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An Investigation of Tillage Systems and Implement Design for Water Conservation in Semi Arid conditions in Botswana

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ABSTRACT

Botswana, as a semi arid country, is faced with serious shortage of moisture for crop production. Its challenging climatic condition makes the little moisture received from summer rainfall insufficient. The development of appropriate tillage systems can assist with sustainable crop production. The aim of this project was to come up with a tillage system to improve the suitability of the physical conditions of soil for effective seeding in rain fed farming in Botswana. Strip, Reservoir (depression) and no tillage systems (control) were therefore investigated. Laboratory investigation of the tillage systems for soil water conservation and erosion was undertaken under different slopes (5 and 10°) and rainfall intensities (55 and 95 mm/hr). Energy requirements and work rates of the systems were analysed. The results showed that slope has effects on the capability of strip tillage to harvest water from rainfall of low intensity. It managed to harvest 69.12% of rainfall from 55mm/hr rainfall at a slope of 5° whereas at 10°slope it harvested about 49%. The effects of slope were not significant for the reservoir tillage and no tillage systems. Under a higher intensity rainfall of 95mm/hr the effects of slope were insignificant. The only source of variance was due soil disturbances and the strip soil disturbance performed better than the other treatments.
When eroded soil was investigated under low intensity rainfall (55 mm/hr), there was no significant difference between strip and depression. Depression and strip soil disturbances reduced soil erosion similarly by 47 and 46 % respectively. Under high intensity rainfall eroded soil was still high under undisturbed soil disturbance. This is due to the fact that when the soil surface is bare, there is a higher risk of soil erosion. But when strips and depression are created, the risk of soil erosion is localised especially at high rainfall intensities.

The evaporation analysis showed no significant difference among the tillage systems. This means that the power of water conservation in semi arid environment lies more on water harvesting than reduction of evaporation.

The analysis of power and work rates showed big advantage of strip tillage system over reservoir tillage in the sense that it required less energy and power to complete a hectare of land. Its work rate is almost double of strip tillage.

From the results it can be concluded that, at low slope and low rainfall intensity strip tillage harvest more water than reservoir tillage and zero tillage systems. When slope is elevated there is no difference between strip and reservoir tillage. The strip tillage system harvest more water than both reservoir tillage and zero tillage at high intensities. Strip and reservoir tillage reduce soil erosion similarly at both low rainfall and high rainfall intensity. The energy requirements and work rate were more positive for strip tillage that reservoir tillage. Therefore with these results a conceptual design of strip tillage system was developed.

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I dedicate this degree to my parents and Tsholo

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J_w	=	total water flux (water vapour + liquid water).
ϕ	=	volumetric water content
ΔS	=	stored water between the soil surface and ground water
ΔW	=	change of water stored in the soil
A	=	average annual soil loss in Mg/Ha (metric tons/ha)
C	=	cropping management factor
D	=	drainage to groundwater
d	=	implement working depth (m)
D_b	=	draw bar force (kN)
D_p	=	Draft power (kW)
Dv	=	diffusion coefficient for water vapour in air
E	=	kinetic energy (m-Mg/ha-mm)
E	=	evaporation
E_p.	=	Potential evaporation
ET	=	evapo-transpiration
FAO	=	Food and Agricultural Organisation
GDP	=	Gross Domestic Product
grad H	=	$\frac{dH}{dz}$ = vector gradient of H
H	=	hydraulic head
i	=	rainfall intensity in mm/hr.
I_i	=	irrigation
J_r	=	flow of water vapour in the soil
K	=	hydraulic conductivity
$K_{(h)}$	=	unsaturated hydraulic conductivity of the porous
K	=	soil erodibility factor, which is the average soil loss in t/a per unit of erosion index for a particular soil in cultivated continuous fallow with an arbitrary selected slope length L of 22 m and slope steepness, S of 9 percent (if k is Mg/ha, change constant 2.24 to 1.0),
K_s	=	saturated hydraulic conductivity (ms^{-1})

LS	=	topographic factor
NAMPAD	=	National Master Plan for Agricultural Development
P	=	conservation practice factor
P	=	precipitation
P_F	=	draft force (kN)
PST	=	precision strip tillage
q	=	flux density (LT^{-1})
Q	=	flow rate
R	=	rainfall and runoff erosivity index by geographic location
R	=	surface runoff
r_s	=	specific resistance (kN/m^2)
s	=	speed 9m/s)
t	=	time
TRW	=	Total Retained Water
V	=	volume
w	=	implement working width (m)
β	=	factor accounting for effects of pore geometry and void space
Θ	=	soil water content
ρ_v	=	is the water vapour density

CHAPTER 1

1.0 Introduction

1.1 Background

1.1.1 Semi arid areas

Semi arid areas may be defined as those regions where the potential evapo-transpiration exceeds the rainfall for most of the year. In those areas 70-90% of the annual rainfall, which is often unreliable and sporadic, will occur during the rainy season (Willcocks, 1981). Bowden (1979) mentioned that normally 80% of the annual rainfall occurs in the summer months of June through September in the northern hemisphere and December through March in the Southern hemisphere, but in some years rain can begin more than a month earlier. Godwin (1990) described it as a low rainfall area where annual precipitation is generally less than 500mm and precipitation is often erratic in amount and frequency. Dry periods of two to four weeks duration regularly interrupt the rain season (Bowden, 1979), and therefore makes the semi–arid farmers slaves of a climate that is neither wet nor dry. This is caused by unpredictable rainfall and extremes of weather in semi – arid areas which seldom experience averages in either precipitation or temperature and changes from humid to arid conditions at rapid frequency. Almost all of these areas have rainfall concentrated in the high sun or summer seasons and have relatively high temperatures; potential evapo-transpiration is relatively high in all areas (Bowden, 1979).

Semi – arid regions have both a physical- climatic and a cultural element in their definition. Bowden (1979) mentioned that this is because achieving a definition that will permit identifying such areas through numerical climatic terms (physical) and relating such terms to the socio economic activities and culture is a valuable initial step in understanding and planning for semi arid regions. The tropical aspect of the term ‘semi – arid tropics’ is meaningful as it refers to temperature rather than to the 47^{o} latitude band bounded by tropics of Capricorn and cancer. Cannell and Dregne (1983) stated that along with these normal rainfall occurrences often comes drought, one of man's worst enemies. Drought can be widespread and unpredictable and may occur over several years in succession in given areas (Godwin, 1990). High intensity winds are also common in many of the semi arid regions (Godwin, 1990), and these winds intensify evaporation rates, with frequent dust storms where the vegetation cover has been seriously disturbed (Bowden, 1979). Soils in many areas are shallow, sandy, low in organic matter, and highly vulnerable to erosion when the surface is unprotected. During the wet season high intensity rains may result in severe runoff and erosion, and this may be followed by dry periods and severe wind erosion (Godwin, 1990).

1.1.2 Dry land farming areas

Many definitions have been used to describe dry land farming. It is the term generally applied to arable agriculture where irrigation water is not provided. Godwin (1990) described it as a practice of crop production without irrigation, whereas Lawton and Wilke (1979) portrayed it as cropping without the use of runoff water or irrigation. Dry farming, growing crops and raising livestock with limited precipitation is a consequence of semi-arid climates (Bowden, 1979). Jury (1979) stated that rain fed farming systems generally occur in areas with 200 to 600 mm mean annual rainfall. Dry land farming is dependent solely on the water available from rainfall and snow (Lawton and Wilke, 1979). In these areas sometimes seeding is done in advance of expected rains that may or may not be adequate to ensure proper growth and maturity of crops. Fields are more often planted than harvested.

Bowden (1979) pointed out that because of dependency of dry land farming systems on rain and snow for moisture; they differ from arid zone systems where irrigation is necessary and from humid zone systems where moisture is adequate for crop growth. Cannell and Dregne (1983) mentioned that the use of total rainfall to describe dry land farming areas is misleading because the evaporative index varies considerably because a given amount of precipitation in one region may be sufficient for crop production, but where average temperatures are much higher and the growing season is longer, the same amount would be inadequate.

Dry land agriculture has been practiced for millennia and has been and is the major supplier of the world's wheat, maize, grain sorghum and millet

1.1.3 Crop management in semi arid areas

Crop management in semi –arid, rain fed environments has many challenges. Isom and Worker (1979) mentioned that the weather of the semi –arid zones is highly variable and with each year, new conditions or combinations of conditions arise. Social, political, religious, economical, and ecological constraints also influence crop production systems. They further mentioned that this leads to different crop management systems in each semiarid zone and a system of crop management that works in one region may not succeed in another. Godwin (1990) stated that the success of dry land farming depends greatly on the capability of the farmer to conserve water and establish a suitable environment for seed germination, root growth and control of soil erosion. This implies that soil water conservation is of paramount importance for plant and animal production in dry land agriculture (Willis, 1983) and this requires minimisation: of water use by weeds, evaporative loss from the soil and unsaturated drainage losses from the crop root zone (Luebs, 1983). Unger (1983) mentioned that although precipitation is limited, average annual precipitation in dry land farming areas would be adequate for favourable yields if all of it was effectively used for crop production. Improving water storage involves increasing infiltration, reducing runoff, evaporation and transpiration; and eliminating undesirable plants (weeds). A balance should be made between precipitation received and losses so that at the end there is net residual soil moisture that is available to plants.

Dry land farmers in semi arid regions have developed some crop production and soil water management systems to conserve the little water they receive from unreliable precipitation. Various crop production systems and techniques are used in semi arid regions to reduce the impact of the severe climatic conditions. The techniques used include well adapted varieties, soil moisture conservation, by means of water retaining structures and appropriate tillage, timely planting, and other field operations and matching plant populations and arrangement to the water and nutrients status of the soils (Rowland and Whiteman, 1993). Water conservation systems like terracing, contouring, basing listing, furrow blocking, application of anti-transpirants, fallowing, mulching and deep ploughing were all developed to enhance crop production.

1.1.4 Tillage systems in semi arid regions

Tillage systems also exist, which are integrated in the above soil water management systems for effective crop production in dry land farming. Tillage system can be Conventional (clean) or Conservational. In conventional or clean tillage system, sometimes called maximum tillage most crop residues are incorporated into soil, and weeds are controlled by implements that partially or completely invert the soil surface layer (Willis, 1983).This is achieved by use of mouldboard plough and disc ploughs. Conservation (reduced) tillage methods were developed to reduce the amount of soil disturbance. Unger (1983) stated that one goal of conservation tillage is to keep crop residues on the surface, which improves erosion control and water storage. The same sentiments are echoed by Godwin (1990) who stated that the aim of conservation tillage is to maintain adequate weed control and maximise residue cover for protecting soil against erosion, and increase water infiltration, without reducing crop yields. Many conservation tillage systems have been developed in different dry land farming areas. These include no tillage (direct drill), stubble mulching, and chemical fallow, modified conventional fallow and strip or row tillage.

It can be said that dry land farming in semi arid region can succeed if and only if soil water management systems and tillage systems are effectively integrated. Dry land farming is not a single, easily applied technique that can magically improve crop production in semi-arid lands. Rather it is a multi – faceted approach to the problem of coping with rainfall limitations without resorting to irrigation (Rowland and Whiteman, 1993). This concurs with Godwin (1990), who mentioned that no single set of management practices can achieve any or all of objectives of tillage practices in dry land systems because of the wide diversity of climatic, edaphic and cropping factors that exist in the dry land regions. Development and application of conservation systems should be of the top priorities in dry farming regions (Godwin 1990).

1.2 General facts about Botswana

Botswana is a semi-arid country in the centre of southern Africa, with a total area of 581 730 km^2 (Els and Rowntree, 2006). It is a land-locked country surrounded by the Republic of South Africa to the east and south, Zimbabwe to the north and east and Namibia to the north and the west as shown by figure1.1. It lies between latitude 17.5°S and 27°S and has an average elevation of 1000 m. Botswana enjoys a warm and dry tropical climate with semi-arid lands. Most of the population lives in the eastern part of the country hence more concentration of arable agriculture. The eastern part is more fertile than the western.

The people of Botswana are called Batswana and most people can speak English (official language) and Setswana (national language). However there are many ethnic groups like most Africa countries. It has small population of about 2 million. Botswana is considered as an upper middle income country due to income generated from sales of diamonds.

Figure 1.1 Geographical map of Botswana (Burges, 2006)

1.3 Soils of Botswana

Botswana is a semi arid country in Southern Africa with the Kalahari sands covering more than 80% of the whole area. The soils of the country can be divided into three types, eastern hardveld, Kalahari sandveld, and alluvial soils with some grey to black cracking clay soils. The Kalahari sandveld soils consist of very dry light red to yellowish sands. Willcocks (1981) mentioned that these sands vary in depth from about 5m to 200 m and support low thorn bush vegetation. The eastern hardveld consists of moderately dry red loamy soils on the plains or mixed with chalky and sandy soils, with brownish rocky clay soils on and around hills (Parsons 1999). It is in the eastern part of the country where sandy loam soils are found and it is where arable farming is mainly conducted. The alluvial soils of the ancient lake beds range from grey loam soils in the wet lands, and grey - green saline soils on the pans, to grey clayish soils to yellowish sandy soils around wetlands very chalky light grey soils round the pans (Parsons 1999).There are also some areas of grey black to black cracking clay in former wet areas such as those around Pandamatenga 'where virgin' maize farming is now being attempted on a commercial scale (Parsons 1999). Parsons 1(999) also stated that the fertility of soils in Botswana is limited by rainfall which is sometimes inadequate on the hardveld and regularly unable to support any cultivation on the sandveld.

1.4 Climate of Botswana

Botswana has hot summers with temperatures that reach as high as 38°C. The winter, from April to August has little rainfall and is warm during the day. But during the night and early morning of winter the temperature often goes below zero and it's very cold and frosty. Figure 1.2 shows the distribution of rainfall in Botswana. The rains are almost entirely limited to summer downpours between December and April, which also mark the season for ploughing and planting (Parsons 1999). Mean annual rainfall generally increases from the south-west of the country (>300mm) to the north-east (600mm). Willcocks (1981) stated that traditionally ploughing does not commence until late spring (Nov/Dec) by which time there is sufficient grass for the draught oxen to be in condition for primary tillage work and the soil has been 'softened' by moisture.

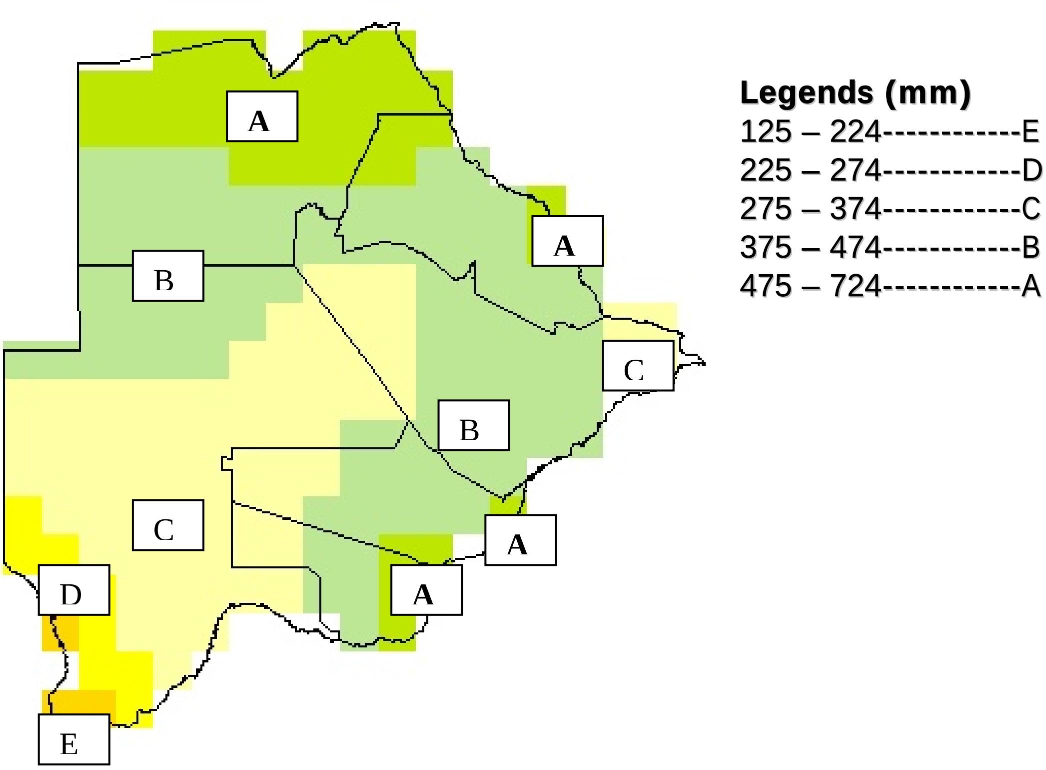

Figure 1.2: Rainfall distribution of Botswana

The high summer temperatures in Botswana as shown by Figure 1.3 and 1.4 also increase inadequacy of rainfall. In summer (which lasts from October to March) temperatures rise to above 34^{o}C (93F) in the extreme north and south west (Parsons 1999). These summers are usually windy, which result in an increase in evapo-transpiration. In winter (which lasts from April to August), there is frequent frost at night and temperatures may fall below 2^{o}C (37 F).

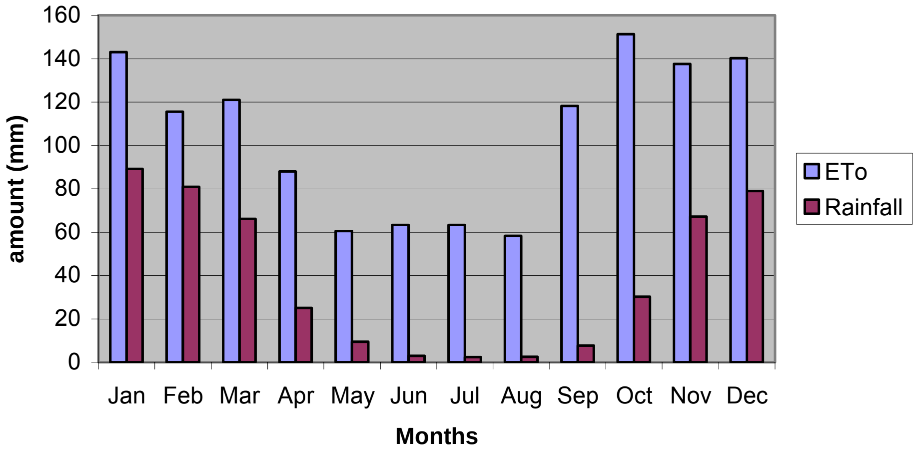

Figure 1.3 Mean monthly rainfall and evapotranspiration of Botswana (FAO, 1984).

The potential of utilising surface water for crop production in Botswana is rather limited. All rivers in the country are seasonal except for the Okavango and Linyanti/Chobe rivers in the northern part of the country. There are six drainage basins or catchments, which assist in the design of water resource projects such as dams. The basins differ in catchment areas and flow system, with the Okavango Delta basin being approximately 12 000 square kilometres (www.gov.bw/atlas/html/chapA.html)

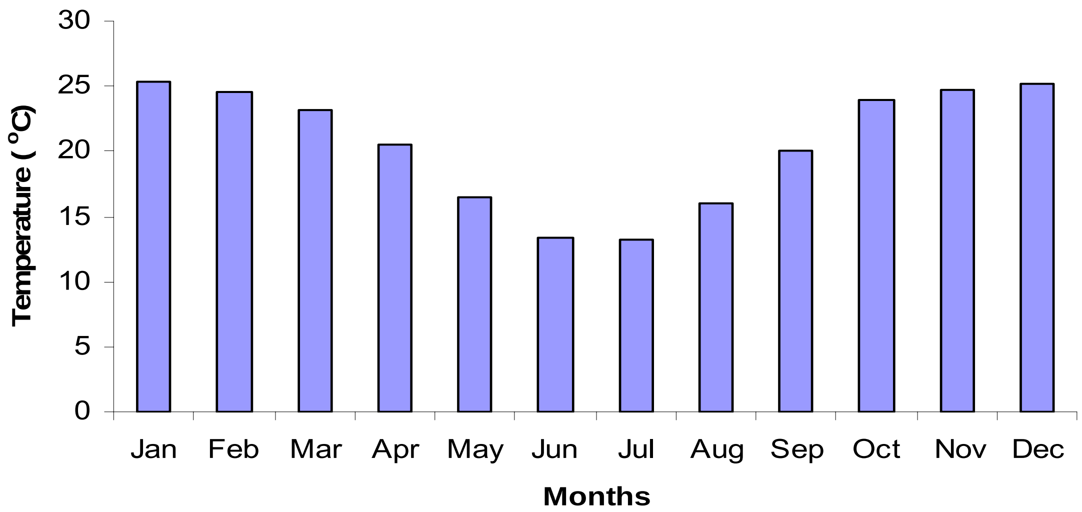

Figure 1.4 Average monthly temperatures in Botswana (FAO, 1984)

1.5 Agriculture in Botswana

Most subsistence farmers in Botswana employ a low-risk strategy-thus avoiding risk of total failure. This results in them using low level of inputs in crop production. Farmer's experience has shown that environmental unpredictability does not warrant the use of expensive inputs (fertilizer, machinery, intensive weeding and other plant protection measures) (Harris et. al, 1992). This resulted in low contribution of agriculture to Botswana GDP. Crop production and livestock contribute approximately 4% to GDP, although they provide support to more than 70% of the population. FAO (1995), stated that the cultivated land in estimated to be around 324 000 ha, comprising 284 00 ha for smallholdings and 40 2000 ha of commercial farms. Popular crops grown in Botswana are sorghum, maize and cowpeas because of their tolerance to low moisture. Some crops such as sunflower, groundnuts, cowpeas and sunflower are grown in small areas. Crop yields are unsatisfactory mostly due to rainfall failure and insufficient draught power machinery. Research and experience in Botswana and elsewhere under similar conditions have shown that with proper execution of mechanical tillage and other cultivation activities, much higher crop yields can be achieved. NAMPAD (2000) reported that sorghum yields can reach 1-3 tons per hectare, which is much higher than the current 300kg/ha.

1.6 Tillage systems practiced in Botswana

There are several tillage systems practiced in Botswana. These fall into two broad categories, conventional tillage and minimum tillage methods. Conventional tillage refers to ploughing the soil several times and deeper (30 – 40cm) in order to create a soil seedbed that is firm and granular, and contains some moisture. Minimum tillage includes all the practices in which soil is less disturbed. The most popular form of tillage in Botswana is deep ploughing with a mouldboard. Willcocks (1981) mentioned that in Botswana, primary tillage and frequently secondary tillage, is conducted using the soil inversion mouldboard plough which was introduced from Europe. This implement was developed over the centuries, under temperate conditions for the burial of weeds and trash as its soil inversion action encourages the action of the soil and hence loss of moisture. Willcocks (1981) with his work in Botswana showed that when the economical implications of the tillage system is considered, the mouldboard system required the highest level of net energy inputs for tillage at over 100MJ/ha for primary tillage and several passes of secondary cultivation were needed to break up the large clods resulting from ploughing. Smith (1993) stated that the depth of ploughing on soils susceptible to erosion should not exceed about 15 cm if a mouldboard is being used. Plough which do not invert the soil, such as disc or chisel ploughs can be allowed to go a little deeper.

This is not the case with Botswana farmers. The majority of farmers use the mouldboard irrespective of soil type and amount of rainfall. This results in high moisture loss through evaporation especially when little rainfall is received. Mostly this deep ploughing is accompanied by broadcasting of seeds. The seeds are spread randomly all over the field and later followed by ploughing without secondary tillage. This could be attributed to very short and unreliable rainy seasons of Botswana, so planting can not be completed on time, especially for those farmers who do not have draught power and farming implements. They try to take advantage of the little moisture available before it dries out but this approach seldom results in high yield especially when rainfall is very low.

Minimum tillage systems are not popular in Botswana. Only very few commercial farms, especially Masedi farm and Pandamatenga farms, practice this system. Masedi farm is a Debswana (Botswana Diamond mining company) farming project, which was established in 1998. Its financial power enables it to import minimum tillage implements from developed countries especially Australia. Willcocks (1981) carried out some work on precision strip tillage in Botswana and found it to be the most reliable and economic system for cultivation of ferruginous sandy loam soils as this technique resulted in micro – catchments of scarce rainfall. The technique required the lowest tillage energy inputs per tonne of sorghum grain yield.

1.7 Challenges to Botswana farmers

The above climatic conditions present challenges to farmers who are dependent on crop production, especially subsistence farmers who have inadequate agricultural machinery. Various crop production systems are used in Botswana in order to try and reduce the impact of these severe climatic conditions but to little effect. Willcocks (1981) mentioned that crop production practices in Botswana must be designed to encourage the infiltration of successive rain water so that crop moisture requirements are adequately met. These crop production systems include tillage methods which are carried out in order to conserve limited moisture and also to provide a good seedbed. In Botswana this entails the pre – rain tillage of capping soils to reduce water loss through runoff and evaporation and thereby build up soil moisture levels to enable early planting. Late tillage and planting certainly limits the amount of soil water available to the crop (Willcocks 1981). This can be attributed to lack of sufficient machinery and soil water management practices which are not suitable for Botswana.

There is a need for critical assessment of the existing soil water conservation and tillage system for effective dry land farming under semi arid conditions in Botswana, where there is high intensity rainfall, high evapo-transpiration during cropping, and mostly capping sandy loam soils. Since there is no single system which can wholly provide adequate conditions for cropping in semi arid conditions, there is a need for a tillage system which can integrate the desirable soil water management systems. The system should be appropriate and sustainable under Botswana conditions; hence this study investigates tillage systems which can be adapted for use in Botswana. Reservoir and strip tillage systems will be examined for water conservation under laboratory conditions. Energy requirements of the two systems will also be evaluated. An understanding of these systems is paramount for effective water harvesting technology to improve crop production in Botswana.

1.8 Aims and objectives

The aim of this project is to come up with a tillage system which can improve the suitability of the physical conditions of soil for effective seeding in rain fed farming in Botswana

The objectives of the project are as follows:-

a) To identify the potential of strip and reservoir tillage systems to capture and conserve moisture under Botswana conditions

b) To evaluate energy requirements, draft force and work rates of the two systems

c) To develop a conceptual design for appropriate implement that can create sustainable tillage systems for Botswana.

CHAPTER 2

2.0 Literature review

2.1 Soil water movement

An understanding of water movement from precipitation through soil is of paramount importance for development of appropriate soil water management systems for dry farming in semi arid areas. The purpose of this section is to discuss theoretical concepts that are applicable and useful in the planning, interpretation and implementation of soil water conservation in dry land agriculture in semi arid areas.

Jury (1979) explained the movement of water from precipitation (P) as follows: When a storm event results in precipitation, P hitting the soil surface faster than the rate at which water can infiltrate, it will pond on the surface. If the soil surface is sloped, pended water will move laterally, a phenomenon known as surface runoff, R. Of the water which has reached the soil surface, part will be lost to the atmosphere by evaporation or transpiration (ET), part will contribute to drainage in the amount of stored water between the soil surface and the ground water table (ΔS) and part will drain to the ground water (D). This may be represented symbolically by the following equation.

$$P = ET + R + D + \Delta S \qquad \text{Eqn. 2.1}$$

Where;	P	=	precipitation
	ET	=	evapo-transpiration
	R	=	surface runoff
	D	=	drainage to groundwater
	ΔS	=	stored water between the soil surface and ground water table

Van Bavel and Hanks (1983) have stated that change in water content is = precipitation -runoff - drainage -upward flow -evaporation.

