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Academic Year: 2004 - 2005

THE DESIGN OF AN IMPROVED EFFICIENCY LAVENDER HARVESTER

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January, 2005

THIS THESIS IS SUBMITTED IN FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF DEGREE OF DOCTOR OF PHILOSOPHY (PhD)

Abstract

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Title: The design of an improved efficiency lavender harvester

The introduction of new methods to solve a specific task was always the ignition for the human mind to find new solutions. Considering the new demands in mechanical lavender harvest for oil production a novel harvester has been developed employing the stripping technique (Klinner et al., 1986a,b,c,d; Hobson et al., 1988) developed for the harvesting of cereals. The harvester works in a unique way for this crop by removing the flower heads in the field, leaving the majority of the stems intact.

Conventional harvesting methods such as hand harvest and mechanical harvest using a cutting mechanism collects both the flower head and a cut length of the stem. This was found to be an inefficient method for the harvest of lavender because most of the oil produced by the plant (97.5 % by weight - Venskutonis, 1997) is located on the flower. Also using these methods the amount of stem collected increases the transportation and the distillation costs, generates more demanding designs, and removes the stem from the field that could otherwise be left as a natural nutrient.

Taking this into account and that the British Pharmacopoeia directs that in making the most refined lavender oil (for medicinal use) it should be distilled from the flowers after they have been separated (stripped) from their stalks (Grieve, 2001) the proposed harvesting technique is ideal for the production of high quality lavender oil.

A prototype lavender harvester was designed, manufactured and optimised. The results show that the proposed design at its best setting increased lavender harvest efficiency from 0.0018 ha/h to 0.2 ha/h compared to the hand harvest method. To determine the efficiency of the machine a methodology was developed during the three year experimental programme in which the percentage of the harvested flower and stem was measured.

An economic analysis of the new proposed method shows that the total cost per litre of oil produced was reduced from £55.00 and £29.40 for the hand harvest and conventional mechanised harvest methods respectively to £14.10. These prices include the cost of transport assuming that the harvested field was 110 miles (175 km) away from the distillery. It was shown also that the most cost effective operation was not achieved at maximum yield but at a set up in which the machine was capable of harvesting the maximum flower head with the minimum stem percentage.

Acknowledgements

This work is dedicated to my father Ioannis, my mother Eirini, and my sister Anna.

I sincerely thank my supervisor, Dr James L. Brighton for his guidance throughout the thesis. His advice, encouragement, and persistence ultimately resulted in the completion of this research. I also sincerely thank Dr Ioannis Kokkoras for his advice and guidance during my research.

I am particularly grateful to the Greek National Institution of scholarships (I.K.Y) for their financial support during my studies.

I would like to personally thank those who helped me over this research, Mr Alec Hunter and Doug Worley for their permission to conduct experiments in their lavender fields. Especially thanks to Bioregional Ltd for their support in the provision of the materials and the test field area.

I would like to personally thank the members of the thesis committee board Dr Peter Crossley and Professor Mike O'Dogherty for their comments and guidance.

Thanks are bestowed to Mr Phil Trolley, Mr Mick Cox, Mr Allen Hilton for their technical assistance and Mr Charles Marshall for his advices on statistical analyses.

I thank the staff and students of NSRI Group and those who shared after work moments of relaxation and sympathetic understanding, especially Pericles Toukiloglou, Anastasios Darras, Nektarios Pompodakis and Marke Jennins-Tample.

"Si quid novistri rectius istis, candidus imperti; si non his utere mecum"

"My friend, if your system works better than mine, honestly spread it throughout in the world, but if not, then use mine"

Horatius

Table of Contents

List of Plates

List of Tables

List of Figures

List of Abbreviations

ANOVA	Analysis of variance
CAD	Computer Aid Design
cm^2	square centimetre
cm^3	cubic centimetre
D.O.R	Direction of rotation
D.O.T	Direction of travel
D.T.STL	Distance to distillery
e.g.	for example
et al.	and others
ft	foot
g	gram
h	hour
ha	hectare
kg	kilogram
km	kilometre
kPa	kilopascal
kW	kilowatt
L or l	Litre
L.S.D	Limited slip differential
LPG	Low propane gas
LSD	Least significant difference
m	meter
m/c	moisture content
m^2	square meter
m^3	cubic meter
max.	maximum
MC	moisture content
mile	mile
min	minute
min.	minimum
mm	millimetre
mm^2	millimetre squared
MPa	Mega Pascal
N	Newton
N°	number
NS	not significant
ø	diameter
O.p	Original position
PAN	Percentage peak area normalisation
PDS	Product Design Specifications
Pers. comm.	Personal communication
r.p.m	Revolution per minute

s	second
S	significant
S.E	standard error
U.c	Under cover
UTS	Ultimate Tensile Strength
V	volt
w.b.	Wet basis
%	percent
<	less than
>	greater than
±	plus or minus
≈	approximately
£	pound
°	degrees angle
°C	degrees Celsius
3D	Three dimensional
4WD	Four wheel drive

