sustainable systems ideology. Of equal concern is the increasing degree of specialization that current policy is engendering as the industry strives to minimize fixed costs. This not only means that the general infrastructure of farms becomes less accommodating of change, but suggests that the knowledge base of individual farmers is becoming more specialized. Interestingly a recent article in the popular press highlights this issue, (Talking Point, Farmer's Weekly 2nd July 1993). A mixed farmer extols the virtues of being able to talk to any other farmer about the industry, but asks the question,

*"How long will it be before an arable and dairy farmer need an interpreter to speak with one another?"*

The above discussion raises questions about the hierarchical level at which adaptability needs to be maintained, i.e soil, field, farm, national etc. It is argued that the concept of sustainability and the notion of adaptability within the agroecosystem are closely linked. However, it is unlikely that adaptability at the level of agroecosystem processes can be maintained unless the farmers themselves have the ability to demonstrate adaptive behaviour. This in itself is governed to a large degree by the policy framework in which they operate, and raises questions about how policy mechanisms can allow for or encourage adaptive behaviour within farming systems.

A crucial question arising from this project concerns the wider applicability of research into "agricultural sustainability". It is suggested that substantive research needs to be carried out to explore the use of this type of research approach when applied to other production systems which interact with the natural environment. These could include a wide range of cropping systems and possibly other systems such as those associated with water and energy. These research projects will inevitably consist of teams of researchers, some of which will be disciplinary specialists. However there is also the need for individuals or small working groups that can conceptualize and explore interfaces within the research project, not only between disciplines but between research at different hierarchical levels.

Before these projects are initiated there may be the need for smaller exploratory projects to investigate both the physical and social systems to identify attributes associated with desirable pathways and to isolate mechanisms for recording and monitoring these attributes. This will target the main research and allow the collection and interpretation of data which can be used effectively to inform the decision making process. Further research work could be usefully undertaken to explore the handling, interpretation and presentation of data from a range of sources in a manner which can usefully inform the decision making process. This will involve the integration of quantitative and qualitative information arising from both physical and social systems research.

Finally, research associated with the concept of sustainability should highlight possible pathways into the future and identify the types of change which are conducive to these pathways and which maintain flexibility and adaptability within the system. If more information arising from this research is to be filtered into the decision making process it may be necessary to direct a greater proportion of funding at proposals in which the linking of scientific research to policy is an integral part of their design. This should not only enable a wider understanding of the concept of sustainability but ensure that decision making in production systems which interact with the natural environment is more aware of the future consequences of change.

## 10.8 THE FUTURE SUSTAINABILITY OF LAND BASED PRODUCTION,

In the introduction to his book on the Entropy Law and Economic progress, Georgescu-Rogen (1971) comments on the use of fossil fuels to maintain order, and more specifically as a resource from which food is produced. However, he is critical of this approach and speculates that at some point in the future man will have to reorientate his thinking to produce gasoline from corn. Less than 25 years after the publication of his book we are witnessing considerable interest in the cropping of land for energy, as well as other alternative cropping systems.

Fossil fuels, and compounds derived from them have allowed our food production needs to be met from an ever decreasing area of land. It is these agroecosystems which have led many people to question the sustainability of agriculture. Whilst in the medium to long-term the optimist may predict that it is possible for the external inputs into agriculture to be derived from sources other than fossil fuels, the replacement of agroecosystem structure due to the use of inappropriate farming systems may not be as foreseeable.

Approximately 750000 hectares of mainly arable land presently lies idle in the UK, an opportunity cost of 1.2 x $10^6$ GJ in terms of wasted potential energy interception, (adapted from Transeau in Colinvaux 1980). Conversely to maintain this idle land, input use is concentrated onto the remaining land area to ensure "economically efficient production". This is at a time when accessible reserves of oil in western Europe are estimated to be only 18 billion barrels. At current extraction rates this will last about 13 years. Against this background farming in the UK continues to rely on many inputs derived directly from these non-renewable resources. Further, the need to constantly cut fixed costs is creating larger farms, which are highly mechanised resulting in a reduction of farm labour and a simplification in the growing systems. In Chapter 1 the production benefits of these systems was viewed in the context of whether these systems can be sustained in the long-term.

In contrast, the vision within this thesis is of productive agroecosystems that are multitiered, well-connected structures that make full use of applied nutrients and incoming radiation for the procurement of food, energy and fibre. Paradoxically these systems do exist in parts of the so called *developing* world. However, to make use of technological innovations and in response to economic and political agendas farming systems in much of the developed world have evolved along a separate path. This has culminated in high yielding systems which are open with respect to nutrient flows, and spatially simplistic.

One part of this thesis has investigated a relatively short step toward this vision of multitiered connected structures and found considerable inertia facing the adoption of these systems. Agroforestry is only one form of intercropping in which woody and non-woody crops are grown in close association. Many other forms of intercropping exist and these can offer a range of ecological benefits, (Vandermeer 1988). Intercropping of arable crops is not commonly practiced in the UK except for specialist purposes. For instance sugar beet is sometimes drilled into spring barley to afford the young sugar beet plants some protection from windblow, (the barley is subsequently burnt off with chemicals). However, research into arable intercropping systems is being undertaken in the UK, (Bulson 1991), and this type of cropping may provide benefits in the future.

Other projects are being undertaken on the fringes of conventional agricultural research. The organic growing organisations fund research into alternative farming systems and there is some interest in more extensive farming systems. For instance the Agricultural and Food Research Council, (AFRC), is undertaking research into less intensive farming and the environment, (the LIFE project), which was established in 1989. This project aims to minimize off farm inputs and to make full use of natural regulatory mechanisms which are seen as an integral part of conserving flora, fauna and landscape.

European Community backing is being provided through a pan-European project, LEAF, (Linking Environment And Farming). The aims of the project are to develop and promote the principles and application of Integrated Crop Management in such a way to help farmers positively address the relationship between farming and the environment. This is similar to research on the continent into integrated farming systems, (El Titi 1992) and that in North America in sustainable agriculture, (MacRae 1990). Although these systems may offer a potential pathway to increasingly sustainable systems, they suffer from similar drawbacks to agroforestry in that they do not fit in with mainstream agricultural ideology.

Continued research and development will gradually raise the profile of various alternative systems, and in particular the knowledge associated with the growing of spatially mixed crops. As the costs of inputs rises, or the price of energy increases the feasibility of many alternative systems may be enhanced, in some cases providing a shift toward increasingly sustainable land based production systems. However, the level of support for these alternative farming practices raises questions as to whether progress can be made toward an increasingly sustainable future in small gradual steps, or whether change will progress in relative leaps in response to external pressure. A good example of the latter was the increased research into sustainable agriculture in the USA following the oil crisis of 1973.

The recent CAP reforms offered little to suggest that policy makers are actively encouraging small but significant steps towards increasingly sustainable farming systems. The increased complexity of agricultural policy following the recent reforms is only likely to reinforce existing practice. However, the possibility exists that production of energy from land will be encouraged either as annual cropping on rotational set-aside or the growth of energy crops, notably trees on non-rotational set-aside. The latter could be a step in the right direction as it reorientates thinking at all levels towards the growing of alternative crops, the possibility of growing energy crops as well as establishing a wider knowledge base associated with the growing of a non-pastoral perennial crops on farmland. If this occurs it will be an incidental step forward rather than a planned one, and is perhaps indicative of the nature of change that can be expected toward increasingly sustainable systems.

GLOSSARY, ACRONYMS AND ABBREVIATIONS.

Abiotic : Non-living, non-organic

ADAS : Agricultural Development and Advisory Service

AFRC : Agricultural and Food Research Council

Arthropoda : Class of animal with joined feet

**Belgian Poplar Clones** : A number of hybrid poplar varieties bred in Belgium but recently introduced in the UK

Benthic : Pertaining from the deep ocean

Biosphere : Word traditionally used by biologist's for the living earth

Biota : Generic term meaning living creatures

**Boreal Forests** : Those situated in the northern hemisphere

**Brash up** : To remove smaller branches from standing or felled timber

Butt log : The biggest log cut from the base of a tree

CAP : Common Agricultural Policy

**Cation Exchange Capacity** : Concerned with the ability of a soil to exchange cations

Chaff : Remains of separated grain husk

**Chemical time-bombs** : The excessive release of harmful substances from soil or silt following a change in holding capacity possibly brought about by a change in acidity

CLA : Country Landowners Association

**Climax** : End result of developmental succession within ecological communities

Coppice : A area of trees grown for periodic cutting

**Cultivation window** : Period of time between harvest and the onset of winter conditions in which autumn drilling usually takes place.

Detritus : Broken down material, organic materials in the process of decomposition

**Dutch Elm Disease** : Deadly disease of particularly the English Elm which spread quickly during the 1960's and 70's to kill the majority of this native hedgerow and parkland tree.

**Enchytraeid** : Type of soil dwelling worm which tends to thrive in soils of low agricultural value

**"Excel"** : Spreadsheet package marketed by Microsoft

**Field capacity** : Is the state of a soil following saturation and subsequent natural drainage

**Guano** : A valuable manure formed chiefly from the excrement of sea-fowl. Imported into the UK mainly in the last century from South America and the Pacific

**Gross Margin** : Total Output from an enterprise minus the variable costs of production

**Gross Primary Production** : Total productivity associated with an ecosystem

**Hemicellulose** : Structural polysaccharides associated with plants

**Heterotrophic** : Organisms which derive at least some of their energy and carbon demand from preformed organic nutrients, i.e. fungi, protozoa, bacteria and all animals

**Horizon** : Horizontal layers of differing material or structure within soils. In undisturbed soils there are usually 3 or 4 horizons

**Horn and corn** : Traditional expression for the mixing cattle or animal enterprises with arable cropping

**Humification** : The decomposition process which changes recognizable plant material into an organic humus whose plant origin is not easily recognisable.

**Intercropping** : The growing of 2 or more crops simultaneously on the same area of land

**Labile** : Unstable and easily decomposed

**Lignin** : Structural material in plants associated with polysaccharides

**Lime** : Calcite based material used for raising the pH of acidic soils

**Loamy soils** : Soils whose predominant constituent is of a silt origin

**MAFF** : Ministry of Agriculture, Food and Fisheries

**Monoculturalistic** : Term applied farming systems in which large areas of land are growing the same type of crop

**Microclimate** : Differing conditions of moisture, windspeed, and sunshine produced in the locality of crops

**Mulch** : A layer on the soil surface of dead plant material or other form of artificial covering

**Nematode** : Pertaining to the class of small parasitic worms, often called eelworms

**Net Margin** : Gross Margin of an enterprise minus fixed costs associated with production

**Net Primary Production** : Is the Gross Primary Production minus that production which goes into the maintenance of existing ecosystem structure

**NFU** : National Farmers Union:

**Pathogen** : Generic name given to disease causing organisms

**Pedon** : American Classification of the small volume that can represent soil at a given site

**Phylum** : A primary group consisting of related organisms descended from a common form

**Plough pan** : A layer of compacted soil below plough depth caused by the use of machinery, often in appropriate conditions

**Poplar peeling** : A technique in which lathes are used to rotary peel poplar logs into thin sheets of laminar

**Protozoa** : The lowest division of the animal kingdom, comprising those consisting of a single cell or a group of cells not differentiated into two or more tissues

**Radiocarbon dating** : Use of $^{14}C$ isotope which occurs naturally to date organic materials

**Residual chemicals** : Chemicals applied to the soil which carry on acting for a period following application

**Rotifers** : A group of minute aquatic animals with swimming organs, usually appearing to have a rotary movement

**Saporophytic** : A form of nutrition in which dead organic matter is digested externally and the products absorbed, (eg Fungi)

**Set-aside** : Name given to the practice of encouraging excess land out of production

**Shifting cultivation** : Typified by a short period of cultivation followed by a long period of forest or savannah fallow

**Silvoarable** : The practice of combining trees and conventional arable crops on the same piece of land

**Silvopastoral** : The practice of actively combining tree systems into pastoral situations on the same piece of land

**Soil Fauna** : Soil dwelling animals

**Soil Flora** : Organisms living within the soil which belong to the plant kingdom

**Soil Moisture Deficit** : The amount of water needed to return an area of land to field capacity

**Soil Profile** : Is a vertical face of a soil pit which typically contains adjacent horizons which are visually different

**Sorghum** : Kinds of grass including Millet

**Taxon** : A particular group or class within the soil

**TFA** : Tenant Farmers Association

**Trophic** : Pertaining to nutrition

"**Turbobasic**" : A simple computer language, a derivative of "Basic"

**Understory** : The crop which is grown beneath the trees in an agroforestry system

**Virgin Land** : Apparently previously uncultivated soil

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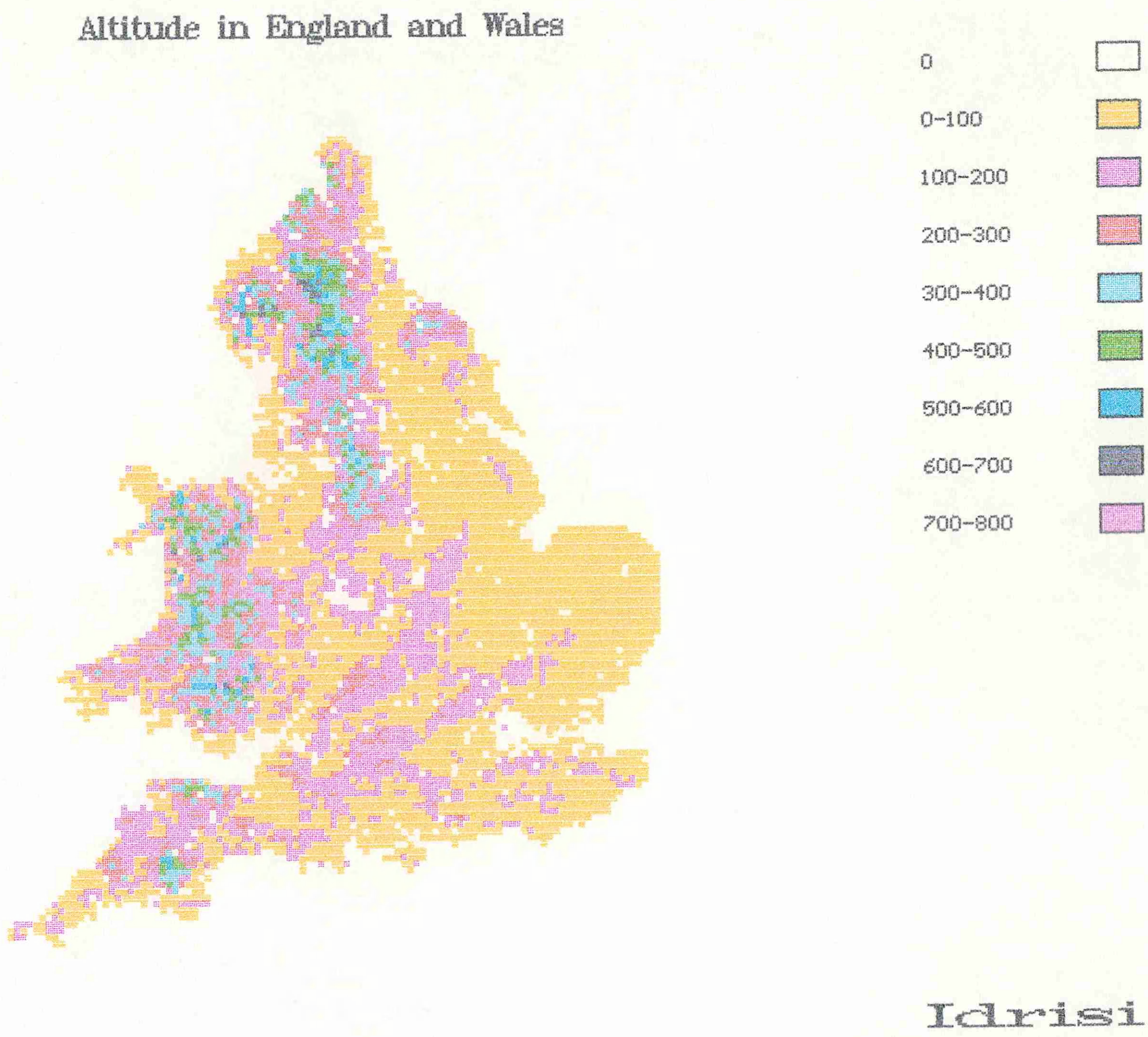
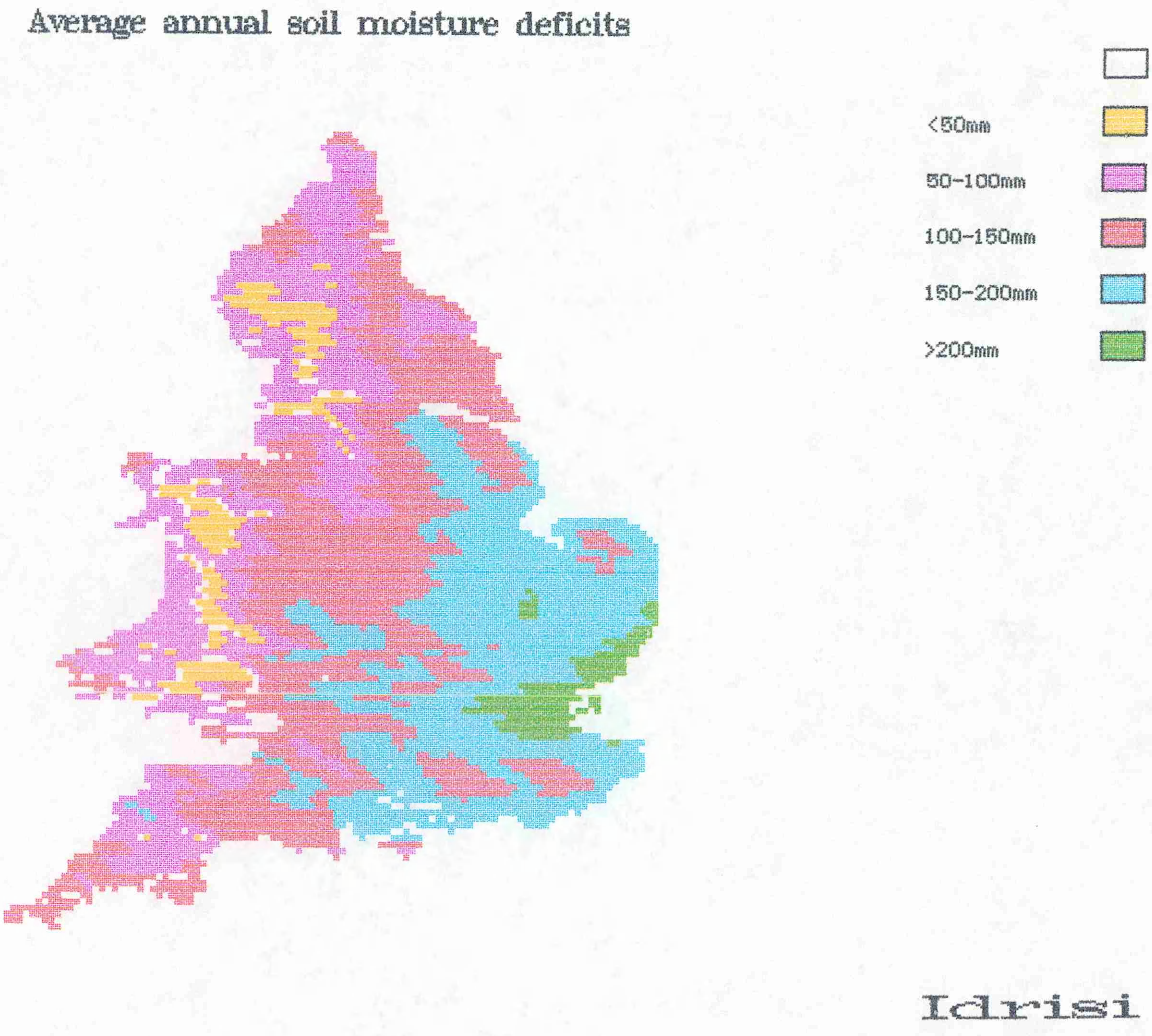
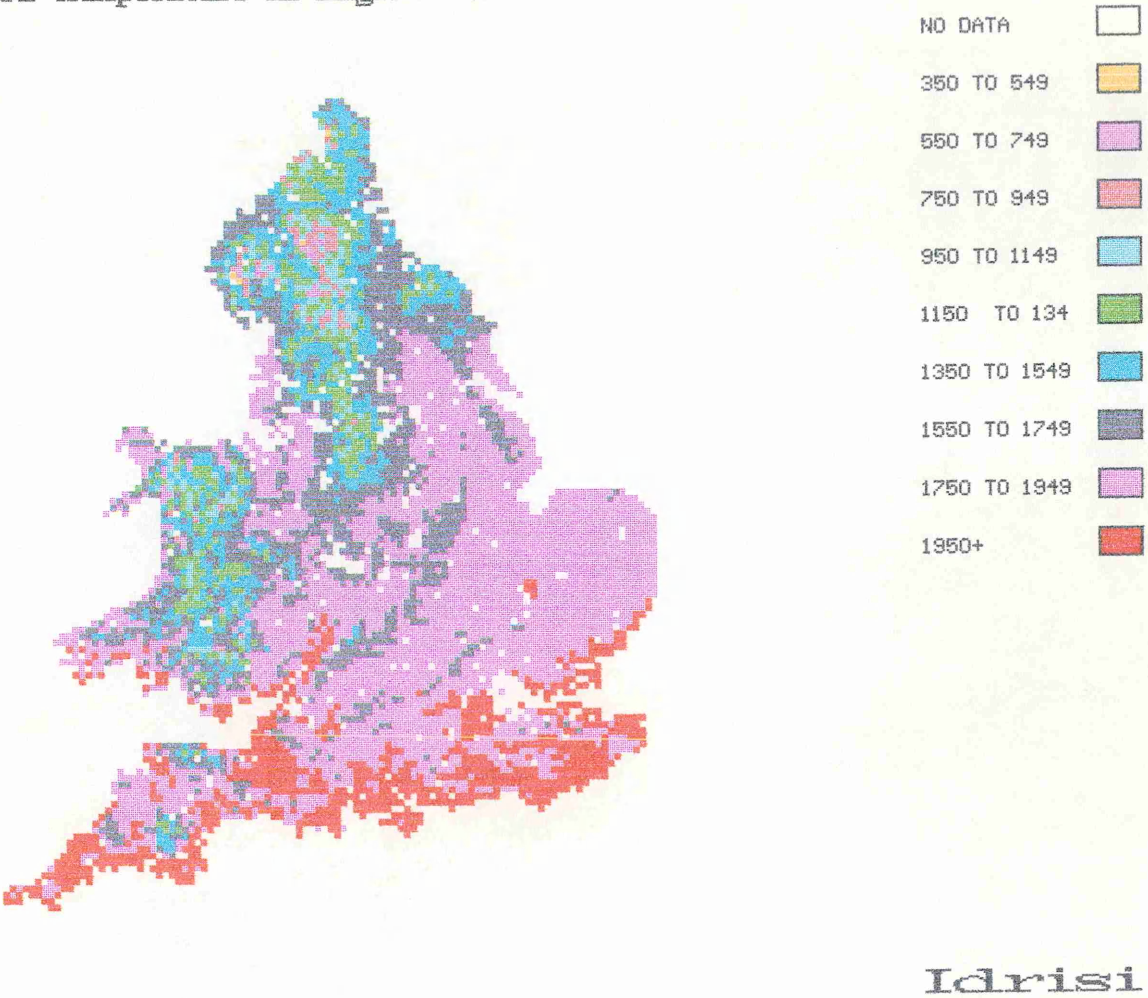
APPENDIX 1 : MAPS FOR ALTITUDE, SOIL MOISTURE AND ACCUMULATED TEMPERATURE USED IN THE GENERATION OF THE SOIL CARBON TURNOVER MAP.