Marshall and Holmes (1988) have a similar explanation to van Bavel and Hanks (1983). They mentioned that within any given period the change ΔW, in the amount of water stored in a zone between the surface and particular depth in the soil can be represented as follows:-

$\Delta W = P + I_i - (R + D + E)$ Eqn. 2.2

Where: P = precipitation

I_i = irrigation

R = surface runoff

D = underground drainage

Equation 2.2 indicates factors which replenish water to the soil and those which take out water from the soil. In view of the author irrigation is irrelevant to dry land farming, which depends solely on precipitation for soil water replenishment. Water reaching the underground water table is not worth consideration under semi – arid condition because in most cases it is far deep to be utilized by crops. Understanding of these factors is very important for soil water management in semi arid regions where source of water for crop production is scarce and unreliable. Jury (1979) stated that the characteristics of semi –arid lands which influence the amount and distribution of these terms (factors) are:-

(1) Potential (energy limited) evapo-transpiration exceeds precipitation on an annual basis
(2) Precipitation is seasonal and variable in amount
(3) Runoff is irregular, short in duration and often marked by intense flooding
(4) Plant cover is limited by the amount and availability of soil water
(5) Deep percolation to acquirers is extremely rare, except during long or frequent storms.

It is paramount to briefly look into these factors especially infiltration, runoff and evapo-transpiration as they are very important for dry farming in semi arid regions.

2.1.1. Surface runoff

One of the purposes of soil water management in semi arid lands is to reduce surface runoff and increase infiltration of water. This purpose can be achieved through knowledge of movement of water on the surface. Surface runoff happens when infiltration rate of the soil is less than precipitation rate. It is a portion of water that is neither absorbed by the soil nor accumulates on its surface, but that runs down slope. According to Marshall and Holmes (1988) quantitatively the process of runoff may be described as

$$R = P - I \qquad \text{Eqn. 2.3}$$

Where; - P = instantaneous precipitation rate

I = infiltration rate.

In agricultural fields, runoff is generally undesirable, since it results in loss of water and often causes erosion, the amount of which increases with increasing rate and velocity of runoff (Hillel, 1980). Routine agronomic practices for controlling runoff include using straw mulches, chiselling to increase surface clods, planting on the contour, strip cropping and reseeding steep crop land to permanent grass.

2.1.2 Infiltration

Infiltration is the entry of water into the soil by downward flow through all or part of the soil surface. The infiltration approach separates rainfall into two parts, one part stored within the soil supplies water to roots of vegetation and recharge ground water. The other part which does not penetrate the soil surface is responsible for surface runoff. Ward and Robinson (1990) and Hillel (1998) mentioned that the relationship between rainfall intensity and infiltration capacity determines how much of the falling rainfall flow over the ground surface (runoff) and how much will enter the soil (infiltration and percolation). Hence the rate of infiltration affects not only the water economy of plant communities, but also the amount of overland flow and its attendant process of soil erosion and stream discharge (Hillel, 1998). Figure 2.1 illustrates relationship of rate of infiltration and time. The figure shows that when water is spread on the soil at a steadily increasing rate, sooner or later the supply rate will surpass the soil's restricted rate of absorption, and the excess will collect over the surface and cause flooding. Hillel (1998) outlined that, when the rainfall rate is higher than the ability of soil to absorb water, infiltration is at maximum rate, and it is then called infiltration capacity. He pointed out the term infiltration capacity is not a good term to describe water movement into the soil and therefore coined the term infiltrability. He described infiltrability as infiltration flux resulting when water at atmospheric pressure is made freely available at the soil surface. In this context, infiltration rate can be expected to exceed infitrability whenever water is ponded over the soil to a depth sufficient to cause the pressure at the surface to be significantly greater than the atmospheric pressure. On the other hand, if water is applied slowly or at sub-atmospheric pressure, the infiltration rate may well be smaller than the infiltrability (Hillel, 1998). As long as the rate of water delivery to the surface is smaller than the soil's infiltrability, water penetrates as fast as it arrives and the supply rate determines the infiltration rate; that is the process is supply-controlled (or flux controlled).

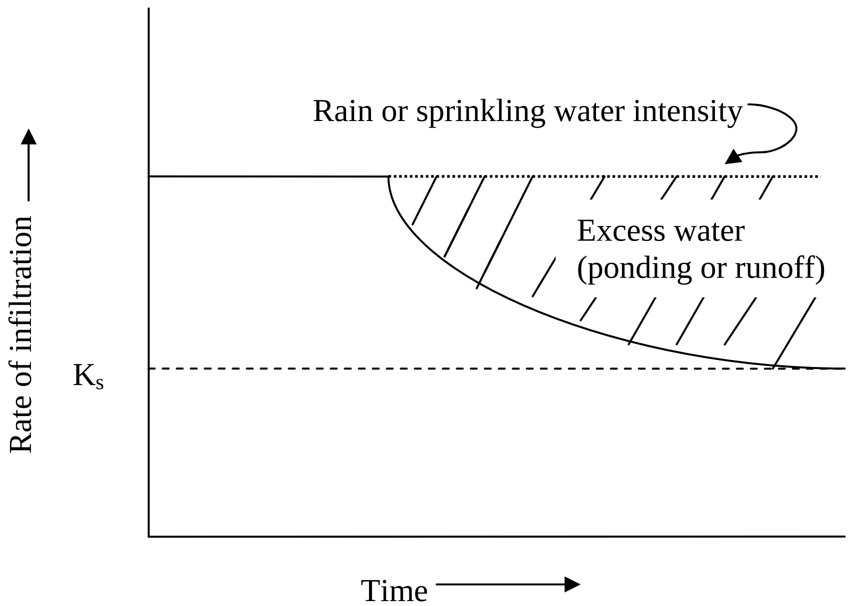

Figure 2.1: Time dependence of infiltration rate under rainfall of constant intensity lower than the initial value, but higher than the final value, of soil infiltrability (Hillel, 1998)

In some circumstances infiltration will be limited by soil surface and surface cover conditions and therefore Hillel (1998) termed it soil controlled. The soil may control (or limit) the rate of infiltration either at the surface or within the profile. Thus the process may be either surface –controlled or profile-controlled (Hillel, 1998). Figure 2.2 shows the relations of infiltrability and time. Many measurements of the rate of infiltration under shallow ponding have shown infiltrability to vary, and generally to decline in time. Thus the cumulative infiltration, being the time integral of infiltration rate, typically exhibits curvilinear time dependence, with a gradual diminishing slope (Hillel, 1980).

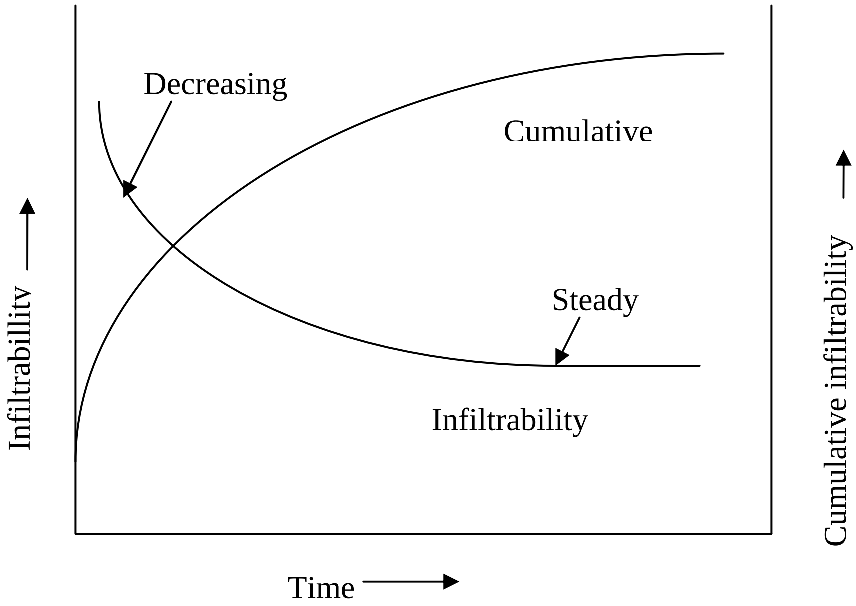

Figure 2.2: Time dependence of infiltrability and of cumulative infiltration under shallow ponding (Hillel, 1998).

Once the water has entered the soil surface, it moves through the soil pores by a process called percolation. Knowledge of water movement in the soil is very essential for design and development of soil water management systems. This section describes some of the process involved in soil water movement especially under semi arid conditions.

There is a lot of literature on soil water movement, under different soil physical conditions. Although saturated soil is not common in semi arid regions because of high intensity rainfall (of short duration and low frequency) which lead to high runoff rates, it is still worth consideration. Kutilek and Nielsen (1994) mentioned that under saturated flow, it is assumed that water is flowing in all pores of the soil under positive pressure head, but under field conditions the soil rarely reaches complete water saturation. It is also assumed that gravitational potential is the only force governing water movement; therefore only vertical movement is considered. This was also mentioned by Marshall and Holmes (1988) According to Kutilek and Nielsen (1994) and Warrick (2003) ,the vertical flow of liquid water is a product of hydraulic conductivity (permeability) and hydraulic gradients which is symbolically written as: -

$$q = -K_s \text{ grad } H, \qquad \text{Eqn. } 2.4$$

This can also be stated as below

$$q = -K_s \frac{dH}{dz}, \qquad \text{Eqn. } 2.5$$

Where; q = flux density (LT^{-1})

K_s = saturated hydraulic conductivity (ms^{-1})

H = hydraulic head

grad H = $\frac{dH}{dz}$ = vector gradient of H

The vertical movement of water through a saturated soil is best illustrated by figure 2.3. At the soil surface during infiltration, the flow rate Q = I.

Equations 2.4 and 2.5 will be deficient if they were only ones used to describe soil water movement in semi arid conditions. This is due to the fact that, under semi – arid conditions soil is rarely saturated, even after some heavy showers. So, an explanation of water movement under unsaturated soil is required.

According to (Jury 1979), water movement through unsaturated soil is an extremely complex process because it involves both liquid water and vapour migration due to differences in soil water potential and differences in vapour pressure within the soil pores.

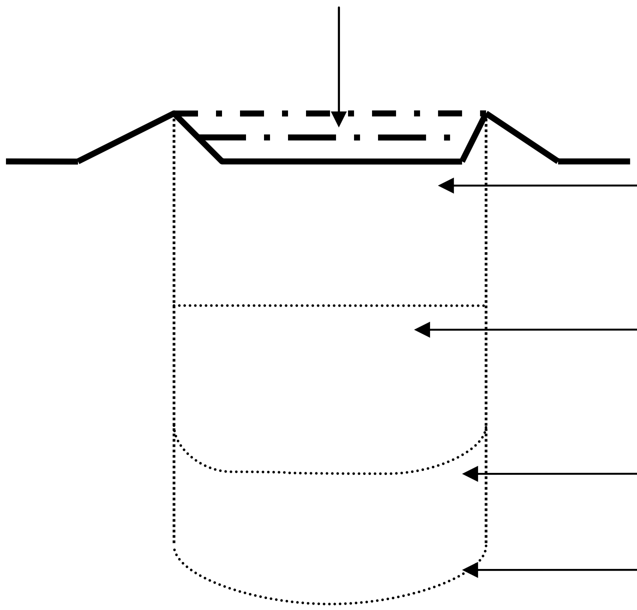

Figure 2.3: A graphical representation of water as it moves through the soil profile (Hillel, 1980)

The pore spaces of an unsaturated soil contain both water and air, so its pore water pressure is negative with respect to the pressure in the air phase, which is customarily assumed to be atmospheric. Kutilek and Nielsen (1994) mentioned that for an unsaturated flow, the fact that a portion of the soil pores filled by air could be re-saturated or drained must be considered.

Kutilek and Nielsen (1994) and (Jury 1979) used the following equation to describe water flow in unsaturated steady flow.

$$q = -K_{(h)} \frac{dH}{dz},$$ Eqn 2.6

Where K$_{(h)}$ = unsaturated hydraulic conductivity of the porous medium.

Equation 2.6 is also expresses as $q = -K_{(h)} \frac{d(h+z)}{dz}$, Eqn 2.7

Where: h+z =H (in units of length) is the hydraulic head in unsaturated soil

$K_{(h)}$ is in units of length /time.

According to Kutilek and Nielsen (1994) the value of $K_{(h)}$ is smaller than that of K_s because the soil is not saturated and flow occurs only in those pores filled by water. The unsaturated hydraulic conductivity K, is physical dependant upon the soil water content θ, because water flow is realised primarily in pores filled with water (Kutilek and Nielsen, 1994).

Kutilek and Nielsen (1994) further stated that equations 2.6 and 2.7 known as Darcy -Buckingham equation are adequate for describing unsaturated flow only if the soil water content is not changing in time. This is not possible under field conditions. So they mentioned that when water content and flux density change in time, the Darcy -Buckingham equation must be combined with equation of continuity. In these situations two equations are needed to describe the flux density and the rate of change of θ in time. The flux density is described by the Darcy -Buckingham equation and the rate of filling or emptying of the soil pores is described by the equation of continuity (Kutilek and Nielsen, 1994).

Equation of continuity is stated as;-

$$\frac{\partial \phi}{\partial t} = -\left[\frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y} + \frac{\partial q_z}{\partial z}\right]$$

Eqn. 2.8

If Darcy -Buckingham equation is inserted in the above equation the result is:-

$$\frac{\partial \phi}{\partial t} = \frac{\partial}{\partial x}\left[K_{(h)}\,\frac{\partial H}{\partial x}\right] + \frac{\partial}{\partial y}\left[K_{(h)}\,\frac{\partial H}{\partial y}\right] + \frac{\partial}{\partial z}\left[K_{(h)}\,\frac{\partial H}{\partial z}\right]$$

Eqn. 2.9

In one dimensional form for H = h +z the above equation becomes

$$\frac{\partial \phi}{\partial t} = \frac{\partial}{\partial z}\left[K(h)\,\frac{\partial H}{\partial x}\right] + \frac{\partial K}{\partial z}$$

Eqn. 2.10

Equation 2.10 is called Richard's equation.

Jury (1979) also considered the flow of water vapour in soil, by extension of Fick's law of binary gaseous fusion.

$$J_r = \beta Dv \frac{\partial \rho_v}{\partial z}$$ Eqn 2.11

Where: - J_r = flow of water vapour in the soil

Dv = diffusion coefficient for water vapour in air

ρ_v = is the water vapour density

β = factor accounting for effects of pore geometry and void space

The transient movement of water should also be considered especially under semi –arid conditions. Jury (1979) mentioned that the description of transient water movement is achieved by combining the flux equation with the continuity equation for mass transport.

$$\frac{\partial \phi}{\partial t} + \frac{\partial J_w}{\partial z} = 0$$ Eqn. 2.12

Where ϕ = volumetric water content

J_w = total water flux (water vapour + liquid water).

t = time

The above equation assumes that there are no sources or sinks of water within the medium.

As Jury (1979) has said, the description of water movement in a soil under semi arid conditions is so complex to be generalised for all soil conditions. In fact, even for the same soil at different depth. Ward and Robinson (1990) stated that the soil surface conditions may impose an upper limit to the rate at which water can be absorbed, despite the fact that the capacity of the lower soil layers to receive and store additional infiltrating water remains unfilled. In general the infiltration capacity is reduced by surface compaction, the washing of fine particles into surface pores and by frost and increases with depth of standing water on the surface, the amount of cracks and fissures at the surface and the ground slope (Ward and Robinson, 1990). They also mentioned that vegetation tends to increase the infiltration capacity of a soil by retarding surface water movement, by reducing raindrop compaction and by improving soil structure.

2.1.3 Evaporation

Ward and Robinson (1990) described evaporation as the process by which liquid is changed into gas and Godwin (1990) expressed it as the process by which soil water is converted from the liquid to the vapour phase and removed from the soil by a means of transfer. Jury (1979) portrayed it as the loss of water from moist soil by the process of vapour transfer away from the soil surface.

Marshall and Holmes (1988) mentioned that if instead of downwards flow of water to a water table, water flows through the soil vertically upwards from the water table to the soil surface where it evaporates, an equation similar to Darcy's law can be considered. He suggested substitution of infiltration by evaporation and came up with the following equation:-

$$-E = K\frac{d\phi}{dz} \qquad \text{Eqn. 2.13}$$

Where E =evaporation

The process of evaporation can occur naturally only if there is an input of energy either directly from the sun or indirectly from the atmosphere itself and is controlled by the rate at which water vapour produced can diffuse away from the earth's surface by means of molecular and turbulent processes (Shuttleworth, 1979). Evaporative water loss from the soil is determined by two basic factors:-

1. The vapour concentration and gradient between the atmosphere and the soil, and
2. The resistance to vapour flow from the site of evaporation to the atmosphere (Godwin, 1990).

Kutilek and Nielsen (1994) stated that evaporation involves three events:-

i. The transport of water to an evaporating surface located either within the soil profile or on the geographical soil surface
ii. A phase change from liquid water vapour from the soil surface
iii. The transfer of water vapour from the soil surface to higher elevations within the atmosphere.

They further mentioned that in general the process includes the simultaneous transport of matter and heat according to conservative concepts of mass and energy.

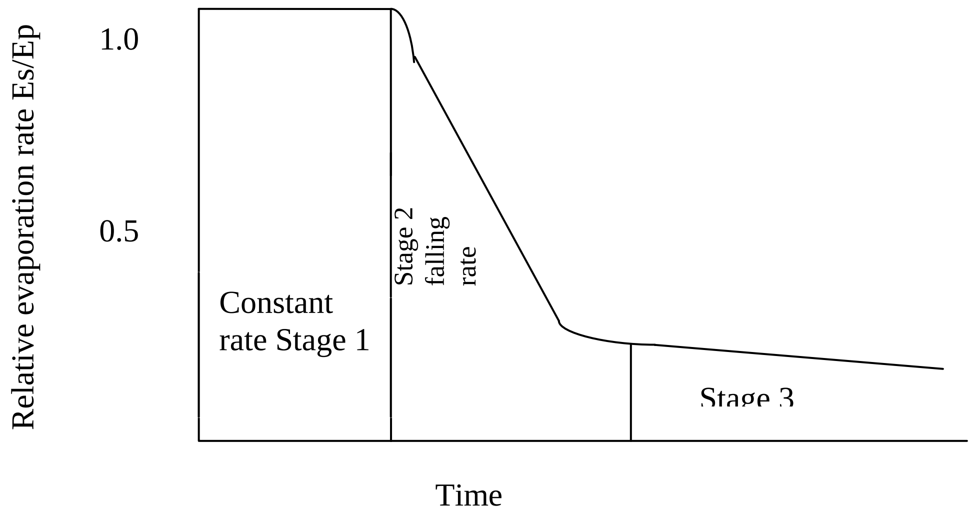

Figure 2.4: Relative evaporation as a function of time (Hanks, 1992).

Kutilek and Nielsen (1994) and Jury and Horton (2004), described three distinct evaporative stages of drying of soil column as shown by figure 2.4

First stage: They mentioned that this stage is governed exclusively by external atmospheric conditions and named it potential evaporation, E_p. Solar radiation, air temperature; air humidity and wind speed are the major environmental conditions affecting potential evaporation. The value of E_p is sustained as the soil water content decreases with time in the top soil owing to the hydraulic gradient increasing sufficiently to compensate for the concomitant decreasing value of K. Eventually as the more water is lost from the top soil, the hydraulic gradient can no longer increase.

At this time when, the decrease of K is not compensated by an increase of the hydraulic gradient, the first stage of evaporation ends.

The duration of the first stage depends upon both atmospheric and soil conditions. If the atmospheric conditions and therefore E_p are the same, the period of the first stage is greater for a clay soil than for a sandy soil and greater for a structure less soil than for a structured soil. Therefore the quality of the soil surface influences the length of the maximum evaporation E_p period and the cumulative evaporation.

Mulching the soil shortens the first stage of evaporation and increases the amount of water stored in the soil profile. Depending upon the atmospheric conditions, the smaller the value of E_p the longer the period of first stage. And if the value of E_p is very small, the soil profile is dried more uniformly with depth owing to small hydraulic gradient required to provide water conduction through the profile.

The second stage of evaporation is characterized by a gradient decrease of the evaporative rate with time with actual evaporation, E being less than potential evaporation, E_p and the difference between both increasing with time. In addition to atmospheric conditions, evaporation depends upon the rate of the profile to the soil surface. Soil water contents continue to decrease with time as well as the value of the hydraulic conductivity. Because the increase of hydraulic gradient is small and often negligible, it approaches a constant value in time, and hence the rate of water movement to the soil surface layer as well as E decreases. With the soil water content near the soil surface being extremely small and near the value of hygroscopic θ, the thickness of the dried surface layer increases with time. The progress of this dry front with soil depth is dependant upon $t^{1/2}$ with water flux through the dry soil surface layer realised as water vapour transport achieved through molecular diffusion. Here the dryer layer acts as a hydraulic resistance and as its thickness increases with time, its resistance also increases.

Third stage: The time at which the third stage of evaporation begins is not well defined by the condition E = E min or when $\frac{\partial E}{\partial t} = 0$. A quantitative measure of the time at which these negligible small evaporation rates occur within a meaningful fiducially limit is presently not feasible.

Soil water movement on, in or out of the soil is a complex system. Its understanding is very vital for informed decision, on which tillage system should be adopted for soil water management. Sustainability is the key for any activity which is carried out to manipulate the soil.

2.2 Water erosion

Erosion is a process that transforms soil into sediments. It can take place naturally without the influence of human beings (geological). Activities of humans like overgrazing, cutting trees, ploughing, building of roads and building can lead to accelerated erosion. Generally accelerated erosion is the most detrimental as it happens at a faster rate than the natural one.

Erosion is more damaging in dry land farming in semi arid areas. That is why you cannot talk about water conservation without mentioning soil conservation. These areas are mostly characterised by poor soils which largely have poor and weak structure. During the dry period these soils are not covered which exposes them to wind erosion. They stay uncovered until the first rains come, therefore exposed to water erosion. Wind and water erosion are mostly regarded as man-made because it is the activities of man like cultivation which destruct the natural covers of the soil. Schwab et al (1981) stated that man-made erosion includes breakdown of soil aggregates and accelerated removal of organic and mineral particles resulting from the improper tillage and removal of natural vegetation. Wind and water erosion are important factors in Universal Soil Loss Equation (USLE). Schwab (1981) and Laflen (1998) stated it as:

A=2.24RKLSCP Eqn. 2.14

Where: A= average annual soil loss in Mg/Ha (metric tons/ha)

R= rainfall and runoff erosivity index by geographic location

K= soil erodibility factor, which is the average soil loss in t/a per unit of erosion index for a particular soil in cultivated continuous fallow with an arbitrary selected slope length L of 22 m and slope steepness, S of 9 percent (if k is Mg/ha, change constant 2.24 to 1.0),

LS= topographic factor

C= cropping management factor

P= conservation practice factor.

The USLE is the current erosion prediction technology used over much of the world today (Laflen 1998). Understanding of its factors is very important for efficient and effective control of soil erosion. It should be understood that the USLE factors are not independent and that the USLE is not a mathematical equation. Hudson (1993) stated that sometimes mistakes are made by using the equation outside its range, for example by using it in slopes higher than 16%. All erosion control practices are designed to address one or more of these factors, but it should be taken into account that there is a large overlapping.

In this study I am mostly concerned with erosion from water especially at field level. Water erosion is affected by raindrop which splashes soil into the air, and runoff which causes rill and sheet erosion. The beating action of rain drops combined with surface flow causes a lot of soil loss from the fields. Brady and Weil (2002) stated that soil erosion by water is fundamentally a three-step process:-

1. detachment of soil particles from the soil mass
2. transportation of the detached particles downhill by floating, rolling, dragging and splashing
3. deposition of the transported particles at some place lower in elevation

They mentioned that detachment of soil particles is due to beating action of raindrops and cutting action of turbulent flow from water concentrated into channels. Schwab (1981) mentioned that the relationship between soil erosion and rainfall energy is determined by raindrop mass, size, size distribution, shape, velocity and direction. The following equation is used to estimate rainfall momentum and energy:-

$$E = 12.1 + 8.9 \log i \qquad \text{Eqn. 2.15}$$

Where: - E = kinetic energy (m-Mg/ha-mm)

i = intensity in mm/hr.

Transportation of splashed soil particles is serious on slopping lands but on level land raindrop splashes is not serious. On sloping fields considerably more soil is splashed downhill than uphill. If the rate of rainfall exceeds the soil's infiltration capacity, water will pond on the surface and begin running down slope (Brady and Weil 2002).The detached soil particles will then run downhill with water. This may account for to a large extent for serious erosion on short, steep slopes. Rill erosion increases with the length of slope and is more serious at the lower end of the field, whereas raindrop erosion occurs over the entire area. Factors affecting the direction and distance of soil splash are slope, wind, surface condition, and such impediments to splash as vegetative cover and mulches (Schwab 1981). Most of the water erosion control practices are there to address these factors. Laflen (1998) mentioned that many current methods focus on controlling soil erosion by management that reduces runoff and soil erodibility. He talked about grass on highly erodible land, crop rows on contour land, diversions and terraces. It can be seen that all these activities are the same as the one which are deployed to harvest and conserve soil water.

Conservation tillage system is the overall answer worldwide. A lot of achievements have been made world wide especially in the United States. Conservation tillage has truly been a revolution in tillage on the American farm (Laflen 1998). He stated that it has virtually replaced the mouldboard in USA whereas farmers in third world countries like Botswana are still using it. The reason may be that most farmers in those countries are resource poor. They cannot afford equipment used in developed countries. So, there is a need for tillage engineers in those countries to develop appropriate and sustainable technologies for those countries.

2.3 Soil and water management practices

There are numerous methods which have been developed for effective soil water management in dry land agriculture. The main objectives of the methods are to increase water storage in the soil and minimize soil water losses. Ramig et al. (1983) stated that the soil water management practices are based primarily on suppressing unnecessary transpiration and evaporation. Luebs (1983) cited that the conservation of water in the soil from precipitation on the land requires movement of water in the soil and control of soil water losses. If water does not enter the soil at a rate of precipitation it will run or pond on the land surface. Any runoff from a unit area of land receiving precipitation decreases water stored in the soil under dry land conditions and decreases precipitation use efficiency (Luebs, 1983). Soil water management practices include terracing, contouring, fallowing, mulching, weed control, timing of planting, ridge and furrow, chemical treatments, micro catchments, and deep ploughing.

2.3.1. Terracing and Contouring

Smith (1993) stated the function of terracing as to reduce slope length. He further mentioned that the ideal terrace for low rainfall areas is the level bench terrace-level both the front to back and from side to side. All the rain water will be retained on the farm, Van Bavel and Hanks (1983) reported high yields with level terraces especially with ends closed and contouring furrows between terraces. Terracing may not be economical for adoption by farmers in Botswana because of cost involved and the low value of crops grown by most of farmers as mentioned by Smith (1993) that the amount of work involved makes it uneconomical and unpopular for most applications.