List of Appendices

1 Introduction

The art of the design of machines has existed since ancient years, but the claim that this art is a science has only been established in recent times. Since the passage of human kind from hunting, fishing and food collection to the planting of seeds or roots in order to reap the ensuing harvest, the evolution of agricultural methods is marked in all sectors by instrument and machine development.

Mechanisation has been increasingly utilized in the harvest of the majority of the cultivated species world wide. For many crops, harvest labour accounts for as much as one-half to two-thirds of the total labour costs (Morris, 1990). These high harvest labour demands are required for a relatively short period of time because of the harvest patterns and the perishable nature of most agricultural crops. Mechanisation contributes to increased crop production and timeliness of operation (Witney, 1988) and has encouraged an increase in field and farm size and specialisation of production systems (Murphy, 1996). Therefore there is always the need for the introduction of new methods or the improvement of existing ones to increase harvest efficiency and consequently reduce the final cost of the product.

A large number of plant species contain secondary plant metabolites, which can be extracted by various methods including steam or hydro-distillation and solvent extraction. There has been an increase in interest in the use of natural substances instead of synthetic chemicals. Essential or volatile oils belong to these natural chemical products (Deans & Svoboda, 1993). They can form from 0.001% to 20% of the fresh weight of a given plant species. Aromatic plants and their essential oils are a source of natural medicines or plant protection chemicals. They contain secondary metabolic products which have biological activity such as antibacterial, antifungal or antioxidant properties (Deans et al., 1993). Lavender is one of those aromatic plants and has been used for its cosmetic, cleansing and healing qualities with the first recorded use dating back to ancient Greek and Roman times. It is a plant distributed world wide and cultivated mainly for its oil, its fresh or dried flowers.

Between 1993 and 1998, world demand for essential oils grew at an average rate of 6.1%, botanical extracts at 15.9%, plant derived chemicals at 9.8%, and gums, gels and polymers at 7.4% (Wondu, 2000). Demand for essential oils and plant extracts is largely driven by the food flavouring industry, cosmetics and fragrance industries. Pharmaceutical and medicinal uses also force the demand for botanical extracts higher. The alternative use of lavender fields for Agro-tourism purposes also encourages farmers consider its use within their cropping regime. These global changes in agricultural markets and the resurgence of non-food crops within the UK have prompted more farmers to consider lavender production as an alternative to traditional crops.

Conventional harvesting methods, such as hand harvesting and mechanical harvesting are expensive due to high labour and operating costs. Consequently farmers owning fields of 1 to 2 ha find it difficult to grow lavender even if they have the will to do so. Further more the current harvesting methods such as hand harvesting and mechanical harvesting for oil production uses a cutting mechanism, which mixes the flower heads with the stem. These methods increase the transportation and distillation costs and are undesirable for the production of high quality oil (Grieve, 2001).

Taking this into consideration, the following three points are significant to any small enterprise wishing to cultivate lavender more economically:

1. The cost of buying a new lavender harvester can reach £20,000-£40,000 representing too high a cost for small enterprises.
2. Hand harvest is not an option to increase productivity and profit in lavender farms due to time constraints and labour cost.
3. Small scale enterprises can further increase their revenue by controlling the marketing and sale of the produced oil in small quantities by diversifying the end product (Desai, 2002).

The development of a small-scale improved efficiency lavender harvester, incorporating a new way to reduce the transportation and distillation costs without affecting the quantity and the quality of the oil compared to the existing harvest methods, will encourage farmers to consider cultivating small to medium field areas with lavender plants as an alternative crop.

1.1 *Aim*

The aim of this research was to improve the overall efficiency of the mechanisation system for lavender oil production for small enterprises.