Average annual soil moisture deficits
<50mm
50-100mm
100-150mm
150-200mm
>200mm
Idrisi

ccumulated temperature in England and Wales above 5.6C



APPENDIX 2 : A COPY OF THE TURBOBASIC PROGRAMME FOR MOVEMOD

```
PRINT "WELCOME TO MOVMOD. THIS IS YEAR 0, MONTH 0"
PRINT "please press the return bar after inputing each value"
DIM r(1000)
DIM p(1000)
az = 0
INPUT "How many years is the model to run for?=", ay
PRINT "Soil humus is the amount of very resistant organic matter. The
A layer is the cultivated profile of the soil"
INPUT "Soil humus in A, in kgs/ha=", ab(az)
INPUT "Dynamic organic matter in A, in kgs/ha =", x(az)
PRINT "The B layer is the sub surface layer below the normal
cultivation depth"
INPUT "Soil humus in B, in kgs/ha=", ae(az)
INPUT "Dynamic organic matter in B, in kgs/ha=", aj(az)
INPUT "Do you want to select cultivation and cropping each year?
(yes=1/no=2)",aaa
IF aaa=2 then
INPUT "Cultivation factor for macrobiomass, 1=no cult, 0.5=heavy
cult.=?", m
INPUT "Cultivation factor for decomposition, 1=heavy cult, 0.3 =no
cult=?", n
INPUT "Input in litter and stubble, in kgs/ha?=", e
INPUT "Quality of litter and stubble?, 0.9 is high quality, 0.1 is low
quality=", c
INPUT "Input in root material?=", am
end if
k(az)=100 rem surface litter
y(az)=200 rem initial humus formed
o(az)=1 rem litter moved to A
l(az)=(ab(az)+x(az)+k(az))*.002 rem macrobiomass
PRINT "Macrobiomass in the soil, kgs/ha="; l(az)
ac(az)=12 rem initial om moved to b
h(az)=(x(az)+ab(az))/25000 rem soil om in A in month 0
i(az)=(aj(az)+ae(az))/25000 rem soil om in B in month 0
PRINT "Total OM % in A profile in month 0 is"; h(az)
PRINT "Total OM % in B profile in month 0 is"; i(az)
ax = 0

OPEN "a:\oma.xls" FOR OUTPUT AS £1
 WRITE £1, "OM in A"

OPEN "a:\omb.xls" FOR OUTPUT AS £2
 WRITE £2, "OM IN B"

OPEN "a:\macro.xls" FOR OUTPUT AS £3
 WRITE £3, "macrobiomass"

open "a:\surface.xls" for output  as £4
 write £4, "surface"
DO UNTIL az = ay * 12
   az = az + 1
PRINT "THIS MONTH=", az
```

```
IF (az - 1) / 12 = INT((az - 1) / 12) THEN
if aaa=1 then
INPUT "Cultivation factor for macrobiomass, 1=no cult, 0.5=heavy
cult.=?", m(az)
INPUT "Cultivation factor for decomposition, 1=heavy cult, 0.3 =no
cult=?", n
INPUT "Input in litter and stubble, in kgs/ha?=", e(az)
INPUT "Quality of litter and stubble?, 0.9 is high quality, 0.1 is low
quality=", c
INPUT "Input in root material?=", am(az)
ax = (az - 1) / 12
end if
end if
IF (az - 1) / 12 = INT((az - 1) / 12) THEN
if aaa=2 then
m(az)=m
e(az)=e
am(az)=am
ax=(az-1)/12
end if
end if
PRINT "This is year", ax
IF (az - 1) / 12 <> INT((az - 1) / 12) THEN
m(az) = 1
e(az) = 0
END IF

LET p((ax * 12) + 1) = 16.1
LET p((ax * 12) + 2) = 14.2
let p((ax*12)+3)=10.7 rem p average monthly temperature
LET p((ax * 12) + 4) = 6.4
LET p((ax * 12) + 5) = 4
LET p((ax * 12) + 6) = 3
LET p((ax * 12) + 7) = 3.4
LET p((ax * 12) + 8) = 5.7
LET p((ax * 12) + 9) = 8.4
LET p((ax * 12) + 10) = 11.5
LET p((ax * 12) + 11) = 14.6
LET p((ax * 12) + 12) = 16.1

Let r((ax*12)+1)=42 rem r's are soil moisture deficit
LET r((ax * 12) + 2) = 40
LET r((ax * 12) + 3) = 28
LET r((ax * 12) + 4) = 3
LET r((ax * 12) + 5) = 0
LET r((ax * 12) + 6) = 0
LET r((ax * 12) + 7) = 0
LET r((ax * 12) + 8) = 0
LET r((ax * 12) + 9) = 0
LET r((ax * 12) + 10) = 0
LET r((ax * 12) + 11) = 15
LET r((ax * 12) + 12) = 34
q(az)=47.9/(1+2.718^(106/(p(az)+18.3))) rem q is temp mod fact
IF r(az) > 20 THEN s(az) = 1 - ((r(az) - 20) * .03)
```

```
if r(az)<=20 then s(az)=1 rem s is the moist mod fact
t(az)=s(az)*q(az) rem t is the temp moist mod fact
l(az) = ((5 * l(az - 1) + ((k(az-1) + x(az - 1) + ab(az - 1)) * .002))
/ 6) * m(az)
 PRINT "Macrobiomass in soil is", l(az)
if m(az)<1 then o(az)=k(az-1)    rem o is litter to A
IF m(az) = 1 THEN IF k(az-1) > l(az) * t(az) / 2 THEN o(az) = l(az) *
t(az) * 4 / 12 ELSE o(az) = k(az-1) / 2
PRINT "Litter moved from the surface to a="; o(az)
IF m(az) < 1 THEN k(az) = k(az - 1) + e(az) - o(az)
IF m(az) = 1 THEN k(az) = k(az - 1) + e(az) - (2 * o(az))
PRINT "Surface litter at the end of month ="; k(az)
w(az)=.75*am(az) rem Roots in A
y(az) = (((w(az) + o(az)) * (c)) * (1 - 2.718 ^ (-10 / 12 * t(az))) +
(x(az - 1) + (w(az) + o(az)) * (1 - c)) * (1 - 2.718 ^ (-.43/ 12 *
t(az)))) * n / 4
PRINT "Humus formed in a ="; y(az)
ac(az) = (l(az) / 12) * .4
PRINT "OM moved from A to B"; ac(az)
x(az)=(w(az)+o(az)+x(az-1))-(y(az)*4)-(ac(az)*2) rem x is the dynamic
OM in A
PRINT "Dynamic OM in A ="; x(az)
z(az) = (ab(az - 1) * (1 - 2.718 ^ (-.02 / 12 * t(az)))) * n
PRINT "Soil humus in A decomposed="; z(az)
ab(az) = ab(az - 1) + y(az) -(0.75*z(az))
PRINT "Soil humus in A ", ab(az)
v(az) = x(az) + ab(az)
PRINT "Total SOM in A="; v(az)
ag(az)=ae(az-1)*(1-2.718^(-.01/12*t(az))) rem ag is humus decomposed
in b
PRINT "Soil humus decomp in B="; ag(az)
ah(az)=am(az)*.25 rem ah is Roots in B
ai(az) = ((ah(az) * (c)) * (1 - 2.718 ^ (-5 / 12 * t(az))) + ((ah(az)
* (1 - c)) + ac(az) + aj(az - 1)) * (1 - 2.718 ^ (-.215/ 12 * t(az))))
/ 4
print "Humus formed in b="ai(az) rem ail is the humus formed in b
aj(az)=(aj(az-1)+ah(az)+ac(az))-(ai(az)*4) rem aj is resistent om in b
ae(az)=ae(az-1)+ai(az)-(0.75*ag(az)) rem ae is total amount of humus
in b
h(az)=(x(az)+ab(az))/25000 rem soil om in A % at end of month
i(az)=(aj(az)+ae(az))/25000 rem soil om in B % at end of month

PRINT "Total SOM % in A at the end of month=", h(az)
PRINT "Total SOM % in B at the end of month=", i(az)

WRITE £1, h(az)
WRITE £2, i(az)
WRITE £3, l(az)
WRITE £4, k(az)
LOOP
CLOSE 1
PRINT "end"
```

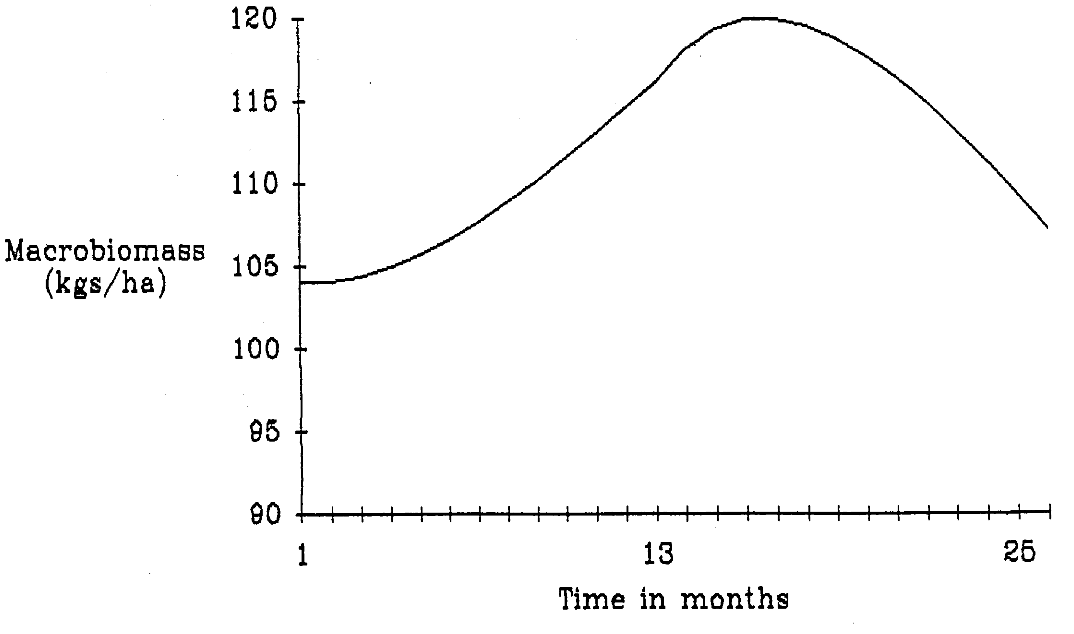
Additional information on the calculation of the weight of macrobiomass.

Within the soil the change in weight of the population of macrobiomass depends on both the birth and death of animals and the growth or weight change of existing animals. The model simplifies these processes by assuming the weight of macrobiomass will be about 0.2% of the overall weight of soil organic matter. This figure is taken from an estimation from Buol (1972). Despite this assumption the model uses an algorithm to fluctuate the population around this percentage figure.

At the end of any month it is assumed that a certain proportion of the macrobiomass from the previous month will have died. This proportion is taken as 16.6%, (1/6), which represents a total turnover of biomass every six months. This is a somewhat arbitrary figure as the life-span of the various animals in the macrobiomass category varies considerably.

Births and change in weight of living macrobiomass is assumed to be dependent on the organic matter within the soil and any surface residues, (i.e the food supply). The model calculates a figure for these by summing the organic matter in the previous month and assuming that each kilogram of organic matter has the capability of supporting 0.2% of its weight in macrobiomass. If cultivation takes place the population of macrobiomass can be reduced by upto a half depending on the severity of that cultivation. For instance ploughing may reduce the population by half whereas light discing may only reduce the population by 80%.

The graph below illustrates the change in weight of macrobiomass over a 24 month period in which the weight of organic matter varies from 50000kgs/ha to 65000kgs/ha and then back to 50000kgs/ha. Although this is a hypothetical situation it demonstrates that providing cultivation does not occur the fluctuation of the macrobiomass population as calculated by the model is limited.

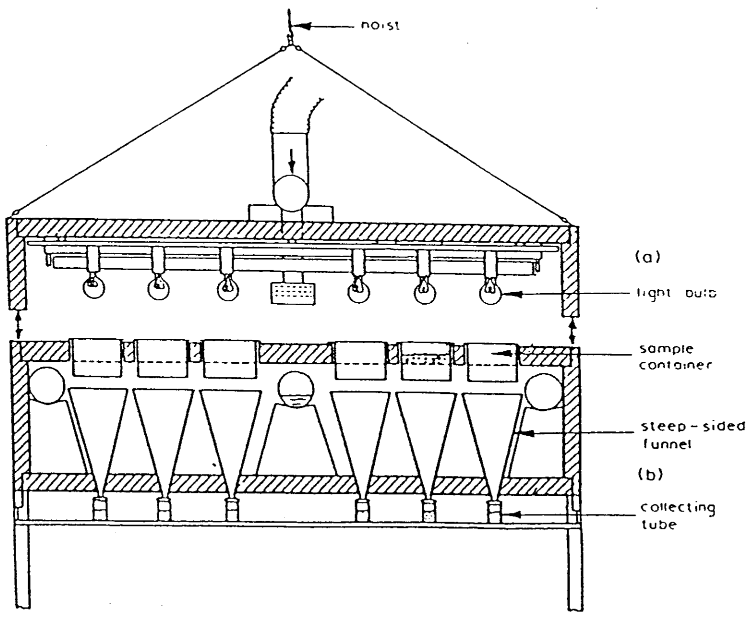


# APPENDIX 3: TULLGREN FUNNEL EXTRACTION: THEORY AND PRACTICE,

## 3.1A Extraction techniques,

Extraction of soil dwelling invertebrates relies on the taking of a number of soil units to a given depth, either in a random or defined pattern. The corer used to sample the Rothamsted plots extracted a core 6.35cm in diameter and 15cm deep. Soil invertebrates can be distributed in clumps necessitating the extraction of a number of cores on each sampling site. The wide range of soil invertebrates means that the equipment and experimental methods for their extraction from soil are numerous. Likewise each individual type of apparatus has been modified slightly to try and improve efficiency by different researchers. However, two broad categories of extraction technique exist; physical and dynamic. These are reviewed in detail by Edwards (1991). A particular type of dynamic extraction using tullgren funnels was selected for these experiments because of the relative ease with which the extraction of large numbers of soil samples can be achieved. Berlese (1905 in Edwards 1991) was the first to adopt the use of dry funnels to extract soil invertebrate, later modified in 1918 by *A.Tullgren*, using a heat source to drive the animals out of the soil sample. Figure 3.1A provides a simplified diagram of the bank of funnels at Rothamsted, and photos are provide to give a clearer impression.

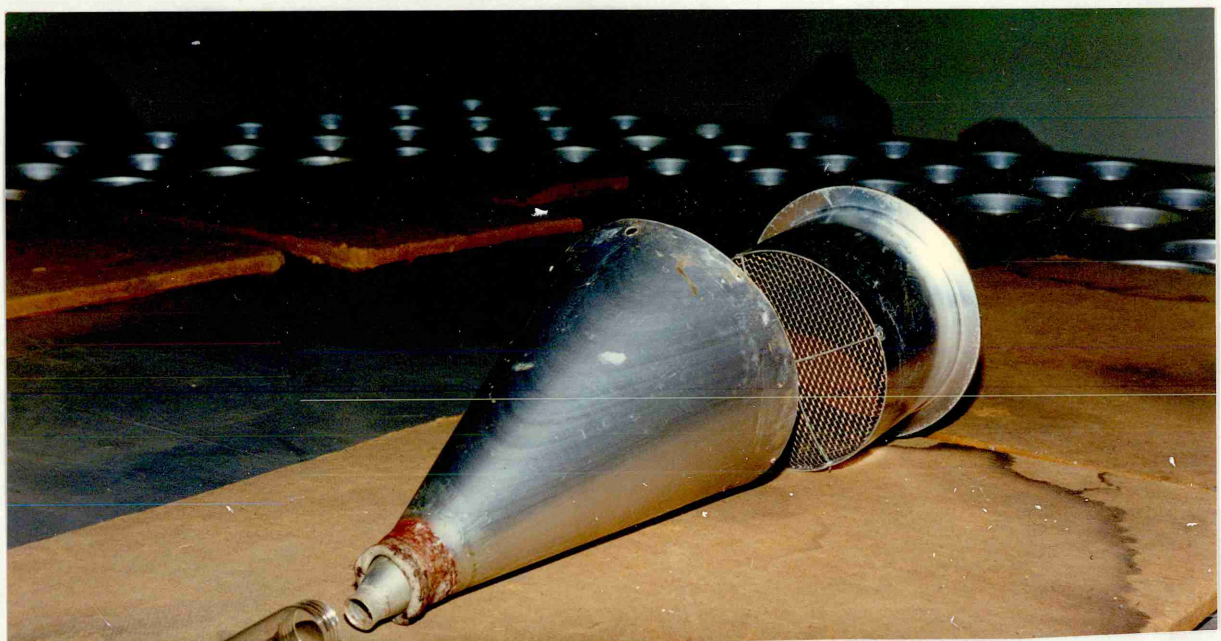
Figure 3.1A Diagrammatic representation of the Tullgren funnel apparatus at Rothamsted, (after Edwards 1991),

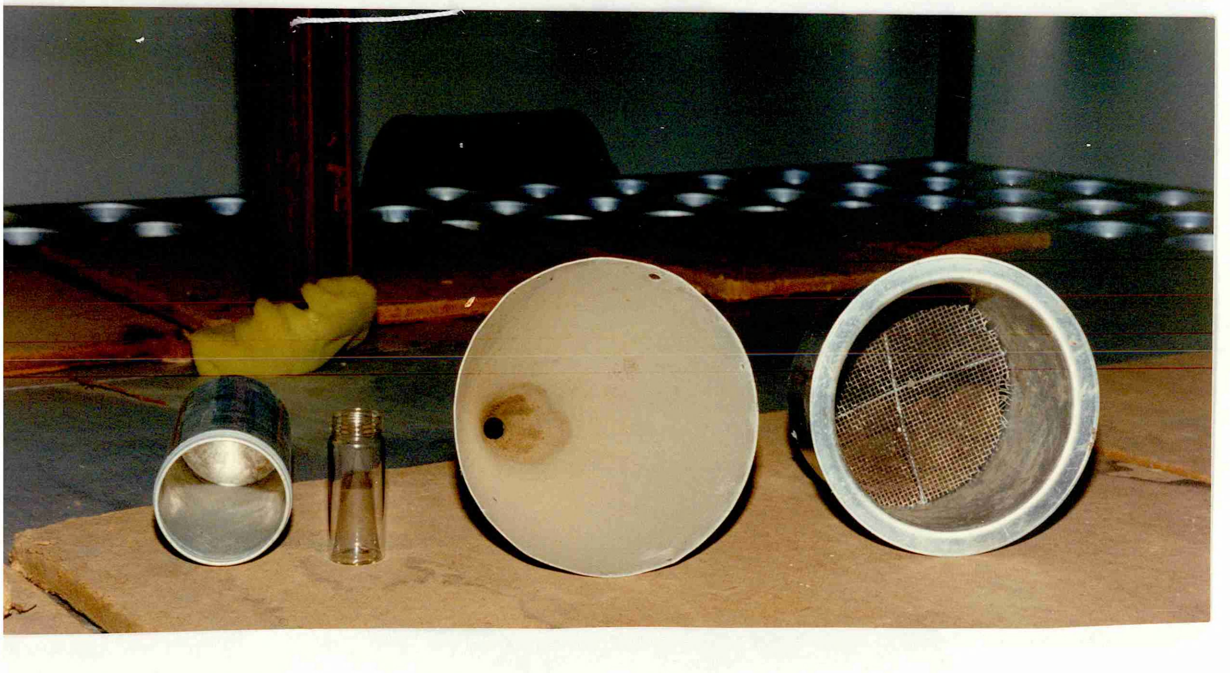



Rothamsted-modified Macfadyen high-gradient funnel. (a) Removable lid lifted by car jack; (b) main body of apparatus.

The apparatus consists of a number of funnels in an enclosed unit. Each soil sample is placed in a sieve, (in this case 1mm), above a funnel with a collecting jar beneath containing a preservative. When all the samples have been loaded into the unit the hoist is used to lower a bank of lightbulbs down, so that a bulb is close to each soil sample. Once the lights are switched on the inside of the unit and the top of each soil sample becomes hot, encouraging any motile animals within the soil to move downwards away from the heat. A temperature differential in the unit is maintained by a refrigeration unit within the room which ensures the bottom of the funnels is kept cooler, thus encouraging the animals to move. The circulation of air also reduces condensation within the funnels which can cause extraction problems. Chemicals can also be used to encourage the soil animals to move, and the author attempted a simple pilot experiment using naphthalene, (mothballs) which produced similar results. General care must be taken to ensure that a minimum of soil enters the collecting jars as this makes subsequent analysis more difficult. The funnels should be kept clean between experiments to ensure that animals cannot lodge on the sides of the funnels. The sides of the funnels are generally steep to ensure as many animals as possible are collected. The technique relies on the soil animals being able to move and therefore is no use where counts of dead animals need to be made. Care must also be taken to ensure the soil surface is not badly smeared as this can prevent the soil animals from leaving the soil.

In these experiments the soil samples were left in place for a week being checked daily to ensure the temperature differential is maintained, (20 to 30 C between the top and bottom of the funnel), and that all of the lightbulbs are functioning. Again during emptying of the equipment care must be taken to reduce the amount of soil that enters the collecting jars.





APPENDIX 4 : PHOTOGRAPHS OF THE MANOR FARM SITE, WOLVERTON, TAKEN IN THE SPRING OF 1993

# APPENDIX 5 : DETERMINATION OF OXIDISABLE ORGANIC MATTER

## Theory

The organic matter is oxidised using chromic acid. Heat is required for the oxidation and this can either be supplied externally by a bunsen, or internally by the dilution of concentrated sulphuric acid.

Using the latter method, somewhat less of the total organic matter is oxidised and this is thought to be an advantage, since the less active organic matter is not measured. (The less active organic matter does not play much part in agriculture).

Using this method, it is the percentage of organic carbon in the soil which is determined and this is multiplied by a conventional factor 1.724 to give the % organic matter. The use of this factor is based on the assumption that soil organic matter contains 58% carbon. To determine the % organic carbon, a known quantity of oxidising agent is added to a given amount of soil, after the oxidation is complete, the amount of unused oxidising agent is determined by back titration. Thus the amount of oxidising agent used can be found and therefore the amount of organic carbon.