Smith (1993) mentioned that on fine and medium texture soils, contour ploughing is a simple and efficient method of conserving soil moisture. Ploughing along the contour greatly increases the potential for storing water on the soil surface until it has had a chance to infiltrate into the soil into the soil (Smith, 1993). It also ensures that excess rainfall does not run downhill in the furrows eroding soil as it does so. This is also a decent system, but the capital involved in make it not feasible for farmers who grow low value crops.

2.3.2 Fallowing

Greb (1983) mentioned that water storage during fallow is subject to many climate, soil and management factors. He outlined the following requirements for improving water conservation and erosion control in the fallow – crop cycle:-

i. weed control for the entire fallow period
ii. stubble left standing over winter
iii. straw mulches kept on the surface during the warm season
iv. hard clods 1 to 8 cm in diameter kept on the soil surface
v. Management for favourable water content in the seed bed to germinate seeds.

Meeting these requirements maximised available soil water storage and soil nitrogen, reduced soil erosion potential to near zero, and minimises the energy and other monetary inputs (Greb, 1983).Unger (1983) stated that, when large amounts of land by one individual and production costs are considered, fallowing may be more economical; in addition fallowing stabilizes crop production. Willis et al. (1983) stated that use of fallow is considered to contribute to stability of income because of the increased soil water storage, accumulation of available N, and better weed control. Distribution and quantity of precipitation are determinants of storage efficiency, as well as the time between when precipitation is received and when soil water is measured. Storage efficiency usually is greater when residues remain on the surface during non growing season, because residues reduce runoff and evaporation rate.

Jong and Steppuhn (1983) mentioned the use of herbicides in fallow can substitute early tillage. But they stated that sometimes herbicides fail to give adequate control of weeds during drought period. Some of these chemicals have extended residual activity that may damage crops seeded into coarse texture soils. Fallowing is practiced to a certain extent in Botswana. After harvesting most of the farmers wait and do not cultivate the soil until cropping season comes, but the benefits of fallowing are eliminated by the conventional tillage. It exposes the soil to hot atmosphere and therefore a lot of moisture is lost.

2.3.3 Mulching

Unger (1983) stated that ancient Romans placed stones and the Chinese placed pebbles from steam beds on soil to conserve water. These and similar practices were practiced when hand labour was plentiful, but they are impractical for modern, large scaled, mechanized agriculture. Willis et al (1983) stated that many materials such as gravel, soil clods, plastic film, asphaltic emulsions and plant residue (straw) have been studied but of these plant residues are the most economical and widely used. The current trend is to use crop residues on farm land and artificial mulches for some high value crops (Unger, 1983). Mulches conserve water by controlling storm water runoff, increasing infiltration, decreasing evaporation, and aiding in weed control (Unger, 1983). According to Greb (1983), by absorbing raindrop impact, mulches help prevent soil paddling and facilitate water infiltration. Mulches also decrease evaporation by cooling the soil by insulation, reflecting the sun’s energy and decreasing wind speed near the soil surface.

Unfortunately, in many farming systems in dry land Africa, straw is in high demands as fuel, animal feed, housing and fencing materials, with the result that little is left for mulching or integration into the soil. Leaving uprooted weeds between the crop rows after weeding is a good compromise solution as long as species likely to re-root are taken away. Sometimes crop residues are left on the soil surface during the dry season, and are then ploughed just before planting. Although this does not provide mulch during the growing season, it is still advantageous since it helps to increase soil moisture reserves and protect the soil when it has no other cover and is therefore vulnerable to soil erosion.

2.3.4 Ridge and furrow

Storey (2003) stated that under this method, the water from the hard cultivated ridges would run into the cultivated absorbent furrow, so that the furrows which are planted receive 2 – 3 or more times the average rainfall. Smith (1993) pointed out that when constructed by hand or with ox-drawn equipment, ridges are feasible to a maximum slope of only about 2 percent, as the methods used mean it is possible to construct only relatively small ridges 10 to 20 cm high. If tractors are used, ridges can be constructed on steeper slopes, the maximum slope depending on the size and spacing of the ridges, and the infiltration characteristics and other physical properties of the soil. However on the soil that have reasonable high infiltration rate, they can be constructed exactly on the contour to maximise moisture conservation, provided they are built fairly high (40 – 50cm) and are well spaced (1.5 – 2m apart). It is also possible to make ridges using a disc plough and mouldboard ploughs by ploughing in alternate direction. Disc ploughs are often better for this than mouldboards (Willis, 1983). If this was to be adopted in Botswana it would be practiced by very few farmers who have tractors. Those who do not have tractors they would find it very difficult to attract manual labour as it is very expensive and also absorbed by more paying industries.

2.3.5 Micro catchments

In order to collect water from runoff, the micro-catchments method has been used in different parts of the world. Kumar (1993) mentioned that under micro catchments, water is harvested from both sides. In inter – row water harvesting, water from the ridge top is collected and directed towards plants grown on furrow. Smith (1993) stated that the catchment area is dependent on the nature of the dry farming area and it is defined as an area treated around a plant to force rainfall from a larger area to the planting area. Different micro catchments have been used in different parts of the world. Smith (1993) showed different possible micro catchments designs. He stated that catchments are usually level to make them flat and they are sometimes treated with chemicals to increase the percentage of runoff. He mentioned that in Banngo district of Kenya, they use semi – circular and diamond designs.

Under the micro catchments method Storey (2003) mentioned the planting pit and ridge system. With this method, shallow pits are dug with the soil being mounded into ridges between the pits. The pits are about 20 cm across and 30 - 35 cm apart. This method normally prevents runoff and concentrates water so that it penetrates deeper and so is not quickly dried out and can keep the plants planted for a larger time. This system can be exploited in Botswana, but there is a need for development of an implement or tool that can make the pockets.

2.4 Tillage systems for dry land farming

Tillage is defined as a set of operations performed on the soil to prepare a seed bed, control weeds and improve physical conditions for enhancing the establishment, growth, and yield of crops, as well as conserving soil and water (Godwin, 1990). Wells et al. (2001) described tillage as the mechanical disturbance of soil with the intent of reducing strength and bulk density thereby alleviating compaction. The objective of tillage system are to control weeds, enhance soil water storage, and retention, reduce erosion, and to prepare a desirable seed bed. But this is not always the case as method used to achieve any one objective may produce a conflict with other objectives. Henderson (1979) stated that the best soil management practice often must be a compromise. He mentioned that the conventional way of ploughing where the soil surface is loose tilled may be favourable for water entry into the soil and can be unequivocally recommended during a fallow period of relatively frequent rainfall as in Mediterranean winter, but this system may result in rapid evaporative losses and would be ineffective or adverse during summer showers. Godwin (1990) echoed the same sentiments by stating that the conventional tillage practices used in dry land farming may result in decreased soil aggregation and there is a greater risk of soil erosion. The burial of crop residues by inverting mouldboard exposes the moist soil to the atmosphere and therefore results in water loss through evaporation.

Most cropping systems involve a spectrum of tillage intensities, ranging from maximum tillage on the one extreme, to no till or zero till (Godwin, 1990). In most cases today the conventional practices is synonymous with maximum tillage or the most intensive system. It is also called clean tillage. Tillage systems of intermediate intensity are generally refereed to as reduced, minimum, or low tillage systems. To come with an appropriate and effective system for dry land farming in semi arid regions, an understanding of the effect of current tillage systems on soil physical conditions is important.

2.4 1 Conventional tillage systems

Most conventional tillage systems consists of a primary tillage operation which involves the use of heavy equipment to initially break up or shatters the soil (Godwin, 1990) and most crop residues are incorporated into the soil (Godwin, 1990 and Willis, 1983). Godwin (1990) mentioned that under dry farming systems, tillage implements used are soil stirring or mixing implements and subsurface or under cutting implements. Conventional tillage systems where mouldboard plough is used were designed for control of weeds in temperate region (Willcocks, 1981) but they are wrongly used for soil water harvesting in semi arid regions. Willcocks (1981) with his work in Botswana found that although the conventional tillage system of using mouldboard plough is popular in Botswana, it resulted in greater moisture loss, so most of planting was dependant on subsequent rainfalls. This may be due to the fact that , though deep ploughing with mould board is able to harvest water from rainfall, its conservation capabilities are limited by low crop residue cover in semi arid regions, which result in high evaporation rates.

Greb (1983) reported that in Central Great Plains of America, although the maximum tillage system kills weeds it destroys all stubble and pulverises the soil surface. He stated that the fallow efficiency from the system ranged from 16 to 22%.

2.4.2 Conservational tillage systems

Uri (1999) stated that conservation tillage is one of many conservation practices developed to reduce soil erosion. According to Unger (1983), one goal of conservational tillage is to keep crop residues on the surface, which improves erosion control and water storage. Similar statement was made by Godwin (1990), who mentioned that conservation tillage is a concept of farming designed to minimise tillage operations, maintain adequate plant cover, or residue on the land to conserve soil and water while minimising labour energy and capital. He further stated that the aim is to maintain adequate weed control and maximise residue cover for protecting soil against erosion, and increase water infiltration, without reducing crop yields. In its broad sense, conservation tillage is defined as a tillage system that leaves enough crop residues on the field after harvest to protect the soil from erosion. In general tillage that leaves a residue cover of at least 30 % after planting is deemed conservation tillage; residue cover will vary however, according to soil type, slope, crop rotation, winter crop cover or other factors (Uri, 1999).

So, the strength of the conventional tillage systems is on their ability to leave a reasonable amount of plant of residue to protect soil surface. When residues are left on the soil surface, the mulch instead of the soil absorbs the energy of raindrops and this prevent the soil aggregates beneath the mulch from being broken apart and dispersed, and the soil is less prone to seal cover and form a crust. Most surface residues act as a thermal barrier by reflecting light, decreasing evaporation, and reducing wind contact with the soil surface (Godwin, 1990).

Conservation tillage systems are described in so many ways but Godwin (1990) stated that terminologies such as plant till, strip tillage., mulch tillage, sod planting, minimum tillage, stubble mulch tillage, no –till, low till, zero tillage, chemical fallow and eco-fallow are used. He further mentioned that conservational tillage has a great potential benefits in the semi –arid regions where rainfall is erratic and soils are highly variable and subject to wind and water erosion. Willcocks(1981) with his work in Botswana found that precision strip tillage method was the most reliable an economic system for the cultivation of ferruginous sandy loam soils when compared with deep ploughing with mouldboard, chisel plough and no tillage system.

2.5 Review of some work on soil water management for Botswana situation

2.5.1 Compacted ridges

The latest work in this system is by Shahid Zadeh (1998) and Abdalla (2002). Both authors' experiments consisted of plastic covered ridges, compacted ridge/furrow and loose ridge/furrow. The bottoms of the furrows were loose. The rainfall intensities used were 2.5mm, 5 mm and 10 mm. They both found that the compacted furrow/ridge system is very effective at harvesting the water at these low rainfall intensities.

The furrow with compacted ridge system for water harvesting is a very good system for low intensity rainfalls (≤ 10 mm / hr). If the system was to be adopted for Botswana, where rainfalls are characterised by high intensities which can well be over 100 mm/hr, the system may result in unfavourable effects. A large amount of water at high speed is likely to be channelled in the compacted ridge and furrows at a very short period of time. This will result in washing away of loose soil at the bottoms of the furrows and therefore result in soil erosion. A harder soil surface will be left behind which would not be able to support plant root development. A system for harvesting and retaining water in situations like

Botswana should have a condition for reducing the rate of runoff and increase infiltration and ultimately thus reduce water erosion. The system should be able to conserve the moisture harvested from high intensity rainfalls of low frequency. Marshall and Holmes (1988) mentioned that the whole idea of water management in dry land farming in semi – arid conditions is to increase infiltration and decrease runoff from high intensive storms. This can practically be achieved by a system which leaves sufficient vegetation cover or crop residue to slow down runoff. So, the compacted ridge/furrow system would bring more negative effects than positive ones as far as erosion is concerned if it is to be taken up by Botswana.

The system removes all the vegetation and residue cover from the soil surface. There is no protection of the soil surface from high intensity rain drops. In situation like Botswana where rainfall season is during hot summers, the likely resultant is baking of the soil surface. A hard soil cap will form on the surface of the loose furrow bottoms and therefore emergence of seeds sown at the bottom of the furrows will be impaired. Willcocks (1981) found that when seeds were sown in the bottom of the furrow, the seedlings had to emerge through a strong concave soil crust, but when seeds were planted below a small ridge, formed by a split-rim wheel were found to give better emergence percentages. The other point is that once the soil crust is formed less water from subsequent rainfalls will infiltrate and the whole idea of water harvesting will be lost.

The rainfall season in Botswana is very short and is characterised by few heavy showers. So the main objective is to harvest as much as possible from the few rainfall storms and conserve for the whole season. So without mulching, in the compacted ridge/furrow system, the conservation aspect is not achievable.

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In conclusion, the compacted furrow ridge system for harvesting water for dry land farming in semi arid condition is suitable for low rainfall intensities. It is not suitable for dry land with high rainfall intensities areas like Botswana. Its incapability to protect the soil from rainfall drop and heat from the sun makes it unsuitable for capping and clod forming sandy soils of Botswana. The system is not capable of minimising evaporation. The likelihood of high cost in the system will not be good for Botswana where most farmers do not have their own farm machinery and also the area of land planted is relatively small.

2.5.2 Strip tillage system

A considerable work in this system was carried out by Willcocks (1981) in Botswana. He compared precision strip tillage (PST) with other four (disc ploughing, sweep cultivation, chisel ploughing and mouldboard ploughing) tillage systems.
He found the infiltration rate to be high in precision strip tillage when compared to other tillage systems. He attribute this to the micro-catchment of water from the untilled interow space to the tilled strip making rainfall less than 10 mm effective to the crop. This can also be enhanced by vegetative cover which slows down surface runoff.
He found the precision strip tillage to be a suitable system for Botswana because it requires less energy and also is able to harvest and conserve soil water.

Morrison (2002) reported a similar work which was conducted at the joint USDA – ARS Grassland Soil and Water Research Laboratory and TAES Blackland Centre at Temple, Texas. The work was to identify strip tillage alternatives that were appropriate for their local conditions (see figure 2.5). He reported that cotton plant stand establishment was increased by both chisel till and spring strip chisel knifing over no till plants stand, indicating superior seed bed conditions. He also found that plant growth was higher for shallow tillage treatments over deep knifing and for strip tillage treatments over conventional chisel ploughing for both soils. He postulated that the deep knife chisel treatments dried the soil prior to planting and this reduced growth in the drought conditions.

Figure 2.5: Strip tillage units and strip tillage in shredded stubble, prior to planting (Morrison, 2002)

The strip tillage treatments produced higher final plant emergence than the tandem disked treatments.

Morrison (2002) concluded that strip tillage appears to be an improvement over strict no till for the soil types in the study, in terms of corn growth and yield. Both deep and shallow types of strip tillage increased corn growth and yield in some cases over conventional chisel ploughing and tandem disking tillage, but there was no advantage to the use of the deeper knife chisel over shallow sweep strip tillage in the soils tested.

The strip tillage system is worth consideration for Botswana condition.

2.5.3 Reservoir tillage

Malley et al. (2003) reported some results on Ngoro (in Tanzania), which is a local name for the pitting conservation system. It is an indigenous means of soil, water and nutrient conservation for land cultivation on steep slopes (2 – 65%).

The system consists of a series of regular pits, traditionally 1.5 m square by 0.1 – 0.5 deep with the crops grown on the ridges around the pits. They stated that the main strengths of the Ngoro system are reduction of soil erosivity of runoff whilst encouraging infiltration and sedimentation. The system enhances soil fertility from the continual incorporation of plant residues into the soil. There is also a creation of a sheltered microclimate in the pit bottom so that there is a stable air/water interface thereby reducing soil water loss through evaporation. They reported similar systems practiced in Mali, Somalia and Nigeria where instead of planting seeds on top of the ridges they are planted right inside the pits or on the sides. From their study which its objective was to evaluate the effects of pit size in Ngoro cultivation systems on labour inputs, soil water conservation, yield of maize and system profitability they concluded that Ngoro production systems effectively conserve water, soil and nutrients on sloping land.

Ventura et al. (2003) reported a new reservoir tillage system for crop production in semi arid areas. The system included horizontal soil subsoiler, a modified raw planter and a roller formed with plastic wheels to improve soil tilth and create mini-reservoirs on the soil surface for “in sutu” rain water harvesting (figure 2.6).Their idea was to prepare soil bed with no inversion of soil by means of horizontal cutting.

Figure 2.6 Combination of a Multirado® subsoiler and an Aquel^{TM} roller for soil preparation (Ventura et al., 2003)

They found that the new reservoir tillage delayed runoff by about 20 minutes over control treatment when a rainfall of 40 mm/hr was simulated. This was attributed to the fact that indentions made by the Aqueel ^{TM} enhanced infiltration especially in the first stage of rain. They also found that both runoff rate and soil erosion were high in the control than the new reservoir tillage. This is due to the fact that rainfall was collected in the mini-reservoirs allowing more time for infiltration which reduced runoff and its great potential to detach and transport soil particles when Aqueel ^{TM} was used (Ventura et al. 2003).

A similar work on reservoir tillage was conducted by Patrick (2005). The project was carried through modelling and experiments under soil bin, rainfall simulator and glasshouse environmental conditions. The intention of the project was to investigate and quantify water storage from reservoir tillage. He used the Aqueel ^{TM} and a soil scooping device to form depression and evaluate their

water harvesting potential under different slopes and rainfall intensities, and also determined optimum planting positions in relation to depression geometry.
He reported that the reservoir tillage reduced surface runoff by 54% and 91% when the depressions were positioned along and across the slopes respectively. . Patrick (2005) indicated that depression formation by Aqueel ™ adversely affected the soil bulk density (bd>1185 kg m^{-3} were recorded) especially for the sandy loam soil and therefore warranted a need for soil tillage before depression formation. This is likely to have some negative effects in Botswana as far as soil erosion and moisture are concerned.
Reservoir tillage is an old system of harvesting water but it has not been evaluated scientifically like other tillage system. Its suitability for Botswana conditions is still questionable. The Aqueel ™ requires ploughing of soil before depressions can be made, therefore exposing the soil to atmosphere. This is likely to results in high moisture loss similar to conventional deep ploughing. It also has some economical implications because there is a need for a second run to create depressions.
Reservoir tillage system can function in Botswana, but lack of sufficient information about it makes adoption of it suspicious. Mechanization of the system is likely to be more complicated than the strip tillage, but it worth consideration.

From the literature review it can be seen that, conservational tillage systems which allow a certain degree of cultivation performs better than both conventional tillage and strict no tillage. The precision strip tillage and reservoir tillage systems seem to be better systems for Botswana condition. The strip tillage system seems to be a new dimension as far as tillage for semi arid regions is concerned. There is also a possibility of the reservoir tillage to be adopted for semi arid conditions. This project will try and evaluate the effects of the two systems on soil physical conditions. The energy requirements for the two systems will be evaluated and finally a conceptual design of suitable implement will be made depending on the results from the experiments.

CHAPTER 3

3.0 Determination of water harvested in both precision strip tillage and reservoir tillage

3.1 Introduction

In chapter 1 and 2 it was shown that the most important factor for crop production in dry land is insufficient moisture. This is compounded by high evaporation rate due to high temperatures during raining season. The best way to alleviate the problem is a prudent management of soil water that can be achieved by water harvesting systems. Soil water harvesting activities reduce surface runoff and optimise infiltration of surface water and its distribution into the soil. This can be achieved by ponding or retaining water on the soil surface for a reasonable time, or by increasing the rate at which water passes through the soil profile. It was found that for Botswana conditions both strip tillage and reservoir tillage have the potential to harvest water from rainfall.

This chapter is concerned with the assessment of the two systems for rain water harvesting and conservation. The aim of this study is to evaluate strip and reservoir tillage on their capability to sustainably harvest water under short duration and high intensity rainfall events.

The specific objectives are to investigate:-

i. Water harvesting capacities of strip and reservoir tillage under different rainfall Intensities,

ii. The effect of slope on water harvesting capabilities of strip and reservoir tillage systems, and

iii. The effect of slope and rainfall intensity on eroded soil

Three systems with different conditions under different rainfall intensities are discussed in this chapter. Runoff water, eroded soil and harvested water are investigated. The effect of ground slope will also be explored. Ultimately, a suitable tillage system which can harvest and conserve water for Botswana conditions will be recommended.

3.2 Methodology

In order to harvest sufficient amount of water from high intensity rainfall of a short duration, it is essential to reduce surface runoff and encourage infiltration and percolation in the concentrating point of water in the collecting area.

3.2.1 Preparation of experimental units

Capping sandy loam soils are mostly used for crop production in Botswana. For this reason sandy loam soil was used in this experiment. Sandy loam soil (75% sand, 18% silt, &7% clay) at 16.04 -19.60% moisture content was compacted to a bulk density of about 1.25 g cm^{-3}. A small steel bin or tray with internal dimensions of 470mm length, 450 mm width and 250mm depth as shown in figure 3.1, was used in this experiment. The design was such that both strip and reservoir tillage can easily be simulated. This was achieved by opening sides of the bin towards one end so that a tine can be run across the bin. The soil was then recapped and the sides closed by flat metal plates. The frame of the bin was made from a 40 mm steel tube. This was to reinforce it so that it can stand numerous compactions and lifting during the experiments.

Figure 3.1: Soil bin filled with sandy loam

3.2.2 Experimental design

A factorial structure was used in these experiments for each rainfall intensity (55 and 95 mm/hr). The treatment combinations were

- tillage systems
- slopes.

Slopes were 5 and 10^{o}, and tillage systems were

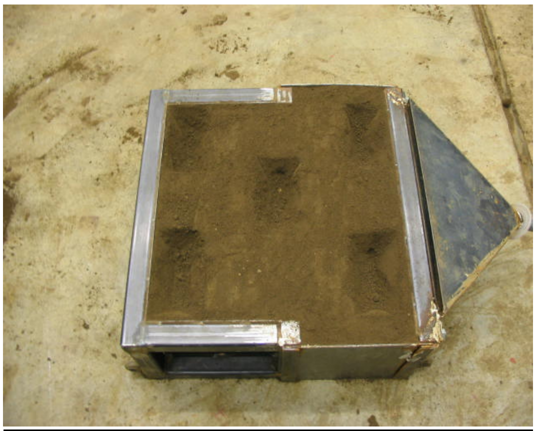
- undisturbed (control),
- strip and
- depression disturbances.

This resulted in 6 treatment combinations for each rainfall intensity which were replicated three times. Therefore the total number of experimental units for each rainfall intensity was 18. The design was complete randomised design.

3.2.3 Depression disturbance

For the depression tillage, a modified tool of Patrick (2005) was used. The depressions were staggered, as Patrick (2005) mentioned that staggering of depressions optimised water harvesting. This is illustrated by figure 3.2. The depression was created manually by scooping with a small amount of pressing to create a shape of depression similar to Patrick (2005). The dimensions of the depressions were as follows:

Upper length 150mm, lower length 90mm, height 70mm and width 95 mm. The space between depressions in the same row was 150 mm whereas across the rows the spacing was 90 mm.



a: Staggered depressions

b. small hand tool (~150 x 70 x 70 mm) used to form depressions

Figure 3.2: Staggered depressions and the scooping tool used to create them.

3.2.4 Strip disturbance

Willcocks (1982) used depths of 300 and 250 mm for strip tillage. This created a soil disturbance about 300 mm wide. For this experiment, a tine with blade of overall width of 150 mm wide at the base was used at a depth of about 150 mm. The tine blade was made from mild steel of 10mm width. The tine created a disturbance of approximately 200 mm wide. The rake angle was 45^{o} as most tines are working at this angle. The dimensions of the tine are smaller than the one used by Willcocks (1982) because of limitation in space and resources. The other reason is that, as this is a simulation of conservative tillage, less soil has to be disturbed.

The tine was attached to a six wheeled carriage so that it could be run across the bin towards the lower end to create strip disturbance. The carriage was made from 30 x 30 x 3 mm mild square tubes and nylon wheel of 80 mm diameter. The carriage was attached to the top of the soil bin using square tube rails as shown in Figure 3.3a.The top four wheels were to carry the carriage on the square tube rails. The lower two wheels which were running underneath the square rail were to counteract the moment created by the tine as it was working across the soil. If these wheels were not there the rear top wheels would have lifted up and therefore prevented the tine from cutting the soil.

Using the single tine model by Godwin and O'Dogherty (2005) a tine with overall wing length of 0.15 m working at a depth of 0.15 m in a loamy soil, on average will require a draught force of about 1.6 kN.

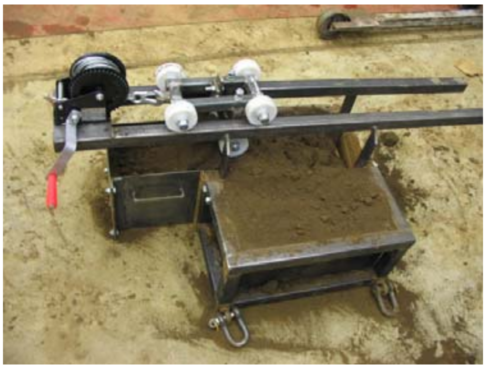
The tine dimension was 0.29 m from the tip of the tine in the soil to the carriage.

Assuming a maximum draught force of 2 kN, this implies that moment of force at the mounting=2000N x 0.29m =580 Nm

For the carriage not to overturn at the front wheels a counteracting moment should be provided as both the soil strength and weight of the carriage cannot prevent overturning.

Distance of front wheels from the tine pivot = 0.105 m, Then the force required at front wheels is equals = 580 Nm / 0.105m = 5523.8 N. The underside wheels were to provide this force.

A hand winch was used to pull the carriage to create the strip disturbance. The winch was used in order to try and simulate what happens practically. The sides of the bin were extended so that the tine can cut across the bin without breaking form of the soil disturbance at the end. This is illustrated by figure 3.3a. The hand winch was used to create the disturbance as it was easy for it to pull the carriage. It was also easier to support it on the bin when compared to other power transmitting devices.



(a)

(b)

(c)

Figure 3.3 Creation of strip disturbance in the experiment: a) assembled tools for creation of strip disturbance; b) winged tine used to create strip disturbance; c) strip disturbance.

3.2.5 Calibration of the rainfall simulator

The rainfall simulator (Fig 3.4) used is part of the normal laboratory equipment in the Norman Hudson building, made of a pan with surface area of 0.32 m^2 with a height of 0.1m, which is located at about 10m from the ground surface. It is constructed from a perplex plastic with holes at the bottom through which small needles are fitted. The plastic cup on the end of the needles is pushed tightly into a 5 mm hole drilled through a rubber cork. The brim of the cup prevents the needle from passing through. The fit is sufficiently tight to prevent water passing between the plastic cup and wall of the hole through the cork. The needles are located at the base of the simulator by fitting rubber corks into the holes in the pan base with a firm fit to prevent water leakage.