1.2 *Objectives*

The objectives of this research were:

1. To determine the parameters that governs the detachment of the lavender flower heads.
2. To design, construct and perfect a cost effective single row mechanised harvester to collect the flower heads of lavender plants.
3. To evaluate the above design with alternative harvesting systems in terms of the total harvest yield of lavender oil, the oil quality and the economic performance of the system.

2 Research methodology

The main research methodology is explained in this section. The methodology used in the experimentation process is clarified in Chapters 4, 6, and 7 independently. A research strategy comprising of four different phases was followed to accomplish the aim of the study. Namely: literature review, design and manufacture, evaluation and refinement, and an economic analysis comparing the prototype harvester with other existing lavender harvest techniques.

Review of lavender plant and harvesting techniques

The initial research consisted of a review focused upon information relating to the agronomic characteristics of the lavender plant and the existing harvesting techniques for the production of lavender oil.

Harvester design and manufacture

To increase the probability of success of a new venture a design process must be carefully planed and executed (Pahl & Beitz, 1999). In particular, an engineering design method must integrate the many different aspects of design in such a way that the whole process becomes logical and comprehensive. Such a logical and comprehensive design methodology, which was chosen for this study, is that proposed by Pahl and Beitz (1999) Figure 2.1. According to the authors the main phases of the design process are:

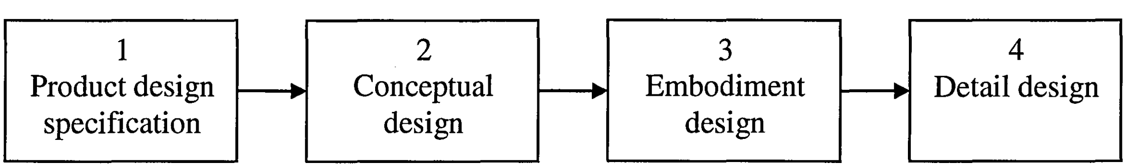


Figure 2.1: Flow diagram of the main phases at the design process (Pahl & Beitz, 1999)

Following the identification of the product design specification a rigorous design process was conducted. A morphological analysis was performed considering the functions required and four conceptual designs were completed. A performance evaluation was then conducted to determine an optimal solution and the embodiment design started. Once complete the design which was detailed using Computer Aid Design (CAD) techniques (Autodesk Mechanical desktop 4) the machine was manufactured.

Machine evaluation and refinement

To identify the critical design parameters influencing the efficiency of the Lavender harvesting operation, two main areas were investigated. The first area consisted of laboratory based experiments relating to the air flow surrounding the rotor, and the second area consisted of field trials which gave valuable data for the performance of the harvester. Both areas were used to draw conclusions and make recommendations for the development of the prototype. Modifications and refinements to the prototype lavender harvester were expected and the aspect where the machine is different from the original in different stages is explained within sections 6.2.3 and 6.3.2 in chapter 6.

Machine comparison and economic analysis

A comparison of a common type commercial harvester, prototype harvester and hand harvest, regarding the work rate, oil quantity and quality, was conducted. An economic analysis of the new method was also conducted to establish the final viability of the machine with reference to existing techniques.

Discussion and Conclusions

An analysis of the benefits of the new harvest system was made and conclusions drawn.

3 Literature review

This chapter reviews research relating to lavender taxonomy and the existing harvest methods used to harvest the lavender plant both for oil and flowers production. The chapter is divided into 4 areas namely: agronomics, harvest technologies and crop management together with a summary. Common names for lavender world wide were found and are presented in Appendix 1 TableA1.1.

3.1 Agronomics

History

Lavender has been in the nature for several thousand years, dating back at least to the times of the ancient Greeks. Its reputation extends to Biblical times when it was called Nardus by the Greeks and Asarum by the Romans (Tangra, 2001). Lavender has been known since the Antiquity. It is mentioned several times in the New Testament of the Bible (Song of Songs 4:13, 4:14 - Mark 14:3 - John 12:3). There it is called Nard or Spikenard. In gospels it is being referred to as the "precious oil of Nard" (after a place in Syria called Nardus).

The first mention of Lavender in any form of literature was by Dioscorides, the Greek physician, who used it for medicinal purposes and wrote that it was excellent as a laxative. The medical books of the 13th century already mention "the Oleum spicae", but it is included only in the first edition of the Dispensatorium Noricum, 1543. The "Oleum lavandulae" is present only in the 1589 edition, together with the aspic and other essential oils (Tangra, 2001).