## Reagents

a) Potassium Dichromate.1/6M solution (49.035 gm potassium dichromate in 1 litre distilled water).
b) Ferrous sulphate. 0.5M (140 gm ferrous sulphate dissolved in 0.25M sulphuric acid and made up to 1 litre).
c) Sulphuric acid. Specific gravity 1.84.
d) Orthophosphoric Acid. 85%
e) Indicator solution.
(Dissolve 0.25 gm sodium diphenylamine-sulphonate in 100 ml. water).

## Method

It is advisable to do both the oxidisation test (a) and the standardisation test (b) up to the end of stage 2 together, because both need to stand for 30 mins to cool. This will avoid wasting time later.

a) Estimation of Organic Matter in Soil

1. Weigh accurately about 0.2 gm. of air dry soil into a dry 500 m.l. concical flask (If there is a very low organic matter content in the soil up to 5 gms. may be used).

2. Add 10 m.l. potassium dichromate. Follow this by 20 m.l. sulphuric acid carefully swirling the flask as it is added. Allow to stand on heat insulating surface (wood) for approximately 30 minutes.

3. Add 200 m.l. distilled water, 10 m.l. orthophosphoric acid and 2 m.l. indicator and shake well.

4. Titrate with the ferrous sulphate solution adding 0.5 m.l. increments until the solution turns to an emerald green colour. (On adding the indicator in 3. the solution is reddish black in colour, with the addition of ferrous sulphate it changes to a bluish-black and finally to green when the end point is reached). Swirl the flask with each increment added

5. Add a further 0.5 m.l. of potassium dichromate, this changes the colour from green back to bluish black. Add the ferrous sulphate drop by drop, swirling well between each addition, until the colour changes to green.

6. Note the total volume of ferrous sulphate required to neutralise the solution, y ml.

b) Standardisation of Ferrous Sulphate

1. Add 10 m.l. potassium dichromate solution into a 500 m.l. conical flask.

2. Add 20 m.l. concentrated sulphuric acid slowly, swirl around and allow to cool, for approx. 30 mins

3. Add 200 m.l. distilled water, 10 m.l. of ortho-phosphoric acid and 2 m.l. of indicator and shake thoroughly.

4. Titrate with the ferrous sulphate solution adding 0.5 m.l. increments until the solution turns to an emerald green colour. (On adding the indicator in 3. the solution is reddish black in colour, with the addition of ferrous sulphate it changes to a bluish-black and finally to green when the end point is reached). Swirl the flask with each increment added.

5. Add a further 0.5 m.l. of potassium dichromate, this changes the colour from green back to bluish black. Add the ferrous sulphate drop by drop, swirling well between each addition, until the colour changes to green.

6. Record the volume of ferrous sulphate used. x m.l.

   1 m.l. ferrous sulphate $\equiv \frac{10.5}{x}$ m.l. potassium dichromate.

   $\equiv$ means reaching equilibrium with
   Equilibrium is reached at the exact point of the colour change

NOTE The end point is extremely sensitive and with some soils slightly difficult to see. Therefore, great care should be taken.

Calculations

Total volume of potassium dichromate used to oxidise the organic matter in the soil.

$$V = 10.5\left(1 - \frac{y}{x}\right)$$

10.5 - total volume of potassium dichromate added.

y - volume of ferrous sulphate used in soil test.

x - volume of ferrous sulphate used in standardisation.

W = weight of soil used in test

- % organic matter in sample = $\frac{0.67V}{W}$

..............

References British Standard 1377/1961

Method of Testing Soils for Civil Engineering Purposes.

## APPENDIX 6A : DATA SHEETS AND RESPONSES FROM ONE OF THE INTERVIEWS, (RESPONDENT 2)

Technical advice

Some of the chemical company literature is very good, and although should always be careful about this, some of it must be true.

Fixed costs,

I could take on more land to reduce fixed costs but I haven't the capital outlay. I'm keeping my machinery longer to reduce replacement costs. However last year I took on 170 acres on a one year contract without expanding my labour or machinery requirement. This has obviously forced down fixed costs. I see this as a period of consolidation rather than one of expansion.

Nitrogen and chemicals,

I would describe myself as a medium nitrogen user applying about 150 units to the acre or about 185 kgs/ha. The heavy land in this area is not prone to leaching therefore am not to worried about this. My chemical usage is very much a function of the weather and the disease levels in the crop. Varietal resistance to disease through better plant breeding has been a big help.

Animals,

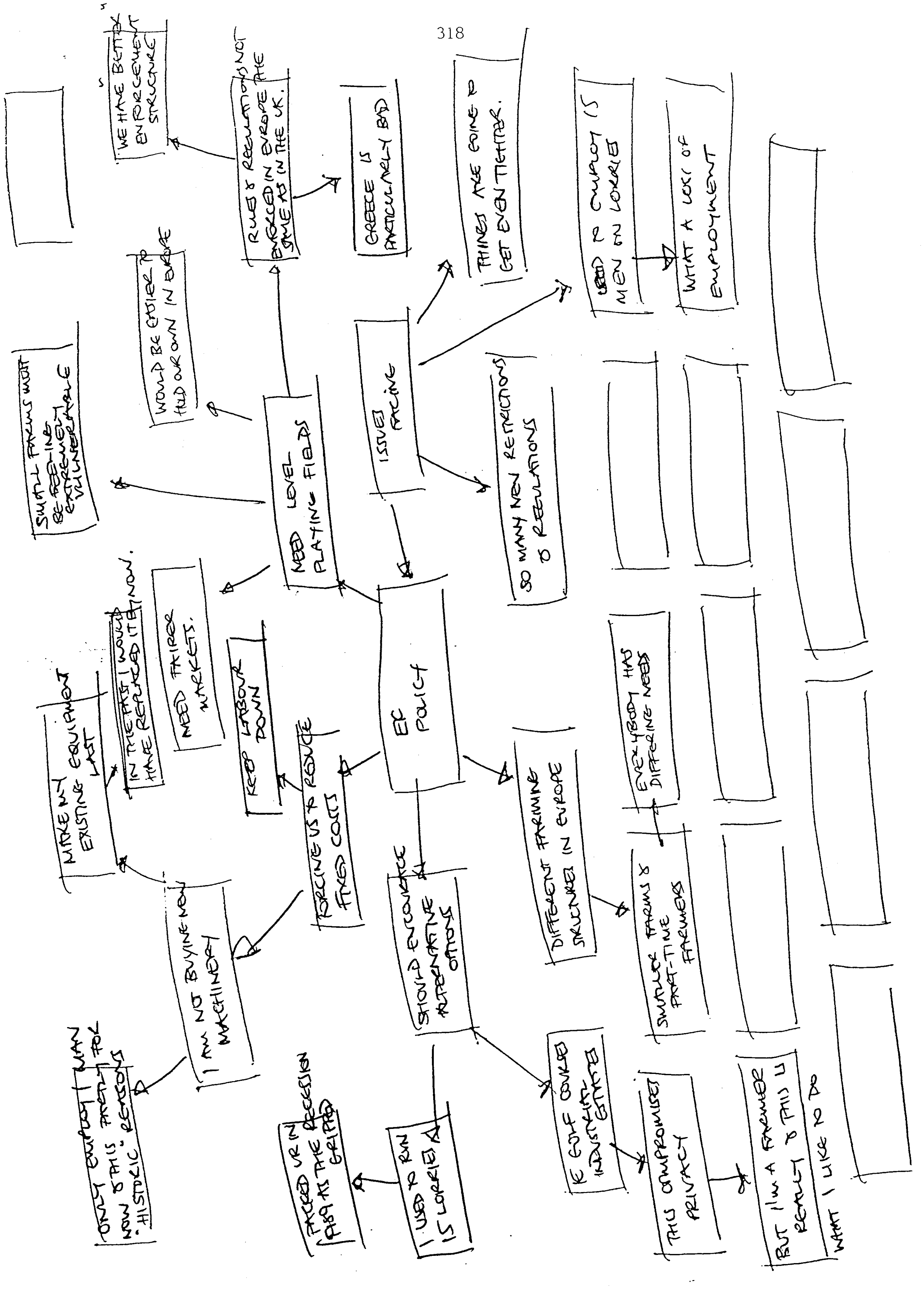
I used to keep sheep but I got out of them because of the workload when I had a haulage business running on the side. I would like to get back into them again as I enjoy working with animals. This is important. It will also give us something to do at quiet times as well as having agronomic benefits.

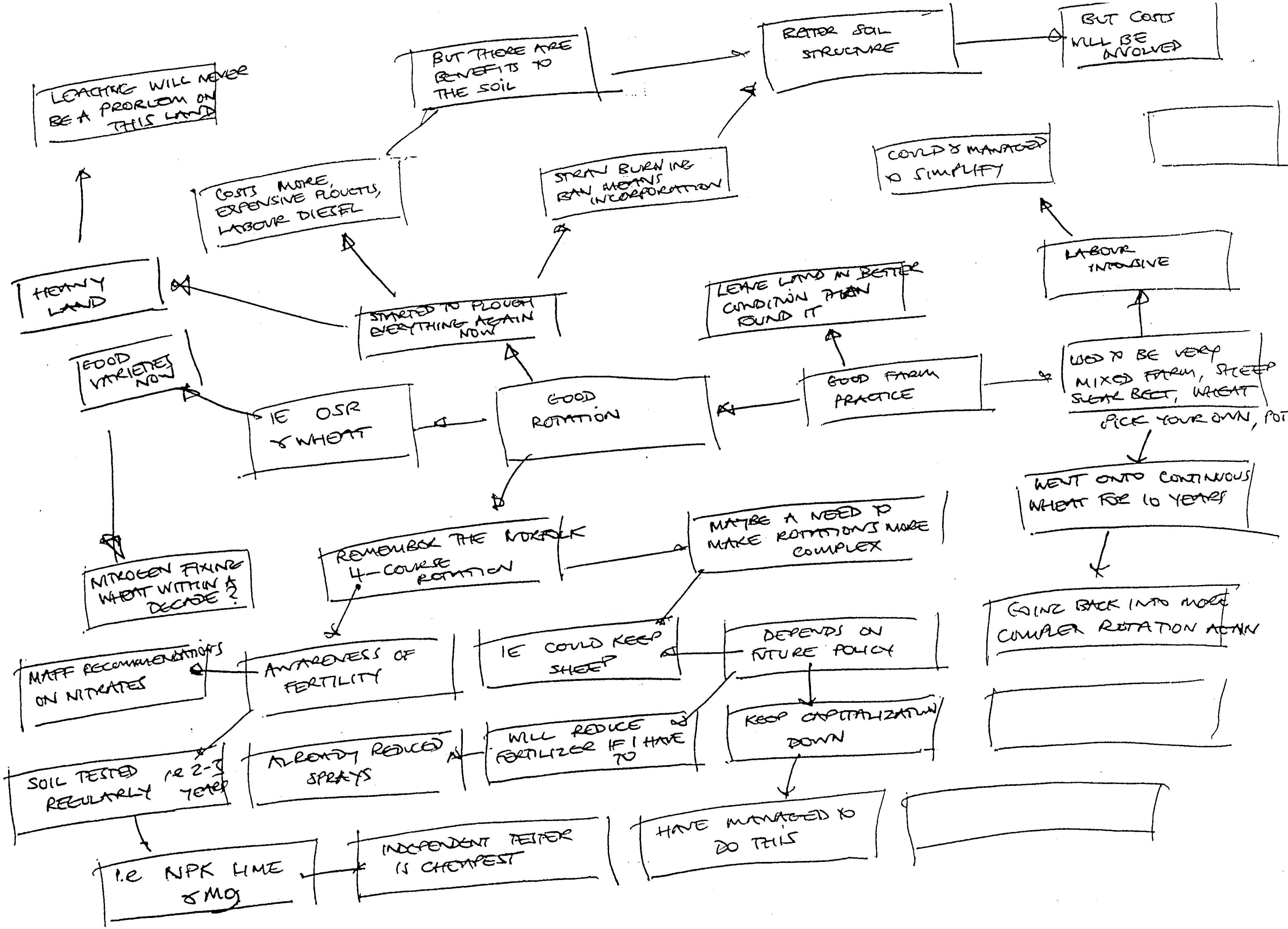
Profitability,

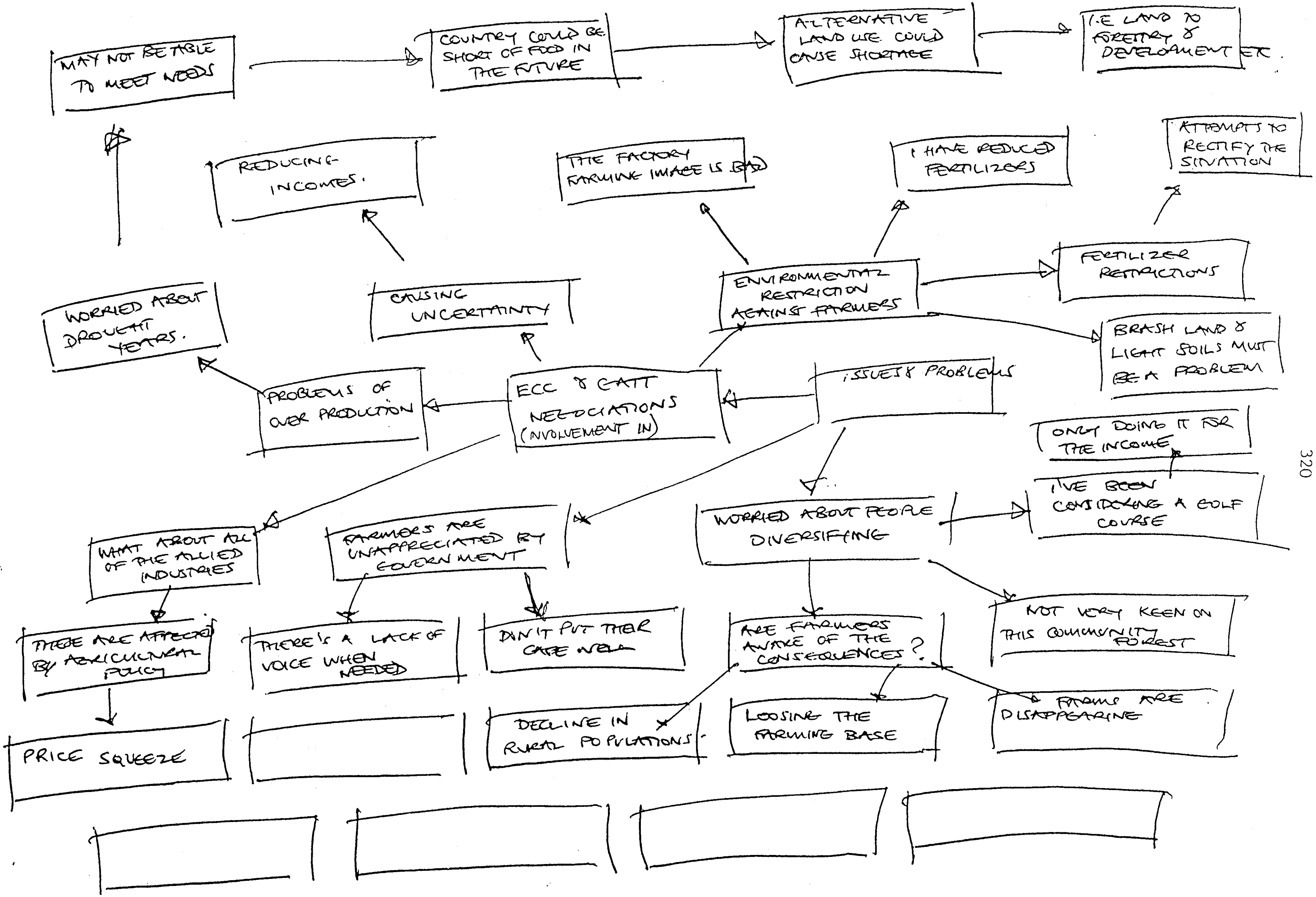
You can still make a living out of farming but all of the variables need to be on your side, i.e weather, markets, diseases, there is therefore a large degree of luck involved.

Environment,

I think much of what environmentalists say about farmers is unfair, although farmers often don't put their case very well. They do a reasonable job although often they are not perfect. The government doesn't seem to put the environmental case over to well and the NFU is a waste of space. In fairness the NFU does do some good else they wouldn't survive. But often the NFU does not put the farmers case over well or appears not to act in the interests of the majority of farmers. They just want to sell insurance.


EC POLICY
ISSUES FACING
NEED LEVEL PLAYING FIELDS
SMALL FARMS MUST BE FEELING EXTREMELY VULNERABLE
WOULD BE EASIER TO HOLD OUR OWN IN EUROPE
RULES & REGULATIONS NOT ENFORCED IN EUROPE THE SAME AS IN THE UK.
WE HAVE BETTER ENFORCEMENT STRUCTURE
GREECE IS PARTICULARLY BAD
THINGS ARE GOING TO GET EVEN TIGHTER.
USED TO EMPLOY 15 MEN ON LORRIES
WHAT A LOSS OF EMPLOYMENT
SO MANY NEW RESTRICTIONS TO REGULATIONS
NEED FAIRER MARKETS.
IN THE PAST I WOULD HAVE REPLACED IT BY NOW.
MAKE MY EXISTING EQUIPMENT LAST
KEEP LABOUR DOWN
FORCING US TO REDUCE FIXED COSTS
I AM NOT BUYING NEW MACHINERY
ONLY EMPLOY 1 MAN NOW & THIS PARTLY FOR 'HISTORIC' REASONS
SHOULD ENCOURAGE ALTERNATIVE OPTIONS
I USED TO RUN 15 LORRIES
PACKED UP IN 1989 AS THE RECESSION GRIPPED
E.G. GOLF COURSES INDUSTRIAL ESTATES
THIS COMPROMISES PRIVACY
BUT I'M A FARMER REALLY & THIS IS WHAT I LIKE TO DO
DIFFERENT FARMING STRUCTURES IN EUROPE
SMALLER FARMS & PART-TIME FARMERS
EVERYBODY HAS DIFFERING NEEDS


LEACHING WILL NEVER BE A PROBLEM ON THIS LAND
BUT THERE ARE BENEFITS TO THE SOIL
BETTER SOIL STRUCTURE
BUT COSTS WILL BE INVOLVED
COULD & MANAGED TO SIMPLIFY
COSTS MORE, EXPENSIVE PLOUGHS, LABOUR DIESEL
STRAW BURNING BAN MEANS INCORPORATION
LABOUR INTENSIVE
HEAVY LAND
STARTED TO PLOUGH EVERYTHING AGAIN NOW
LEAVE LAND IN BETTER CONDITION THAN FOUND IT
GOOD VARIETIES NOW
IE OSR & WHEAT
GOOD ROTATION
GOOD FARM PRACTICE
USED TO BE VERY MIXED FARM, SHEEP SUGAR BEET, WHEAT PICK YOUR OWN, POTS
WENT ONTO CONTINUOUS WHEAT FOR 10 YEARS
REMEMBER THE NORFOLK 4-COURSE ROTATION
MAYBE A NEED TO MAKE ROTATIONS MORE COMPLEX
NITROGEN FIXING WHEAT WITHIN A DECADE?
GOING BACK INTO MORE COMPLEX ROTATION AGAIN
MAFF RECOMMENDATIONS ON NITRATES
AWARENESS OF FERTILITY
IE COULD KEEP SHEEP
DEPENDS ON FUTURE POLICY
KEEP CAPITALIZATION DOWN
SOIL TESTED REGULARLY IE 2-3 YEARS
ALREADY REDUCED SPRAYS
WILL REDUCE FERTILIZER IF I HAVE TO
HAVE MANAGED TO DO THIS
I.E NPK LIME & MG
INDEPENDENT TESTER IS CHEAPEST


MAY NOT BE ABLE TO MEET NEEDS
COUNTRY COULD BE SHORT OF FOOD IN THE FUTURE
ALTERNATIVE LAND USE COULD CAUSE SHORTAGE
I.E LAND TO FORESTRY & DEVELOPMENT ETC.
REDUCING INCOMES.
THE FACTORY FARMING IMAGE IS BAD
I HAVE REDUCED FERTILIZERS
ATTEMPTS TO RECTIFY THE SITUATION
FERTILIZER RESTRICTIONS
WORRIED ABOUT DROUGHT YEARS.
CAUSING UNCERTAINTY
ENVIRONMENTAL RESTRICTION AGAINST FARMERS
BRASH LAND & LIGHT SOILS MUST BE A PROBLEM
PROBLEMS OF OVER PRODUCTION
ECC & GATT NEGOCIATIONS (INVOLVEMENT IN)
ISSUES & PROBLEMS
ONLY DOING IT FOR THE INCOME
I'VE BEEN CONSIDERING A GOLF COURSE
WHAT ABOUT ALL OF THE ALLIED INDUSTRIES
FARMERS ARE UNAPPRECIATED BY GOVERNMENT
WORRIED ABOUT PEOPLE DIVERSIFYING
NOT VERY KEEN ON THIS COMMUNITY FOREST
THERE ARE AFFECTED BY AGRICULTURAL POLICY
THERE'S A LACK OF VOICE WHEN NEEDED
DIDN'T PUT THEIR CASE WELL
ARE FARMERS AWARE OF THE CONSEQUENCES?
PRICE SQUEEZE
DECLINE IN RURAL POPULATIONS.
LOOSING THE FARMING BASE
FARMS ARE DISAPPEARING

APPENDIX 6B : SUMMARY OF STATEMENTS IN RESPONSE TO THE TWO BROAD QUESTIONS AND THE FOUR MORE SPECIFIC QUESTIONS,

## STATEMENTS REFERRING TO SATISFACTION TO DO WITH THE JOB

| Resondant number | Statement |
|---|---|
| 1 | Variety of work |
| 2 | Work in country |
| 3 | Work is my hobby |
| 4 | Growing good crops |
| 5 | Being own boss |
| 6 | Work with animals |
| 7 | Producing good product |
| 8 | Looking after stock |
| 9 | Pride in one's own farm |
| 10 | Involvement in countryside |
| 11 | All farm activities |
| 12 | Start to finish activity |
| 13 | Life is farming |
| 14 | Working with cattle |
| 15 | Harvesting a high yield |
| 16 | Variety in the work |
| 17 | Variety in the work |
| 18 | Allows self expression |
| 19 | Way of life, work is social as well |
| 20 | Working with livestock |
| 21 | Being independent |
| 22 | Achievement at the end of year |
| 23 | Seeing crops harvest well |
| 24 | Running own business |
| 25 | Growing the crops |
| 1 | New technology |
| 2 | Look after environment |
| 3 | Work/live in country |
| 4 | Working the land |
| 5 | Working with stock |
| 6 | Farming is business |
| 7 | Economic efficiency |
| 9 | Working on own farm |
| 10 | Seeing job through |
| 11 | Working with stock |
| 12 | Beating previous yield |
| 13 | Producing good crops |
| 14 | Living in countryside |
| 15 | Satisfaction from good work |
| 16 | Mixed farm provides interests |

| Resondant number | Statement |
|---|---|
| 17 | Always something to do |
| 19 | Antithesis of commuting |
| 20 | Always learning |
| 21 | (Doesn't like being told what to do) |
| 22 | Completion of the growing cycle |
| 23 | Seeing changes in crops |
| 24 | Quality of life due to farming |
| 25 | Drilling & seeing seedlings emerge |
| 1 | Individualistic |
| 2 | Producing food |
| 3 | Good style of living |
| 4 | Planting new crops |
| 5 | Satisfied at end of day |
| 6 | Farming is way of life |
| 7 | Quality product, Grain size |
| 9 | Custodian of countryside |
| 10 | Doing a good job |
| 11 | Less social nowadays |
| 12 | Can get deeply involved |
| 13 | Doing things well |
| 14 | Running own business |
| 15 | Looking over crops/achievement |
| 17 | Lifestyle, open air |
| 19 | See a lot of family |
| 22 | How much going to weighbridge |
| 23 | Repairing machinery |
| 24 | Involvement in the countryside |
| 25 | Barnful of corn |
| 1 | However can be lonely |
| 3 | Just being a farmer |
| 4 | Hate paper work |
| 6 | Working with people |
| 7 | Yield per hectare |
| 11 | Social side of farming has gone |
| 12 | Doesn't know what else would do |
| 13 | Looking after equipment |
| 19 | Work can be lonely |
| 23 | Beating last years results |
| 24 | Ethos to do with farming |
| 25 | Trying different things &seeing |
| 19 | Not meet many people |
| 23 | Competing against disease etc |
| 19 | Long hours |