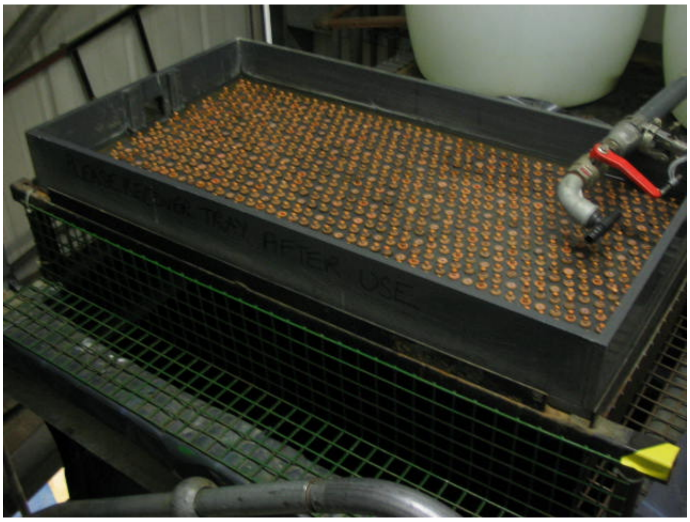


Figure 3.4 Hypodermic rainfall simulators

A constant head was maintained by a weir device at one end. The excess water flows over a plastic weir plate, through the front wall of the pan and down the overflow tube. By using different height weir plates, the water level can be maintained at any height up to 0.09 m which is the inside depth of the pan, thus different intensity rainfall can be achieved by either changing the head of water or the number of needles or by using different needles or changing the size of needles. In order to make the rainfall drops uniform, a square mesh is located under the pan in a height of about 2m.

In order to calibrate rainfall simulator, a small container (~ 25 cm width, 50 cm length and 12 cm height) was placed on the platform under the rainfall simulator tower. Rainfall was simulated for 45 and 30 minutes for 55 and 95 mm rainfall respectively. Then using:

$$i = \frac{volume(ml)}{1252.49} * \frac{60}{\min utes} * 10 \qquad \text{Eqn. 3.1}$$

Where; i = rainfall intensity (mm/hr)

1252.49 is the cross sectional area of the container in cm^2.

The number 10 is a conversion factor for units.

After a specific time, the amount of water collected was measured using a measuring cylinder and the intensity was calculated. Anything within ± 3 mm/hr was accepted as it is difficult to obtain the exact intensity all the time.

3.2.6 Setting of experiments

After all the treatments were created, and the desired intensity set, the bin was put on a trolley (700mm length, 500mm width and 100mm height) using a 150 kg capacity hydraulic lifter. The slope was created by sliding a square tube of 600mm length between the base of the bin and the trolley as shown by figure 3.5.

Figure 3.5: Soil bin put under the rainfall simulator

The square was made by welding 50 mm square tubes together. This made one side of the tube 50 mm and the other to be 100 mm. Changing the sides of the tube when inserting it under the bin allowed slopes of about 5 and 10 ^{o} to be set easily.

The length of the bin was approximately 550 mm, so $\tan^{-1}(\frac{50}{550}) = 5.2^{o}$, which is sufficiently close to the desired angle of 5^{o}. Then $\tan^{-1}(\frac{100}{550}) = 10.3^{o}$ which is also a good approximation to 10^{o}.

5^{o} and 10^{o} were selected for this experiment as most arable lands in Botswana are in a range within the two limits. The trolley was then put on the platform under the rainfall simulator and a desired rainfall was simulated on them. The experiment was replicated three times and analysed using complete randomised design at 5% level of significance.

3.2.7 Collection of data

The most important data from this experiment is the infiltration (both rate and cumulative), runoff (amount and rate) and eroded soil. To estimate infiltration the total volume harvested by the bin should be known. The internal dimensions of the bin were 470 mm length, 450 mm width and 250 mm height. For estimation of rainfall, length and width are important for calculation of area exposed to rainfall. Because of the reinforcing 40 mm square tubes used to strength the bin the overall external dimension of the bin were 550 mm length and 530 mm width. This raises a question on which dimensions (internal or external) to use to estimate area exposed to rainfall. Some of the water which fell on the square tubes ran in and infiltrated into the soil especially at the beginning of the experiment and later added to the runoff water. If a narrower square tube was used most of the water will have infiltrated into the soil. It was thought that for this reason it will better to use external dimensions to estimate the area harvesting water with some correction.

The correction which was made is that, at the beginning of the experiment, before runoff started there was some water collected from the collecting container. This water was likely to have run off from the front 40 mm square tube. To correct for this early runoff, the bin was put under the rainfall simulator without soil. This was repeated three times in order to get an average estimate of it. It was then subtracted from the water harvested when the bin was filled with soil. This implies now that the external length of the bin was reduced by 40 mm to become 510 mm. This made the area of the bin exposed to the rainfall to be 510 mm x 530 mm which equals 270300 mm^2.

The volume of rainfall received by the bin at any instant time was calculated as follows:

$$\text{Volume } (mm^3) = 270300\ mm^2 * \text{rainfall intensity (mm/hr)} * \frac{time(\min)}{60} \quad \text{Eqn. 3.2.}$$

For 55mm/hr rainfall runoff measurement was taken every five minutes for a period of 45 minutes. This implies that for every interval rainfall received was: -

$$270300\ mm^2 * 55\ mm/hr * \frac{5}{60}\ hr = 1\ 238\ 875\ mm^3.$$

For 95mm/hr, measurements were taken every 3 minutes for a period of 30 minutes. Then the interval rainfall was:-

$$270300\ mm^2 * 95 mm/hr * \frac{3}{60}\ hr = 1\ 283\ 925 mm^3.$$

A shorter time was used in 95 mm/hr rainfall intensity whereas a longer one was used in 55mm/hr. This was done because the soil got saturated faster in high intensity rainfall than in shorter rainfall intensity. There was no need to run the experiment beyond saturation as runoff rate was almost uniform.

The water collected from runoff was measured in ml which is the same as cm^3. So for units consistency the volume of water from rainfall was converted to cm^3 as follows:

$$V\ (cm^3) = \frac{V(\ mm^3)}{1000} \quad \text{Eqn. 3.3}$$

Then the interval rainfall for 55mm/hr rainfall was V (cm^3) = $\frac{1238875}{1000}$ =1238.875 cm^3 whereas for 95mm/hr was 1283.925cm^3

It is also common to express rainfall in mm, so the total rainfall received from a 55mm/hr equals to: 55 x 45/60 = 41.25 mm, whereas for 95 mm/hr is: 30/60 x 95 =47.5 mm.

A bucket was put at the lower end of the bin to harvest runoff water. To get infiltrated water, runoff water was subtracted from the volume of water received from rainfall. Any water drained down through the holes at the bottom of the bin was just treated as infiltrated water. Very little drained water was only experienced in the strip soil disturbance; other treatments did not show any signs of infiltration.

Infiltration and runoff rate is commonly expressed graphically in length/time. So there was a need to convert them from volume /time to length /time.

Eroded soil was recovered from runoff water by putting the water into aluminium foils and dried in an oven at 105^{o}C for 24 hours. The mass of eroded soil was then separated from the mass of the foil.

The analysis of variance was done using statistica 7. A 5% level of significance was used to test statistic.

3.3 Results and discussion

3.3.1. Effects of slope and soil disturbance on infiltration, runoff and eroded soil from 55mm/hr rainfall

Infiltration and runoff are very important process for dry land farming in semi arid areas. Insufficient soil moisture is one (if not the major) limiting factors for crop production in Botswana. So, any tillage system which shows a high degree of infiltration and reduce runoff will be examined with great interest.

A. Infiltration

For 55mm/hr rainfall intensity, the analysis of variance table (Appendix 2; Table A: 2.1) shows that there was a significance difference in slope, soil disturbances, and interaction between slope and soil disturbances. A strip disturbance at 5° harvested more water than other factorial combinations. It managed to harvest 69.12% of rainfall, followed by depression at 5° (65%).

Table 3.1 Cumulative runoff of slope x soil disturbance for rainfall at 55 mm/hr rainfall (mm)

Time (Hr)	5 x depression	10 x depression	10 x undisturbed	5 x undisturbed	5 x strip	10 x strip
0.08	0.09	0.09	0.52	0.08	0	0
0.17	0.21	0.38	3.94	2.41	0.33	0.215
0.25	0.74	2.05	7.36	5.95	1.53	1.585
0.33	2.65	4.32	11.6	9.93	2.69	4.225
0.42	5.05	6.73	15.76	13.93	3.89	7.325
0.5	7.58	9.26	20.03	17.95	5.25	10.595
0.58	10.32	12.4	24.29	22.04	7.4	13.865
0.67	13.21	15.37	28.6	26.12	10	17.245
0.75	16.21	18.54	32.9	30.19	12.74	20.925

The undisturbed at 10° was the least as only 18.5% of rainfall water infiltrated into the soil. This is illustrated by Table 3.1 and Figure 3.6 which shows that infiltration rate of strip disturbance at 5° is the highest. It is then followed by depression at 5° and depression at 10°. The treatments in which soil was not disturbed were the worst. This is due to the fact that, the soil was not manipulated to enhance infiltration, and so most of the water was lost through runoff. The effect of

slope-soil disturbance interaction on infiltration was mostly applicable to the strip soil disturbance, as infiltration rate at 5° was significantly higher than one at 10°.

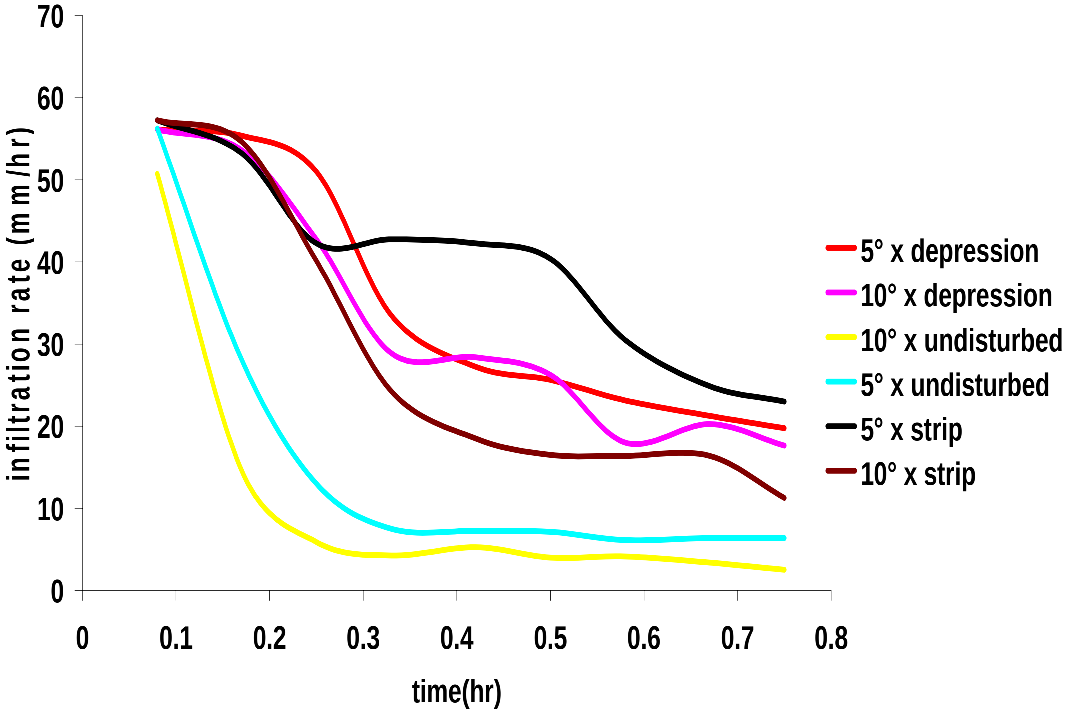


Figure 3.6 Infiltration rate of slope x disturbance combination of rainfall at 55 mm/hr

This is well illustrated by Figure 3.6 and Appendix 2 (Table A 2.2, Figure A 2.1.) The other soil disturbances did not show any effects of the interaction at 55 mm/hr rainfall. This shows clearly that at low rainfall intensity (55mm/r) and low slopes (5°) the strip tillage system is capable of harvesting more water than depressions and no tillage systems. When higher slope (10°) is considered both strip and depression have similar performance, which means either of them can be considered for water harvesting at lower intensities and higher slopes. If field have high surface slope, less water will be harvested and result in runoff which encourages soil erosion. Flat field usually results in water logging which result in poor soil aeration.

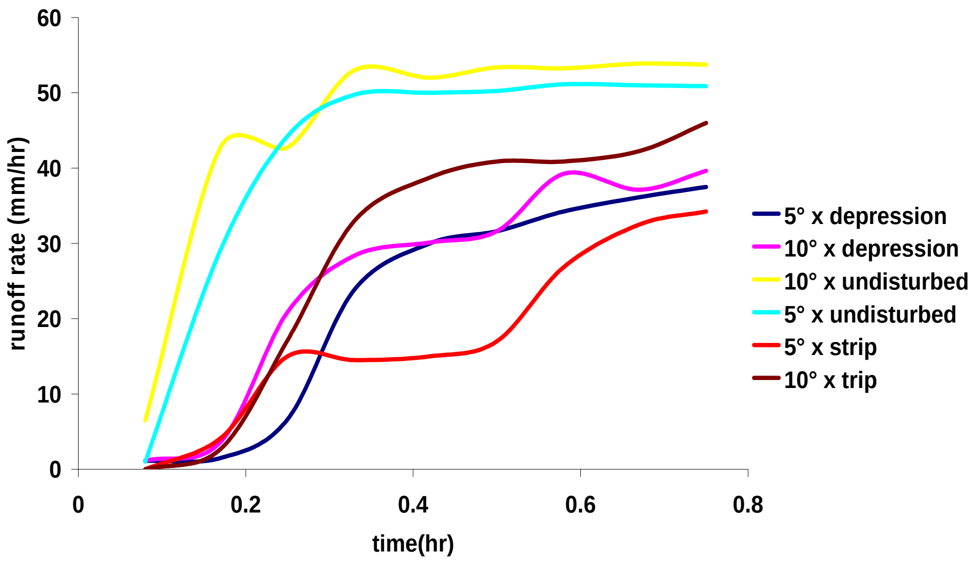


Figure 3:7: Runoff rate of slope x disturbance combination of rainfall at 55 mm/hr

B. Runoff

Figures 3.7 and cumulative runoff (Appendix2; Table A: 2.3) show the effects of the interaction on runoff. As runoff is the inverse of infiltration, the treatment combination which had low infiltration resulted in high runoff. They show clearly that the undisturbed treatments had high runoff rate. Kang and Zhang (2000) in their work in China found that creation of furrows on the field decreased runoff rate. They stated that this was because the cultivation of a furrow tillage field was more complete than normal tillage. The soil structure was fairly loose and the soil density was low along the furrows. This may be the reason why strip soil disturbance performed better than undisturbed and depression soil disturbance in this project. It should be understood that in this experiment there was no plant or crop cover on the soil surface. Under field conditions these would be investigated as they play vital role in controlling erosion due to raindrop splash and runoff. Bhatt and Khera (2006) found minimum tillage to reduce runoff by 33% and they stated that if it is coupled with mulch is highly effective in increasing moisture content by providing maximum surface cover.

When differences between the soil disturbances were considered, irrespective of slope there was no significance difference between strip and depression. The undisturbed treatment was significantly different from the other two. Strip disturbance harvested about 59.2% of rainfall whereas depression harvested about 58.65% (Appendix 2 Table 2.2). The value of depressions is similar to the findings of Patrick (2005). Figures 3.8 and cumulative runoff (Appendix2; Table A: 2.4) express clearly the comparison between the treatments.

The runoff rate of depression and strip were similar whereas undisturbed was higher than them. The same applies to both cumulative runoffs as it was high in undisturbed treatments. The undisturbed was the lowest as far as infiltration is concerned, and therefore resulted in high runoff. In undisturbed treatments runoff started immediately especially at higher slope. This could be attributed to very little soil manipulation which did not create enough soil disturbances to delay runoff and encourage infiltration. Ventura et al. (2003) in their work in Mexico found that Aqueel^{TM} depressions managed to delay runoff by about 20 minutes when compared to the conventional method. This indicates that the depressions play a major role in enhancing infiltration especially during the first stages of rain. Although depression and strip disturbances were different in soil manipulation (figure 3.9), the amount of water they harvested is comparable.

This shows that you can cultivate soil in many different ways to get the same results. This is a plus to soil management techniques because it gives farmers alternative systems.

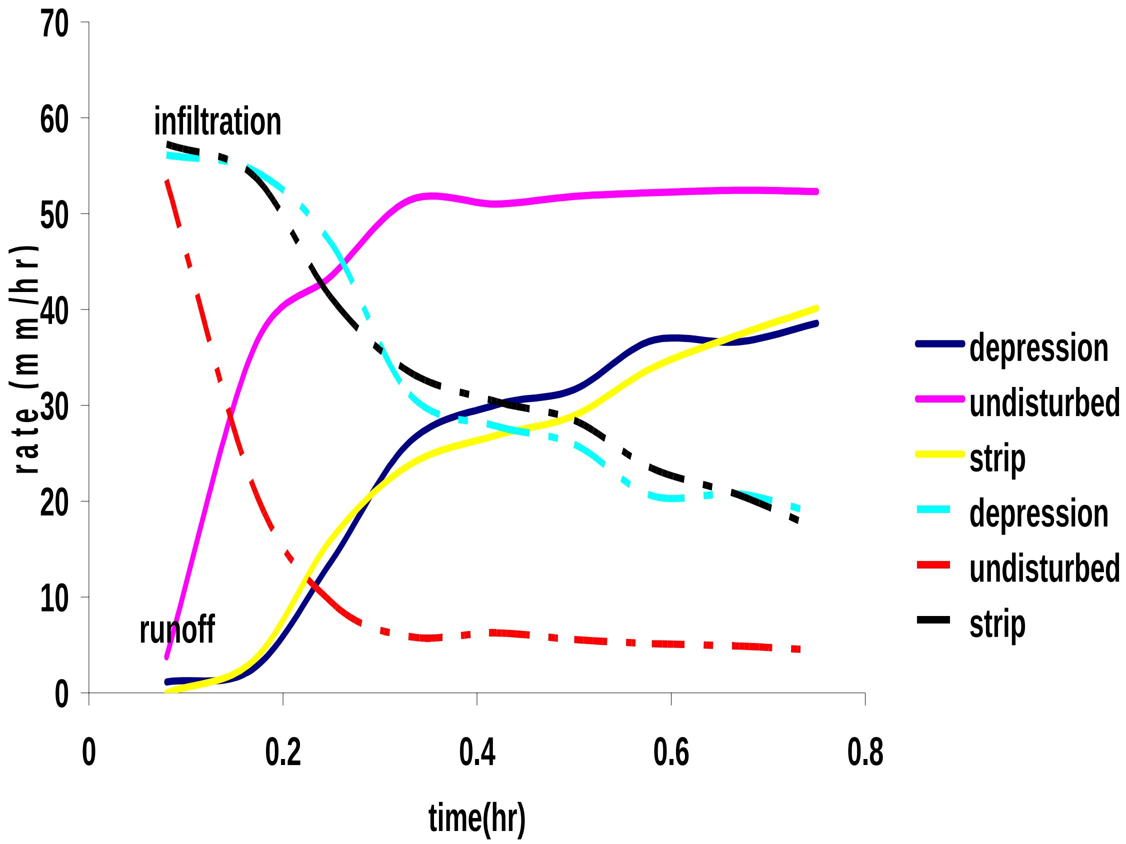
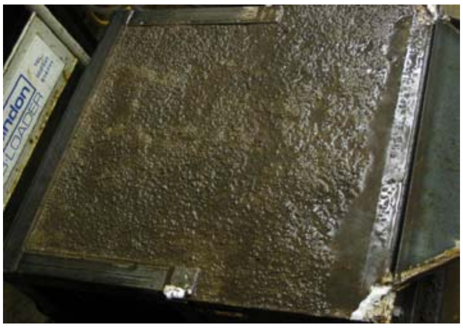


Figure 3.8: Effects of soil disturbances on both infiltration and runoff rate for rainfall at 55 mm/hr

A higher percentage of water was harvested at lower slope across all the treatments (Appendix 2, Table A 2.2). This implies that a reasonable and practical slope should be preferred for harvesting water. If fields have high surface slope, less water will be harvested and result in runoff which encourages soil erosion. For such fields the soil water management systems which reduces land slope should be exploited. On the other hand if the field is flat, they would be water logging, especially after heavy showers.

a



b

c.

Figure 3.9 Soil disturbances after harvesting water from simulated rainfall: a. depression disturbance, b. undisturbed; c. strip disturbance.

C. Eroded soil

Another parameter which was investigated was eroded soil. The results showed that more soil was eroded at higher slope, and both strip and depression were very effective in reducing erosion due to runoff especially at lower slopes. There was significant difference between the slopes and also between the soil disturbances. The effects of interaction were not significant.

Results showed that there was no significant difference between strip and depression. The undisturbed soil disturbance was significantly different from the other two. Depression and strip soil disturbances reduced soil erosion by 47 and 46 % respectively. The indentions and furrows which were created by the two systems reduced the speed of runoff water and therefore less power to detach top soil.

Figure 3.10 shows overlapping of strip and depression which clearly indicated similar results whereas the undisturbed was higher. In undisturbed treatment less soil was manipulated and therefore resulted in less impediment of runoff water movement. The runoff water washed top soil with it and hence high amount of eroded soil. A similar finding was stated by Ventura et al. (2003) who mentioned that the mini reservoirs allowed more time for infiltration, which reduced runoff and its great potential to detach and transport soil particle when the Aqueel^{TM} was used.

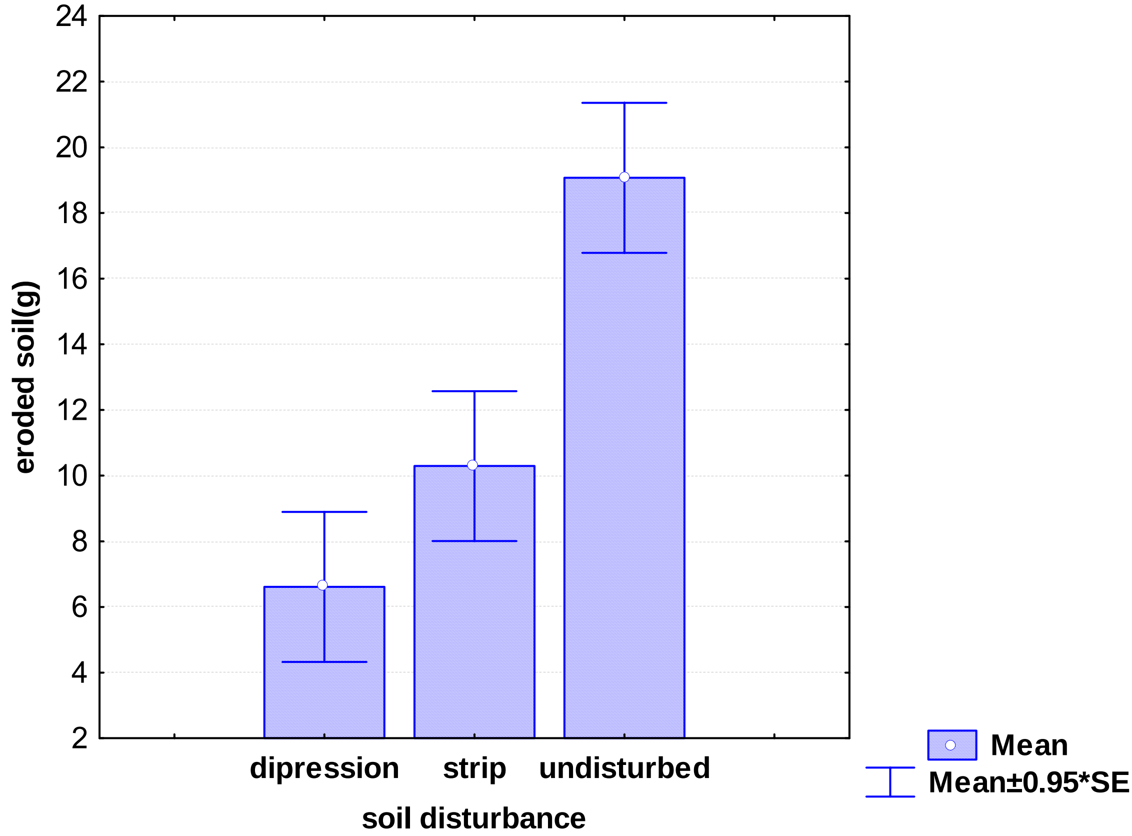


Figure 3.10: Effects of soil disturbance on eroded soil of rainfall at 55mm/hr.

Figure 3.11 indicated the effects of slope on eroded soil. High slope resulted in a larger degree of soil erosion across the treatments. This agrees with the well known fact that soil erosion increases with an increase in land slope. This could be attributed to the fact that high slope increased the velocity of runoff water and therefore increased its energy to detach top soil. It then washed it down the slope and hence high soil erosion. The effects of runoff water on soil erosion are more serious on steep slopes. High slopes give the runoff more energy to detach soil particle from surface and wash them downhill.

This section indicated clearly that under low rainfall intensities and relatively lower slopes, strip tillage can be exploited. If the slope is relatively high both reservoir and strip tillage could be exploited. In the opinion of the author, slightly different results could have been achieved if soil cover was integrated in the experiment. This was not done because of logistics and the condition for which the experiment was carried for. It must be understood that soil of fields in semi arid countries remains bare after harvesting until the first rains. Most of erosion occurs during that time and therefore it was worth to carry out the experiment without cover and get better estimate of eroded soil.

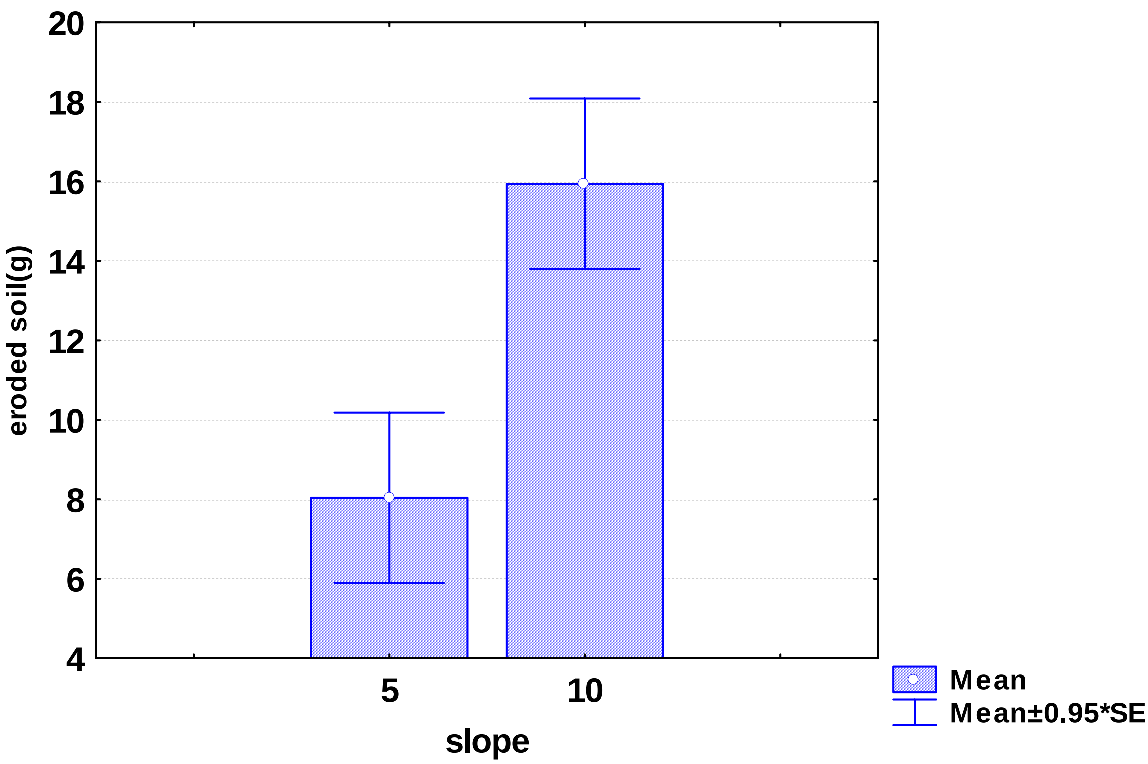


Figure 3.11: Effects of slope on eroded soil of rainfall at 55 mm/hr.