The Romans contributed most to the spread of lavender throughout Europe. They used the lavender oil in soap in the baths as well as for washing their linen during the wars. It was the Romans who named the oil *Lavandula* (from the Latin verb lavare which means to wash).

Lavender plant is distributed from the canary and Cape Verde Islands and Madeira, across the Mediterranean Basin, North Africa, South-West Asia, the Arabian Peninsula and tropical North-East Africa with a disjunction to India.

Lavender species of commercial importance are native to the mountainous regions of the countries bordering the western half of the Mediterranean region of Europe (Upson et al., 2000). Wild lavender *(Lavandula spp.)* occurs in a crescent shaped distribution from the Atlantic islands in the west, over the Mediterranean Basin, North Africa, and Arabia (Figure 3.1). It does not occur in the wild in the southern hemisphere.

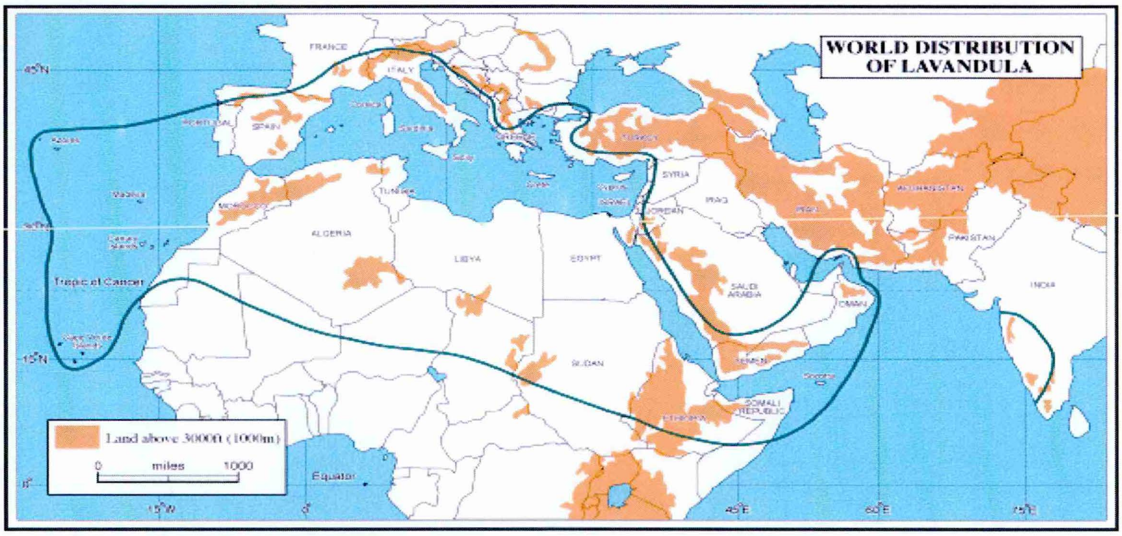


Figure 3.1: Nature lavender population (John Head, 1999)

(Orange colour indicates lavender locations)

Botany

Lavender plant and it's taxonomic category with hierarchical interrelation based on the Takhtajan system in the modifications proposed by Frohne and Jensen (Botanic Index , 2004) presented below:

Kingdom: **Plantae**

- Division : **Spermatophyta**
    - Subdivision : **Magnoliophytina** = Angiospermae = Angiospermophytina
        - Class : **Magnoliatae** = Magnoliopsida = Dicotyledoneae
            - Subclass : **Lamiidae** = Tubiflorae
                - Order : **Lamiales**
                    - Family : **Lamiaceae** = Labiatae

Lavender is part of the mint family. The botanical family is called *Labiatae* (in Latin means 'lips') and belongs to the genus *Lavandula*. Other herbs of this family are: basil, thyme, rosemary, sage and savoury. These herbs are aromatic and characterized by square stems, lipped flowers and paired leaves. The genus *Lavandula* is divided into six sections, namely *lavandula, stoechas, dentata, pterostoechas, chaetostachys* and *subnuda* (Chaytor 1937; Miller 1985; McNaughton, 2000) Table 3.1.

Table 3.1: Classification of lavender after McNaughton, (2000)

Family	Genus	Genus sections
		Lavandula
		Stoechas
Labiatae(Lamiaceae)	Lavandula	Dentata
		Pterostoechas
		Chaetostachys
		Subnuda

There are more than 32 published and accepted species of lavender with hundreds of various genotypes. The total number is yet to be determined as some are in the process of being described, suggesting a total of about 36 species (Headfamily, 2003).