# STATEMENTS REFERRING TO ISSUES AND PROBLEMS

Resondent number Statement

1 Straw ban
2 Involvement in EC and GATT talks
3 Marketing
4 Financial problems
5 Fall in incomes
6 Lack of capital
7 Marketing and uncertainty
8 Europe
9 Straw incorporation
10 Can't make living from 150 ewes
11 Outside interference from EC
12 Uncertainty about the future
13 Price squeeze
14 Difficult to decide direction
15 CAP reform
16 EC restrictions
17 Increase in restrictions
18 Politics control farming
19 Uncertainty in political direction
20 Run down in production
21 Economic survival
22 Macsharry proposals
23 CAP reforms
24 Static end prices
25 CAP reforms
1 Cereal co-responsibility level
2 Not level playing fields
3 Government causing uncertainty
4 Legislation and restrictions
5 Wheat price is aproblem
6 Uncertainty
7 Fluctuating prices
8 Cheap/clean food demanded
9 EC attitudes against farmers
10 Wool money
12 EC policy, its centralization
13 Uncertainty
14 Policy uncertainty
15 People must decide what they want
16 CAP is not always reaching farmers
17 Constant moving of goal posts
18 Similar to other industries
19 Lack of skilled labour
20 Price squeeze
21 CAP and uncertainty
22 Price squeeze
23 Own health problems
24 Fallen standard of living
25 Uncertainty
1 Uncertainty
2 Drought years?
3 Capital tied up
4 Price squeeze
5 Increase in regulations
6 Public opinion
7 Advised to over capitalize
8 Price squeeze
9 Lack of product information
10 Attitudes of British public
12 Straw ban, agronomic problems
13 Presssures and restraints
14 Difficult to get students on farm now
15 Future uncertainty
16 Not strong enough in the market
17 Uncertainty
18 Problems for those over borrowed
20 Bad publicity
21 Hard enforcement of restrictions in UK
22 Set aside
23 Lack of confidence within industry
24 Shortermism
25 Lack of ability to plan
1 Policy is out of farmers hands
2 Adhoc diversification
3 Individualistic
4 Over production
6 Legislation
8 No ley or roots, poor soil quality
10 Amount of time he works
12 Price sqeeze
13 Making sheep pay is a problem
14 Alot of CAP budget not getting to farmers
15 High standards in the UK
17 Machinery cost and complexity
20 Land price beyond earning capacity
21 To good at "playing cricket" in the UK
22 Public image
23 Reduction in number of parish farmers
24 The continual need to squeeze inputs
25 Fire risk from straw ban
1 Price squeeze
2 Factory farming image
3 Price squeeze
4 Individualism
6 Farmer's individualistic
8 UK government plays it by the rules
12 Individualistic farmers
13 straw ban
17 Water supply is becoming an increasing pro
21 NFU no longer has much power
22 Costs, both fixed and variable
23 No confidence in neighbours when need sup
24 Uncertainty of GATT
25 Petty attitudes of officials
2 Uneven palying fields
3 Uncertainty
4 Overdraft
8 Legislation is too stringent
12 Capital cost of diversification
13 No leeway in farming anymore
17 Dead capital
2 Need to reduce fixed costs
3 Huge logistical problems
6 EC policy encouraged over production

# STATEMENTS REFERRING TO POLICY ISSUES

| Resondent number | Statement |
|---|---|
| 1 Straw ban | Ill thought out, problem on heavy land, + costs,yields + value |
| 2 No strong concern | Free market in agriculture is a pipe dream |
| 3 Set aside | Is a nonsense |
| 4 Set aside | Poorly thought through |
| 5 Quotas | Hard when introduced (1984), less so now |
| 6 Nothing specific | Regulation and legislation forcing small farmers out of business |
| 7 N restrictions | Excess N reduces quality and causes disease problems |
| 8 Straw ban | Opposedto all restrictions that are difficult to implement |
| 9 Nothing specific | EC policy imbalances; especially horn and corn excepting dairying |
| 10 Sheep subsidy | Moved from lambs to ewes, has halved income |
| 11 Nothing specific | EC policies have caused uncertainty in Britain |
| 12 Straw ban | Farmers didn't kick up enough fuss |
| 13 Straw ban | Will cause big problems |
| 14 Nothing specific | Strong views on the EC as a whole |
| 15 New agenda | Farming needs to identify and address a long term agenda |
| 16 Straw ban | NFU have done a poor job at representation |
| 17 Set aside | Difficult to justify, encourages distribution of weed seeds |
| 18 No strong concern | Passive towards policy change |
| 19 One year set aside | Need permanent and not rotational set aside for local ecology |
| 20 No strong concerns | Academics and plant scientists should be shot |
| 21 No not really | But restrictions are increasing |
| 22 No | Many policies associated with restrictions often benefit farmers in the long run |
| 23 not specific | Not sure about EC at present |
| 24 Setaside | bad for conservation and for public image |
| 25 Footpath laws | Having to maintain paths, some of which haven't been used for thirty years |
| 2 GATT | Must be implemented fairly |
| 3 Co-responsibility | Very silly |
| 4 Straw ban | Has both good and bad sides |
| 5 Dairying | Most profitable enterprise |
| 7 Extensification | Agree in certain areas |
| 8 Co-responsibility | Against the increase in the levy |
| 12 Set aside | In farming to farm, not to put land to one side |
| 13 Set aside | Will be a big problem if it becomes compulsary |
| 19 Set aside | Bad for farmers morale, the countryside and the CAP pocket |
| 20 99 | Policies lead to more bureuacracy |
| 21 99 | Mis match , British farmers have ability to produce, yet people starving. Politian |
| 22 99 | Some famers wear blinkers when it comes to change |
| 23 Not specific | Conservation is being pushed by small minority |
| 24 Inhritance laws | Will allow longer term planning for land owners, better for conservation |
| 25 General | General increase in petty officialdom, ie transport of fertilizers |
| 4 Quotas | May be a good thing if they allow more planning |
| 5 Co-responsibility | Cereal co-responsibility levy is high |
| 12 GATT talks | Must favour the EC farmers of which he is one |
| 13 Political activity | Can farm against the weather but not the politicians |
| 19 Straw ban | Burning unacceptable, bad public press: dependent on soil type |
| 25 General | Labelling of chemical stores which acts as a advert, "valuable and dangerous |

# STATEMENTS REFERRING TO FUTURE ISSUES FACING FARMING

| Respondant number | Statement |
|---|---|
| 1 | Need to compete in world market |
| 2 | Rural structure |
| 3 | Co2 budgets may be the salvation of the farmer |
| 4 | Tackling the concept of over production |
| 5 | Farming is cyclical and will come right |
| 6 | No future in farming 100 acres |
| 7 | Pricing agreements to enable longer term planning |
| 8 | Farms will get bigger |
| 9 | Farmers will weather storm over next five years |
| 10 | Grim future for small businesses |
| 11 | Increasing importance of financial aspects in farming |
| 12 | UK farmers are innovative and adapt to change |
| 13 | Optimistic for the future, if farming is efficient |
| 14 | Things will get better but some will not survive |
| 15 | Must identify priorities i.e lower imports, feed the world? |
| 16 | Maintain flexibility, some are over borrowed and specialized |
| 17 | Little promise for the future, some will go out of business |
| 18 | Optimistic for those who pursue good business practice |
| 19 | Address gulf with the "green lobby", many common interests |
| 20 | Big farmers will survive, small specialists will struggle |
| 21 | People will always need to eat |
| 22 | Next 5 to 10 years will be critical for many |
| 23 | Reduction in farm numbers due to lack of hiers |
| 24 | Profitability will only be increased by continual cost saving |
| 25 | Now is the greatest period of flux since started farming |
| 1 | Improved marketing |
| 2 | Thought into food production |
| 3 | Farmers will survive, many forecasts are pessimistic |
| 4 | Getting food to where it is needed |
| 5 | Land price will drop, bad for those with high borrowings |
| 6 | May grow trees to improve environment for horse activities |
| 8 | Europe will remain an issue into the future |
| 9 | World food supply problems must be sorted out |
| 10 | Only large concerns can compete with U.S and Canada |
| 11 | More planning required for young people |
| 12 | Planning for uncertainty is made difficult |
| 13 | Currently keeping close control on cost and working hard |
| 14 | What will happen to younger generations needs addressing |
| 15 | Population must decide the countrysides' function and look |

# STATEMENTS REFERRING TO FUTURE ISSUES FACING FARMING

| Respondent number | Statement |
|---|---|
| 16 | Need level playing fields |
| 17 | Those with high rents and/or capital borrowing vulnerable |
| 19 | Improve the public perception of farming activity: NFU role |
| 20 | Small producers will need cooperative strength |
| 21 | Next generation are going to find it very difficult |
| 22 | Fossil fuels will become more critical |
| 23 | Standards and efficiency will continue to improve |
| 24 | Farming needs to become much more involved with public |
| 25 | Worker harder just to standstill |
| 1 | More thought to what is produced |
| 2 | Government cannot let all farmers go down, support important |
| 4 | Questions the influence individuals have on policy making |
| 9 | European Community |
| 11 | Young have better access to information, should be O.K |
| 12 | Diversity advantageous but capital cost is often prohibitive |
| 14 | Things will turn full circle |
| 15 | Rethinking on inputs re spray and fertilizers |
| 16 | Quotas are not a good long term policy |
| 17 | Banks have lent on equity in land and then "pulled the plug" |
| 20 | Some land will be found to be clogged up with residues |
| 21 | Some will have to consider second income options |
| 22 | Contracting will become stronger |
| 23 | Farms getting bigger is just a natural progression |
| 24 | CAP reforms will alter the appearance of the countryside |
| 25 | Optomist, things will get better, but when? |
| 1 | People producing for specialist markets |
| 2 | Fixed costs, need to make machinery last longer |
| 12 | Yields remain the motivating factor alongside price squeeze |
| 14 | CAP seems to be out of hand |
| 15 | Europe to feed poorer nations? |
| 21 | More optimistic about MacSharry because thinks he is small farmer |
| 22 | Will look at alternative combinable fuel crops |
| 23 | Many small farmers are reluctant to cooperate, but may have to |
| 24 | Fuel cropping will become of increasing importance |
| 25 | Eastern european farming may have large impact if get act together |
| 1 | Quotas are likely to become more prevalent |
| 2 | Now is a time of consiladation |
| 12 | Farmers are not strong enough as a group |
| 14 | Larger farmers usually involved in the NFU because they have time |
| 15 | Political and not scientific decisions |
| 25 | Global warming may make productive regions like the UK valuable |

# GENERAL STATEMENTS

| Resondent number | Statement |
|---|---|
| 1 | Restrictions not well thought out |
| 2 | Farmers don't put their case well |
| 3 | Stongly commited to the NFU |
| 4 | Involved in NFU but feels power has diminished |
| 5 | Straw ban not a problem for them , use it all |
| 6 | Bank charges too much |
| 7 | Strive to improve yields, personal satisfaction |
| 8 | Can't afford to crop leys or roots |
| 9 | Grows pulses |
| 10 | Diversification spreads risk |
| 11 | Small farms are more suited to stock |
| 12 | To the public, a little knowledge is dangerous |
| 13 | Uncertainty in weather is no longer major issue |
| 14 | Need policy on long-term basis |
| 15 | Setaside |
| 16 | Cooperation is very important |
| 17 | Town people and the countryside |
| 18 | Ploughing in straw puts humus back |
| 19 | Policy puts farmers under financial pressure |
| 20 | Low input farming doesn't acidify the soil |
| 21 | Farming companies taking over the countryside |
| 22 | Farmer pride and independance |
| 23 | Bought "newish" combine & possible contract |
| 24 | Difficult OSR establishment following incorp. |
| 25 | Difficult to find the right labour |
| 1 | May have to expand to survive |
| 2 | NFU are a waste of space |
| 3 | UK farmers no longer have strong lobby |
| 4 | Should be harvesting something on setaside |
| 5 | Regulations increasing dead money |
| 6 | Double standards with regard to public opinion |
| 7 | Fertility out of a bag |
| 8 | Loss of knowledge amounst younger farmers |
| 9 | Straw ban may increase pollution |
| 10 | Part-time farmer because feels is in the blood |
| 11 | EC farmers have stronger lobby |
| 12 | In the past some farmers been negligent |
| 13 | Public access |
| 14 | Farmers have to react to money offered |
| 15 | Diversified into BandB |
| 16 | Big coops like the mmb are too impersonal |
| 17 | Manure from straw yards |
| 18 | Land is kinder in tough spots due to straw |
| 19 | Setaside is wrong |
| 20 | Knowledge will die with him |
| 21 | Sheep provide variety and use bi products |
| 22 | Alternative spray regimes |
| 23 | Estates have taken in tenancies |
| 24 | Some farmers put up barriers against the public |
| 25 | Population centre(bedford) has pros &cons |

## GENERAL STATEMENTS

| Resondent number | Statement |
|---|---|
| 1 | Benefits from straw burning £25 per acre |
| 2 | In farming will always need some luck |
| 3 | Supermarkets are having a bigger influence |
| 4 | Over-production is a regional problem |
| 5 | Keep bought in labour down |
| 6 | Standards abroad are not so strict |
| 7 | Subsidies |
| 8 | Over production is a major issue |
| 9 | Arsonists may put match to unburnt straw |
| 10 | Loss of rural infrastructure |
| 11 | Lifestyle associated with farming is important |
| 12 | Need to seek advice |
| 13 | Ploughing and burning |
| 14 | Young generation not given the chance |
| 15 | Farmers make decisions on own situation |
| 16 | Quotas generally reduce flexibility |
| 17 | Townies responsible for water problem |
| 18 | Need to anticipate the future |
| 19 | Evolution of countryside cannot be on & offed |
| 20 | In the past beef producing land was the richest |
| 21 | Same man employed for 40 years |
| 22 | Ploughing in straw increases humus |
| 23 | Industry geared to expect subsidies |
| 24 | Setaside may well increase flexibility for some |
| 25 | Continuous cereals |
| 1 | Sheep may utilize straw |
| 2 | Could cope with more land to spread costs |
| 3 | Uneven playing fields within Europe |
| 4 | Farming cycles set up for given flows |
| 5 | Little say in what goes on |
| 6 | Biggest margins go to food retailers |
| 7 | Export markets |
| 8 | Little faith in the union |
| 9 | Mixed rotations as possible |
| 10 | Farmers don't take on labour , buy bigger tackle |
| 12 | Sheep good but had to be got rid of |
| 13 | Using more machinery |
| 14 | Share farming creats shortermism |
| 15 | Setaside could be looked at as insurance |
| 16 | Quotas are not a long-term policy |
| 17 | Not politically active |
| 18 | Step outside the farming scene |
| 19 | Driving force is short-term and financial |
| 20 | Farming will soon be all chiefs and no indians |
| 21 | contracting and share farming spread costs |
| 22 | Soil analysis saves money in the long run |
| 23 | Tries to act like a big farmer although only small |
| 24 | Has looked closely at energy cropping |
| 25 | Farmers in financial difficulty not "bad" farmers |

GENERAL STATEMENTS

| Resondent number | Statement |
|---|---|
| 2 | Heavy land minimises leaching |
| 3 | Governmental shortermism |
| 4 | Quotas may allow farmers to plan |
| 5 | Beneficail to carry horn and corn |
| 6 | Public access and awareness |
| 7 | UK should have larger say in EC |
| 8 | Capital investment in specialized machinery |
| 9 | EC restrictions not always enforced fairly |
| 10 | Small farmers squeezed out of business |
| 12 | Public protest is important |
| 13 | Timeliness is very important |
| 14 | ADAS discourages innovation |
| 15 | CO2 budget and ads of burning oil seeds |
| 16 | Need to maintain flexibility |
| 17 | Pay for not using fertilizer rather than setaside |
| 18 | Acts as an umbrella for small farmers |
| 19 | Family farms have much to be said for |
| 20 | Welsh auctions allow selectivity |
| 21 | Independance is being eroded |
| 22 | 5000acres by one man if delegation is good |
| 23 | Will apply ferttilizer even when indexs are high |
| 24 | 250 acres not viable anymore, ie the share farm |
| 25 | Important to look outside farming |
| 2 | Level playing fields within Europe? |
| 3 | Agricultural constitution |
| 4 | Straw ban has caused him to plough more |
| 6 | Distribution costs |
| 8 | 500 acres a resonable acrage today |
| 9 | Buy big tackle to get on quick |
| 12 | Farmer s not strong enough as a group |
| 13 | Labour down to reduce fixed costs |
| 15 | Could farm more to spread fixed costs |
| 16 | Arable land benefits from animal muck |
| 17 | Milking is best thing to be in, but hard work |
| 18 | Attempting to reduce labour |
| 19 | Continuity of family farms |
| 21 | Sons won't be able to make a living on the farm |
| 22 | Burning was a hastle anyway |
| 23 | Sells potatoes at, gate to reduce middleman |
| 24 | Sheep fit in well |
| 3 | Nitrogen should be bonded and taxed |
| 4 | Hates paperwork but seems to be more |
| 6 | None level playing fields |
| 8 | Straw burning |
| 9 | New OSR policy |
| 12 | Could handle 250ha more on same fixed costs |
| 13 | Some farming "enterprises" no longer farming |
| 18 | Some ground under wheat for 10 years |

| Respondent number | Statement |
|---|---|
| 19 | Lobby organizations have litle clout |
| 23 | NFU don't represent the views of small farmer |
| 24 | High degree of non-farm diversification |
| 25 | Uncertainty of setaside |
| 4 | Having to keep machinery longer at present |
| 6 | Increased paper work |
| 8 | fertility |
| 9 | Benefits in the soil from residues |
| 10 | Loss of farming families is sad |
| 12 | One of the only surviving farmers in the parish |
| 23 | Farmers often diversifying out of "farming" enterprises |
| 24 | Young still think can make farming alone profit |
| 25 | Continuity on farms |

APPENDIX 6C : COPY OF THE REPORT SENT TO FARMERS,

**REPORT TO FARMERS ON CURRENT ISSUES FACING THE AGRICULTURAL INDUSTRY:**

Prepared by: Julian Park June 1992

Working from: Innovation and Technology Assessment Unit, International Ecotechnolgy Research Centre,

Cranfield Institute of Technology,
Cranfield, BEDS
0234-750111 ex 2016

**INTRODUCTION,**

In all discussions were held with 25 farmers, the majority of these being located within Bedfordshire and Buckinghamshire. The farm sizes ranged from 15 to 1200 hectares (average 263ha) and included a wide range of tenure, soil types and enterprises.
(Arable ,sheep, dairy, beef and pigs and various combinations).

The aim of the discussions was to ascertain an overview of the current situation in agriculture "through the eyes" of the farming community, and to examine the use of informal discussions as a research tool in this context.

The notes taken will be analysed as part of my own research which aims to address some of the issues facing agriculture in the future, and provide a method of assessment of future cropping practices.

In addition it is hoped that the overview obtained from the discussions will be incorporated into a published paper. This will argue the need for policy makers to recognize the complexity of issues facing the farming community and the need for longer term positive objectives within the industry.

Because of the diverse interests of the farmers with whom I spoke and the nature of the discussions I have only included the main topics discussed. Within these there will be some comments contrary to those expressed by individuals, however, I have tried to interpret the majority view. The order in which issues are discussed is not necessarily relative to their importance. I have illustrated the text with diagrams where appropriate. These are extracts from the notes recorded in individual conversations.

**PROBLEMS AND ISSUES FACING FARMERS,**

**"What are the main issues/problems facing you as a farmer at present?"**

**Not surprisingly the financial side........**

.......of the farm business was of great concern to the majority. For instance the lack of capital, fall in incomes, the price squeeze, the overdraft were all very topical issues.