3.3.2. Effects of slope and soil disturbance on infiltration, runoff and eroded soil of 95mm/hr rainfall.

A. Infiltration and runoff

Different results were observed when the same treatment combinations were investigated at higher rainfall intensity. At 95mm/hr rainfall intensity, the analysis of variance table (Appendix2; Table A: 2.6, Table A 2.7) shows that there was no significant difference in slope and the effects of interaction were insignificant. The only source of variation was due to the soil disturbances. There was significant difference between all soils disturbances. The strip soil disturbance performed better than the other treatments. It managed to harvest 58.40% of rainfall when compared to 47.69% and 22.42% of depression and undisturbed surfaces respectively.

Table 3.2 Infiltration and runoff rates of soil disturbance for rainfall at 95 mm/hr rainfall (mm)

	Infiltration			Runoff		
Time (Hr)	depres.	strip	undist.	depres.	strip	Undist.
0.05	93.5	95	70.8	1.23	0	24.2
0.10	80.1	23.39	89.8	14.9	5.23	71.6
0.15	34.5	18	81.2	60.5	13.77	77
0.20	28.4	14.1	70.3	66.5	19.525	80.9
0.25	24.3	15.1	56.3	70.7	38.7	79.9
0.30	19.7	11.1	43.3	75.3	51.7	83.9
0.35	20	16.5	33.5	75	61.5	78.5
0.40	17.3	13.8	28.2	77.6	66.8	81.2
0.45	16.4	14.3	25.8	78.6	69.2	80.6
0.50	14.6	13.4	24	80.4	71	81.6

Table 3.2 and Figure 3.12 illustrate that strip soil disturbance is superior to undisturbed and depression at 95mm/hr rainfall intensity. The graph indicates clearly that at higher rainfall intensities, the strip soil disturbance is more effective in water harvesting. It seems that the furrow cut across the soil surface delayed runoff more than the depressions. This is likely to be the type of conditions which you would experience in Botswana; high rainfall intensities on bare soils. It is possible that if the experiment was carried out under field conditions, the results would be the same. For that reason it would be realistic

for strip tillage system to be exploited more and be evaluated under field conditions against ploughing which is the most popular in Botswana. A similar result on strip tillage system was reported by Willcocks (1981), in which he found it to be superior to other tillage systems which were investigated in Botswana.

One general observation which was made from this experiment is that the soil disturbances under investigation in this experiment lost their water harvesting capacities at high slope and high rainfall intensities. The results indicate that at high slopes and high rainfall intensities the efficiency of the systems got reduced, as the water flows over the soil surface at a faster velocity, and therefore insufficient time is available for infiltration. This resulted in large volume of water lost through runoff.

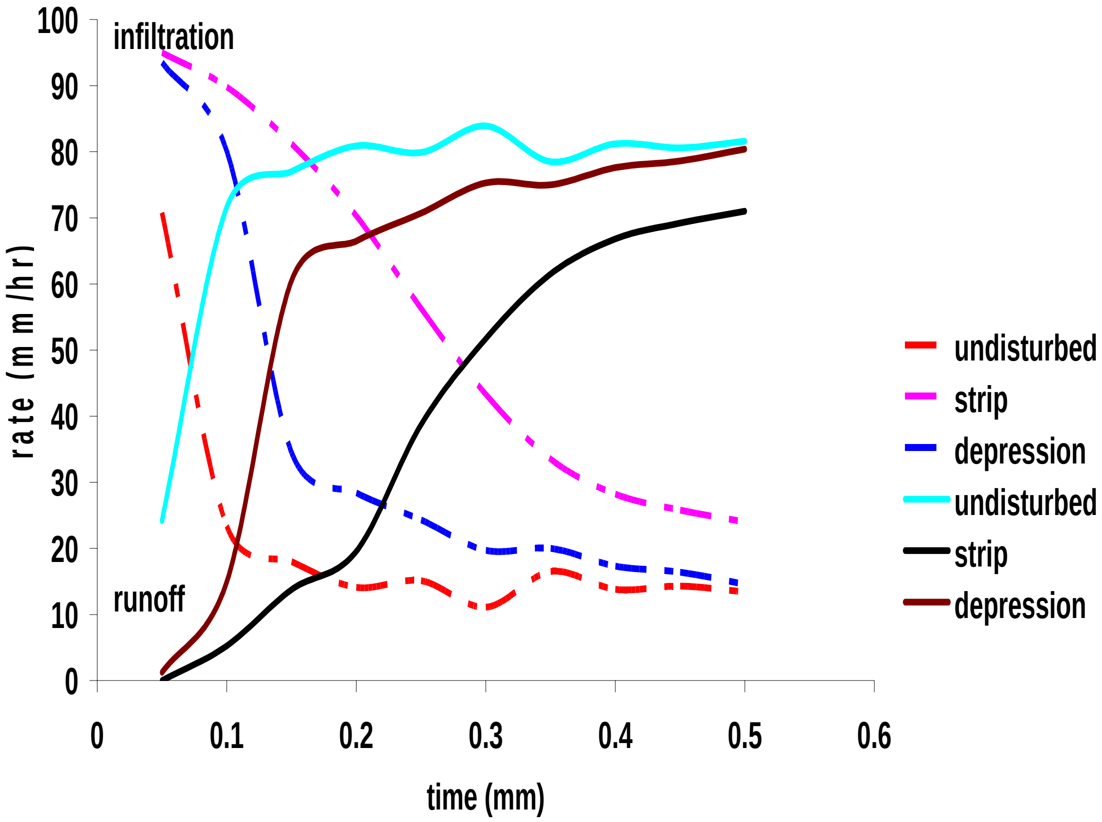


Figure 3.12: Effects of soil disturbance on both infiltration and runoff rate for rainfall at 95 mm/hr

B eroded soil

There was an effect of slope*soil disturbance interaction on eroded soil when the treatments were investigated under 95 mm/hr rainfall. This effect was revealed by the treatments in which soil was not disturbed (Appendix Table A 2.9). The undisturbed at 5° treatment was significantly different from undisturbed at 10°. Other treatment combination did not show any effects of interaction. Figure 3.13 indicates a big difference on soil eroded between the two undisturbed combinations, whereas the strip and depression combinations showed small differences. This implies that when the soil surface is undisturbed (and when there is no surface cover) there is a higher risk of soil erosion at high slopes than at low slope. But when strips and depression are created, the risk of soil erosion is localised especially at high rainfall intensities. The soil particles which could have washed and deposited further away from the field are collected in depressions and furrows within the field. Then, overall there is no net loss of soil from the field.

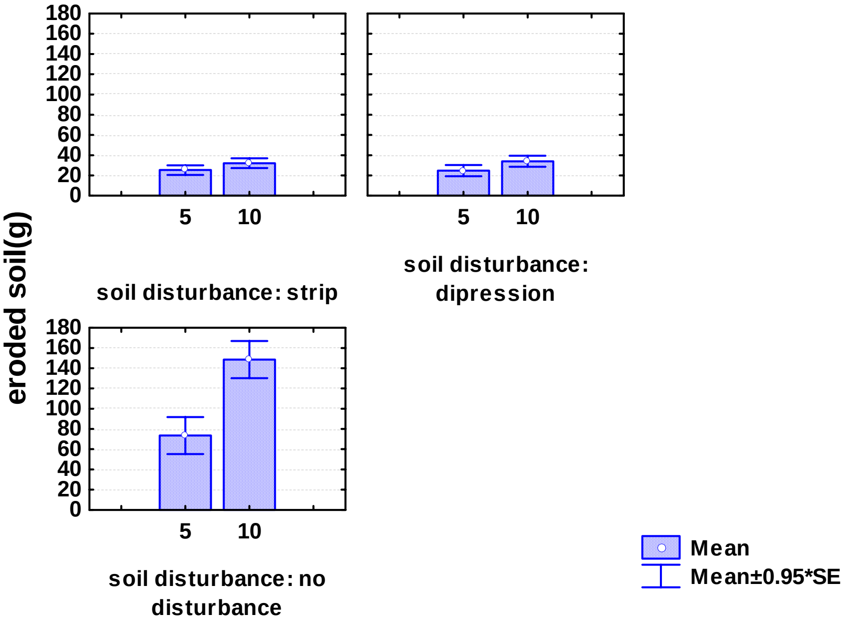


Figure 3.13: Effects of slope*soil disturbance on eroded soil at 95mm/hr rainfall.

There was also a significance difference between the undisturbed treatment and the other two treatments, as illustrated by figure 3.14.This can be attributed to the form of the disturbance which was created. In undisturbed treatments there were no indentions or furrows to prevent soil to be washed down the slope with water. In strip and depression treatments, the soil which would have been washed down the slope was caught in the furrow and depressions, and therefore less soil was transported down the slope.

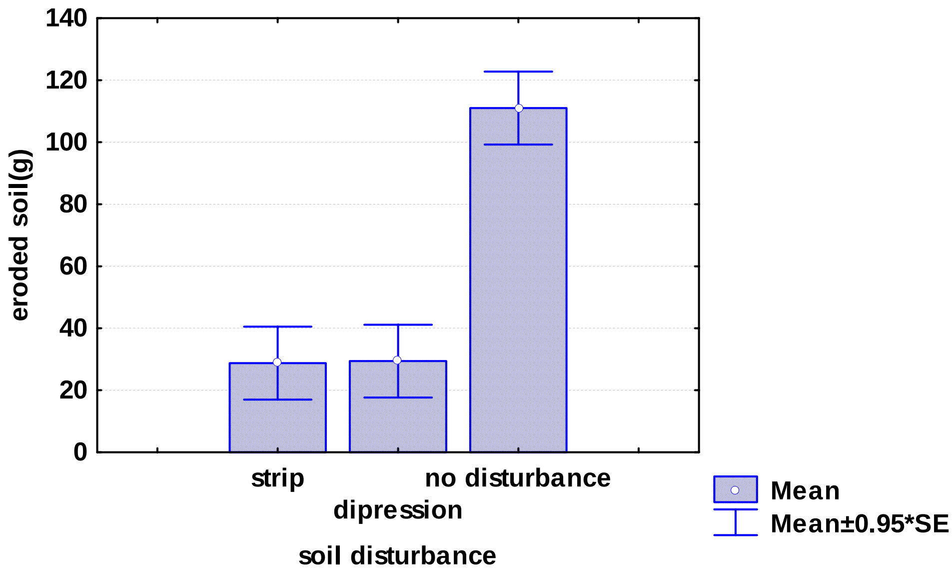


Figure 3.14: Effects of soil disturbance on eroded soil at 95mm/hr rainfall

The effect of slope factor was also significant. This can be attributed mostly to the difference undisturbed combinations. This was highly expected, because high rainfall intensity mostly results in large amount of soil eroded especially at higher slopes. This is illustrated by Figure 3.15. Soil erosion at 5^{o} was almost half at 10^{o}.

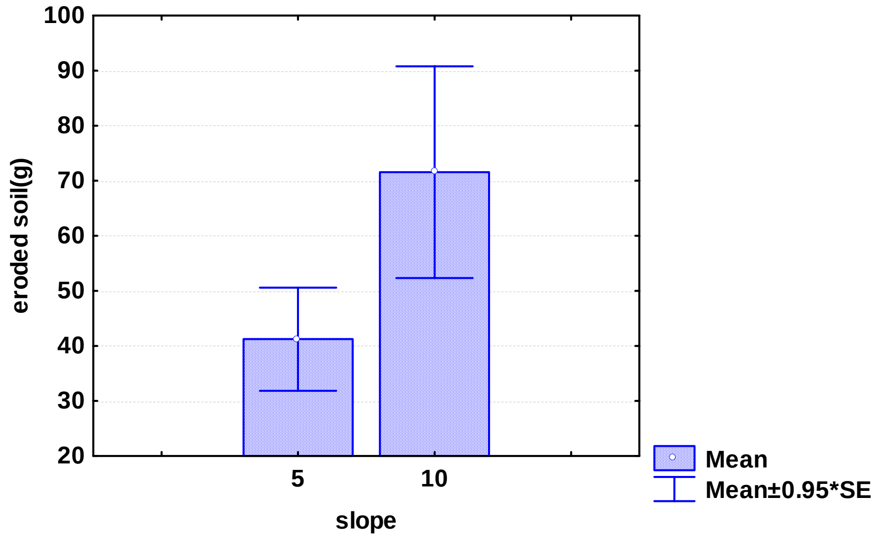


Figure 3.15: Effects of slope on eroded soil at 95mm/hr rainfall

In most cases the soils in semi arid Botswana spend most part of the year bare. This exposes them to high risk of erosion. The first rains are mostly intensive and large amount of topsoil is lost even before crops are planted. Creation of some soil disturbances especially just before first rains may alleviate this problem. In the opinion of the author, the presence of crop cover would also help as the velocity of runoff would be reduced and therefore less soil would be washed away from the field.

3.4 Conclusion

From the results it can be concluded that, at low slope and low rainfall intensity strip tillage harvest more water than reservoir tillage and zero tillage systems. When slope is elevated there is no difference between strip and reservoir tillage. The strip tillage system harvest more water than both reservoir tillage and zero tillage at high intensities. Strip and reservoir tillage reduce soil erosion similarly at both low rainfall and high rainfall intensity.

The experiment was carried out in reference to Botswana which is characterised by high rainfall intensities. From this experiment strip tillage seem to suit Botswana more than reservoir tillage and no tillage.

Chapter 4

4.0 An investigation of evaporation loss from strip and reservoir tillage systems

4.1 Introduction

Water loss from field takes place in two processes - evaporation which is a loss through the soil surface, and transpiration which is a loss through plants. During a cropping season usually the soil is covered with plants and therefore it is difficult to separate the two processes. The processes are therefore put together and called evapo-transpiration. In semi-arid areas, the most part of the year the soil is not covered and hence loses most water through evaporation. This is usually exacerbated by high temperatures and wind which sweeps away the little vapour from the soil surface. Transpiration takes place later during the cropping season and therefore adds to evaporation loss.

The high evapo-transpiration losses in semi-arid regions necessitated sensible soil water management systems which can lower the losses. In most case the target is the first stage of evaporation called potential evaporation. The lower the potential evaporation rate, as measured from a free water surface, the longer does a constant rate persist (Marshall et. al.1996). So, control measures devised to reduce the rate of evaporation depend primarily on:-

1. reducing the potential rate of evaporation at the surface by modifying atmospheric conditions there, or
2. reducing the amount of water retained near the surface when water is added to soil.

Either of these ways will allow plants to utilize water before it is lost through runoff. This prompted the invention of conservational tillage which like mulching reduces the amount of radiant energy absorbed and minimises air flow over soil surface. So any system adopted for soil water conservation should satisfy either of the above two points.

From chapter 1 and 2 the strip and reservoir tillage were seen as the two systems which could have potential in harvesting water for rain fed agriculture in semi arid climates. Chapter three looked at their ability to harvest water from rainfall of both high and low intensity rainfall. This chapter take a step further to look at how much will be lost from the harvested water. Any conclusion about the soil water conservation performance of the two systems can only be drawn after both infiltration and evaporation are investigated against them.

The objective of this study was to investigate the evaporation loss from strip and reservoir tillage system under a semi arid environmental condition.

In this chapter the amount of evaporation loss from the two tillage systems exposed to a constant source of radiant heat will be investigated.

4.2 Methodology.

In order to simulate evaporation loss from fields in the arid areas, wind and high temperatures should be provided. Research has shown that these are the most important factors. Wilcok (1989) stated that initial evaporation from radiation and wind were the same but found that total evaporation was greater for wind. For this experiment the effect of wind was not incorporated due to logistical difficulty in simulating wind effects.

4.2.1 Preparation of experimental units

Ten small wood boxes with internal dimensions of 470mm length, 450 mm width and 250mm depth as shown in figure 4.1b, were used in this experiment. The boxes were specifically designed for each tillage system and therefore resulted in: - three for strip disturbance, three for depression disturbance and finally three for undisturbed (control). The same types of soil disturbances as in Chapter 3 were created in the trays. A soil similar to one used in Chapter 3 was used. It was compacted to a bulk density of about 1.25 g cm^{-3}. After creating the soil disturbances, the boxes were placed under rainfall of 45mm/hr intensity. Low rainfall intensity was used in order to allow more water to slowly infiltrate in the soil. Three boxes at a time, one from each treatment were then randomly placed under the simulator. The boxes were left to saturate under the simulator for 2 hours. After the soil was saturated the boxes were then left overnight to allow the soil moisture to set itself to field capacity.

a.

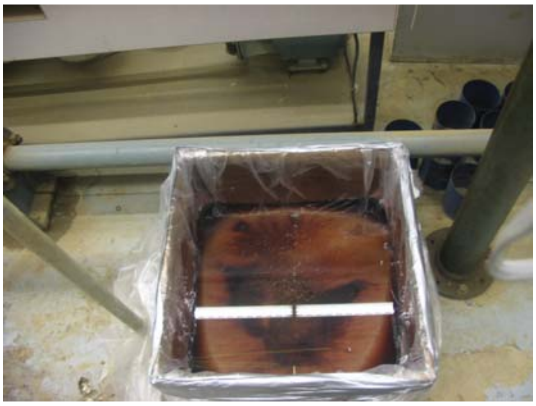
b.

Figure 4.1 Nozzle of a simulator used and wooded boxes filled with soil wetted under the simulator

4.2.2 Setting of experiments

After all the treatments were created, and wetted, they were then placed on a flat area. The area was about 2m x 4m in order to accommodate all the experimental units. Radiation lamps were then suspended on top of the boxes as shown in Figure 4.2a.

a



b

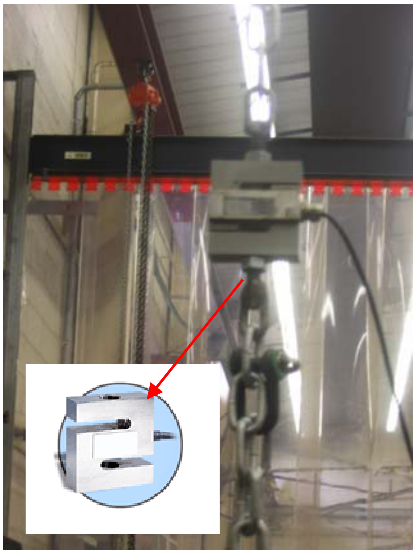
Figure 4.2 Setting of treatments and free water box

The temperature above the trays was set to about 30^{o}C by adjusting the length of the chains holding the lamps. This temperature was chosen because it is close to average summer temperatures in Botswana. A tenth box lined with plastic inside and filled with water was placed in the same environment as the treatments. This is shown by figure 4.2b. This was used in order to compare the evaporation loss from the treatments to free water.

4.2.3 Data collection using S/Z – beam load cell

Data collection for this experiment was carried out using an overhead crane with a 2 tonne capacity, 200kg S/Z beam load cell and Dasylab8 programme. S-Beam load cells get their name from their S shape. S-Beam load cells can provide an output if under tension or compression. It is a transducer which converts force into measurable electrical signals. The gauges themselves are bonded onto a beam or structural member that deforms when weight is applied. When weight is applied, the strain changes the electrical resistance of the gauges in proportion to the load. Before the load cell was used it had been calibrated using 20 kg masses. The calibration was done from 20 kg to 100kg. From the calibration Figure 4.3 was produced which shows a relationship between voltage and mass load. This graph gave a formula which was put onto the Dasylab 8 programme. This was done so that the mass changes can be read directly on the computer.

An overhead crane and s- beam load cell connected to dasylab8 programme was used to measure the weight of the boxes. Using this procedure the volume of evaporated water lost was measured for 10 days, calculated from the loss of weight in each treatment. The experimental design was complete randomised design. The analysis of variance was carried out using statistica 7.



a. box lifted by crane

b. z beam load cell connected between box and crane

Figure 4.3 Taking measurement using overhead crane and z beam load cell

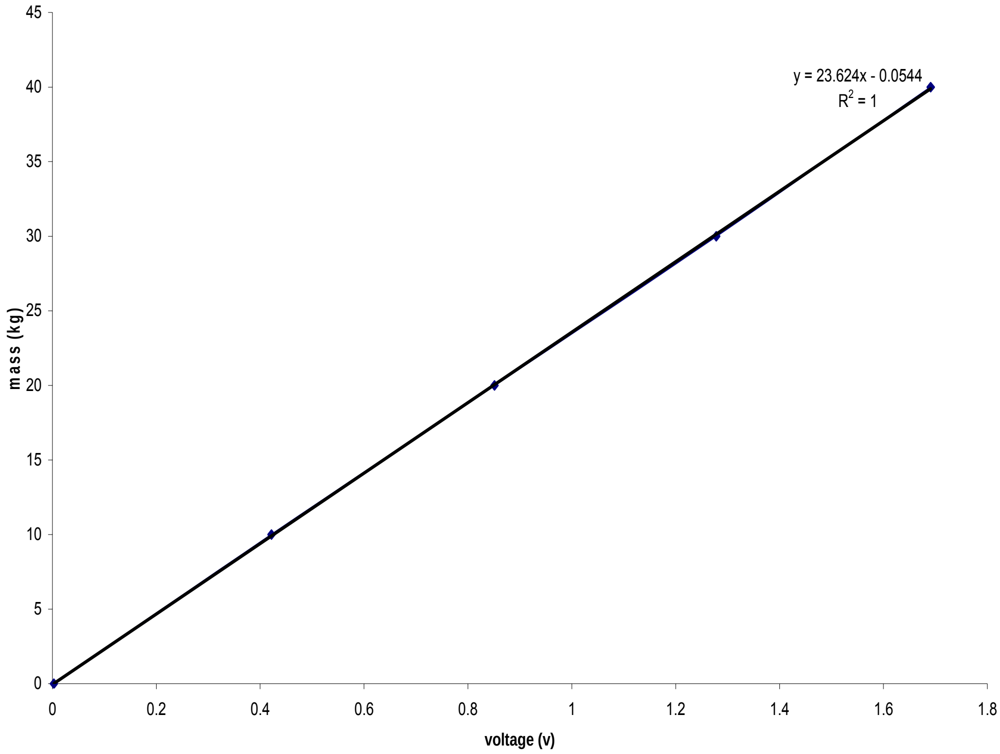


Figure 4.4 Calibration graph

4.3 Results and Discussion

The evaporated and retained water after 10 days are discussed in this section. The analysis of variance, (Appendix Table A 3.1) shows that there was a significance difference between the treatments as far as evaporation is concerned.

The difference was due to the free water box. The main treatments did not show any significant difference. This is the case despite the fact that both strip (10.05 litres) and depression (10.16 litres) had more water at the beginning of experiment than the undisturbed treatment (7.66 litres). This implies that the strip and depression disturbance did not lose a large portion of their harvested water whereas the undisturbed lost more than three-quarters of what it had harvested. The percentage total volume of water lost from the three disturbance treatments were 79%, 58 .6 %. 49.7% for undisturbed, strip and depression respectively.

Table 4.1: Cumulative evaporation from the disturbed surfaces

days	undisturbed	Depression	Strip	free water
1	8.58	5.94	12.18	13.24
2	18.16	12.38	16	29.31
3	22.59	15.52	18.18	46.34
4	26.09	19.45	21.05	62.41
6	27.15	21.91	23.05	81.8
8	28.12	23.5	24.92	100.71
10	28.82	24.57	26.43	119.15

Although the amount of water lost from the disturbed treatments is similar, the form and rate at which it was lost differs between the treatments. This was observed during the first two days. Table 4.1 and Figure 4.5 shows that there was no significant difference between the treatments on the first day, but as time passed, the difference between evaporation loss from the free water and the main treatment became significant. After one day the strip lost more or less the same amount of water as the free water. This could be due to the fact that the water molecules were held loosely between the soil particles along the disturbed strips; therefore it was easy for them to escape to the atmosphere. On the other hand the depression and undisturbed were similar in cumulative evaporation. After the second day the undisturbed lost more water than both strip and depression. This is attributed to the fact that most water molecules in the undisturbed treatment were held at the top layer, and therefore it was very easy for them to escape into the atmosphere. The water in the strip and depression percolated down to the lower layer and so it was difficult for them to evaporate.

When the soil profile was taken to reveal the drying zone, it was clearly seen in the strip and depression tillage when compared to no tillage. The no tillage boxes harvested a small amount of water which wetted only the top 2 cm section of the soil. This section almost dried completely to the moisture content before the boxes were saturated and therefore it was less defined. On the other hand, there was gross difference between the dry top section and lower moist section on the strip and depression treatments. This is due to the fact that more water managed to infiltrate deeper in these treatment than in no tillage treatment. This explains why there was more retained water in strip and depression tillage.

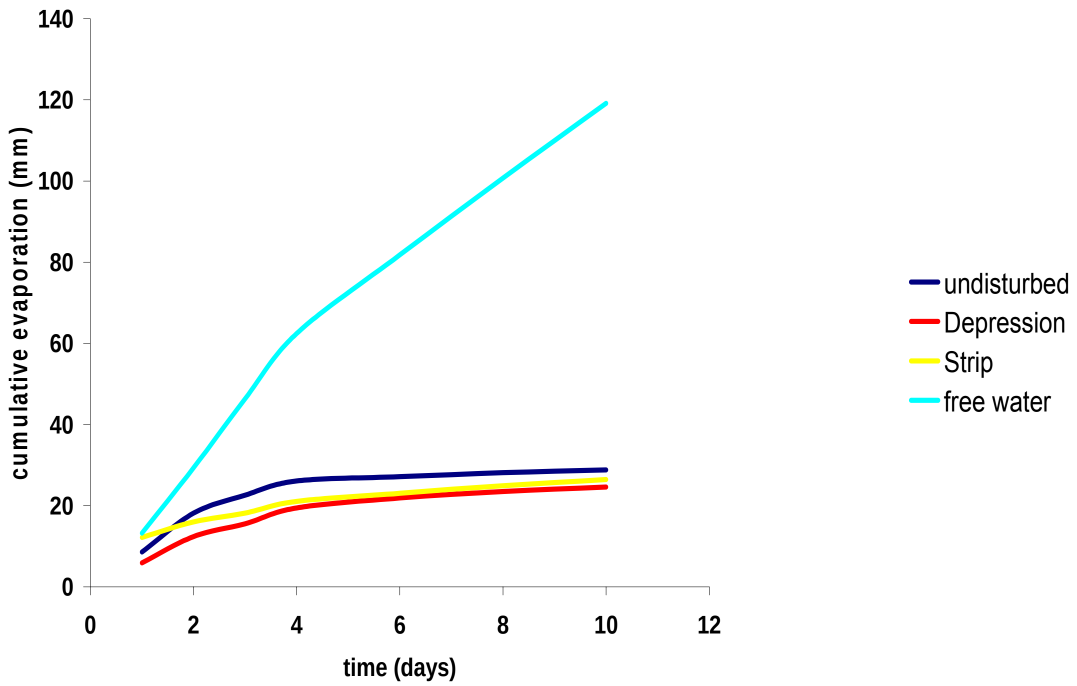


Figure 4.5 Cumulative evaporation from the disturbed surfaces

Another parameter which may worth consideration is the water retained in the soil after evaporation. There was a significance difference between the treatments. The lsd test showed that there was no difference in retained water between strip and depression whereas the undisturbed was significantly different from the other two.