The species and all the genotypes of lavender are differentiated by variations ranging from growth form to chemical composition of essential oil (McNaughton, 2000). On the basis of its hexacoplate pollen (Erdtman, 1945) and accumulation of essential oils (Hegnauer, 1989) *Lavandula* clearly belongs to the subfamily Nepetoideae of the Lamiaceae. Also according to phylogenetic and molecular studies, *Lavandula* is a distinctive clade in the Nepetoideae without close relatives (Kaufmann & Wink, 1994).

According to Tucker and Hensen, (1985) lavenders can be distinguished by their bracts; those of *L. angustifolia* are ovate-rhombic in outline, with a length/width ratio of 0.83 to 2.20 with bracteoles absent or up to 2.5 mm long. In Australia, the Charles Sturt University (CSU) has also been conducting headspace analysis of a range of varieties of lavender to look at the potential for chemotaxonomic differentiation of varieties. This would enable a rapid identification test that could potentially be conducted in the field, (Haig & Antolovich, 2001).

Within the family genus *Lavandula* and its species is the most common commercially applied variety. The nomenclature of the genus *Lavandula* is rather confused in the literature, with several redundant names still appearing from time to time.
The correct botanical names now in use describe the shape of the leaves of the plant

- *"Lavandula angustifolia Mill"* or *"English Lavender"* meaning narrow leaves
- *"Lavandula latifolia" or "spike Lavender"* meaning broad leaves and
- *"Lavandin" or "Lavandula x intermidia"*, which is a hybrid between *"Lavandula angustifolia"*, and *"Lavandula latifolia"* and has intermediate characteristics.

Uses

Lavender is being grown mainly for the production of essential oil, besides that, it is also cultivated for fresh cut flower or as a dried plant for ornamental and potpourri uses. The essential oil of lavender is only produced from the flowers and flower-stalks and is isolated by a distillation process from fresh or dry plant heads
Studies have found that essential oil from lavender can replace chemical methods currently in use to suppress sprouting in potato tubers during storage. This produces a safe non-chemical method to store potatoes and at the same time prevent microbial attack (Vokou, 1993). In bioactivity studies in India, *Lavandula* species have been proven to show potent activity against insect pests (Sharma et al., 1992).
A Study in Austria provided evidence of the sedative effects of the essential oil of lavender after inhalation. They proved through experimentation that the essential oil of lavender did indeed facilitate falling asleep and a minimization of stressful situations (Buchbauer et al., 1991).
Other studies have examined the potential for lavender as a local anaesthetic (Lis-Balchin & Hart, 1999). They have indicated that any such activity appears to be due to the compounds linalool and linalyl acetate present in the oil. According to AFNOR (Association French Normalization Organization Regulation) standards the main compounds of lavender oil that must be measured for the qualitative classification are 13 and are presented in Table 3.2.

Table 3.2: Predominant lavender oil compounds according to AFNOR standards

Compounds		
1,8-cineole	camphor	lavandulol
limonene	linalool	lavandulyl acetate
trans-b-ocimene	linalyl acetate	a-terpineol
cis-b-ocimene	terpinen-4-ol	
3-octanone	borneol	

Research studies have found an alternative use for lavender oil to be as a pesticide (Landolt, 1999). In a study of the efficacy of 27 different essential oils on codling moth, lavender oil was the most effective in controlling this parasite.

The essential oil of lavender and especially that from "true" lavender is used in some parts of the world in food manufacturing to flavour beverages, ice cream, sweets, baked goods, and chewing gum. Cooking requires the more subtle and delicate taste of "true" lavender exclusively. Non-food products manufactured with lavender oil include soaps, shampoos and many skin products (Lawrence, 1985).

The use of the oil for the plant

Volatile oils produced by aromatic plants often stored in isolation from the normal physiological processes of the producing plant in extra cellular spaces of glands or ducts. This implies the absence of any role in the normal physiological processes of the plant (Hay and Waterman, 1993). While the absence of a physiological role for volatile oils is assumed, some evidence about their use involves other activities of the plant.

According to Hay and Waterman (1993) those are:

- Attractants

Volatile oils associated with flowers can play a significant role in attracting pollinators.

- Feeding deterrents

Mono and sesquiterpenes (essential oil constituents) have both been widely implicated in the defence of plants against herbivores. The taste and the aroma force the herbivores to ignore these species from their diet.