This was usually reinforced by comments about future uncertainty thus making planning difficult with both CAP and GATT seen as major contributing factors, See figure 1,

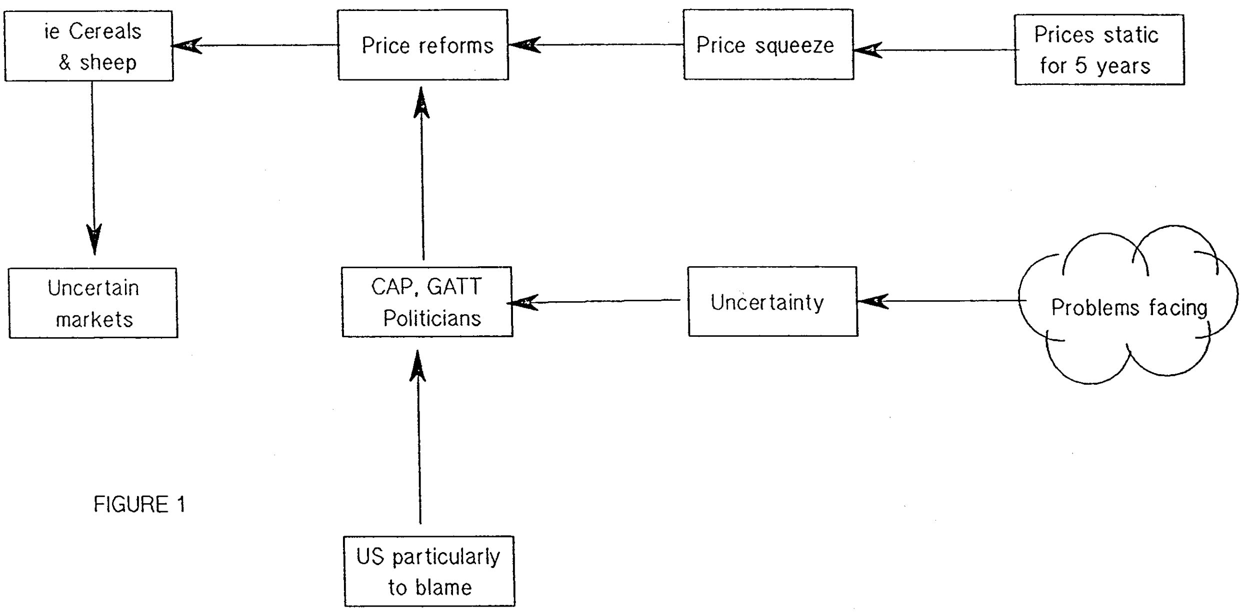



FIGURE 1

**The increasing amounts of legislation and restrictions......**

.........facing the business was of concern and was thought by some to be "overwhelming" even though the perception existed that some of it was of good intention but ill directed, with often limited oversight of the whole agricultural business by decision makers, See figure 2,

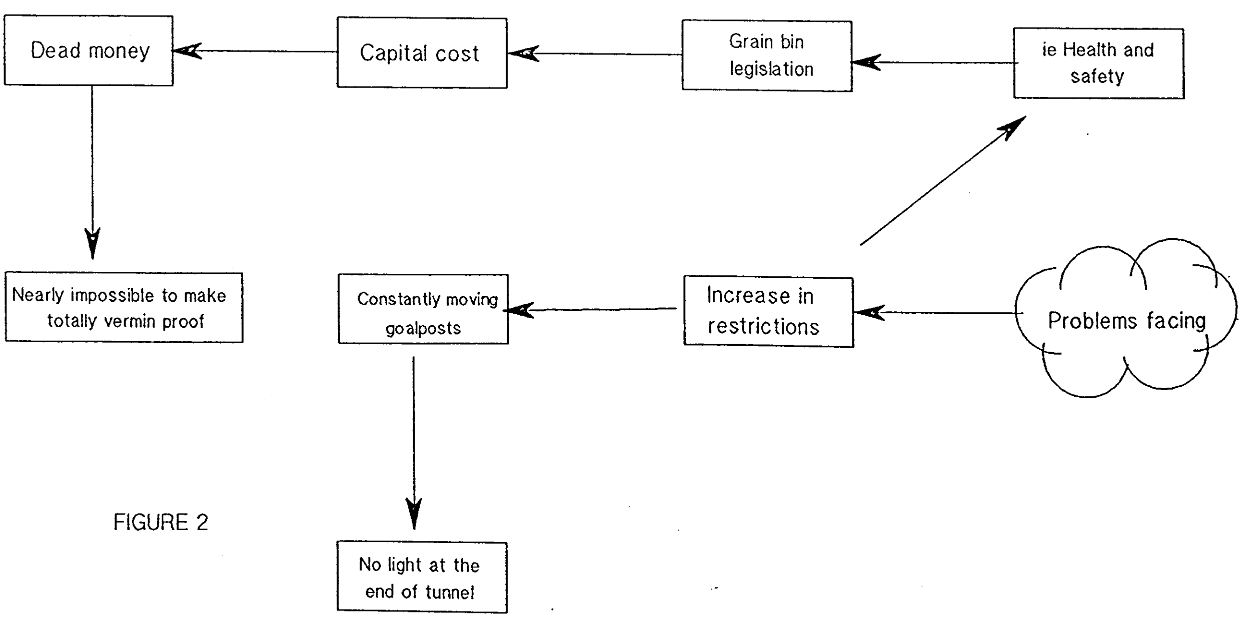



FIGURE 2

It was felt that Britain's EC partners, although happy to agree to legislation, did not enforce it as eagerly as the UK government. This gives rise to the comment about "lack of even playing fields", or that the British are, "too good at playing cricket," possibly because of some of the regulatory structures that are already in place within the UK.

**Legislation was seen to have several effects:**

Leading to the tying up of "dead" capital with examples such as the laws applying to slurry and those regarding vermin control.

Increased access to the farm of an increasing number of "little gods" who some felt, were compromising their ability as individual farmers.

**The image of farmers through the public eye........**

....... was raised as an issue. Few would argue that farming had a good public image but the overall feeling was that attempts were being made to improve this. The majority felt this image to be very important and cited the media as playing a central role in image portrayal. Part of the reason for the increased degrees of restriction placed on some farm practices, ie the straw ban, was seen to be due to "the lack of understanding" by those not involved in the farming community, See figure 3,

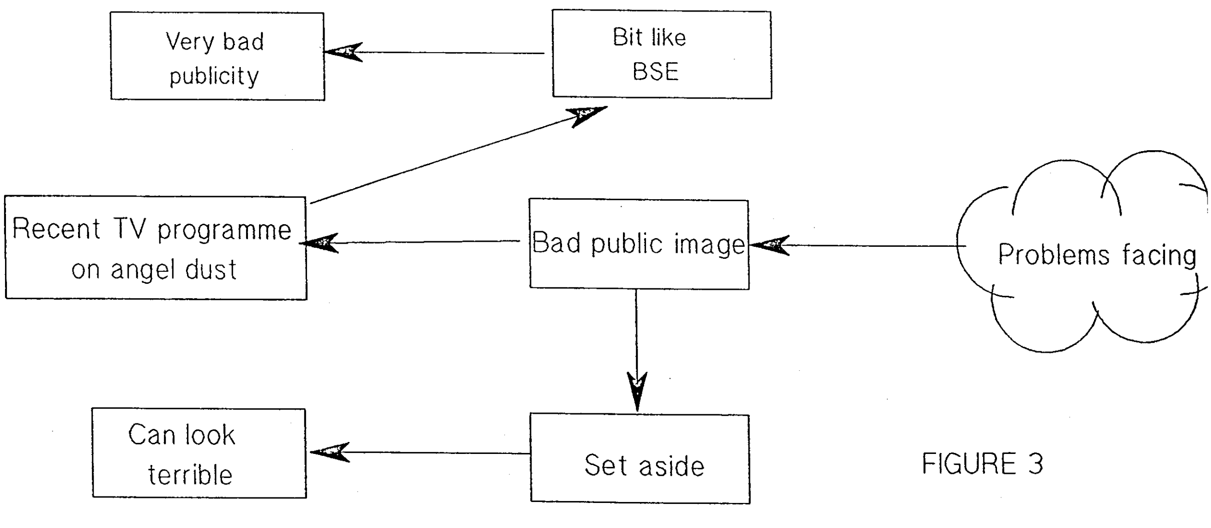



FIGURE 3

Past behaviour by individuals within the farming community as a whole was stated as having tarred many with the same brush, although some admitted that they themselves had not always acted benignly. (but were changing their ways.)

Some felt that many urban dwellers had some form of idealistic picture of the countryside, but little perception that this was only maintained by a continual change process.

Several stressed that they were actively promoting farming to the public. These activities varied from a "large scale farming and conservation day" to direct involvement with local schools.

Both direct selling and provision of services to the public were seen as beneficial in the long run as they provided a tie between the food producer and the end consumer, a link which has been gradually eroded in past decades. However, there was also a feeling that closer relations with the general public would have some effect on lifestyle, although not always desirable. As could be expected, this feeling was stronger on the "isolated" farms.

**Individualism on behalf of farmers.......**

........ was cited as being a problem, although it was clear that many had close ties, both business and social within the local farming community. But despite this the reluctance to co-operate was seen as part of the reason for a decline in the political and marketing power of the industry, See figure 4,

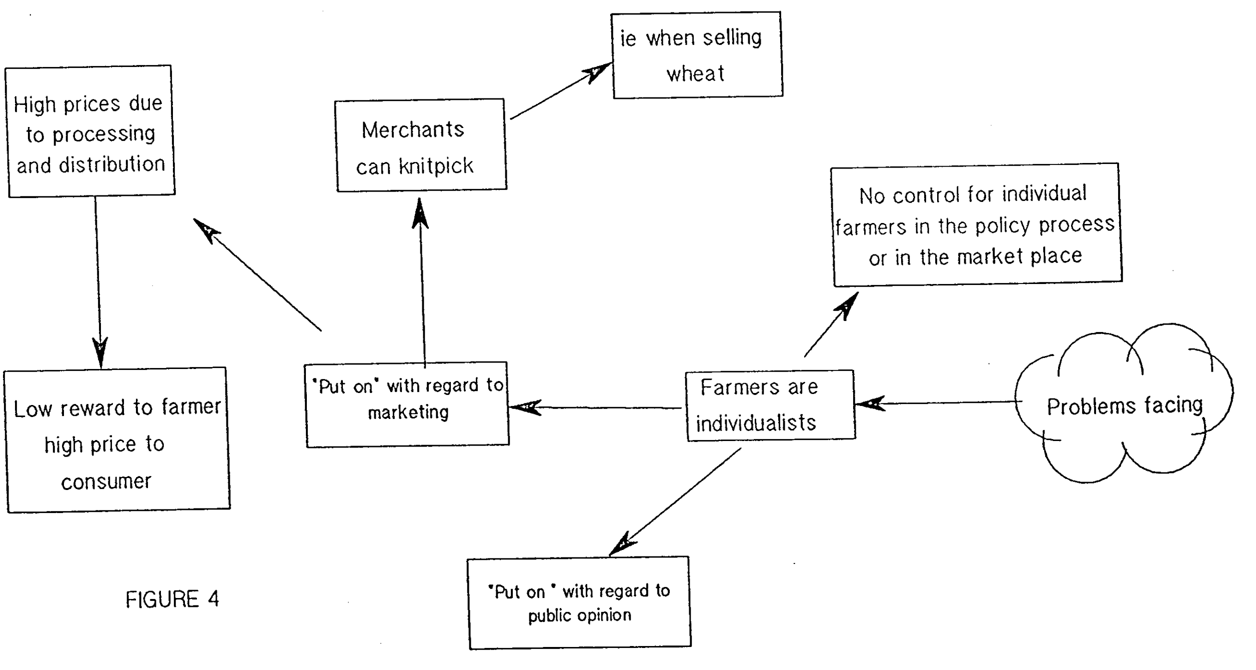



FIGURE 4

Cooperation in its widest sense was mentioned as a possible way forward. Cooperation, formal or informal is already a way of life for some with regard to the marketing or sharing of machinery, but surprisingly it was those who perhaps could benefit the most who were reluctant. (This was often recognised by the individuals themselves). The fact that some cooperatives become so big that the individual loses his identity was a relevant issue.

**GOOD FARM PRACTICE,**

**"What do you understand by the term good farm practice?"**

**Many linked good farm practice to......**

....... "Financial/economic survivability" and a need to be aware of the "future". This awareness of the future equated with the need to "keep the land in good heart", "maintenance of the productive capability of the soil" and a general consideration of the environment in which farming takes place. The old saying, "..Live as if you will die tomorrow but farm like you will live for ever," was much in evidence, see figure 5,

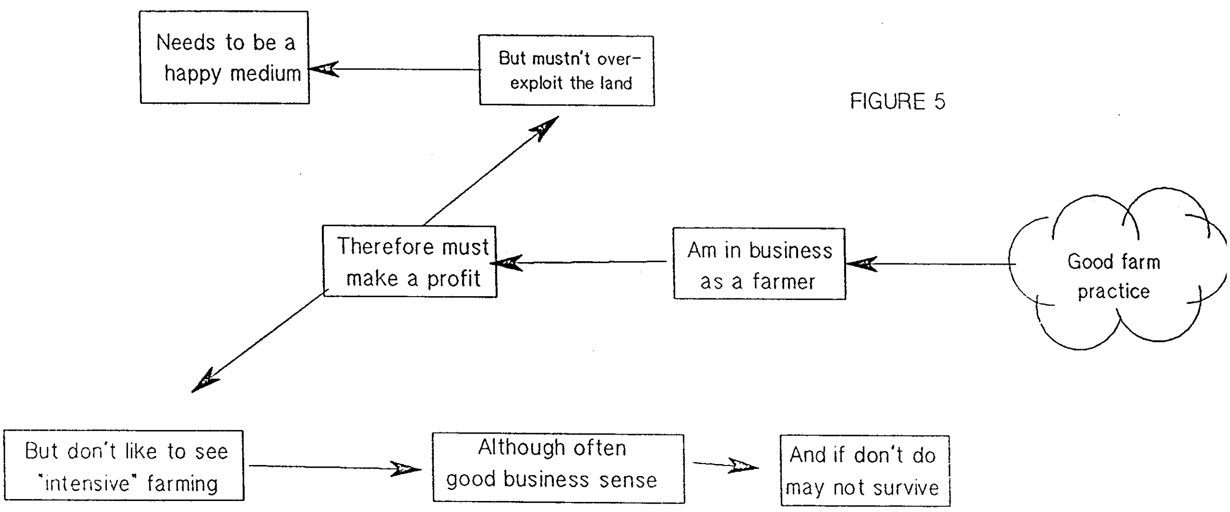



FIGURE 5

The need for tidiness and order about the farm was often equated with good farm practice, as was the maintenance of hedges, trees and field boundaries etc. Good farm practice is also equated with clean crops and well tramlined fields.

**The need to keep the soil in "good heart"......**

....... was a key issue, the main themes were the nutrient status, drainage, and lime status. Humus content was related to ease of working and aeration of the soil, See figure 6,

The soil condition was usually assessed by regular testing and was thought to be improved by "good rotation". Some argued against this saying that rotation was not necessary to achieve high margins. One farmer had been growing white strawed crops continuously for 25 years. Under such a system he felt that minimisation of machinery compaction was a critical issue, see figure 7,

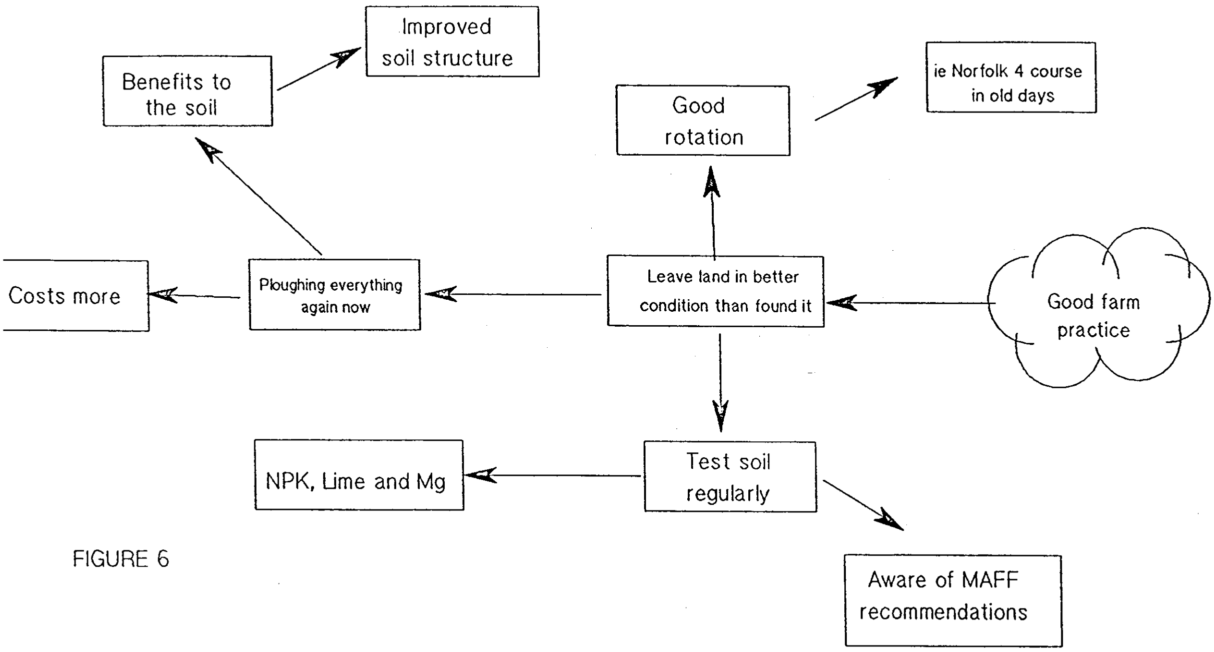



FIGURE 6

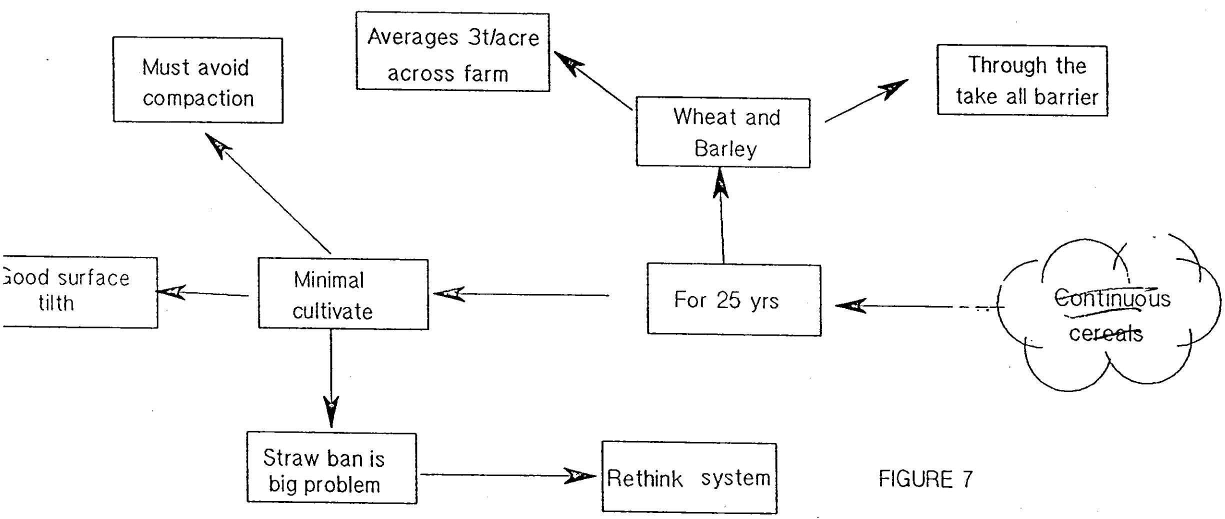



FIGURE 7

**Rotation was seen as a method of maintaining or increasing diversity......**

....... of farm enterprises carried, reducing the risk due to failure in any one. This led onto the benefits of mixing "horn and corn." One person commented that he was quite willing to keep enterprises "ticking over", (providing they weren't making a huge loss), because farming is inevitably cyclic, (and inherently uncertain) and what is not in good form today may be the thing to be in tomorrow.

Well over half of those spoken to had either considered, or taken on what are often referred to as non-farming enterprises. These included stabling, eventing courses, bed and breakfast, fishing ponds, golf courses and haulage. Again this was seen as a way of spreading risk as well as exploiting potentially lucrative markets. Reservations were expressed because of the capital input needed into some of these ventures and this had certainly stopped the adoption of a variety of schemes, see figure 8,

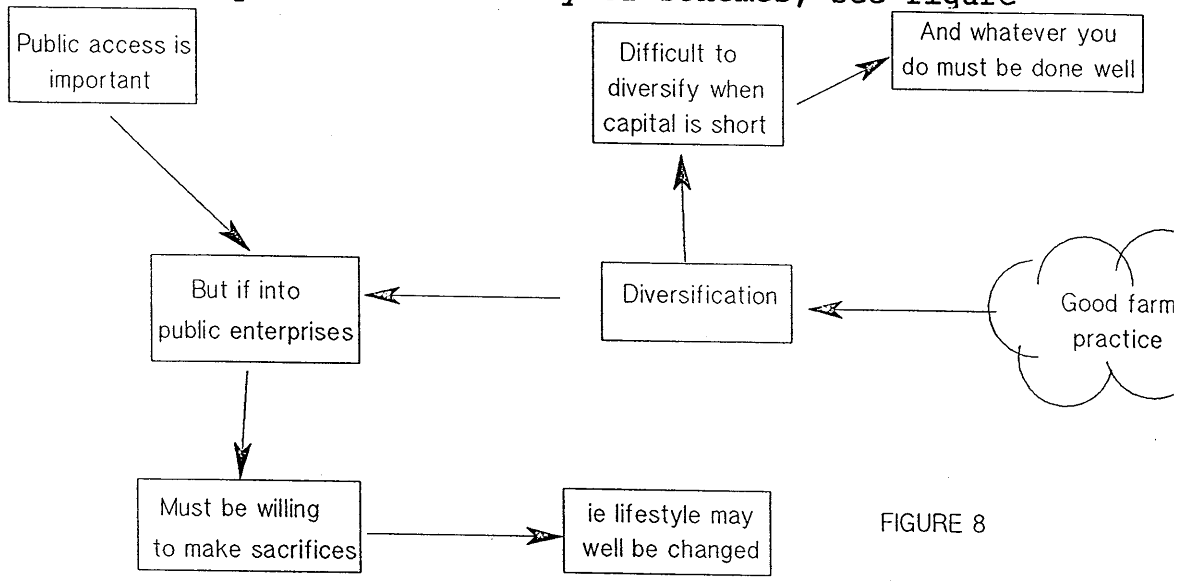



FIGURE 8

Concern was also expressed that markets were often ill researched and that some farmers had been encouraged to, and jumped headlong into business ventures which they knew little about. It is obvious that individuals differ in their ability and willingness to take on board new enterprises. With regard to the latter comments were made such as, "I'm a farmer because I like to farm and its a bad job if I can't make a living doing what I'm good at and enjoy."

**The ability to carry out general maintenance......**

...... about the farm is being compromised by the financial pressure facing some individuals, accentuated by a gradual shedding of labour which has reduced the potential opportunity to carry out such work. Combined with this machinery is being kept for longer periods, increased amounts of on farm maintenance of machinery is being undertaken, and the use of contractors and machinery sharing is being explored to a greater degree, See figure 9,

**OTHER POPULAR ISSUES DISCUSSED,**

**The lack of representation.......**

....... of the farmers by their union, the NFU, was cited by some as being part of the reason why farming in general has a poor reputation. Balanced against this, a sizable group who felt the union was doing a good job and

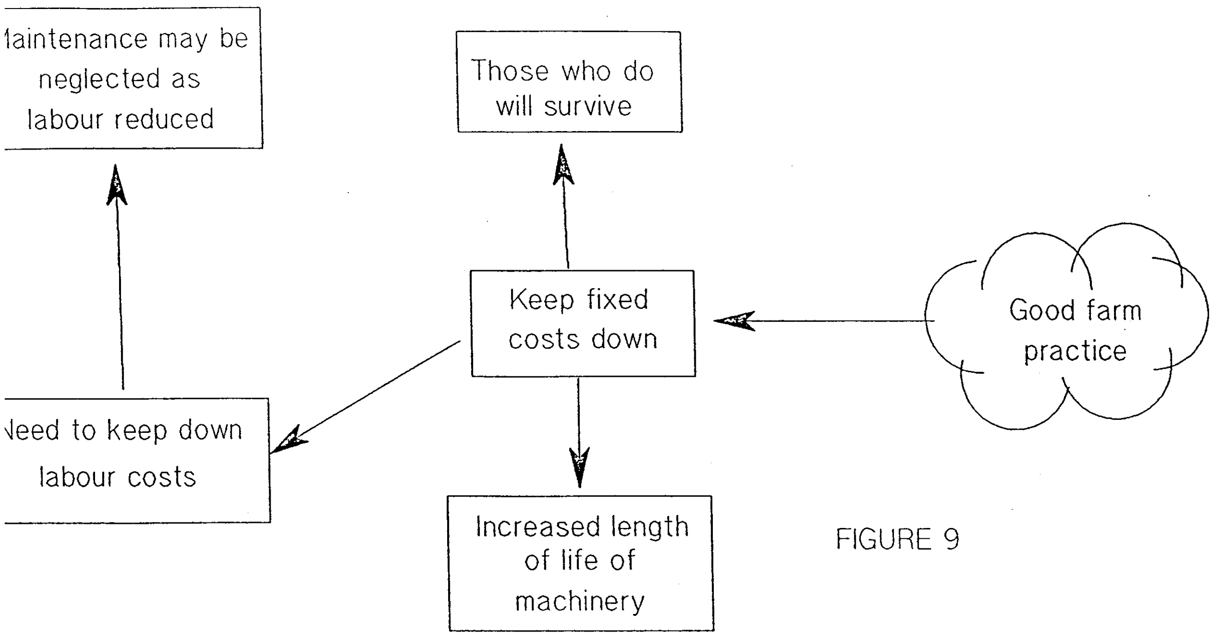



FIGURE 9

that it is "apathy" on behalf of those who belonged to the union but didn't contribute to it which is the cause of the problem.