The undisturbed disturbance lost larger portion of harvested moisture through evaporation and therefore resulted in low retained water. Strip and depression have almost equal amount of retained water. This makes them to be more suitable for semi arid conditions. It is likely that under field conditions strip would harvest more water than the depression. This is due to the fact that, when the soil boxes were saturated with water, some water drained through the holes at the bottom of the boxes. The boxes limited the depth through which water can percolate. Under field condition, this water will be conserved in the lower soil profiles.

The results in this chapter show that the first two days are very critical for reduction of evaporation. In the opinion of the author decreasing of evaporation in the first few days will result in more water conserved in the soil. It was found that, for Botswana condition, strip tillage harvested more water than depression reservoir tillage and no tillage system. If the water harvested is accompanied by control of evaporation at the soil surface by mulching, the intensity of potential evaporation will be reduced. This will result in more moisture available for the plants.

4.4 Conclusions

From the result it could be concluded that the evaporation of water from the soil disturbances was similar, but undisturbed lost higher percentage of harvested water than the other disturbances. The water molecules in the undisturbed soil did not percolate deeper in the soil therefore it was easy for it to be lost to the atmosphere. Retained water was higher in strip and depression disturbances. It is also worth mentioning that the first few days after rainfall are very critical for water harvesting. Any system which reduces potential evaporation will be suitable for water conservation.

Chapter 5

5.0 Total Retained Water and Energy requirements of the tillage systems

5.1 Introduction

In semi arid regions, the selection of soil water management is clear; as much rainfall as possible must be retained by methods that reduce storm-water runoff, improve infiltration and boost the water storage capacity of the soil. The system should also be cost effective for acceptance by the farmers. Most farmers in semi arid regions are in third world countries which cannot afford the sophisticated machinery found in developed countries like the United States and Australia. Any soil water management system should take into consideration the socioeconomic implications of the target clients. The practicability and energy requirement of the system is pivotal for adoption by farmers. This chapter will look on the overall discussion of the investigated tillage systems in consideration of the above points.

5.2 Total Retained water (TRW)

The leading theory for water harvesting and conservation is founded on the water balance model, which describes available water as the difference between precipitation and surface runoff, drainage and evaporation loss. For cultivation in semi-arid conditions the crucial result is the residual water harvested and retained from a given rainfall event. For the purpose of this project, this retained water is termed 'Total Retained Water (TRW)'. It is the difference between harvested water and evaporated water. The total retained water is time specific, thus it depends on the time of measurement and it is a transitional phenomenon. This total comprises the amount harvested during rainfall (described in Chapter 3) minus the amount subsequently lost through evaporation (described in Chapter 4). The difference provides the water retained in the soil which can potentially be used by the plant.

Chapter 3 showed clearly that under low rainfall intensity, strip and reservoir tillage systems harvested similar amount of water. They performed better than no tillage. This clearly indicated that they could be selected for water harvesting under low intensity rainfall. It is however very important to balance this harvested water with evaporated loss which was covered in chapter 4. Chapter 4 indicated that there is no significant difference between the three tillage systems as far as evaporation loss is concerned. The evaporation loss was similar under the set conditions of the experiments, whereas infiltration was higher in strip and reservoir tillage. Therefore the balancing of harvested water and evaporated water indicates clearly that, under low rainfall intensity, strip and reservoir tillage systems are likely to retain more water than a no tillage system. This is due to the fact that although evaporation loss is similar across the tillage systems, strip and reservoir had harvested more water than no tillage. This therefore implies that water lost through evaporation was a small component of harvested water in both strip and reservoir tillage, but it was much larger in no tillage.

Total retained water does not have a bearing in Botswana conditions until it is evaluated under high intensity rainfall. Strip tillage was better in harvesting water than both reservoir and no tillage system under high intensity rainfall. If this is balanced with evaporated loss in chapter 4, then this means that strip tillage would have high total retained water than the other two tillage systems. High intensity rainfall and the conditions which were set for evaporation experiment in chapter four were close to Botswana conditions. This implies that, under these conditions, the tillage system which showed high total retained water would be suitable for Botswana. This indicates that if total retained water is the only factor for selection, strip tillage system is the best system for Botswana.

5.3 Energy requirements, draft forces, draw bar power and work rates of the tillage systems

The conservation of scarce water and energy are prime concerns of semi-arid agriculture; but these resources are insufficient to achieve future food production requirements with currently practiced tillage systems. Willcocks (1982) stated that in semi arid agriculture more efficient use will have to be made of limited resources of water and draught power by employing reduced tillage techniques that lower energy inputs. Thus that any decision taken on the suitability of tillage system should consider both its energy requirements and ability to harvest and conserve moisture. The previous section dealt with water credentials of each system, so this section will concentrate on energy requirements of the tillage systems. Willcocks (1982) mentioned that tillage is the only crop production operation requiring high draft input of up to 320MJ/ha and therefore reductions in its energy requirements should significantly reduce crop production input cost. He further stated that in USA nearly 1/3 of the total power consumption in agriculture is used for tillage. In consideration of the above raised points this section will specifically look into energy required for Strip and Depression reservoir tillage system, as the no tillage system has been proved unsuitable for Botswana. Required power, pull and work rate for each system will also be evaluated in this section as they are vital for determination of the performance of the implement. According to Srivastava et. al. (1993) the performance of tillage implements is determined by their draught and power requirements and the quality of work.

5.3.1 Required draught force for each tillage system

The implements which are used to cut soil require a force for the desired soil disturbance. The soil cannot be disturbed or cut until this force is applied. This force is called draught force and sometimes the term draw - bar force is used. The force depends on implement width, working depth and soil specific resistance. This force is very important for determination of the performance of the implement.

$D_b = w \times d \times r_s$ Eqn. 5.1

Where; D_b = draw bar force (kN)

w = implement working width (m)

d = implement working depth (m)

r_s = specific resistance (kN/m^2)

a) Depression reservoir tillage

Patrick (2005) has stated that an effective way of forming depression is by ploughing the soil and follows that by Aqueel™ roller. This means that there are two operations which must be carried out before seeding. Witney (1988) showed that the specific resistance can be as high as 105kN/m^2 under sandy loam soil. Most farmers in Botswana use a 3 furrow mouldboard plough. The width of the cutting part is 30 cm. This makes the total working width to be 0.9 m. In most cases depth of cut is 20 -25 cm. For that reason the maximum draw bar force required will be;-

0.9 m x 0.25 m x 105 kN/m^2 = 23.6 kN.

This implies that any source of power used should be able to provide a pull of more than 23.6 kN to cultivate the soil.

To obtain the force needed to create depressions, a 0.72 m Aqueel™ roller was run over a loose soil (bulk density 1.1g/cm^3, moisture content of 6%) in the soil bin, and the results are presented in Table 5.1.

Table 5.1: Draft force for Aqueel™ roller at different speeds

Speed (m/s)	Draft force (kN)	Draft force/m (KN/m)
1	0.063	0.088
1.2	0.126	0.175
1.5	0.315	0.438

This table shows that the force increases with speed. From table 5.1, the maximum draft force needed to create depressions will be 0.438 kN/m. This indicates that this force is lower than one needed for ploughing.

b) Strip tillage

For the strip tillage, Willcocks (1981) recommended use of a subsoil type tine of 50 mm tip at 0.75 m row interval and four tines were used at a time. From chapter three working depth was 0.15 m and a wing was attached at the base which made working width to be 0.15 m. Thus that the total working width will be 0.6 m.

Then the maximum draft bar force required will be;-

0.6m x 0.15m x 105 kN/ m^2 = 9.45 kN. This is very close to the findings of Willcocks (1981) where the draught force needed for strip formation was 12.1±3.23 kN.

The required source of power should provide more than 9.45 kN of pull. The width and depth of the tine could be increased depending of the soil condition and crop grown.

This indicates that as far as draw bar force is concerned the implement for strip tillage will be more advantageous than the implements for depression reservoir tillage.

5.3.2 Energy requirement for each tillage system

a) Depression

For the depression reservoir tillage, the mouldboard plough covers a width of 0.9 m at a time. To plough a hectare of land, the implement has to cover a distance of 11.111 km. The means that the energy required for ploughing one hectare will be about 262 MJ. To create depressions with an Aqueel™ with six rollers the effective width will be 0.72 m as the width of an individual roller is 0.12 m. The energy required for one hectare will then be 4.4 MJ. This makes the total energy required to make depression reservoir tillage to be 266.4 MJ.

This is almost twice the findings of Willcocks (1981). This could be attributed to fact that he used specific resistance of 60 kN/m^2 instead of 105 kN/m^2 which was used in this project.

b) Strip tillage

For the strip tillage, the standard crop spacing for cereal crops like maize and sorghum is 0.75 m. If an implement has four tines, the width of one run will be 3 metres. To till a hectare of land; the implement has to cover 3.33 km. This makes the energy required to complete a hectare to be about 31.5 MJ. This is similar to Willcocks (1981) who found it to be 40 MJ/ha.

This shows clearly that energy required for strip tillage is almost 1/8 of what is required for reservoir depression. If energy requirement was the only criterion needed for selection, the strip tillage comprehensively outperforms depression reservoir tillage.

5.3.3 Required draw bar power for each tillage system

No matter what the draft, adequate power must be availed to move the machine quick enough to perform appropriately. Excessive power may break implements if not properly harmonized. But too little power wastes time, may damage tractor by overloading gears and engine. This means that sufficient draw bar power is required to pull or move the implement at a uniform speed. It is usually stated as draft bar force times working speed and stated as:-

$$D_p = P_F \text{ x } s \qquad \text{Eqn. 5.2}$$

Where; D_p = Draft power (kW)

P_F = draft force (kN)

s = speed 9m/s)

For both ploughing and cultivation with tine, Willcocks (1981) used a forward speed of 3 km/ hr, which equals 0.83m/s. The wheel slip reduced this to 0.71m/s.

At this speed, the draft power required for ploughing will be 16.76 kW and 3.124 kW will be required for making depressions. For formation of tillage strips the power required will be 7.81 kW. If one considers the fact that most tractors in Botswana are 60 hp (45 kW), then the forward speed can be increased to take advantage of the available power.

For mouldboard plough the speed could be increase to about 1.4 m/s (5.04km/hr) and for strip, the speed could be increased to 4.8 m/s (17.28km/hr-practically unacceptable.). The maximum speed for most implements is around 10 km/hr. This indicated that for strip tillage the speed could be maximised. This will increase the working rate.

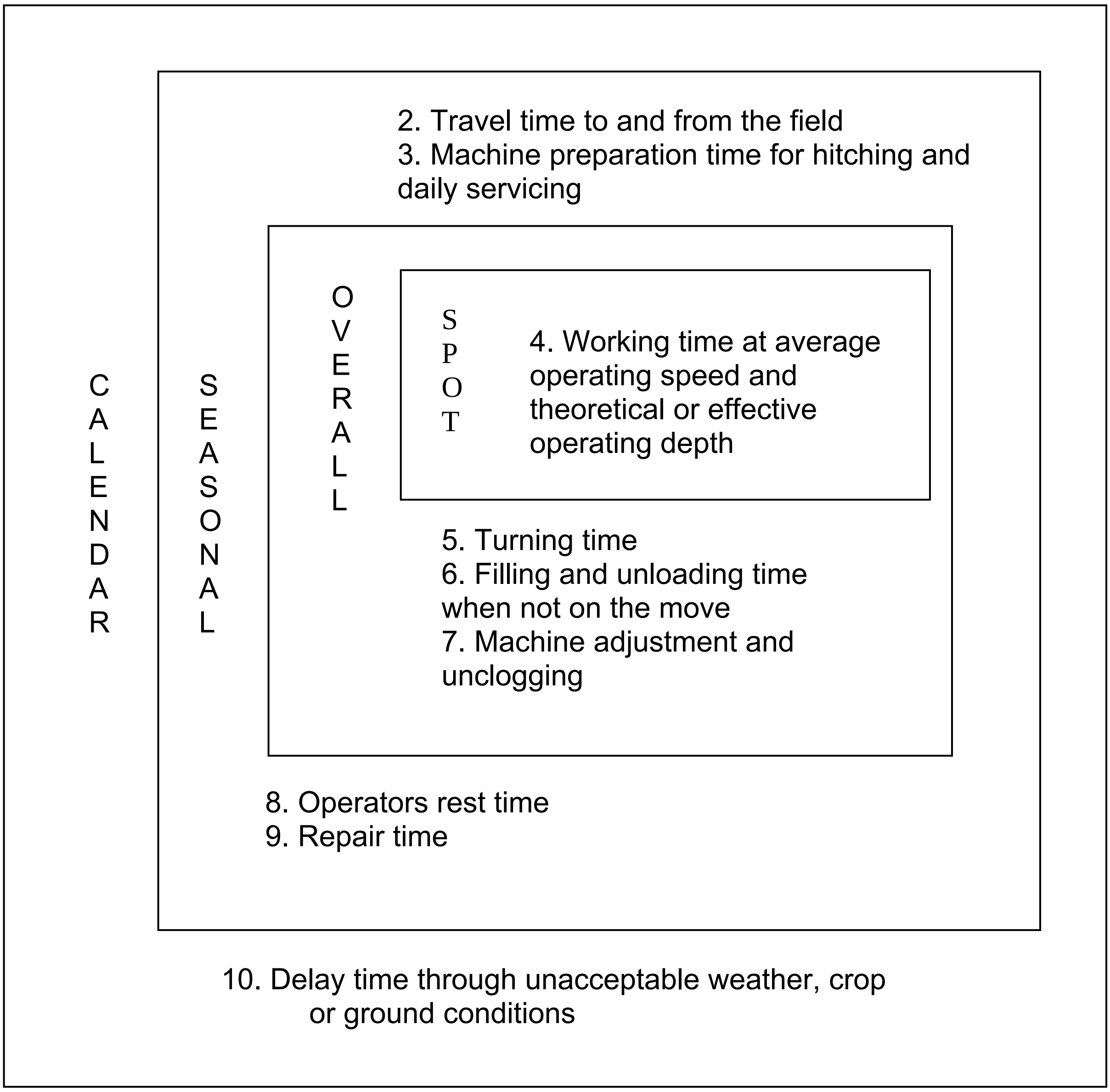
5.3.4 Work rates for each tillage system

Work rate of an agricultural machine is paramount for the assessment of its performance. Witney (1988) stated that the performance of agricultural machine is assessed by the rate at which an operation is accomplished and by the quality of the output. The work rate in the field depends on the forward speed. The other aspect which should be considered here is efficiency, but in most farm machinery it usually assumed to be 0.8. Witney (1988) classified work rates in four different types as summarised in Table 5.2.

Using Table 5.3, seasonal work rate could be estimated from productive work. The assumption made is that, the time proportions are for the whole season.

Table 5.2 Time elements with different rates of work for machine operations in the field (Witney, 1988).

RATE OF WORK	Time element
	1. Machine preparation time before and after storage.



a) Depressions

For the depression reservoir tillage, the field must be ploughed first before the Aqueel roller is used. To calculate the productive work and spot rate of work, the distance covered in a hectare must be estimated. If the effective with of a plough is 0.9 m, then the distance travelled to cover a hectare will be 11. 111km. If the speed is 5km/hr, then the time needed to complete a hectare will be 2.22hrs. This gives work rate of 0.45ha/hr. It is similar to the one found by Willcocks (1981) who found the work rate to be 0.4 ha/hr.

Table 5.3 Proportion of time spent on productive work in fields of increasing size (Witney, 1988)

Field Size, a	Proportion of time on productive work, %				
	Productive work	turns	Headlands	Changing fields	Contingencies
2	37	20	4	22	17
4	47	19	3	14	17
8	57	15	3	8	17
10	59	14	3	7	17
20	65	12	2	4	17
40	71	8	2	2	17
80	74	7	1	1	17

The spot work rate of creating depressions depends on the size of the Aqueel roller. The roller could be as long as 4m but, if the roller is combined with a planter (which is appropriate for Botswana) a 0.96m working width could be assumed.

For making depressions with the effective width of 0.96 m, the distance needed to cover a hectare will be 10.417 km. The speed of pulling a roller could be maximised to 10 km/hr if one considers that it requires less force to pull it. The time needed to complete a hectare will be 1.04 hrs. This gives a spot work rate of 0.96 ha/hr. This makes the total spot work rate of complete depression reservoir tillage to be 0.705ha/hr.

From Table 5.3, we know that productive work is 37% of the whole seasonal work. The calculations above showed that 3.26 hrs is needed for productive work on one hectare of a field. The total seasonal time will be:-
3.26 / 0.37 = 8.81hrs. The seasonal work rate will be 1ha/8.81hr which equals 0.114 ha/hr. Rain fed crop production in Botswana is dominated by small traditional farms of about 5 hectares. This means that 43.86 hrs of seasonal time will be needed to cultivate one farm of 5 ha.
Most ploughing in Botswana takes place between November and January. This means there is 90 day window which could be used for ploughing.
If a 10 hr work day is assumed, then there are 900 hrs available for farming. Using depression reservoir tillage systems 20.5 (900/43.86) farms will be cultivated in a season.

b) Strip tillage

Willcocks (1981) with his work in Botswana showed that the work rate of strip tillage implement is higher than of mouldboard plough. The work rate was 1.0 ha/h whereas a plough implement was 0.4 ha/hr. If one assumes a width of 3 m, the distance needed to cover a hectare will be 3.333 km. With a speed of 10 km/hr, the time needed to cover a hectare will be 0.333 hr. This gives spot work rate of 3 ha/hr. This indicates clearly that it is faster to use strip tillage implement than the depression reservoir tillage implement.

The seasonal time needed to cover one hectare is 0.333/0.37 which equals 0.9 hrs. The seasonal work rate would be 1ha/0.9hr =1.11ha/hr. The time needed to cultivate 5ha would be 4.5 hrs. Using the strip tillage, 200 farms would be cultivated in a seasonal.

5.4 Conclusion

From this chapter it could be seen clearly that strip tillage system has more positives than depression reservoir tillage. At the moment most of the available strip tillage implements are not appropriate for Botswana. They are either designed for soft soils or tractors of bigger power. Even after the work of Willcocks (1981), less initiative were undertaken to encourage farmers to try the system.

This could be attributed to unavailability of proper implements. Taking this into consideration, chapter six is concerned with the conceptual design of an implement to create sustainable strip tillage for Botswana. The target group is those farmers who hire tractors for ploughing as they are the majority.

CHAPTER 6:

6.0 Conceptual design for a tillage implement that is suitable for Botswana

6.1 Introduction

Most farmers in Botswana still practice the old-fashioned crop production systems. Even some of the farmers who have tractors as sources of power still broadcast seeds. This can be attributed to the fact that Botswana receives rainfall in a short period of time (~3 months). Farmers broadcast so that they can utilize the little moisture available before it dries out. The other point is that conservative tillage implements available at the moment are too sophisticated and expensive for Botswana cropping systems. This led to idea of specifying a simple and robust implement which can be tractor drawn. The implement should be able to till and plant at the same time.

The previous chapters showed clearly that Botswana conditions need a tillage implement that can harvest and conserve moisture from high intensity rainfalls of a short duration. To make the implement more effective, it must have a provision to seed with cultivating the soil simultaneously. Strip tillage seemed to be a realistic choice for Botswana as it managed to conserve moisture better than either no tillage or reservoir tillage. The overall results of the previous chapters showed clearly that, although depression reservoir tillage has potential, its energy requirement makes it very costly for Botswana. The clod-forming sandy loams make it difficult for the technique as there will be need for ploughing. If one is interested in an implement which can be suitable for the whole country, a strip tillage system with planter attachment is the answer.

The logic of the planter attachment is that it should be able to follow the strip tillage tool and place seeds at the desired place and depth. The depth of planting and distance from the strip created should be easily adjustable. The implement size must be suitable for the tractor draught power available in Botswana. Currently rain fed farming in Botswana is dominated by small farmers who plant less than 10 ha. Most of them hire tractors of about 60 hp for ploughing and planting at the same time. They broadcast the seeds first and follow that by ploughing them in. This leads to poor germination and therefore undesirable low plant population on the fields. This ultimately results in crop production yield failure. So with this in mind the implement thought of should be suitable for available tractor draught power and should integrate soil and water conservation in the whole process.

The objective of this study is to develop a conceptual design of strip tillage – planter implement for Botswana condition.

6.2 Concept design for strip –tillage planter

Pahl & Beitz (1988) defined conceptual design as the process in which the basic solution path is laid down. They mentioned that it succeeds the clarification of the task. Conceptual design is the process by which the design is initiated, carried to the point of creating a number of possible solutions, and narrowed down to a single best concept. It is sometimes called the feasibility study (Dieter, 2000). Dieter stated the following as the activities considered under conceptual design:-

a. Identification of customer needs
b. problem definition
c. gathering information
d. conceptualization
e. concept selection
f. refinement of the product design specification and
e. design review

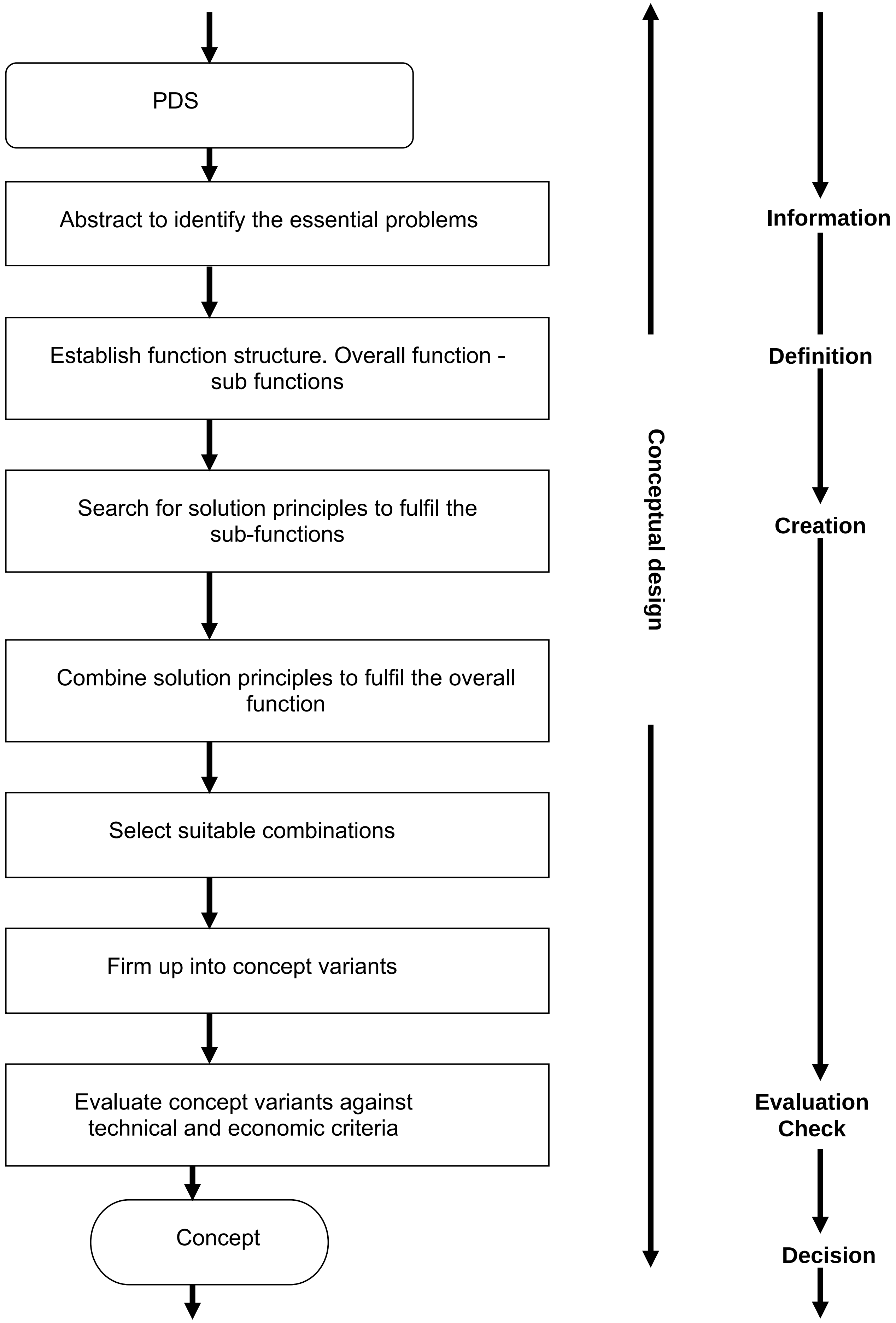


Figure 6.1 Steps of conceptual design (Pahl & Beitz 1988)

Pahl and Beitz (1988) showed the steps graphically (Fig 6.1) and their idea was followed in the formulation of the conceptual design process in this project.

6.2.1 Product Design Specification (PDS)

PDS is a detailed document that describes what the design must be in terms of performance requirements, the environment in which it must operate the product life, quality, reliability, cost, and a host of other design requirements (Dieter 2000). It is a benchmark and evolutionary document for the design process. It describes in writing the product that is intended to be made.

The product design specification for the proposed implement is as follows:

Product title

Strip tillage- planter implement

Purpose

The implement envisaged should create strips to:-

Depth range of 150 to 300mm.

Inter row spacing of 400-750mm

Place seeds at desired depth of 20 -50 mm

Inter row planting spacing of 400 -750 mm

Intra raw planting spacing of 300 – 400 mm

Press and cover the seeds to created conducive conditions for germination.

The various ranges are to give the implement versatility so that it could be utilized for various crops. Most farmers in Botswana practice mixed cropping so an implement that could be utilised for 3 or more crops would be desirable.

New or special feature

The implement should encourage soil and water conservation principles. The implement will be the first of its kind in Botswana. It should be simple to operate.

Competition

Conservative tillage systems are not popular in Botswana. Not much competition is expected as the implement is targeting group of farmers who hire tractors. This is very important as they are the majority. The whole idea is to give them a positive alternative to conventional ploughing which is detrimental to Botswana soils.

Intended market

This implement is targeting farmers who use tractors for ploughing and planting.

Need for product

There is a serious need of this implement as most farmers in Botswana still use plough and broadcast seeds which result in disastrous crop yields.

Price

The price for the implement should be within farmers reach. It has advantage in the sense that it could combine cost of two crop production implements. I am not sure of the prices of mouldboard ploughs in Southern Africa, but the envisaged implement should cost about 60% of the current mould board ploughs prices.