Several felt that the union couldn't carry out its dual role as insurer and national representative properly and in some issues ended up representing both sides. Others were worried that it only had the interests of the bigger farms at heart, see figure 10,

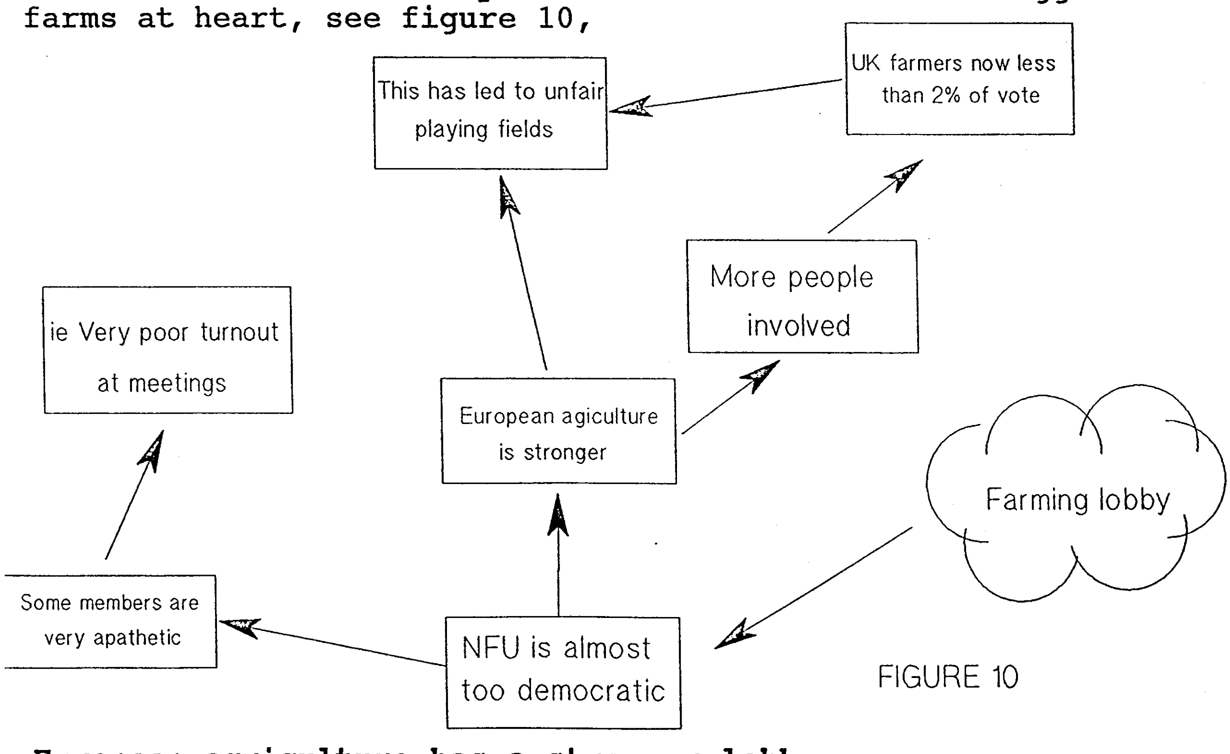



FIGURE 10

**European agriculture has a stronger lobby......**

....because there are more people involved. The apparent power of the farming lobby in France was discussed, and the fact that their inheritance laws tend to result in a larger number of people with an interest in land ownership. Fewer people being involved in farming and their individualism was cited as the main reason why the farming lobby had lost much of its power in this country.

**The benefits of having extra land........**

......... were discussed by several and it was felt by many that they could manage more hectares without having to increase their fixed costs to any significant degree. This would obviously reduce costs per hectare and increase profitability. But the price of land in relation to its earning capacity meant that money would likely be better off in the bank.

One farmer commented on the change in land tenure in the particular village in which he lived, See figure 11, The manager\owner of a large farm commented that he had been approached by several small farms in recent years with regard to share or contract farming and this had resulted in the expansion of his business. Another similar farmer when asked what he thought the acreage he as an individual was capable of managing thought that 5000 acres would be feasible providing the staff were reliable and tasks were well delegated.

**The family farm......**

......... was generally held in high regard, and was thought to be a major contributor to the functioning of the countryside. One young farmer mentioned the importance of the family farm with regard to intergenerational continuity. Knowledge of the land, soil, rural community etc passed down from his father together with "traditional farming skills" combined well with his own progressive education, ideas and innovations.

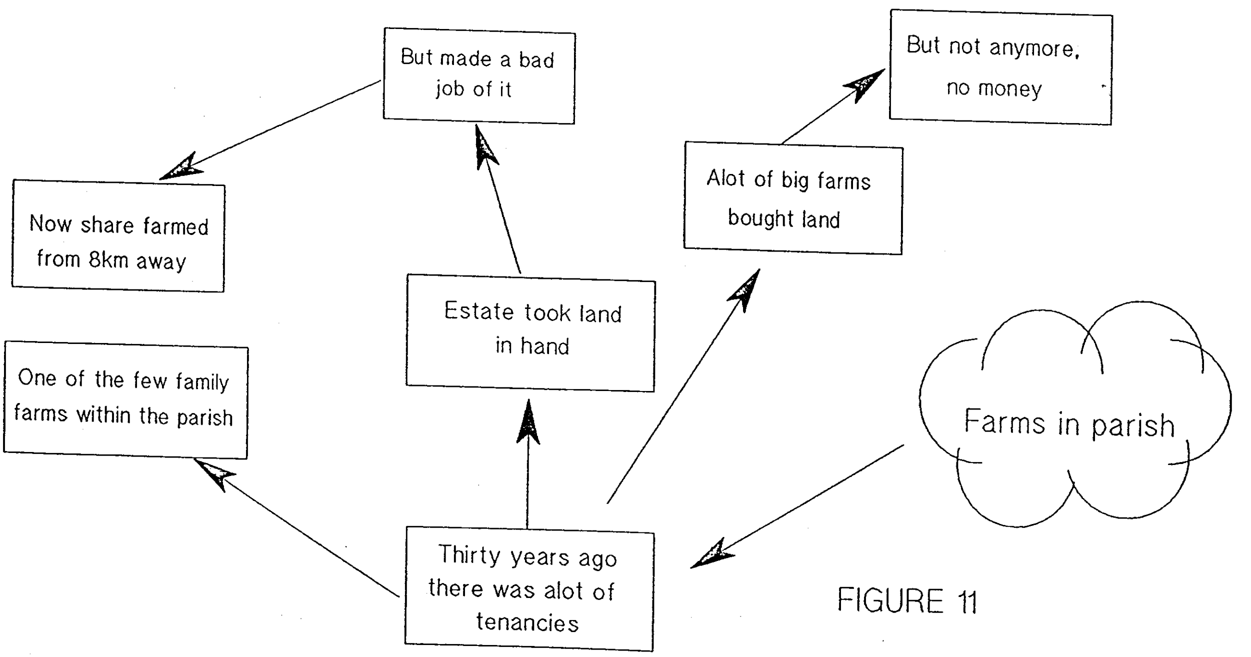



FIGURE 11

The laws of inheritance were also seen by some as important in this feeling of continuity, and it was felt by many that until recently the laws had not favoured continuity in the countryside. Such continuity was seen as important in the maintenance of the rural environment. " We don't inherit land from our fathers but borrow it from our children," See figure 12

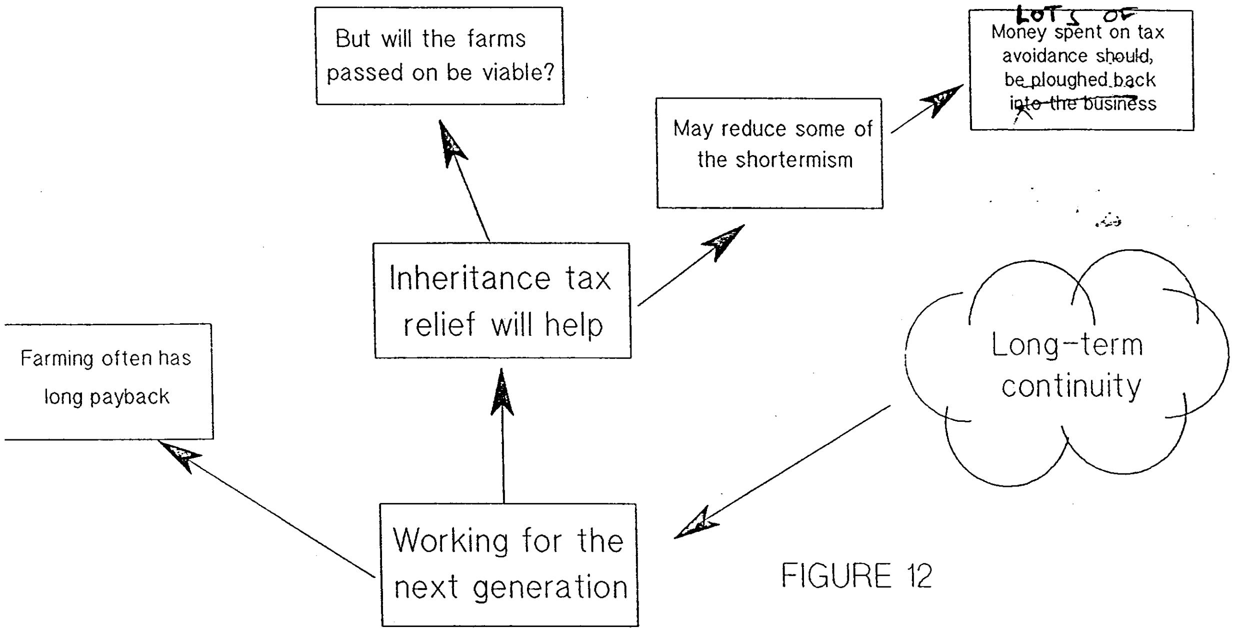



FIGURE 12

**Setaside and the ban on straw burning........**

.......were hotly debated. For some the introduction of a ban on burning has meant a total rethink of their cultivation practices. Many have taken the "bull by the horns" and have been experimenting with various methods of incorporation over several years. Issues surrounding the straw ban include establishment problems, disease carry over, increased cultivation, more fossil fuels burnt, large tracts of straw laying on the surface.

But not all comments were negative, several commented that they had already noticed an improvement in workability of some of the land into which they had been incorporating for several years. One large farmer commented that it actually increased the "timeliness" of operations now that he was fully geared up to get on.

**Few thought that setaside........**

.......was a sensible policy. Of particular concern was the fact that it acted as a reservoir for weeds and disease. On the other hand some found it difficult to come to terms with the fact that land was lying idle, especially when there are millions in the world starving. It was thought that the public would just see setaside as "paying the farmers to do nothing" and this would do little to enhance their image.

The use of "spare land" as a resource to grow fuel crops is seen as a possibility, although the feeling is that at present the economics, or in some cases the market for the end product make such ventures unfavourable.

**FUTURE ISSUES,**

**The majority view was that the future......**

....... in agriculture is difficult to predict at the best of times, and now isn't the best of times! One farmer commented that "now is the greatest period of flux since he started farming".

Uncertainty due to the CAP and GATT has caused, is still causing, and will no doubt continue to cause problems for every sector of the industry.

Farming is an industry which traditionally has had to deal with uncertainty in the weather and the "environment" in which it takes place. Individuals have been able to adapt to this, but the continual uncertainty due to changing policies was felt to be more difficult to deal with. As one farmer said, " I can farm against the weather but not against the politicians."

**The small farmer and highly geared businesses.......**

......... were seen as those who would find the "weathering of the storm" most difficult. Many thought the next five years would be critical to their survival, and their ability to keep a tight reign on fixed and variable costs would be crucial. Several mentioned they were working harder just to stand still and two smaller farmers were working part-time elsewhere.

**Wider issues such as world trade.......**

....... were on many minds, and indeed it was generally thought that these "global issues" concerning international markets and food distribution were central to the problems facing the UK industry.

Many felt that there was a need "to decide what is wanted in the long-term". This was mentioned with regard to the decisions being taken in Europe about food production, our role as providers of food to the world population, but also closer to home, with regard to the type of countryside people want to see.

**More specific issues that many felt......**

........ would become important in the future is the use of land for fuel cropping, the collective power of the agricultural industry, the relations with the public, the education and training of the agricultural workforce and the productive capabilities of Eastern Europe.

**OVERALL COMMENT,**

There was recognition that although farming is by its nature a industry with high levels of uncertainty, the current policy environment is seen to be exaggerating this problem. There seems to be a need for the setting of long -term objectives within the industry. These need to be set on positive criteria, even if the criteria for measuring efficiency are different to those we use today. Negative objectives such as setaside, reducing stocking rates, and reduction of production can provide little motivation or satisfaction to the individual producer.

This is linked with the need to maintain continuity within the countryside as a whole. As one farmer said, "Farmers feel they are custodians of the countryside, and this evolves in such a way that it cannot be switched on and off".

The family farm, whether "small or large", is central to this continuity. Within such units "hard earned experiential learning" of older generations can be integrated with the enthusiasm and innovative ideas of the young. Combined with this is often an intimate historical knowledge of the land farmed and the surrounding rural community. Many discussed the problems faced by their children with regard to following in their footsteps. Several had sons and daughters undertaking various levels of agricultural education.

From these discussions it is clear that the majority farm according to what they see as good practice and are aware of the influence they have on the countryside as a whole. This may well differ from the perceptions of the environmentalists and many of the general public and is part of the reason for increase in regulations and restrictions facing the farmer.

At the heart of any long-term objectives must be the recognition of what good farm practice is. This in itself is a changing concept as our knowledge of both the scientific and social world continues to increase. This suggests that such objectives will only be successfully formulated when the complexity of the issues involved are recognized by all parties concerned, but particularly by those formulating policy.

APPENDIX 6D : RETURN SHEETS FROM FARMERS IN RESPONSE TO THE REPORT ON THE CURRENT ISSUES FACING THE AGRICULTURAL INDUSTRY,

INNOVATION AND TECHNOLOGY ASSESSMENT UNIT

RESPONDANT NUMBER 2

**It would be of great help if you could spend a couple of minutes answering the four questions below and putting the sheet in the post paid envelope, thanks again.**

1. Any general comments/critisms about the discussions, the report etc

I thought the report to be very informative as to the overall 'picture' of farming a lot of effort being seen in the reading and overall the issues were well set out in a easy ~~to~~ visual format.

2. Given that the discussions set out to give an insight into the world as seen from the farmers viewpoint, how well do you think it does this from your own point of view?
(Please circle number on the sliding scale)

| Very representative | | | | | | | | | A bad representation |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | (7) | 8 | 9 | 10 |

3. Even if the report itself doesn't agree with your own viewpoint do you think it expresses more or less the views of the wider farming community?
(Any comments would be useful)

Very well

4. I mentioned in the covering letter a specific interest in Agroforestry. I would be pleased to hear your views on such a cropping practice as well as outlining what I see as its pros and cons. Please circle with regard to me contacting you in November/December.

(YES) I maybe able to help you again, ?

NO Please don't contact me again,



IERC Cranfield

RESPONDANT NUMBER 13

**It would be of great help if you could spend a couple of minutes answering the four questions below and putting the sheet in the post paid envelope, thanks again.**

1. Any general comments/critisms about the discussions, the report etc

A GOOD REPORT - SUMS UP THE SITUATION WE ARE IN TODAY VERY WELL!

2. Given that the discussions set out to give an insight into the world as seen from the farmers viewpoint, how well do you think it does this from your own point of view?
(Please circle number on the sliding scale)

| Very representative | | | | | | | | A bad representation | |
|---|---|---|---|---|---|---|---|---|---|
| (1) | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |

3. Even if the report itself doesn't agree with your own viewpoint do you think it expresses more or less the views of the wider farming community?
(Any comments would be useful)

YES - VERY INTERESTING READING. CONFIRMS MY OWN VIEWS!

4. I mentioned in the covering letter a specific interest in Agroforestry. I would be pleased to hear your views on such a cropping practice as well as outlining what I see as its pros and cons. Please circle with regard to me contacting you in November/December.

(YES) I maybe able to help you again,

NO Please don't contact me again,



IERC Cranfield

INNOVATION
AND TECHNOLOGY
ASSESSMENT UNIT

RESPONDANT NUMBER 14

**It would be of great help if you could spend a couple of minutes answering the four questions below and putting the sheet in the post paid envelope, thanks again.**

1. Any general comments/critisms about the discussions, the report etc

2. Given that the discussions set out to give an insight into the world as seen from the farmers viewpoint, how well do you think it does this from your own point of view?
(Please circle number on the sliding scale)

| Very representative | | | | | | | | | A bad representation |
|---|---|---|---|---|---|---|---|---|---|
| 1 | (2) | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |

3. Even if the report itself doesn't agree with your own viewpoint do you think it expresses more or less the views of the wider farming community?
(Any comments would be useful)

YES.

4. I mentioned in the covering letter a specific interest in Agroforestry. I would be pleased to hear your views on such a cropping practice as well as outlining what I see as its pros and cons. Please circle with regard to me contacting you in November/December.

YES I maybe able to help you again,

(NO) Please don't contact me again,



IERC Cranfield

INOVATION
ND TECHNOLOGY
SSESSMENT UNIT

RESPONDANT NUMBER 15

It would be of great help if you could spend a couple of minutes answering the four questions below and putting the sheet in the post paid envelope, thanks again.

1. Any general comments/critisms about the discussions, the report etc

Interesting reading.

2. Given that the discussions set out to give an insight into the world as seen from the farmers viewpoint, how well do you think it does this from your own point of view?
(Please circle number on the sliding scale)

| Very representative | | | | | | | | | A bad representation |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | (3) | 4 | 5 | 6 | ~~7~~ | 8 | 9 | 10 |

3. Even if the report itself doesn't agree with your own viewpoint do you think it expresses more or less the views of the wider farming community?
(Any comments would be useful)

Seems to show that many people have ~~...~~ have got a ~~...~~ bad feeling about A.F. etc, and are disgusted.

4. I mentioned in the covering letter a specific interest in Agroforestry. I would be pleased to hear your views on such a cropping practice as well as outlining what I see as its pros and cons. Please circle with regard to me contacting you in November/December.

YES I maybe able to help you again,

~~NO~~ ~~Please don't contact me again.~~

IERC Cranfield

INNOVATION AND TECHNOLOGY ASSESSMENT UNIT

RESPONDANT NUMBER 16

It would be of great help if you could spend a couple of **minutes answering the four questions below and putting the sheet in the post paid envelope, thanks again.**

1. Any general comments/critisms about the discussions, the report etc

Makes very interesting reading.
It put forward well, a summary of farmers views.

2. Given that the discussions set out to give an insight into the world as seen from the farmers viewpoint, how well do you think it does this from your own point of view?
(Please circle number on the sliding scale)

| Very representative | | | | | | | | | A bad representation |
|---|---|---|---|---|---|---|---|---|---|
| (1) | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |

3. Even if the report itself doesn't agree with your own viewpoint do you think it expresses more or less the views of the wider farming community?
(Any comments would be useful)

yes, very much so.

4. I mentioned in the covering letter a specific interest in Agroforestry. I would be pleased to hear your views on such a cropping practice as well as outlining what I see as its pros and cons. Please circle with regard to me contacting you in November/December.

(YES) I maybe able to help you again,

NO Please don't contact me again,



IERC Cranfield

NOVATION
D TECHNOLOGY
SESSMENT UNIT

RESPONDANT NUMBER 19.

It would be of great help if you could spend a couple of minutes answering the four questions below and putting the sheet in the post paid envelope, thanks again.

1. Any general comments/critisms about the discussions, the report etc

I would be very interested to know what happens to this report now. Where does it go? Who reads it? What impact will it have?

2. Given that the discussions set out to give an insight into the world as seen from the farmers viewpoint, how well do you think it does this from your own point of view?
(Please circle number on the sliding scale)

| Very representative | | | | | | | | | A bad representation |
|---|---|---|---|---|---|---|---|---|---|
| 1 | (2) | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |

3. Even if the report itself doesn't agree with your own viewpoint do you think it expresses more or less the views of the wider farming community?
(Any comments would be useful)

Yes it does, but again this report & others like it must be used effectively to help formulate future EC ~~post~~ policy.

4. I mentioned in the covering letter a specific interest in Agroforestry. I would be pleased to hear your views on such a cropping practice as well as outlining what I see as its pros and cons. Please circle with regard to me contacting you in November/December.

(YES) I maybe able to help you again,

NO Please don't contact me again,



IERC Cranfield

INNOVATION AND TECHNOLOGY ASSESSMENT UNIT

RESPONDANT 24

It would be of great help if you could spend a couple of minutes answering the four questions below and putting the sheet in the post paid envelope, thanks again.

1. Any general comments/critisms about the discussions, the report etc

I found it very interesting and would agree with nearly all the conclusions. After a year in set Aside it will be interesting to see if the views about it become stronger or we just accept it?

2. Given that the discussions set out to give an insight into the world as seen from the farmers viewpoint, how well do you think it does this from your own point of view?
(Please circle number on the sliding scale)

Very representative — A bad representation

1 (2) 3 4 5 6 7 8 9 10

3. Even if the report itself doesn't agree with your own viewpoint do you think it expresses more or less the views of the wider farming community?
(Any comments would be useful)

Yes I would go along with most of the report but think that the NFU can sell insurance through the mutual (They understand the problems) & can represent the farming industry. Who else is there to represent us?

4. I mentioned in the covering letter a specific interest in Agroforestry. I would be pleased to hear your views on such a cropping practice as well as outlining what I see as its pros and cons. Please circle with regard to me contacting you in November/December.

(YES) I maybe able to help you again,

NO Please don't contact me again,



IERC Cranfield

Pleased you enjoyed the conservation day. Interested in the Agroforestry. Sorry this is so late in coming back to you

David.