Functional performance

This could be divided into two; strip tillage creation and seed metering and placement.

i. Strip tillage creation

To create strip tillage on clod forming sandy loam soils in Botswana

The implement should create tillage strip (150-300mm width, and 150 - 300mm depth)

Spread the soil to both sides of the strip created

A minimum of four strips at a spacing of between 400-750mm should be created at a time.

ii. Seed metering and placement

Seeds must be fully protected in planting process

Place seed at desired depth of 3-5 mm

Spacing between individual plants should range between 200-300mm (depending on the crop planted)

Spacing between rows should range be 400-750 cm

Seed rates of 3 – 6kg /ha.

Seeds should be covered with soil immediately after placement

Physical requirements

i. strip tillage creation

Required draw bar pull: 12 kN at a speed of 5km/s

The implement must be suitable for use with a 60 HP tractor

It must have three point linkages for mounting and transportation by tractor

Tine could be rigid or spring loaded.

Working width: 3 metres

ii. Planter

Minimum ground speed: 5 km/hr

Hooper capacity: 100 kg

Provision for attachment to the tool bar

6.2.2. Establishment of function structures

The formation of strip tillage in a field is a challenging process. To come up with a soil engaging tine for a particular soil, especially clod forming sandy loam soils in Botswana need a sensible planning. Draught power requirement and conservation of water should be considered. The combination of tool for creating tillage strips and seeding part will need more power and coordination.

The first thing in conceptual design is to find the overall function that needs to be accomplished. The goal here is to generate a single statement of the overall function on the basis of the customer requirements (Ullman, 2003).

From the specification, two main functional systems of the implement are recognised, thus strip creation and, seed metering and placement. Figure 6.2 shows the systems and their overall functions.

a) Systems

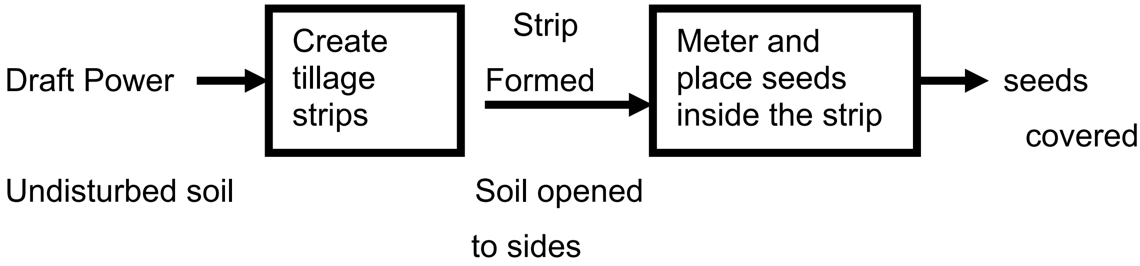


Figure 6.2 Overall functions of the systems involved in strip tillage – planter implement.

After determining the main functions of the product, it is vital to decompose it into sub functions depending on the complexity of it. Pahl and Beitz (1988) stated that the objective of breaking down the main functions is to facilitate search for solutions and come up with a simple and unambiguous function structure. This creates a detailed understanding at the beginning of the process about what the product is expected to do (Dieter, 2000).The design problem is described in terms of a flow of energy, material and information.

b) Create tillage strips subsystems

The following sub functions were generated from this system.

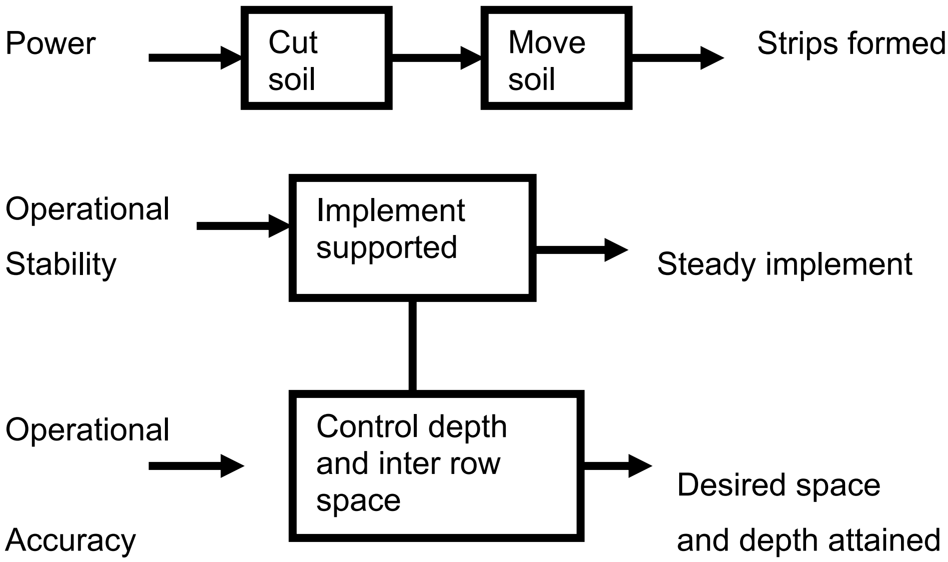


Figure 6.3 Sub functions involved in strip tillage creation.

Operational stability and accuracy are secondary functions because although they do not play any role directly in the function of the implement, they play a big role as support of the whole system.

c) Seed metering and placement

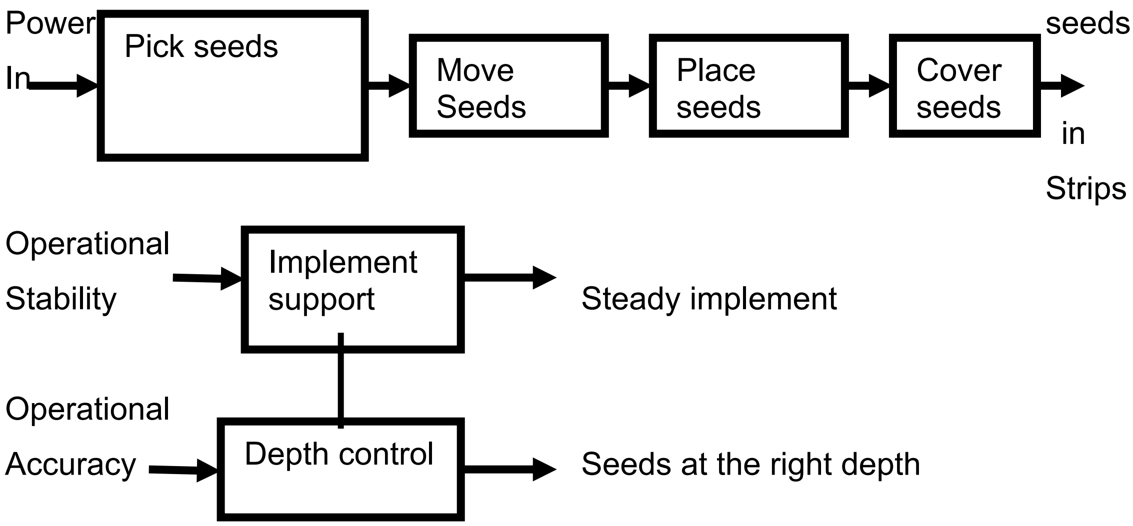


Figure 6.4 Sub functions involved in seed metering and placement.

6.2.3 Concept development

After a function structure is established, the search for solutions starts. This is to address every sub-function established and also this will take into consideration Botswana conditions. This is achieved by generating design concepts which answer how the functions can be achieved. The whole idea is to find as many concepts as possible that can provide each function identified in the decomposition.

A morphological chat (Table 6.1), which was proposed by Zwicky (Dieter, 2000) will be used to organize functions and sub-functions in rational order. Dieter (2000) stated that the purpose of this system is to uncover combinations of ideas that comprise design concepts that might not be generated.

6.2. 4. Combining concepts

After all the concepts are developed, there is a need to combine them to arrive at a set of definitive design concepts. According to Pahl and Beitz (1988), to fulfil the overall function it is necessary to elaborate overall solutions from the combination of principles. The method here is to select one concept from each function and combined those selected into a single design (Ullman, 2003). From the morphological chart, many concept combinations can be generated. The most suitable and appropriate for Botswana conditions are presented in Table 6.2. The table shows four concepts combinations which will later be evaluated for Botswana suitability.

Table 6.1 Morphological chart for the design of strip tillage planter implement.

Sub function	Concepts		
	(1)	**(2)**	**(3)**
1.0 Strip formation			
1.1 Power	Draw bar	PTO	
1.2 Cut soil	rigid tine	spring tine	rotating blades
1.3 Move soil	furrow opener	no need	
1.4 Implement Support	tool bar	steel wheels	Pneumatic tyres
1.5 Transport	Fully mounted	trailed	semi - mounted
1.6 Control depth	depth wheel	skids	
1.7 Control interrow spacing	adjusting axle	positioning the tines	
2.0 Seed metering and placement			
2.1 Planter drive	ground wheel (+ mechanical gears)	PTO (+ m. gears)	ground wheels (+chain drive)
2.2 Pick seeds and metering	Seed plate	orifice	roller feed
2.3 Move seeds from the hopper	gravity	flexible hose tube	air feed
2.4 Furrow opener	curved runner	disc	hoe
2.5 Cover and firming seeds	press wheel	drag bar	drag chain
2.6 Implement support	mounted on the tool bar	trailed behind the tool bar	
2.7 Depth control	depth wheel	skids	no need

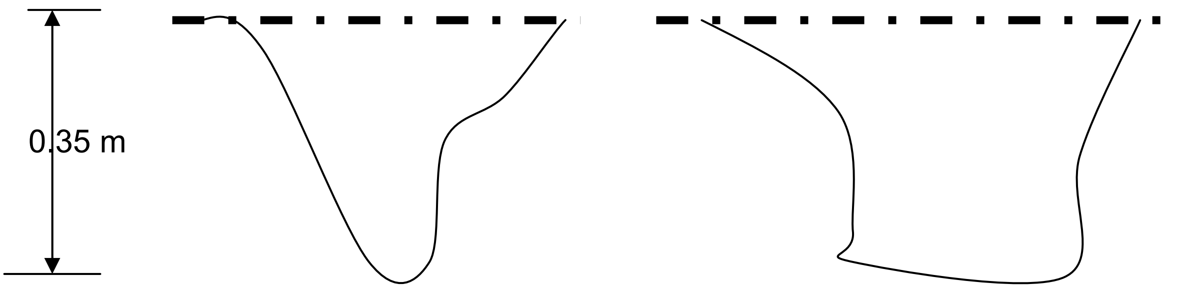
Table 6.2 Concept combination for the design of strip tillage planter implement.

Sub function	Concept Combination			
	A	**B**	**C**	**D**
1.0 Strip formation				
1.1 Power	Draw bar	Draw bar	Draw bar	draw bar
1.2 Cut soil	rigid tine	spring tine	rigid tine	spring tine
1.3 Move soil	furrow opener	no need	no need	furrow opener
1.4 Implement Support	steel wheels	pneumatic	tool bar	steel wheels
1.5 Transport	semi mounted	fully mounted	fully mounted	semi mounted
1.6 depth adj.	depth wheel	depth wheel	depth wheel	depth wheel
1.7 Control interrow spacing	adjust axle	shifting tines	shifting tines	adjust axle
2.0 Seed metering and placement				
2.1 Planter drive	ground wheels (+ mech. gears)	ground wheels (+mech. drive)	ground wheels (+chain. drive)	ground wheel (+chain drive)
2.2 Pick seeds and metering	Seed plate	roller feed	seed plate	roller feed
2.3 Move seeds from the hopper	flexible h.tube	flexible h.tube	flexible h. tube	flexible h.tube
2.4 Furrow opener	curved runner	curved runner	curved runner	curved runner
2.5 Cover and firming seeds	drag chain	press wheel	press wheel	drag chain
2.6 Depth control	depth wheel	depth wheel	misalign	depth wheel

6.2.5 Development of some conceptual variants

i. Selection of suitable tine for cutting soil

The whole idea here is to create suitable strip tillage economically. It is well documented that depth/width ratio and rake angle are major variable in the selection of appropriate tine. The tine thought of here is a winged tine working at a rake angle of about 45°. Attachment of wings on the tine reduce depth/width ration and therefore result more efficient use of draft force. Spoor and Godwin (1978) showed that attaching wings at the foot of the tine doubled the disturbed area for an increase in draught force of 30% as shown by Figure 6.4.



	Conventional subsoiler	Winged subsoiler
Draught	20.43 kN	26.58 kN
Disturbed area	0.098 m^2	0.184 m^2
Specific resistance	208 kN/m^2	144 kN/m^2

Figure 6.5. Effects of adding wings to subsoilers (Spoor and Godwin 1978).

This increases the effectiveness of the operation by reducing specific resistance. This is very important for creating larger reservoir for water harvesting and retention. John Deere & Co. (1993) stated that with these types of tines the soil is grooved to catch and hold water and help control wind erosion. The choice between spring and rigid tine is not very important as the benefits are not conclusive. John Deere & Co. (1993) stated that results have varied widely and frequently contradictory, but in general total energy input has not been significantly reduced.

ii. Planter drives

To obtain the crop spacing of seeds in the row at varying travel speeds and under varying soil and topographic conditions, the planting unit drive mechanism must be keyed to the forward travel of the planter (John Deere & Co., 1993). This is obtained by using a ground driven wheel to turn the seeding mechanism. The ground wheel can be carrying wheel, gauge wheel or press wheel.

a. carrying wheel drive

b. gauge wheel drive

c. press wheel drive

Figure 6.6 Types of ground wheel drives (Deere & Co., 1992)

To maintain the cost of the whole implement as low as possible, a ground wheel coupled with either mechanical gears or chains will be appropriate for this type of implement. Both of these types of drive give constant speed ratios, gears being adopted to close centre, intersecting, or crossing shafts, and chain drives being used for parallel shafts with moderate centre distances (Kepner et. al, 1978).

iii. Seed feed mechanism

The primary objective of any planting operation is to establish an optimum plant population and plant spacing and thus obtain maximum net return per hectare. Kepner (1978) and John Deere & Co (1992) mentioned that the functions of a seed planter is to open the furrow to the proper depth in the soil, meter the seed, place or deposit seed in the furrow in an acceptable pattern, cover the seed and compact the soil around the seed to the proper degree for the type of crop involved.

There are numerous types of furrow openers (fig 6.5) but for the imagined implement a curved runner will be use to open furrows for placing seeds. The reason is that it is a simple device that works well at medium depths. It is suitable for the average conditions encountered by cereals grown in Botswana. The other advantage with the runner is that apart from opening furrow it moderately pack the soil at the bottom of the seed and thereby help in moisture conservation.

Seed pick and metering is an important function of every planter. It has two aspects; the first; metering rate which refers to the number of seeds that are released from the hopper per unit of time and second; the placement of seeds at uniform spacing in each row.

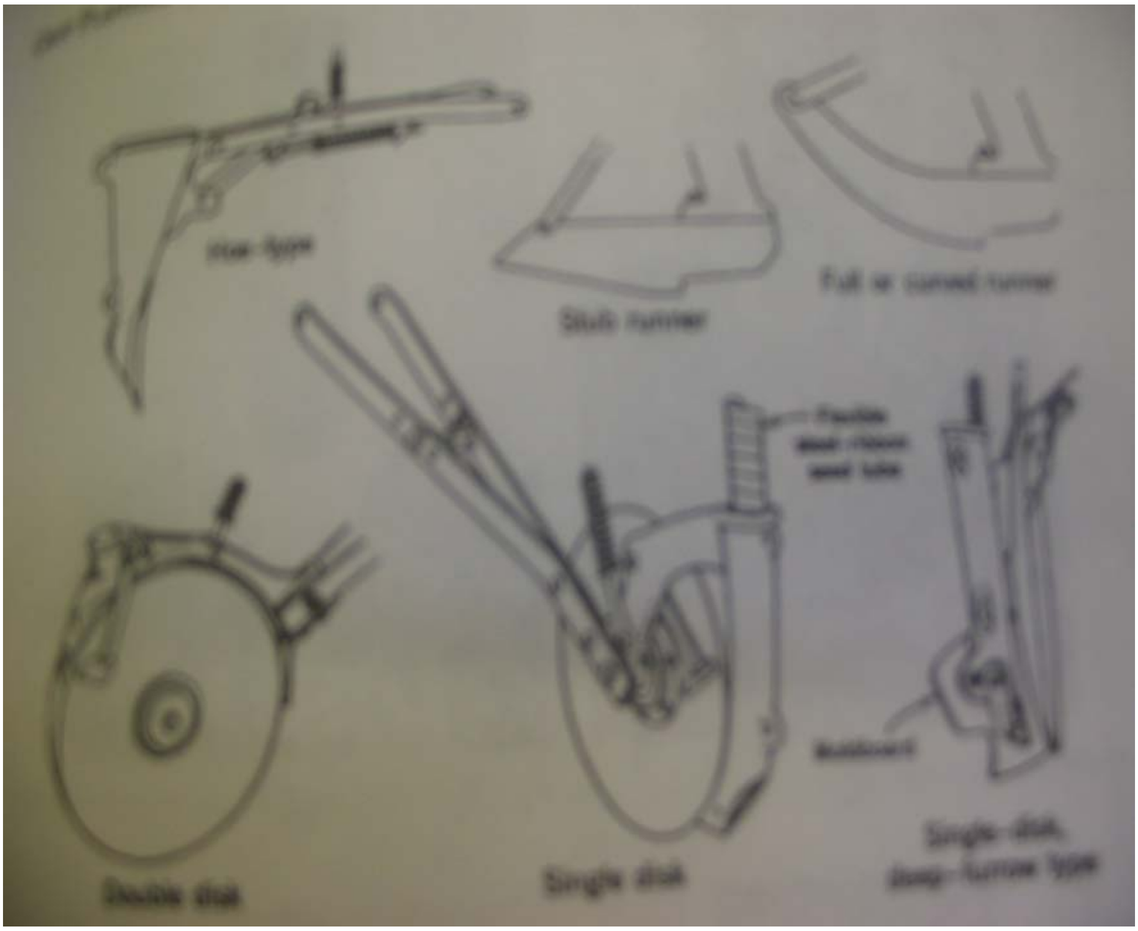
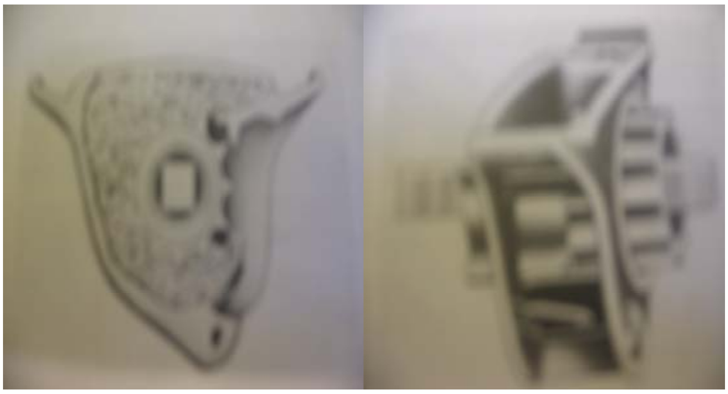


Figure 6.7. Some of the common types of furrow openers (Srivastava et al. , 1993).

There are many types of seed metering systems but for the envisaged implement, the inclined seed plate and roller feed are more appropriate.

The inclined plate metering devices (fig. 6.8b) have cups or cells around the edge that pass through a seed reservoir and lift seeds to the top of the plate, and drop them into the delivery tube.

This type of mechanism has an advantage over horizontal plate in the sense that larger seeds are not crushed and therefore results in uniform seeding. Inclined discs often operate without special devices for removing doubles and triplets (Stout and Cheze, 1999). They mentioned that this is due to the falling back of seeds into the hopper as the system plate rotate.



a. fluted wheel

b. inclined plate

Figure 6.8. Fluted wheel and inclined plate seed metering systems (Kepner, 1978).

The fluted wheel (fig. 6.8 a) is the most popular roller type metering mechanism. The fluted wheels are positioned at the bottom of the hopper, so that seed can flow into the openings by gravity. Srivastava et al., (1993) mentioned that it provides quasi-positive –displacement metering, thus seeds in the flute openings are carried toward an adjustable gate as the fluted wheel rotates. The fluted wheel can be moved endwise to control the volumetric flow rate of seeds. Speed of the wheel and gate size control the seed rate. For this implement, the inclined plate would be selected.

Covering and firming of the seed are performed simultaneously in most planters. Some implements used to cover and firm the seeds are spike tooth harrow, chains, cult packer, drag bars, shovels, press wheel. In modern planters the press wheel is most popular (fig. 6.9)

Figure 6.9 Types pf press wheel (John Deere &Co., 1992).

For the implement thought of press wheel would be suitable. The press wheel would also help in the reduction of evaporation by reducing the porosity of disturbed soil along the strips.

6.2.6 Concept evaluation

After development and arriving at a set of definitive design concepts, there is a need to evaluate them to see which one is close to satisfying the set specifications. Dieter (2000) stated that evaluation involves comparison, followed by decision making. An evaluation is meant to determine ‘value’, ‘usefulness’ or ‘strength’ of a solution with respect to given objective (Pahl and Beitz, 1988). This is very important because it helps to choose at early stage of design which concept to develop into finished designs. The resources will then be channelled to that selected concepts instead of all generated concepts.

In this design, the criteria used was weighted criteria matrix which involves ranking the design criteria with weighing factors and scoring the degree to which each design concept meets the criterion. The assessment is presented in Table 6.3. An 11 point scale (0-10) was used to rate the concepts. The weighing factors are described as follows:-

i. Safety: Safety is paramount for every machine. The whole implement must be easy to use and perform with minimum operational problems which can injure the user. It must be easy to replace safety parts incorporated in the implement.

ii. Accuracy: It is important that the implement must be adjusted accurately for major crops grown in Botswana. The planter must follow the strip created by the tines precisely and cope with various ground conditions.

iii. Control: The implement must be easily manipulated during operation. It must be compact for easy turns at headlands.

iv. Power requirement: The draught power required to operate the implement must be kept to a minimum in order to match the popular tractor models in Botswana. This is very important for the adoption of the implement by the farmers.

v. Ease of manufacture: The construction of the implement must be as simple as possible. Mass production parts must be used where possible. Knowledge of the local mechanics must be taken into consideration, as this will help in maintenance of the implement. The implement must be compact enough so that it could be easily being transported on three point linkage of the tractor.

vi Durability: This implement is targeting farmers who are not reach, and therefore the longer it lasts the better. The material used must not break easily and be hard enough to resist corrosion. The soil tine foot, furrow openers and other soil engaging parts must be easily changeable.

Table 6.3 Weighed decision matrix for a strip-tillage planter implement.

Concepts		A		B		C		D	
Design Criterion	**weight factor**	**rating**	**score**	**rating**	**score**	**rating**	**score**	**rating**	**score**
Safety	0.20	5	1.0	6	1.2	7	1.4	6	1.2
Accuracy	0.15	6	0.9	8	1.2	8	1.2	6	0.9
Control	0.15	4	0.6	5	0.75	6	0.9	4	0.6
Power Requirement	0.15	5	0.75	6	0.9	7	1.05	5	0.75
Ease of Manufacture	0.15	8	1.2	8	1.2	8	1.2	8	1.2
Durability	0.20	6	1.2	5	1.0	5	1.0	6	1.2
Total score			**5.65**		**6.25**		**6.75**		**5.85**
Rank			4		2		1		3
Continue?			NO		NO		**YES**		NO

6.3 Selected concept combination

Although the difference between the concepts is not large, the evaluation process ranked concept combination, C (Table 6.2), the highest as it gave highest total score. This concept combination gives a flexible, simple and economical system for Botswana conditions. The implement is comprised of two main functions; strip tillage creation and planter attachment. The creation of the strips could be carried out without planting.

6.3.1 Strip tillage creation

The tine is the main part for creating the strip tillage and therefore it must be simple to make. It has two components; tine leg and tine foot. The tine foot is attached to the tine leg by bolts and nuts as shown by figure 6.8. This allows easy choice of different tine foot which can be attached depending on the type of the soil in a field. This would allow strips of different depths and widths to be created.

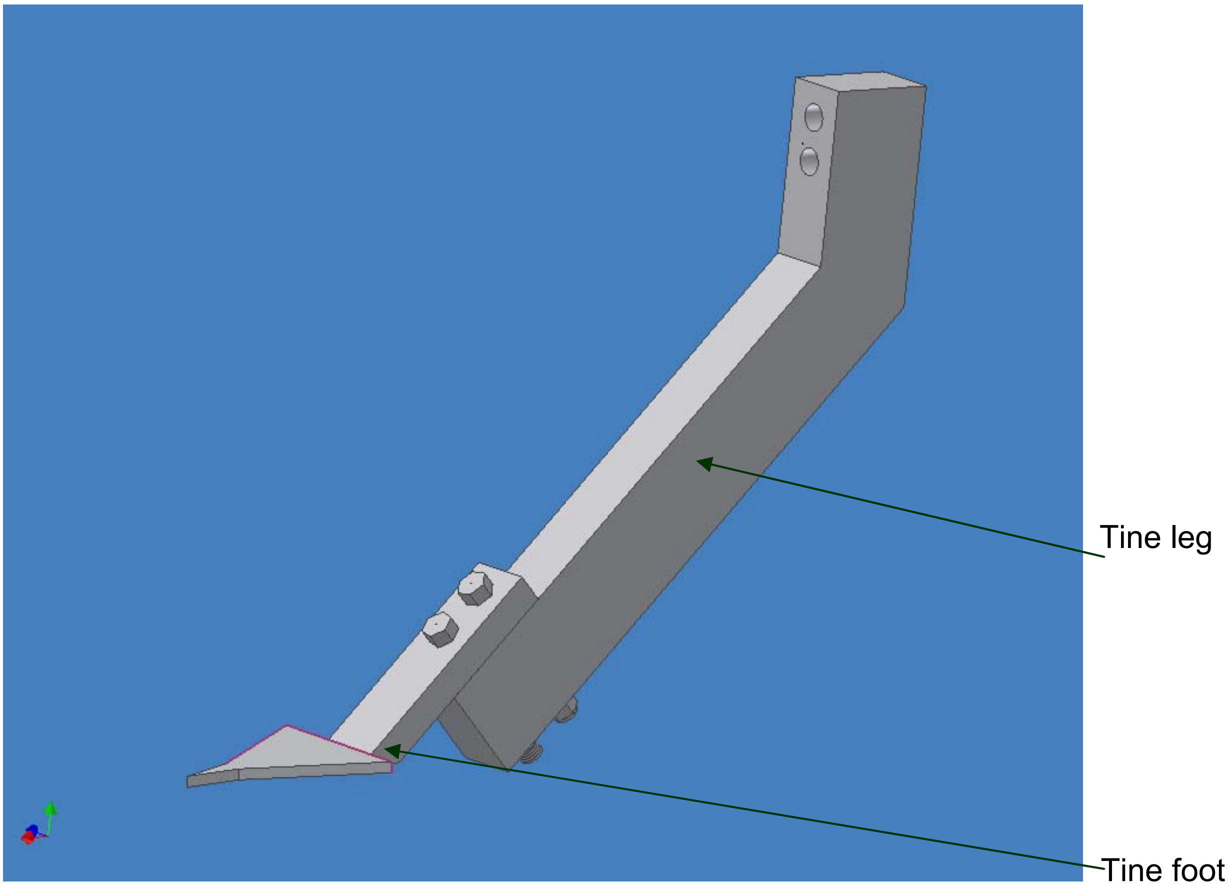


Figure 6.10 Tine for creating strip tillage

For the tine to work it must be attached to a tool bar to make a complete implement. Four tines would be attached to the tool bar at a spacing of up to 0.75 m (figure 6.9). The attachment allows flexible adjustment of tine space to suit specific crops.

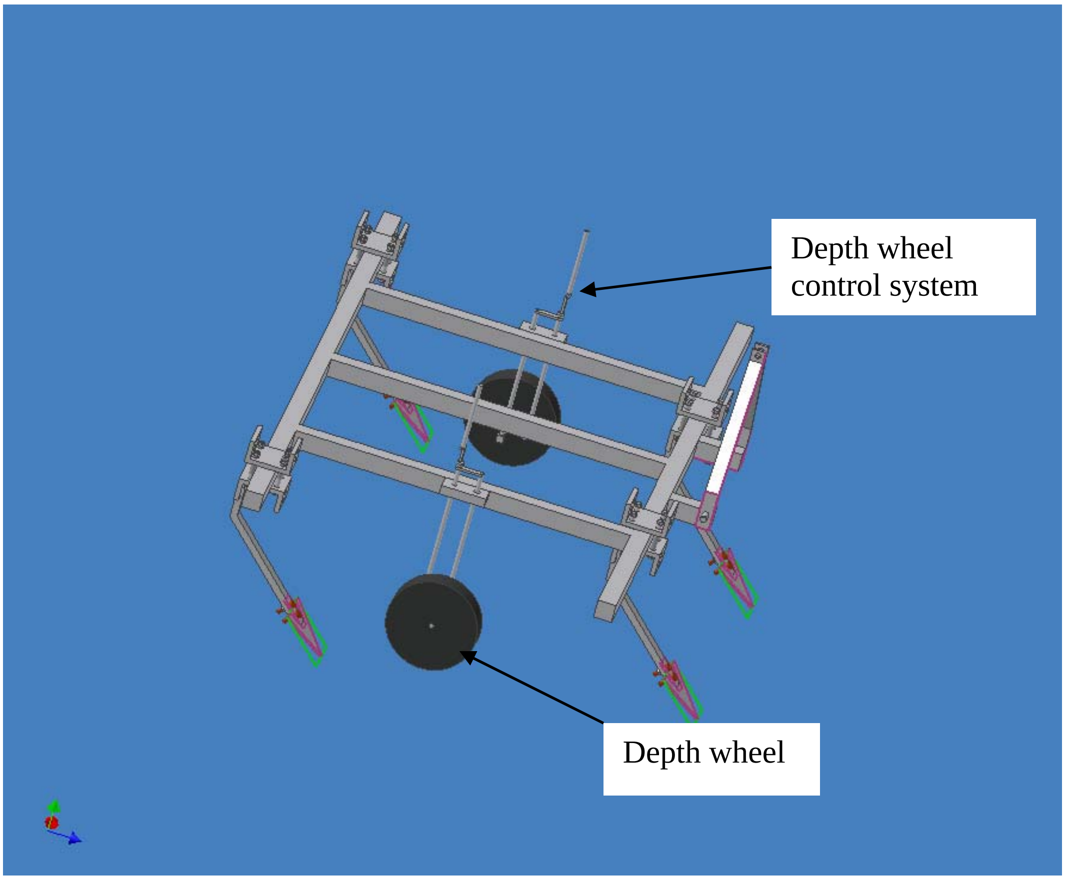


Figure 6.11 Tool bar assembly

Specifications of the tool bar frame.

i. material: 80 x80x 5 mm steel

ii. Two main members of 3500mm length

iii. Three cross members of 1 – 1.5 mm length

iv pneumatic wheels of Ø 330 and width 200

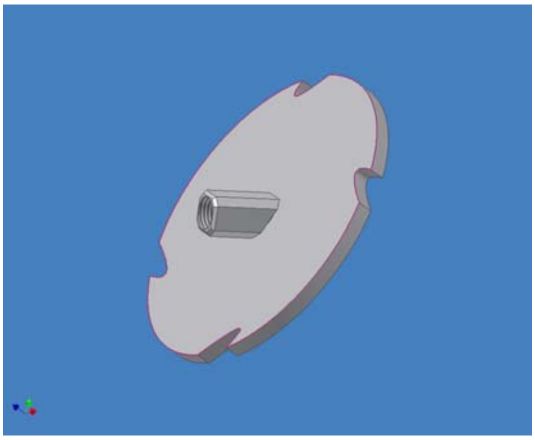
v. Height adjustment unit of about 600 mm height

The spacing between the individual tines is controlled by closing in or opening out the tines as they are held on the main frame by bolted brackets. This allows more tines to be added if a narrow row crop is planted.

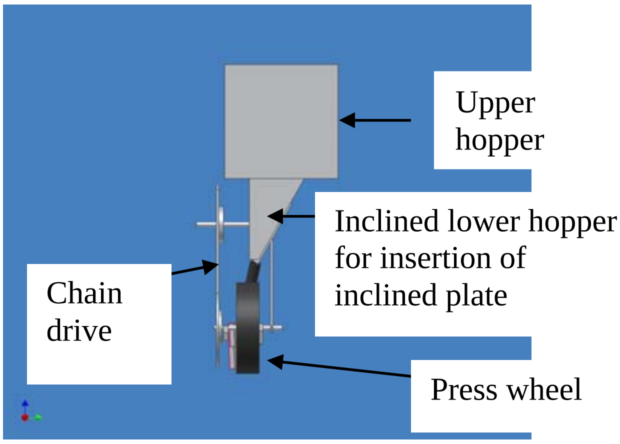
The depth wheel control is done by threaded systems which can easily reduce or increase the height of the height of the toolbar.

6.3.2 Planter attachment.

The planter part of the implement is as important as the tillage part. The attachment of it to the main toolbar helps to avoid second pass in the field. This helps in reducing energy consumption and compaction of the soil. The planting mechanism is a vertically inclined plate driven by chain drive. The press wheel is used for covering and firming the soil above the seeds and also for driving the seed metering mechanism.



a. inclined plate



b. planter assembly

Figure 6.12 Planting components of the implement

Specification of the seed plate:

i. Angle of inclination: 0-15°

ii. Diameter: 200-300 mm

iii.material: hardened steel

It must be noted that the number and size of cells around the seed plate depends on the crop planted. For small seeds like sorghum the cells size could be reduced to avoid overcrowding of the seeds and vice versa for bigger seeds like maize. Likewise the intra-row space is controlled by increasing or reducing the number of cells on the seed plate. The idea is to keep the driving system the same and change the seed plates depending on the type of crop planted.

The interow spacing is aligned with the tine spacing. The planting depth is controlled by misaligning the planter from the strip created by the tine. The centre of the strip is the deepest, so by shifting the planter few centimetres either side would reduce depth of planting.

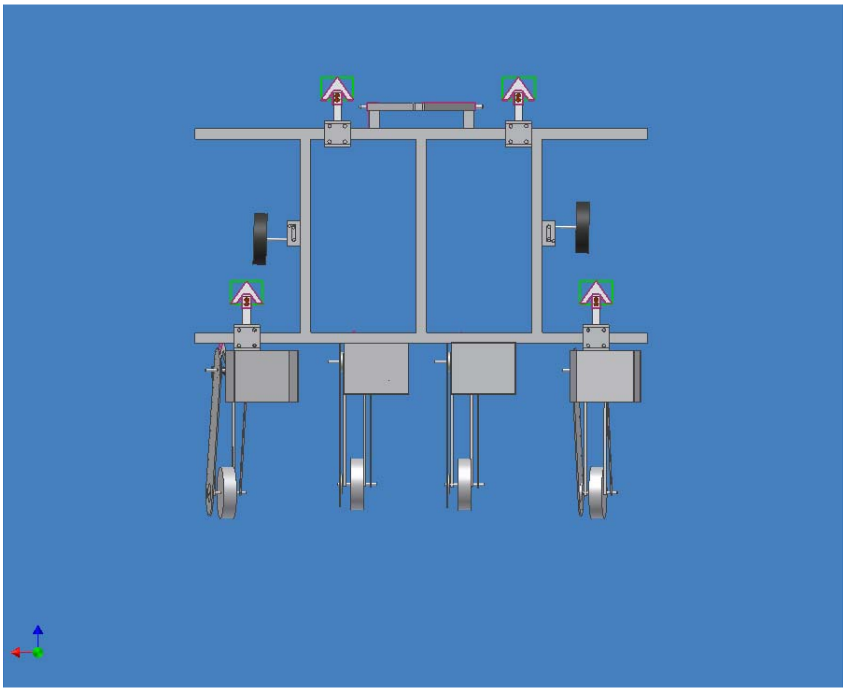


Figure 6.13 Plan view of the Strip tillage-planter implement.

6.4 Discussion

Introduction of a new technology always come with some suspicion and reserved judgement from farming communities especially in developing countries. They rate their experience and knowledge acquired through many years of farming higher than new innovation. This makes them reluctant to change or adopt new technologies and in particular to take risks that might jeopardise production of their vital crops. Consequently the introduction of this implement will be likely to encounter some negative perceptions from the farmers. There is therefore a need for support mechanisms to encourage farmers to adopt this tillage system. The farmers must be made aware of the benefits of strip tillage over the conventional tillage. Some of the benefits of the proposed strip tillage- planter were spelt out in this chapter and therefore must be relayed and made clear to the farmers.

Most farmers in Botswana who have tractors plough their fields twice in a season before planting. Instead of a second ploughing they could be encouraged to use the strip tillage-planter implement. This is likely to enhance infiltration in the same way as ploughing but reduction of evaporation would be higher as only the very top surface of the soil would be disturbed. Alternatively they could plough their fields once in every four or five years and use the strip tillage- planter implement in between years. This would reduce costs of crop production and increase work rate and therefore be able to cultivate more hectares within the available ‘three months window’. The soil structure would also be improved as less crop residue would be destroyed. In the opinion of the author, the high work rate of the implement would also encourage farmers to share it. They could have a syndicate and thereby spread costs amongst themselves.

Most introducers of new technologies to farmers in Botswana made a lot of mistakes by discouraging the local knowledge. It is paramount to complement what the farmers are doing and gradually introduce new ideas through on-farm trials. This would encourage farmers to be part of the innovation and therefore be proud to adopt it.

Government intervention is vital for the adoption of this implement. Currently rain fed farming in Botswana is under-going some reviewing and reform. The Ministry of Agriculture engaged services of TAHAL Consulting Engineers Ltd. of Israel in preparation of a master plan for Agricultural development in Botswana. The whole idea of the plan is to encourage farmers to farm commercially. The plan would be based on Botswana natural resources, rural infrastructure, socio-economic, institutional and environmental issues as well as policy. It would be advantageous that during the implementation of the plan, the strip tillage - planter is incorporated within the system and assessed at the same level as popular conventional ploughing.

6.5 Conclusions

This chapter shows clearly that the strip tillage planter implement has a lot of positives as far as crop production in Botswana is concerned. The attachment of the planting unit to the tool bar reduces both time and energy required to complete the crop production operations. The ease of manufacture and control of the implement makes it suitable for the low income farmers who could not afford the sophisticated and more expensive implements. Government intervention would encourage diffusion and adoption of the technology.

CHAPTER 7

7.0 Conclusions and Recommendations

7.1 Conclusions

1. Strip tillage system has more potential to harvest and conserve moisture than both reservoir tillage and no tillage systems. In laboratory tests with a sandy loam soil under low rainfall intensity (55mm/hr) and low slope (5°) the strip tillage system harvested more water (69.12%) than depressions (60.65%) and no tillage system (26.79%). When the systems were evaluated under higher slope, strip and depression harvested water similarly whereas no tillage was lower than them. The harvested percentages of rainfall were 49.21%, 56.64% and 18.54% for strip, depression and no tillage respectively.

2. Under test conditions simulating high rainfall intensity 95mm/hr (which is a characteristic of Botswana) more water infiltrated into strip tillage. It managed to harvest 58.45% of rainfall compared to 47.69% and 22.42% of depression and undisturbed surfaces respectively. The effects of slope were insignificant under high intensity rainfall and therefore it did not influence the capability of the systems to conserve and harvest water from rainfall.

3. Both depression and strip tillage system reduced soil erosion similarly as eroded soil in them was lower than the no tillage system. They reduced soil erosion by 47% and 46% respectively when compared to no tillage.

4. Although the percentage total volume of water lost from the no tillage, depression and strip was 79%, 50 % and 59% respectively, there was no significant difference between the treatments as far as evaporation is concerned.

5. Energy requirement for strip tillage system at a predicted 31.5 MJ/ha was lower than for reservoir depression system (266.4 MJ). It was almost 1/8 of

what was required for depression tillage system. The spot work rate was high in strip tillage (3 ha/hr) than depression tillage (0.705ha/hr). This was enhanced by the combination of the cultivating with the planting unit.

6. The experimental results led to the development of a conceptual design of strip tillage- planter implement which is appropriate for Botswana. The projected seasonal work rate of the device would be 1.11ha/hr compared with 0.925 ha/hr for a conventional system and 0.114 ha/hr for the equivalent depression forming system

7. Based on the laboratory test results and the conceptual design exercise, strip tillage system has the potential for water harvesting under high intensity rainfall and therefore can be used for crop production in Botswana

8. It is suggested that farmers in Botswana might adopt the proposed new tillage strategy provided it is evaluated in their fields, thus on farm trials and assisted financially to acquire the implement. This could be enhanced by considered in National Master Plan for Agricultural Development.

7.2 Recommendations

The following recommendations are suggested for future work.

a. The experiments should be carried out under field conditions in Botswana and incorporate other factors which influence soil water conservation like residue cover.

b. A prototype of the implement should be developed and tried in Botswana. Its influence on seed germination, establishment, yield and weed control must be investigated.

CHAPTER 8

8.0 References

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9 CHAPTER NINE: Appendices

9.1 Appendix 1 (Data presented here relate to Chapter one).

Table A 1.1 General statistics for Botswana

Parameter	level
Land area (km^2)	582, 000
Population (millions)	1.5
Population in rural areas	50%
National language	Setswana
Official language	English
Gross National Product (Per capita GNP in $)	3 3000 (1997)
Contribution of agriculture to GNP (% of GNP)	3.1
Total cultivated area (ha)	279 000
Annual rainfall (mm)	250 - 650
Employment generated by agriculture	20%
Major cereals grown	sorghum, maize, millet
Mean annual cereal production (metric. tons)	8 200 – 175 000

9.2 Appendix 2 (Data presented here relate to Chapter 3)

Table A 2.1 Analysis of variance for runoff, infiltration and soil erosion for 55mm/hr rainfall

Effect (ml)	df	runoff (ml) SS	runoff (ml) MS	runoff (ml) F	runoff (ml) p	infilt. (ml) SS	infil. (ml) MS	infil. (ml) F	infil. (ml) p
Slope	1	6506427	6506427	24.55	0.00334	10524874	10524878	36.977	0.00055
Soil disturbance	2	66528318	33264159	125.512	0.00000	74555028	37277514	130.966	0.00
Slope*soil disturb.	2	2411941	1205971	4.550	0.03383	6598382	3299191	11.591	0.001575
Error	12	3180320	265027			3415628	284636		
Total	17	78627006				95093916			

Effect		eroded Soil (ml) SS	eroded soil (ml) MS	eroded soil (ml) F	eroded soil (ml) p
Slope	1	281.003	281.003	18.0266	0.001136
Soil disturbance	2	491.799	245.899	15.7747	0.00438
Slope*soil disturb.	2	52.634	26.317	1.6882	0.225914
Error	12	187.059	15.588		
Total	17	1012.494			

Table A 2.2 Means of percentage rainfall harvested by the different soil disturbance x slope combinations across different rainfall Intensities

treatment	% rainfall harvested 55 mm/hr (41.25mm)	95mm/hr (47.50mm)	Mean
5 x strip	69.12	57.89	63.51
10 x strip	49.21	57.35	53.28
mean	**59.165**	**57.62**	**58.40**
5 x depression	60.65	38.82	49.74
10 x depression	56.64	34.64	45.64
mean	**58.65**	**36.73**	**47.69**
5 x undisturbed	26.79	23.28	25.04
10 x undisturbed	18.54	21.06	19.80
mean	**22.67**	**22.17**	**22.42**
Mean	46.83	38.84	

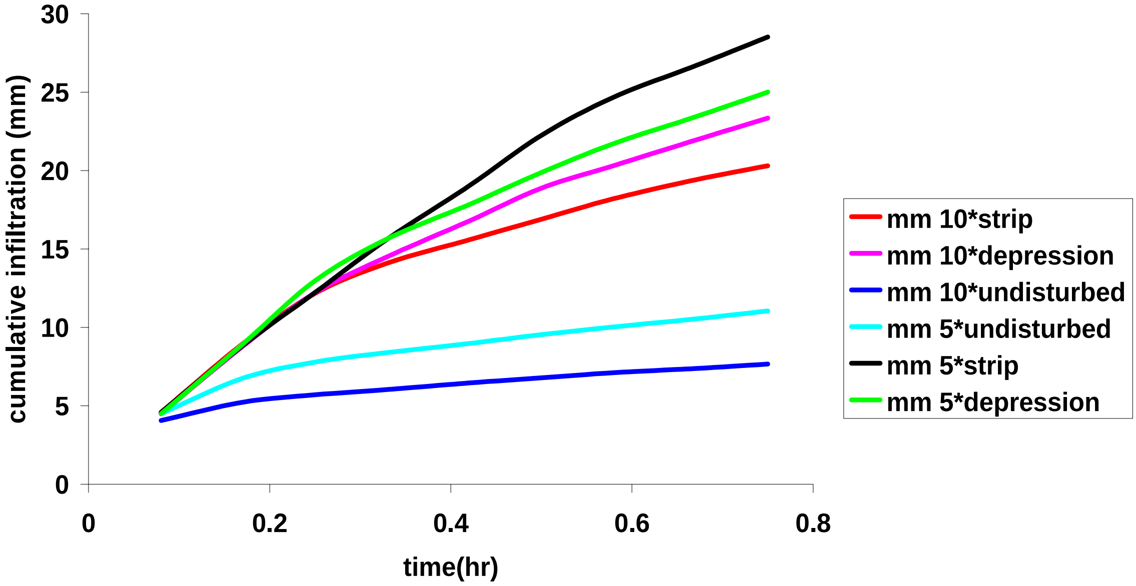

Figure A 2.1: Cumulative infiltration of slope*soil disturbance combination of rainfall at 55mm/hr

Table 2.3 LSD test; variable infiltration (ml) and runoff (ml) at 55 mm/ hr rainfall intensity for slope x disturbance

Cell no.	slope	soil disturbance	LSD test; variable infiltration(ml) (55rainfall.sta) Probabilities for Post Hoc Tests Error: Between MS = 2846E2, df = 12.000					
			{1} 8786.5	{2} 6762.9	{3} 2987.5	{4} 5486.5	{5} 6314.9	{6} 2067.5
1	5	strip		0.000777	0.000000	0.000008	0.000138	0.000000
2	5	depression	0.000777		0.000002	0.012604	0.324027	0.000000
3	5	undisturbed	0.000000	0.000002		0.000094	0.000006	0.056333
4	10	strip	0.000008	0.012604	0.000094		0.081506	0.000005
5	10	depression	0.000138	0.324027	0.000006	0.081506		0.000000
6	10	undisturbed	0.000000	0.000000	0.056333	0.000005	0.000000	

Note: Red figures shows significant difference

Table A 2.4 Cumulative infiltration and runoff of soil disturbance for rainfall at 55 mm/hr rainfall (mm)

	Runoff			infiltration		
Time (hr)	depression (mm)	strip (mm)	undisturb. (mm)	depression (mm)	strip (mm)	undisturb. (mm)
0.08	0.09	0	0.3	4.49	4.58	4.28
0.17	0.295	0.2725	3.175	8.85	8.895	5.99
0.25	1.395	1.5575	6.655	12.59	12.19	6.745
0.33	3.485	3.4575	10.765	15.08	14.87	7.215
0.42	5.89	5.6075	14.845	17.31	17.3	7.715
0.5	8.42	7.9225	18.99	19.38	19.57	8.16
0.58	11.36	10.6325	23.165	21.03	21.45	8.57
0.67	14.29	13.6225	27.36	22.69	23.04	8.96
0.75	17.375	16.8325	31.545	24.18	24.41	9.355

Table A 2.5 LSD test; eroded soil (g) at 55 mm/ hr rainfall intensity for soil disturbance

cell no.	LSD test; variable eroded soil(g) (55rainfall.sta) Probabilities for Post Hoc Tests Error: Between MS = 34.713, df = 15.000			
	soil disturbance	{1} 10.290	{2} 6.6117	{3} 19.072
1	strip		0.296621	0.020848
2	depression	0.296621		0.002308
3	undisturbed	0.020848	0.002308	

Table A 2.6 Analysis of variance for runoff, infiltration and soil erosion for 95mm/hr rainfall

Effect (ml)		runoff (ml) SS	runoff (ml) MS	runoff (ml) F	runoff (ml) p	infilt. (ml) SS	infil. (ml) MS	infil. (ml) F	infil. (ml) p
Slope	1	4.110222E+05	4.110222E+05	0.874	0.368233	396050	396050	0.8753	0.367945
Soil disturbance	2	6.268366E+07	3.134183E+07	66.660	0.00000	62814519	31407260	69.4104	0.00000
Slope*soil disturb.	2	1.752861E+05	8.764306E+04	0.186	0.832296	164808	82404	0.1821	0.835767
Error	12	5.642133E+06	4.701778E+05			5429833	452486		
Total	17	6.891210E+07				68805211			

Effect		eroded Soil (ml) SS	eroded soil (ml) MS	eroded soil (ml) F	eroded soil (ml) p
Slope	1	4140.20	4140.20	9.6206	0.009161
Soil disturbance	2	26850.84	13425.42	31.1966	0.000018
Slope*soil disturb.	2	4489.88	2244.94	5.2166	0.023429
Error	12	5164.18	430.35		
Total	17	1012.494			

Table A 2.7 LSD test; variable infiltration and runoff (ml) at 95 mm/ hr rainfall intensity for soil disturbance

Cell no.	soil disturbance	LSD test; variable infiltration(ml) (95rainfall.sta) Probabilities for Post Hoc Tests Error: Between MS = 3994E2, df = 15.000			LSD test; variable runoff(ml) (95rainfall.sta) Probabilities for Post Hoc Tests Error: Between MS = 4152E2, df = 15.000		
		{1} 7398.4	{2} 4715.9	{3} 2846.8	{1} 5518.3	{2} 8219.2	{3} 10063
1	strip		0.000002	0.000000		0.000003	0.000000
2	depression	0.000002		0.000125	0.000003		0.000173
3	undisturbed	0.000000	0.000125		0.000000	0.000173	

Table A 2.8 Means of infiltrated water for 95 mm/hr rainfall

slope*soil disturbance; LS Means (95rainfall.sta) Current effect: F(2, 12)=.18211, p=.83577 Effective hypothesis decomposition

	slope	soil disturbance	Infiltration (ml)	Infiltration (ml) Std. Err.	Infiltration (ml) -95.00%	Infiltration (ml) +95.00%	N
1	5	strip	7432.583	388.3667	6586.405	8278.762	3
2	5	depression	4984.250	388.3667	4138.072	5830.428	3
3	5	undisturbed	2989.250	388.3667	2143.072	3835.428	3
4	10	strip	7364.250	388.3667	6518.072	8210.428	3
5	10	depression	4447.583	388.3667	3601.405	5293.762	3
6	10	undisturbed	2704.250	388.3667	1858.072	3550.428	3

Table A 2.9 LSD test; variable eroded soil (g) at 95 mm/ hr rainfall intensity for slope*soil disturbance

Cell no.	slope	Soil disturbance	LSD test; variable eroded soil(g) (95rainfall.sta) Probabilities for Post Hoc Tests Error: Between MS = 430.35, df = 12.000					
			{1} 25.383	{2} 24.790	{3} 73.530	{4} 32.143	{5} 34.047	{6} 148.51
1	5	strip		0.972632	0.014828	0.696830	0.618302	0.000010
2	5	depression	0.972632		0.013894	0.671897	0.594738	0.000009
3	5	undisturbed	0.014828	0.013894		0.030964	0.037999	0.000826
4	10	strip	0.696830	0.671897	0.030964		0.912388	0.000017
5	10	depression	0.618302	0.594738	0.037999	0.912388		0.000020
6	10	undisturbed	0.000010	0.000009	0.000826	0.000017	0.000020	

Table A 2.10 Means of eroded soil for 95mm/hr rainfall

slope*soil disturbance; LS Means (95rainfall.sta) Current effect: F(2, 12)=5.2166, p=.02343 Effective hypothesis decomposition

	slope	soil disturbance	eroded soil (g)	eroded soil (g) Std. Err	eroded soil (g) -95.00%	eroded soil (g) +95.00%	N
1	5	strip	25.3833	11.97704	-0.7124	51.4791	3
2	5	depression	24.7900	11.97704	-1.3057	50.8857	3
3	5	undisturbed	73.5300	11.97704	47.4343	99.6257	3
4	10	strip	32.1433	11.97704	6.0476	58.2391	3
5	10	depression	34.0467	11.97704	7.9509	60.1424	3
6	10	undisturbed	148.5100	11.97704	122.4143	174.6057	3

9.3 Appendix 3 (Data presented here relate to Chapter 4)

Table A 3.1 Analysis of variance table (Evaporated water)

effect	Degree of freedom	Evaporated water ss	evaporated water ms	evaporated water F	evaporated water P
Soil disturbance	3	912.323	304.108	450.285	0.000
error	8	5.403	0.675		
Total	11	917.725			

Table A 3.2 Means of evaporated water

soil disturbance Means (evaporated water) Current effect: F(3, 8)=450.28, p=.00000 Effective hypothesis decomposition

	soil disturbance	evaporated water mean	evaporated water Std. Err.	evaporated water -95.00	evaporated water +95.00	N
1	strip	5.88992	0.474471	4.79579	6.98405	3
2	depression	5.19571	0.474471	4.10158	6.28984	3
3	undisturbed	6.08913	0.474471	4.99500	7.18326	3
4	free water	25.84680	0.474471	24.75267	26.94093	3

Table A 3.3 LSD test for evaporated water

Cell no.	soil disturbance	{1} 5.8899	{2} 5.1957	{3} 6.0891	{4} 25.847
1	strip		0.331121	0.774121	0.000000
2	depression	0.331121		0.219725	0.000000
3	undisturbed	0.774121	0.219725		0.000000
4	free water	0.000000	0.000000	0.000000	

Table A 3.4 Analysis of variance table (retained water)

effect	Degree of freedom	Retained water ss	Retained water ms	Retained water F	Retained water P
Soil disturbance	2	18.8441	9.4221	8.5234	0.017645
error	6	6.6326	1.1054		
Total	8	25.4767			

Table A 3.5 LSD test; variable retained water (retained water.sta)

Probabilities for Post Hoc Tests Error: Between MS = 1.1054, df = 6.0000				
cell	Soil disturbance	(1) 4.1640	(2) 4.9702	(3) 1.5780
1	Strip		0.383946	0.023628
2	depression	0.383946		0.007525
3	undisturbed	0.023628	0.007525	