## APPENDIX 7: DESCRIPTION OF ROWMOD,

### Description and formulation of the model.

ROWMOD was designed to be used as a stand alone calculating process, but also for use within a series of interviews with farmers. For ease of working the model was designed so that all of the variables that the farmer could want to change were on the computer screen at the same time. However the underlying calculating processes was not visible, but linked directly to the visible variables via a series of equations within the spreadsheet. At the end of this appendix are two sheets of formulae one of which is the part of the model designed to be visible on the screen, (highlighted with a black box), the other containing the underlying calculating process. In the ensuing text the model formulae and construction is exposed, referring back to the main text where appropriate.

*Year*:- The model is designed to run over 15 years or three tree rotations.

*Cutting rotation*:- Describes the year of tree growth since planting or previous harvest.

*Crop*:- Describes in abbreviated form the understory arable crop being grown.

*Area of farm down to agroforestry*:- This is measured in hectares and is important because it can effect the level of grant received.

*Growth conditions of poplar*:- Growth conditions need to be estimated. A figure of "1" represents ideal conditions whereas a value of "0.6" represents poor conditions.

*Approximate or actual crop gross margins*:- Is the total output from the crop enterprise in a given year minus the variable costs associated with production. Average figures for the gross margins of a range of crops can be found in the Farm Management Pocket-book, (Nix 1993), which is an annual publication.

*% change in agricultural prices*:- Allows a variety of scenarios to be investigated through a one off % change in prices.

*Future gross margin*:- Is the present gross margin modified depending on the % change in agricultural prices that has been imputed,

*Farm size*:- In hectares is used to calculate farm fixed costs per hectare from a total farm figure.

*% change in fixed costs*:- Allows a variety of scenarios with respect to changes in fixed costs to be investigated.

*Fixed costs/ hectare*:- Calculated on an annual basis depending on the % change in fixed costs that is imputed.

*Normal crop net margin*:- Is calculated by subtracting fixed costs from the figure for crop gross margin. It is recognised that it is difficult to allocate fixed costs accurately to specific enterprises, and thus this remains as a weakness within the model.

*Agroforestry row width*:- This is the distance in metres that the tree rows are to be planted at. The closer the rows, the greater will be the amount of arable land that will be lost to tree production. This will also effect the degree of shading.

*Number of trees per hectare*:- Assumes the trees are planted at 1M intervals within row. Thus number of trees per hectare is a direct function of the distance between the rows of trees.

*Agroforestry crop net margin*:- Is the net margin from the arable crop under an agroforestry regime. The model reduces the crop net margin depending on the planting width of the trees which directly takes land out of arable production. However, in addition to this the yield of the arable crop is reduced from year 3 onwards due to a shading effect from the trees, (see main text).

*% change in poplar price per year*:- Allows the price of poplar to be changed on a yearly basis.

*Price of poplar in £/$M^3$*:- See main text

*Market Opportunity*:- Allows premium markets to be explored. A value of "1" refers to a base price for the poplar. This can be increased by upto 50% to a value of "1.5".

*Actual poplar income*:- Is derived from the cutting of the trees every five years. It is calculated from an assumption that each tree contains .05$M^3$ of timber at 5 years of age. This figure is multiplied by the number of trees per hectare, the growing conditions for poplar, the price in £/$M^3$ and any premium markets that are available.

All other variables are discussed within the main text.

FORMULAE FOR "VISIBLE" (I.E. ON COMPUTER SCREEN) PORTION OF THE MODEL

| | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | yr | crop | farm | growth | farm | % cha. | farm | labour | agfor | % cha. | price | market | extra | Int.. | FC or |
| 2 | | | area | conds. | crop | ag prix | size | fuel | row | pop. | poplar | oppor | fixed | rate | MAFF |
| 3 | | | agfor | 1=high, | gm's | | | repairs | width | price | £/M3 | 1 , 1.5 | costs | | supp |
| 4 | | | ha | .8=med | | | | total | | | | | | | total |
| 5 | | | | .6=low | | | | | | | | | | | 681 |
| 6 | 1 | WW | 13 | 0.8 | 545 | 0 | 250 | =G6*345 | 14 | 0 | 11 | 1 | 0 | 7 | =O5*0.7 |
| 7 | 2 | WW | =C6 | =D6 | 545 | =F6 | =G6 | =H6+(H6*J37/100) | =I6 | =J6 | =K6+(K6*J6/100) | =L6 | 0 | =N6 | 0 |
| 8 | 3 | WBE | =C7 | =D7 | 495 | =F7 | =G7 | =H7+(H7*J38/100) | =I7 | =J7 | =K7+(K7*J7/100) | =L7 | 50 | =N7 | 0 |
| 9 | 4 | WBA | =C8 | =D8 | 425 | =F8 | =G8 | =H8+(H8*J39/100) | =I8 | =J8 | =K8+(K8*J8/100) | =L8 | 0 | =N8 | 0 |
| 10 | 5 | OSR | =C9 | =D9 | 530 | =F9 | =G9 | =H9+(H9*J40/100) | =I9 | =J9 | =K9+(K9*J9/100) | =L9 | 200 | =N9 | =0.2*O5 |
| 11 | 6 | WW | =C10 | =D10 | 545 | =F10 | =G10 | =H10+(H10*J41/100) | =I10 | =J10 | =K10+(K10*J10/100) | =L10 | 0 | =N10 | 0 |
| 12 | 7 | WW | =C11 | =D11 | 545 | =F11 | =G11 | =H11+(H11*J42/100) | =I11 | =J11 | =K11+(K11*J11/100) | =L11 | 0 | =N11 | 0 |
| 13 | 8 | WBE | =C12 | =D12 | 495 | =F12 | =G12 | =H12+(H12*J43/100) | =I12 | =J12 | =K12+(K12*J12/100) | =L12 | 50 | =N12 | 0 |
| 14 | 9 | WBA | =C13 | =D13 | 425 | =F13 | =G13 | =H13+(H13*J44/100) | =I13 | =J13 | =K13+(K13*J13/100) | =L13 | 0 | =N13 | 0 |
| 15 | 10 | OSR | =C14 | =D14 | 530 | =F14 | =G14 | =H14+(H14*J45/100) | =I14 | =J14 | =K14+(K14*J14/100) | =L14 | 200 | =N14 | =0.1*O5 |
| 16 | 11 | WW | =C15 | =D15 | 545 | =F15 | =G15 | =H15+(H15*J46/100) | =I15 | =J15 | =K15+(K15*J15/100) | =L15 | 0 | =N15 | 0 |
| 17 | 12 | WW | =C16 | =D16 | 545 | =F16 | =G16 | =H16+(H16*J47/100) | =I16 | =J16 | =K16+(K16*J16/100) | =L16 | 0 | =N16 | 0 |
| 18 | 13 | WBE | =C17 | =D17 | 495 | =F17 | =G17 | =H17+(H17*J48/100) | =I17 | =J17 | =K17+(K17*J17/100) | =L17 | 50 | =N17 | 0 |
| 19 | 14 | WBA | =C18 | =D18 | 425 | =F18 | =G18 | =H18+(H18*J49/100) | =I18 | =J18 | =K18+(K18*J18/100) | =L18 | 0 | =N18 | 0 |
| 20 | 15 | OSR | =C19 | =D19 | 530 | =F19 | =G19 | =H19+(H19*J50/100) | =I19 | =J19 | =K19+(K19*J19/100) | =L19 | 200 | =N19 | 0 |
| 21 | | | | | | | | | | | | | | | |
| 22 | | | | | | COST OF ESTABLISHMENT/HA | | | | | | =U36 | | | |
| 23 | | | | | | ASSUMED GRANT PER HECTARE | | | | | | =O5 | | | |
| 24 | | | | | | NPV OF AGROFORESTRY | | | | | | =SUM($AA$36:$AA$50) | | | |
| 25 | | | | | | NPV OF CONVENTIONAL CROPPING | | | | | | =SUM($AB$36:$AB$50) | | | |
| 26 | | | | | | BENEFIT OF AGROFORESTRY | | | | | | =L24-L25 | | | |

| yr | cutting rotation | crop | area of farm down to agfor ha | growth conditions 1=high, .8=med .6=low | approx or actual farm gm | % change in ag. prices | future gross margin | farm size | % change in fixed | fixed cost | average fixed costs/ha | normal crop net margi | agfor row width | number of trees per ha |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | WW | =C6 | =D6 | =E6 | =F6 | =F45+(F45*G45/100) | =G6 | 0 | =H6 | =K45/I45 | =H45-L45 | =I6 | =(100/N45)*100 |
| 2 | 2 | WBe | =C7 | =D7 | =E7 | =F7 | =F46+(F46*G46/100) | =G7 | =J45 | =H7 | =K46/I46 | =H46-L46 | =I7 | =(100/N46)*100 |
| 3 | 3 | WBa | =C8 | =D8 | =E8 | =F8 | =F47+(F47*G47/100) | =G8 | =J46 | =H8 | =K47/I47 | =H47-L47 | =I8 | =(100/N47)*100 |
| 4 | 4 | OSR | =C9 | =D9 | =E9 | =F9 | =F48+(F48*G48/100) | =G9 | =J47 | =H9 | =K48/I48 | =H48-L48 | =I9 | =(100/N48)*100 |
| 5 | 5 | WW | =C10 | =D10 | =E10 | =F10 | =F49+(F49*G49/100) | =G10 | =J48 | =H10 | =K49/I49 | =H49-L49 | =I10 | =(100/N49)*100 |
| 6 | 1 | WW | =C11 | =D11 | =E11 | =F11 | =F50+(F50*G50/100) | =G11 | =J49 | =H11 | =K50/I50 | =H50-L50 | =I11 | =(100/N50)*100 |
| 7 | 2 | WBe | =C12 | =D12 | =E12 | =F12 | =F51+(F51*G51/100) | =G12 | =J50 | =H12 | =K51/I51 | =H51-L51 | =I12 | =(100/N51)*100 |
| 8 | 3 | WBa | =C13 | =D13 | =E13 | =F13 | =F52+(F52*G52/100) | =G13 | =J51 | =H13 | =K52/I52 | =H52-L52 | =I13 | =(100/N52)*100 |
| 9 | 4 | OSR | =C14 | =D14 | =E14 | =F14 | =F53+(F53*G53/100) | =G14 | =J52 | =H14 | =K53/I53 | =H53-L53 | =I14 | =(100/N53)*100 |
| 10 | 5 | WW | =C15 | =D15 | =E15 | =F15 | =F54+(F54*G54/100) | =G15 | =J53 | =H15 | =K54/I54 | =H54-L54 | =I15 | =(100/N54)*100 |
| 11 | 1 | WW | =C16 | =D16 | =E16 | =F16 | =F55+(F55*G55/100) | =G16 | =J54 | =H16 | =K55/I55 | =H55-L55 | =I16 | =(100/N55)*100 |
| 12 | 2 | WBe | =C17 | =D17 | =E17 | =F17 | =F56+(F56*G56/100) | =G17 | =J55 | =H17 | =K56/I56 | =H56-L56 | =I17 | =(100/N56)*100 |
| 13 | 3 | WBa | =C18 | =D18 | =E18 | =F18 | =F57+(F57*G57/100) | =G18 | =J56 | =H18 | =K57/I57 | =H57-L57 | =I18 | =(100/N57)*100 |
| 14 | 4 | OSR | =C19 | =D19 | =E19 | =F19 | =F58+(F58*G58/100) | =G19 | =J57 | =H19 | =K58/I58 | =H58-L58 | =I19 | =(100/N58)*100 |
| 15 | 5 | WW | =C20 | =D20 | =E20 | =F20 | =F59+(F59*G59/100) | =G20 | =J58 | =H20 | =K59/I59 | =H59-L59 | =I20 | =(100/N59)*100 |

| agfor crop NM/ha | change in poplar price/yr % | price of poplar £/M3 | market oppor 1 , 1.5 | actual poplar income | estab costs | extra fixed costs | FC or maff supp |
|---|---|---|---|---|---|---|---|
| =IF(B45>2,(M45*(((N45-1.5)/N45))*(1-(B45/(2*N45)))),(M45*(N45-1.5)/N45)) | =J6 | =K6 | =L6 | 0 | =IF(D45>9,O45*0.7,O45*0.8) | =M6 | =O6 |
| =IF(B46>2,(M46*(((N46-1.5)/N46))*(1-(B46/(2*N46)))),(M46*(N46-1.5)/N46)) | =J7 | =K7 | =L7 | 0 | 0 | =M7 | =O7 |
| =IF(B47>2,(M47*(((N47-1.5)/N47))*(1-(B47/(2*N47)))),(M47*(N47-1.5)/N47)) | =J8 | =K8 | =L8 | 0 | 0 | =M8 | =O8 |
| =IF(B48>2,(M48*(((N48-1.5)/N48))*(1-(B48/(2*N48)))),(M48*(N48-1.5)/N48)) | =J9 | =K9 | =L9 | 0 | 0 | =M9 | =O9 |
| =IF(B49>2,(M49*(((N49-1.5)/N49))*(1-(B49/(2*N49)))),(M49*(N49-1.5)/N49)) | =J10 | =K10 | =L10 | =O49*0.05*R49*S49*E49 | 0 | =M10 | =O10 |
| =IF(B50>2,(M50*(((N50-1.5)/N50))*(1-(B50/(2*N50)))),(M50*(N50-1.5)/N50)) | =J11 | =K11 | =L11 | 0 | 0 | =M11 | =O11 |
| =IF(B51>2,(M51*(((N51-1.5)/N51))*(1-(B51/(2*N51)))),(M51*(N51-1.5)/N51)) | =J12 | =K12 | =L12 | 0 | 0 | =M12 | =O12 |
| =IF(B52>2,(M52*(((N52-1.5)/N52))*(1-(B52/(2*N52)))),(M52*(N52-1.5)/N52)) | =J13 | =K13 | =L13 | 0 | 0 | =M13 | =O13 |
| =IF(B53>2,(M53*(((N53-1.5)/N53))*(1-(B53/(2*N53)))),(M53*(N53-1.5)/N53)) | =J14 | =K14 | =L14 | 0 | 0 | =M14 | =O14 |
| =IF(B54>2,(M54*(((N54-1.5)/N54))*(1-(B54/(2*N54)))),(M54*(N54-1.5)/N54)) | =J15 | =K15 | =L15 | =O54*0.05*R54*S54*E54 | 0 | =M15 | =O15 |
| =IF(B55>2,(M55*(((N55-1.5)/N55))*(1-(B55/(2*N55)))),(M55*(N55-1.5)/N55)) | =J16 | =K16 | =L16 | 0 | 0 | =M16 | =O16 |
| =IF(B56>2,(M56*(((N56-1.5)/N56))*(1-(B56/(2*N56)))),(M56*(N56-1.5)/N56)) | =J17 | =K17 | =L17 | 0 | 0 | =M17 | =O17 |
| =IF(B57>2,(M57*(((N57-1.5)/N57))*(1-(B57/(2*N57)))),(M57*(N57-1.5)/N57)) | =J18 | =K18 | =L18 | 0 | 0 | =M18 | =O18 |
| =IF(B58>2,(M58*(((N58-1.5)/N58))*(1-(B58/(2*N58)))),(M58*(N58-1.5)/N58)) | =J19 | =K19 | =L19 | 0 | 0 | =M19 | =O19 |
| =IF(B59>2,(M59*(((N59-1.5)/N59))*(1-(B59/(2*N59)))),(M59*(N59-1.5)/N59)) | =J20 | =K20 | =L20 | =O59*0.05*R59*S59*E59 | 0 | =M20 | =O20 |

| agfor cash flow NM's | disc rate | disc. value agfor | disc value conv. | cashflow difference conv-agfor | normal crop net margin | agfor cash flow NM's |
|---|---|---|---|---|---|---|
| =P45+T45-U45-W45+X45 | =N6 | =Y45*(1-(Z45/100))^A45 | =M45*(1-(Z45/100))^A45 | =Y45-M45 | =Y45-AC45 | =Y45 |
| =P46+T46-U46-W46+X46 | =N7 | =Y46*(1-(Z46/100))^A46 | =M46*(1-(Z46/100))^A46 | =Y46-M46 | =Y46-AC46 | =Y46 |
| =P47+T47-U47-W47+X47 | =N8 | =Y47*(1-(Z47/100))^A47 | =M47*(1-(Z47/100))^A47 | =Y47-M47 | =Y47-AC47 | =Y47 |
| =P48+T48-U48-W48+X48 | =N9 | =Y48*(1-(Z48/100))^A48 | =M48*(1-(Z48/100))^A48 | =Y48-M48 | =Y48-AC48 | =Y48 |
| =P49+T49-U49-W49+X49 | =N10 | =Y49*(1-(Z49/100))^A49 | =M49*(1-(Z49/100))^A49 | =Y49-M49 | =Y49-AC49 | =Y49 |
| =P50+T50-U50-W50+X50 | =N11 | =Y50*(1-(Z50/100))^A50 | =M50*(1-(Z50/100))^A50 | =Y50-M50 | =Y50-AC50 | =Y50 |
| =P51+T51-U51-W51+X51 | =N12 | =Y51*(1-(Z51/100))^A51 | =M51*(1-(Z51/100))^A51 | =Y51-M51 | =Y51-AC51 | =Y51 |
| =P52+T52-U52-W52+X52 | =N13 | =Y52*(1-(Z52/100))^A52 | =M52*(1-(Z52/100))^A52 | =Y52-M52 | =Y52-AC52 | =Y52 |
| =P53+T53-U53-W53+X53 | =N14 | =Y53*(1-(Z53/100))^A53 | =M53*(1-(Z53/100))^A53 | =Y53-M53 | =Y53-AC53 | =Y53 |
| =P54+T54-U54-W54+X54 | =N15 | =Y54*(1-(Z54/100))^A54 | =M54*(1-(Z54/100))^A54 | =Y54-M54 | =Y54-AC54 | =Y54 |
| =P55+T55-U55-W55+X55 | =N16 | =Y55*(1-(Z55/100))^A55 | =M55*(1-(Z55/100))^A55 | =Y55-M55 | =Y55-AC55 | =Y55 |
| =P56+T56-U56-W56+X56 | =N17 | =Y56*(1-(Z56/100))^A56 | =M56*(1-(Z56/100))^A56 | =Y56-M56 | =Y56-AC56 | =Y56 |
| =P57+T57-U57-W57+X57 | =N18 | =Y57*(1-(Z57/100))^A57 | =M57*(1-(Z57/100))^A57 | =Y57-M57 | =Y57-AC57 | =Y57 |
| =P58+T58-U58-W58+X58 | =N19 | =Y58*(1-(Z58/100))^A58 | =M58*(1-(Z58/100))^A58 | =Y58-M58 | =Y58-AC58 | =Y58 |
| =P59+T59-U59-W59+X59 | =N20 | =Y59*(1-(Z59/100))^A59 | =M59*(1-(Z59/100))^A59 | =Y59-M59 | =Y59-AC59 | =Y59 |
| | | | =SUM($AA$45:$AA$59) | | | |
| | | | =SUM($AB$45:$AB$59) | | | |
| | | | =$AB$60-$AB$61 | | | |

# APPENDIX 8 : PILOT STUDY AT BANBURY MARKET

An exercise in information gathering was carried out on Thursday 2nd May 1991 at Banbury market in Buckinghamshire. The aims of this exercise were to provide general information on some of themes being developed in the early stages of the thesis. After gaining permission from the market auctioneers farmers were approached and asked if they minded answering a few questions relating to farming in respect to a research project. A simple questionnaire was used which contained 22 questions. It is recognised that this form of interviewing has many limitations but it did provide some useful background information to the study. Ten farmers were interviewed in a 2 hour period. The question sheet used and the responses to the questions are provided below:

ENTERPRISES; Pigs,Beef,Dairy,Poultry,Sheep,Cereal,Root crops,Oil crops,Fodder crops,Forestry,Other............
AREA

Are you aware of any changes in structure and fertility of the land over the period you have farmed it?

Improved 4 No change 5 Got heavier 1

What visible effects of soil erosion have you seen?

None 7 Subsidence 1 Wind 2

What crops do you consider maintain or increase the fertility of the soil?

Beans 1 OSR 2 Grasses 5 Mixed 2

Could you manage without nitrogen fertilizers?

No 5 Yes 5

Do you, or have you grown leguminous crops?

Yes 8 No 2

How do you think tractive machinery will be powered in fifty years time?

No idea 4 Same as now 4 Rapeseed 1 Electric 1

Do you think cropping for energy production or producing electric for the national grid will become widespread on farms?

No 3 Yes 7

Would you consider growing trees as a commercial enterprise?

No 6 Yes 4

If you produced wood as a product on your farm what do you consider its uses might be ?

No idea 6 Off farm 3 On farm 1

What do you understand by the term agroforestry?

Nothing 8 Correct 1 Incorrect 1

What problems would you envisage if trees were grown in combination with conventional crops?(ie at spacings of 13m across the field?)

Mechanical 4 Many 3 No idea 3

Would you consider on farm electricity production from waste products or wood?

| | | | | | |
|---|---|---|---|---|---|
| Yes | 7 | No | 2 | Undecided | 1 |

Does the fact that there are EEC surplus's affect your production decisions?

| | | | |
|---|---|---|---|
| Yes | 6 | No | 4 |

Are their alternatives to set aside?

| | | | | | |
|---|---|---|---|---|---|
| Yes | 2 | No | 4 | Reduce nitrogen | 4 |

To what degree do you feel production on your farm is manipulated by external factors?

| | | | | | |
|---|---|---|---|---|---|
| Low | 1 | Medium | 1 | High | 8 |

Do you feel strongly about the preservation of the small farming business?

| | | | | | |
|---|---|---|---|---|---|
| Yes | 7 | No | 1 | Undecided | 2 |

How do you class small? (acres)

| | | | | | |
|---|---|---|---|---|---|
| <100 | 5 | 100-200 | 4 | >200 | 1 |

Does it matter that a large portion of the cash crops we produce are fed to animals?

| | | | | | |
|---|---|---|---|---|---|
| No | 6 | Yes | 2 | No idea | 2 |

How great is the influence of farmers on the countryside as a whole?

| | | | |
|---|---|---|---|
| Large | 9 | Small | 1 |

Should more governmental money be available for the protection of the countryside?

| | | | |
|---|---|---|---|
| Yes | 9 | No | 1 |

What do you understand by sustainable in terms of agricultural production?

Keep same level 3 Nothing 4 Making a living 1
Future production 1 Low input farming 1

Should individual producers be concerned with national over production in certain commodities?

| | | | |
|---|---|---|---|
| Yes | 8 | No | 2 |

## APPENDIX 9 : COMMENTS ARISING FROM THE PHASE 2 INTERVIEWS

(Numbers refer to the farm identification number. See table 7.1 for cross reference)

### GENERAL COMMENTS

2 Contract to grow 26ha of industrial feedstock on set-aside
2 Didn't believe agricultural prices would fall
2 Geared up to 40' tramlines
2 Considerable interest in non-farming enterprises
4 Drilling spring beans and rape for the first time in a while this spring
4 Considered many diversification projects as a means of bringing money in
4 Particularly interested in coppicing
6 Already thinking about planting small copse
6 Put in for WGS to plant 6 acres of mixed broadleaved and conifer wood
6 Waiting to hear about non-rotational setaside next year
6 Plants trees about the place anyway in twos and threes
6 Generally interested in the biomass trials at Shuttleworth and the variety of species being grown
7 Must be economically viable
7 Do the tree roots send up suckers into the arable crop?
7 Tree roots will hold soil, i.e. on hillsides
7 Plant trees down the side of the field as a windbreak
13 Farm is very heavy Bedfordshire clay and drilling was too difficult in the autumn.
13 Systems that were harvested regularly and that could be mechanised would be the best
13 Wanted to maintain a system where he and his son could manage all of the work
13 My main specialism is in arable farming
13 The bad harvest last year may effect set-aside
15 They are hoping to rejuvenate hazel coppice in Moulsoe woods
15 Trees provide a useful aesthetic cover for grain bins
15 Have planted a great many trees over the last twenty years
15 Only useful for screening noise when they are in leaf
15 Trees may reduce windspeed
23 Suffered badly due to the bad weather in autumn

### FIRST IMPRESSIONS

2 Problem with trees of long-term commitment
2 Should we be growing tree crops on land that can grow food,
2 Flexibility of the system is very important,
2 Impressed with the idea of long term systems
2 Would like to keep a few sheep about the place
2 The long term agroforestry systems would provide useful keep
2 Sheep quotas make it difficult to keep sheep now
4 Would much prefer to grow trees in blocks
4 Enjoys shooting and can see the benefits of growing small blocks

of land for cover

6 Had heard of agroforestry but had not seen this particular system

7 Worried about damaging the sprayer booms

7 Leaves dropping onto the surface may carry over disease

7 Would be useful on a hop farm to reduce windspeed

9 Initially unenthusiastic because of the community forest

9 Hadn't seen these systems before

9 Lack of experience may put him off, but it didn't put me off growing OSR

9 Although the systems was generally appealing because it was innovative didn't see a place for these systems on his farm

9 Could see some general benefits but not at all willing to commit himself to such systems

12 I am an arable manager and sceptical about diversifying too far from this base

12 Committing oneself to long -term systems is not a good idea in todays economic climate

12 Would wait to see how others got on with agroforestry systems before Committing himself.

12 Longer rotation systems useful if stock already on the farms

12 The capital outlay of gearing up to deal with stock is unlikely to make it worthwhile

12 Existing drainage could be wrecked by the vigorous rooting of the poplar

12 Location soil type and tenure would have a large impact on whether individuals adopted these systems

12 His present boss is likely to want to keep the farming system as simple as possible

13 Not at all keen on growing trees on the farm

13 Is a possible option that the government might try to encourage in the future

13 Mainly against tree because of the long-term nature of the investment

13 The longer term 25-30 year rotations are only a generational /inheritance option and are not commercially viable

13 Younger generation may accept systems better, these seem such a change to established systems

13 If anything would be most tempted by willow coppice because it can be mechanised

13 Coppice needs a market, for instance burning at local hospitals

15 These systems may appeal to the more adventurous

15 Having to carry out normal arable operations in the trees may put people off.

15 Long-term systems would require some animal production

15 Economics would depend on how far apart pure stands of trees are planted and the loss in arable yield

15 Would probably plant trees in blocks

15 The benefits maybe out weighed by the operational problems

23 Trees presently have no place as a revenue crop on the farm

23 Have always planted trees and will no doubt continue to do so

23 In the present economic environment there is no way I could grow trees commercially

23 Used to grow a few Xmas trees to sell and this gave a good little earner

23 Can see no advantage of planting the trees in the crop, would sooner plant them in blocks
23 Poplar would go well in small clumps as shelter belts
23 Longer systems utilizing grazing could lead to damage of the trees
23 Needs as much flexibility in his growing systems as possible
23 Ability to respond to changes in price and weather is essential
23 Whatever I grow must fit my overall cashflow
23 Tree growing most appropriate to those who already have knowledge of the systems
23 Farmers are likely to be more interested in RME because they know how to grow rape
23 Who is paying for research into these systems, is it something the market wants
23 Research should be market lead
23 Doubt that farmers are generally interested in mixed cropping, its harder to manage
24 Alot of existing woodland on farm
24 Involved in several planting schemes
24 Tried growing cricket bat willow but this was not too successful, probably due to lack of maintenance
24 A small 3 acre patch of Xmas trees provides an annual income of £1000
24 Continually replacing Xmas trees under a local council planting scheme
24 Would be extremely cautious before committing myself to 30 year system
24 Favours shorter rotation because of quicker returns
24 Time lag between planting trees and their first harvest is a problem
24 Considered a price of £30/tonne for cord wood was far too high
25 Have heard of agroforestry and seems to hold no advantages!
25 Is agroforestry economic?
25 Planted a sizable windbreak about 15 years ago
25 Planted other trees to replace elm
25 From a replacement of drainage point of view should plant trees in small blocks
25 A useful way to establish amenity woodland
25 Could be useful in establishing the community forests
25 Wouldn't the stock damage the trees in longer term systems
25 If I was going to establish trees I would sooner put them in blocks
25 Would be happier to see other people give it a go first
25 Farming is complicated enough at the moment
25 New systems need to be financially sound plus a big bit more
25 Short term energy growing is most favourable, i.e. miscanthus or coppice willow
25 RME fits in with existing farming system
25 Need to consider input /output ratios for energy cropping, Rape may not be that favourable.

PLANTING AND AGRONOMIC COMMENTS

2 Not a good idea to grow poplar and willow over gas mains
2 Need to remove stumps

2 Presently considering planting 3.5 acres of outlying land with trees
2 Would prefer to grow trees in blocks
2 No general machinery problems
2 Problems at when harvesting the arable crop
2 Would extra fertilizer be needed for the trees
4 Planted and managed a great deal of woodland over 18 years
4 On plantation is ready for thinning
4 Has been on training courses to improve chainsaw skills
4 Is about to buy safety gear for chainsaws, think this very expensive
4 Intends to start thinning next winter
4 Rows of trees would cause cultivation problems
4 Spraying would be made difficult
4 Soil wouldn't dryout very well, heavy clays
4 Growing trees in this spatial layout maybe counterproductive to arable production
4 Shelterbelts are very useful on the blowing land of eastern England
4 Many friends in Eastern counties hadn't planted a single tree
4 Trees reduce windspeed and add stability to the soil through their roots
4 Easier management for the farmer in smaller blocks
4 Could plant five blocks in rotation to get continuous supply
4 Didn't think this type of system would suit his heavy soils
6 Shading effects would be a major problem especially with regard to drying the land
6 Poor drying would cause concern at drilling and harvesting
6 i.e could often work field centres but not the headlands
6 Reduction ion windspeed may affect timeliness of drilling
6 Would trees affect the water table and therefore crop supply?
6 Water supply may only be critical in drought years
6 Orientation of row planting would have considerable bearing on shading and drying
6 Would the trees harbour overwintering aphids?
6 Shelter afforded by the trees may allow spraying of arable crop in windy conditions
7 Won't rabbits eat the young trees?
7 Worried about the diseases of the poplar trees
7 Demand of trees for potash and phosphate
7 Do the trees take water that the crops want?
7 Planting wouldn't be a problem
7 Must get the tramlines straight
7 What happens in the field headlands?
7 Ploughing and cultivations will be a problem,
7 Will the roots effect cultivations?
7 Strip will act as reservoir for rubbish and vermin
9 Direction in which the trees planted would be very important
9 Worried about shading of the main crop and the falling yields
9 Main concern with the drying out of the soil in wet periods
12 Worried about shading and the lack of soil drying
12 Wet soil would affect the rates of drying
12 Drying of the crop is extremely important during a wet harvest
12 Worries excentuated by an extremely wet previous harvest on very

heavy soils
12 Trees may act as harbours for pests, for instance pigeons would use the trees effectively
12 Having problems already with both pigeons and rabbits
12 Dying poplar leaves would accumulate on the surface
12 Leaves tended to accumulate in still years and impinged germination of the autumn crop
12 Already had experience with planting trees on the farm
12 Interested in the equipment that could be used to mechanise planting
12 Would hole borers smear the sidewalls therefore reducing establishment
12 The farm has both the labour and machinery to deal with such systems
12 Would plant trees on the worst patches if he was going to plant anywhere
12 What about the ability of trees to pull excess water from the soil
13 Very little experience with trees
13 The trees are going to cause problems with the inaccessibility of tackle
13 Spray booms would catch the trees
13 Spreading tree branches would cause big problems
13 Brashing up of tree would be a unwanted chore
13 Very accurate tramlining would be needed adding time to field operations
13 Strips into which the trees were planted would harbour many pests
13 Would the strips need spraying?
13 Planting of trees between November and March would be a major problem on his fields
13 Like to keep off the land altogether in the winter
13 Polar trees generally grow well in this area
13 Has planted poplar in the past
13 Land is really a little too heavy for poplars
13 Rows of trees would restrict the direction of cultivation
13 With straw incorporation need as many cultivation options as possible
13 One way cultivation nearly always results in ridges
13 Cross cultivating or slightly skewed cultivating would not be possible
13 Have enough problems without putting trees in the middle of my fields
13 Increase shading may cause disease due to change in microclimate
13 Rabbits would enjoy the shelter provided by the uncultivated strip
15 Yield relationship as the trees get bigger
15 In some cases crop yield will be significantly reduced
15 Moisture not a problem on heavy soil but could be on light ones
15 Trees could be vulnerable to arable sprays
15 Could easily level between the rows using a power harrow
15 No need to cross plough therefore cultivation wouldn't be a problem
15 Usually when tree planting the grant covers the cost and I plant them
15 Weeds will move into the arable crop from the tree rows
15 Possibility of change in microclimate causing disease

15 Have planted trees because they block noise from the M1
15 Most of my farm is underdrained
15 Would sub-soiling be a problem
15 Poplar will be a big problem with underdrainage
15 Trees will take up moisture and deprive the crop
23 Shading by the trees would effect both the quantity and quality of the arable crop
23 Yields on shaded headlands are always reduced
23 Brussels sprouts will not reach optimum size if shaded
23 Wouldn't grow trees on the south side of a field
23 Once had a crop of strawberries which were all bush because of the shading from trees
23 Would like to know more about the diseases of poplar and the quality of the wood
23 Spatial layout of the trees may attract rabbits and pigeons
24 Most of my ground is undulating and trees would provide machinery difficulties
24 would have to cultivate in one direction
24 Roots may mess up expensive drains
24 Shading would inevitably be a problem
24 Will poplar deprive main crop of water?
24 In years when pushed for time, trees would be added burden
24 Weed ingression from tree rows could cause difficulties at arable harvest
24 Problems with branches as the trees get older
24 Combine would struggle under low branches
24 Would the sprays used on arable crop damage the trees
24 Will need a great deal of information on the pest interactions
24 Would need to use full width fertilizer spreader rather than cross pattern
24 Geared up for 24m tramlines therefore wider spaced trees
24 How could I deal with chopped straw out of the back of the combine?
24 Usually ploughs across direction of combine, better straw incorporation
24 Need to use biodegradable polythene mulch
24 Could use the chipped branches as a mulch
24 Do the trees deplete the trace mineral content of the soil?
24 Fens are ideally suited for poplar growing
25 Will reduce light to the arable crops and give no end of pest and disease problems
25 50% yield from maincrop would be a realistic estimation
25 Headland yields are always reduced
25 Shading problems would increase as the trees get bigger
25 Tends to minimum cultivate in one direction so trees would perhaps be no problem
25 Possibility of damaging expensive tackle on the trees
25 Larger pests such as pigeons and rabbits would have a field day.
25 Increased humidity between trees could lead to fungal diseases
25 Microclimate would depend on orientation of the trees
25 Timelinees of operations could be changed due to water
25 At present waiting to get back onto the fields following rain
25 Tree and nutrient interactions
25 If removing the trees every five years then what about phosphate

and potash
25 Sceptical about poplar rooting much deeper than wheat at 2m
25 The roots will damage the tile drains
25 there isn't 10 acres on the farm that isn't underdrained
25 Large leaves of poplar would reduce germination of arable crop following leaf fall
25 Look at tree varieties with smaller leaves

HARVESTING

2 Owned chainsaw
2 Plenty of previous experience in dealing with trees
2 Extra training for staff needed to produce quality product
2 Spring crop needed in the year of tree harvest
2 Damage to main crop should be avoided
2 Harvesting trees in frosty weather would damage maincrop
2 Plan arable rotation around tree cutting
2 Farm labour could deal with the harvest
2 Planting of trees could perhaps provide extra work during quiet times
4 Woodcutting is hard work and very time consuming if not set-up properly
4 Economically unsound unless carried out in spare time
4 Useful activity at quiet times
7 Harvest on bare land in the autumn
7 Could be a labour clash at this busy time
7 Wouldn't like to attempt to harvest trees in the growing crop
7 Would the crop dry out at harvest?
9 Quite happy to grow trees
9 Would attempt to carry out tree management in the winter
9 Needed to fit in with his existing system
9 Considers it could take upto two years for the poplar wood to dry out thoroughly
12 Nagging doubt about growing trees on land which is suitable for food production
12 Both himself and the men on the farm had been on chainsaw courses
12 Used to dealing with the numerous small copses on the estate
12 Could fit in tree work in slacker periods when the demand for labour is less
12 In the year of tree harvest could possibly plant a spring crop
12 What about finishing the system if it doesn't suit the farm
12 Would take stumps five years to rot off once they were killed
12 Has to thin existing woodlands quite soon
12 Large estates have own sawmills, better equipped to deal with agroforestry systems
13 Wouldn't want to be involved in the harvest of the trees
13 Have a chainsaw about the place
15 Would cut them with chainsaw and cart them away in a trailer
15 More even labour distribution is easier said than practiced
15 Would harvest through the winter and plant spring costs
15 Am or would be happy to fell trees at 5 years
15 Speed or good equipment to deal with trees could be an issue
15 Already burn some poplar but must be well dried out

23 Quite happy cutting down trees with chainsaw
23 The management of the trees would take up a considerable amount of time
23 How easily could the stump be removed?
23 May be best to have somebody in and clear fell the trees
23 The sue of contract felling would require a reasonable area to be grown
23 Poplars regrowing from the stool would have an advantage over Christmas trees
23 Coppiced poplars would be better off in a plantation
24 Ability to harvest the trees would depend on the acreage grown
24 A logger fo firewood supply may cost £4000 second hand
24 Easiest to harvest trees on the stubble
24 Could grow a spring crop in the year of tree harvest
24 If harvesting annually to give continuity of supply then arable rotation could get complicated
24 Don't like to travel on land when it is wet because of compaction
25 Am used to harvesting trees, have also sold Xmas trees
25 Mechanical harvesting would be a bonus

MARKETS

2 Possible premium market for wood in MK
2 Cashflow from the two enterprises is extremely important
2 Would view the planting of trees as a longer-term "on the side" investment
2 Concerned about the quality of poplar timber
2 May be a local firewood market
2 Chipping for amenity use in parkland would be a possibility
2 Premium markets will attract neighbours into same operation!
2 Benefits if existing marketing structures were in place,
2 Not worth having a straw burner whilst fossil fuels are so cheap
2 Wood burners need alot of labour
4 Only use of wood on the farms was in open fires
4 Bought wood in this winter to use on the fires
4 Arable farm with little use for of wood for building or fencing
4 Would prefer to grow quality timber over a long time period, as a bonus to normal farm income
4 Couldn't make his mind up about coppicing, would need market before he committed himself
4 Local market may take chips for groundwork
4 Small market for trestles and basket work
4 Not much demand locally for firewood because many on gas or in a smokeless zone
6 Had a ready use for wood chips in his horse arena
6 Presently uses about 100m3 of wood chips costing him £11/m3
6 Not very enthusiastic about growing his own chips
6 Worried about the resin content of poplar
6 High resin woods picked up in the horses feet
6 Had a wood burner, a passing public and woodfires in the house
7 Centralized use for wood.
7 Markets need developing for young timber
9 Has a wood burning stove on farm which he heats the house and swimming pool

9 Uses old pallets at present in the wood burner
9 If the pallets ran out he would go back to straw
9 At present had no use for poplar on his farm
9 Worried about the burning abilities of poplar and its tar production in the boiler
9 He was in favour of growing wood because of the high amount of timber the UK imported
9 Worried that the present end market for wood just didn't appear to make it very economic
12 On farm use of timber was limited despite this being an estate
12 Little use for posts and rails on this arable farm
12 Not keen for using wood on farm as a fuel
12 Used to be a woodburner to heat the farmhouse, this was removed when the supply of dead elm ran out
12 Oil is much easier and at present priced very favourably
12 Final price of timber would depend on transport costs and nearest sawmill
12 Very little wood appeared to be grown locally therefore local markets maybe lucrative
13 No idea of the off farm market for poplar wood
13 Could use on farm through a burner
13 Could perhaps use heat generated in the grain store
13 Probably more appropriate to dry grain with electric as only uses the dryer about 1 year in 5
13 Being an arable farmer he had little use for timber on the farm
13 Off farm marketing of timber could be problematic
13 Spend years growing the crop then may not get a fair price at end of the day
15 At present I use thinnings etc from existing woodlands for fire
15 Could be very useful for making fencing panels
15 Could possibly use on farm for fencing but have no great demand
15 As the price of oil goes up the sense of home grown energy will become better
15 I have been considering buying a wood/straw burner
15 I burn wood in the house
23 Larger farms more able to dabble in a few acres
23 Probably a local market for firewood
23 Firewood is time consuming with little reward
23 Better retailing wood rather than growing it
23 Difficult to predict markets in 20 to 30 years
23 Comparison with the revenue from Xmas trees and poplar is not favourable
23 Woodburning stove initially supplied by elm, but more recently from local windblown timber
23 Oil is cheaper and cleaner
24 Markets always seemed to be depressed when I want to sell mature timber!
24 A lumber yard could make as much in 6 months as the farmer makes in 25 years.
24 Profit is in the value added therefore must get the marketing right
24 There is a local market for wood but don't know how big
24 Advantages in marketing living next to an urban centre
24 Any transport costs would reduce financial viability considerably

24 Worried about the burning properties of poplar and its loss of weight on drying out
24 Does poplar wood spit when on an open fire?
24 Uses about 200 stakes a year on the estate
24 Dubious about the capabilities of poplar as a building material
24 No market in the area for wood chips, therefore couldn't make a commitment on this basis
24 Present employee earns a bit of pin money selling logs
24 Has a woodburner which still runs on dead elm
24 Will be looking for another source of fuel for the wood burner in a couple of years
4 Agroforestry could be useful for the farmer in a non-wooded situation
25 Relative price of the two crops would determine the financial viability of agroforestry
25 Shorter systems better because of payback
25 Longer term systems, will be dead by their harvest!
25 Can't see a ready market for poplar cut early
25 Would be better off burning straw rather than wood
25 Local CHP projects could possibly provide a market
25 Wouldn't be economic to move wood more than about 10 mile radius
25 Would soon get a glut of poplar if everybody put a couple of acres in
25 Does poplar burn well and what is its weight loss during drying?
25 Does it spit on an open fire
25 No stock on farm therefore little fencing
25 Don't think poplar is a very resilient wood
25 A source of heating for greenhouses

PUBLIC AND THE ENVIRONMENT

2 Public would like to see trees growing in broad plains of Beds.
2 Straight lines wouldn't be too much problem
2 Clumps of trees would be better for wildlife
4 Think the public would rather see clumps of trees, aesthetically pleasing
4 Was sceptical about general environmental benefits,
4 Could see possible beneficial pest interactions
4 Ladybirds may attack overwintering aphids
4 Thought wildlife would prefer small clumps of trees
7 Trees will clean atmosphere by removing carbon dioxide
12 Rows of trees would be useful to block out noise , say from new road projects.
12 Would be more acceptable to the public than large tracts of unbroken land
12 Public may not like to see trees cut down once they have grown
12 Tree cover could also be useful for shooting on the farm
12 Rows of trees could reduce the risk of windblow in Norfolk
13 From a image point of view these systems must be better than set-aside
15 Public probably like to see trees planted in any configuration
23 Planted hedgerow trees to replace dead elm
23 Planted trees for love of the countryside and not to appease any conservationists
23 Systems may be useful for shooting

23 Very sceptical about the ecological benefits of these systems
23 Growing in this spatial layout as a windbreak is the only benefit I can see
23 The public might like such a system but don't really care about that
24 Game birds would like the tree cover
24 Difficult to say how the public would react
24 Public may not like the rows of foreign trees compared to native plantings
24 Definitely need to plant something on set-aside

POLICY

2 Financial protection needed for long term commitment
2 Greater incentives needed before farmer will plant trees commercially
2 Guaranteed price for wood might help
2 More information needed about the total concept
2 Talks on the planting , machinery disease and markets
2 In present economic environment wouldn't want to commit himself to planting more than the odd acre
2 Who knows what will happen to set-aside in the future?
2 A couple of bad harvests and set-aside would be out of the window
2 Could use set-aside as a carrot , i.e. plant 10% of land with trees and be excused the other 5% set-aside
2 Incentives to set up marketing coops
2 Participation of farmers in national forest could increase access to information and expertise.
4 A local generating plant would demonstrate commitment to such a project
7 Could plant on land that isn't the best.
7 Non rotational setaside would make these systems favourable
7 Would sooner plant in blocks than in rows.
9 The uncertainty to do with existing subsidies didn't favour agroforestry systems
9 Increases in the cost of energy could make such systems more favourable
9 Whilst oil and gas are cheap most people will continue to use them
12 Uncertainty about future is a major obstacle to committing oneself to these systems
12 Ever changing policy frameworks
12 If policies put in place to make poplar growing more favourable, how long would they last?
12 The set-aside issue has a major bearing on these systems
12 One of the main policy incentive would be to encourage ready markets
12 Governmental encouragement to form marketing coops
12 Possibly could give guaranteed market for the end product
12 Without being exposed to the calculation process itself, how can I be sure of the validity of the results it produces
12 Informal type group discussion may be a good way of gathering information.
12 Financially the model needs to demonstrate that the systems are in the right "ball-park"

13 Economic viability is a prerequisite of cropping systems despite a host of other considerations
13 Need a secure profitable market for wood in the future before it was even considered
13 How can they subsidise farm energy when they are letting coal mines close?
15 Rotational set-aside is not turning out too badly for us
15 As a small 450 acre tenanted farm we are less likely to try these systems
15 Large estates may be in a better position to try out these alternative systems
15 We are treating the rotational set-aside as a traditional fallow
15 Poplar and willow could be a possibility on permanent set-aside
23 As a small farmer I haven't the time or the land to invest in dodgy enterprises
23 Would need a definite economic market place before making any commitment
23 Could make the growing of timber financially acceptable
23 If arable price was dropped to favour timber I would probably have to leave farming
23 Bring in national woodland policy
23 Government could buy up land to plant trees
24 Corby council could set up wood burning centre, offering farmers stable contract
24 Unless systems became very financially viable he would rather plant trees in clumps
24 Government may be backing of tree planting because of instability in world markets
25 Not enough stability in agriculture to commit oneself to trees
25 It would be more favourable if 20 year set-aside was introduced
25 Need to establish markets to encourage farmers to undertake energy cropping in any form