- Antibiotic activity

Evidence for the antifungal and antibacterial activity caused by volatile oils has been stated by various researchers. The oil components can present a significant barrier to the infection of plant tissues by pathogens after tissue damage. The oil through rupture of the gland or duct spreads a coating of oil over the wounded area which in this way reduces the risk of infection.

- Allelopathy

Many secondary metabolites find their way into the soil where they exhibit phytotoxicity, either inhibiting or delaying the germination of seeds or the growth of competing species.

- Species existence

For some species, fire plays a part in ensuring successful reproduction. All such ecosystems seem to be dominated by plants rich in volatile oils. As monoterpenes will burn at relatively lower temperatures a fire fuelled by monoterpenes is basically less harmful to living plant material than would a fire fuelled by for example burning cellulose.

- Monoterpenes as natural solvents

Another possibility for the use of the oil for the plant is that some monoterpenes are produced because of their ability to act as solvents for bioactive lipophilic compounds. For example in some plants when oil glands are fractured the monoterpenes flow rapidly over the broken surface carrying with them the less volatile components of the oil. Then the monoterpenes evaporate to leave the less volatile components more widely distributed over the wounded area.

Growing environment

Lavender was successfully domesticated and cultivated in the early twentieth century. It has become wide spread, because it can generate a high yield from relatively unproductive soil. The profit from lavender growing can overcome profit of other plants (rye, oats, etc) which are cultivated on the same kind of soil (Tangra, 2001).

With its resistance to drought, low temperatures and pest and disease tolerance compared to conventional agricultural crops it is very suitable for planting on poor grade, sloping grounds which are protected from any further erosion by this plant. Studies indicated that lavender can successfully grown in highly metal polluted areas without any risk of essential oil contamination (Zheljazkov & Nielsen, 1996).

All types of lavender require a mean temperature range between 8°C and 24°C. Plants are tolerant to both moderate frosts and drought but not high humidity. Also they need very well drained soil and a soil pH of 6.0 to 8.0 to grow well. Plants will not tolerate waterlogged soil conditions. However, irrigation should be provided in dry areas while the plants are establishing, and when the flower heads are developing. Water stress during this period can decrease the number of flowers on the plant and therefore lower the yield. Severe and especially late frost will damage the plants. "Tru" or English lavender *(Lavandula angustifolia)* is typically grown at higher altitudes (up to 900 m above sea level) while lavandin *(Lavandula x intermidia)*, and "spike" *(Lavandula latifolia)* lavenders grow better at lower altitudes.

3.2 Crop management

The difference in weather conditions from place to place can have an affect on the crop management of lavender. For example, in UK there is a lot of rain meaning much more weeds to control. The information relating to crop management is therefore a combination of literature and personal communication with cultivators within U.K.

Plantation

There are two methods of planting lavender. First is by hand and the second is by the use of a transplanter machine. The planting design will depend in part on which cultivar is being grown and in part the harvest method that is to be used. For mechanical harvest the row spacing must match the machinery.

In an appropriate climate, lavender (*Lavandula spp*) is a long-lived perennial with a typical productive life of approximately 10 years. Usually lavender cultivated 8 to 10 years for oil production in U.K., with the maximum oil yield at 4^{th} and 5^{th} year (Alexander, 2003). Meunier reports that in France crops of lavender have remained productive for up to 15 years (Meunier, 1985).

In general lavandin cultivars need fewer plants per hectare than Augustifolia because of the different bush dimensions that they develop. A lavandin cultivar population needs 11,000 plants/ha and Augustifolia about 20,000 plants/ha. Distance between the rows varies from 1 to 2 m depending upon the cultivation and harvest method and the distance between plants with in the row varies from 0.4 to 0.75 m (Bulletin, 2003) (Hunter, 2002).

Irrigation and nutrition

Irrigation and nutrition in lavender production are two areas of management that appear to have conflicting perceptions of importance by growers. Lavender is actively promoted as a xerophyte, and is therefore, water hardy, not requiring irrigation, once established. Unfortunately this characteristic appears to be taken to the extreme by some growers and flower and oil yields subsequently suffer. As with many other essential oil producing plants there will be key stages of growth that are critical to flowering and essential oil accumulation. Little research is available concerning irrigation and the application of fertilizers to lavender. When the plants are young the nutritional status of the plants has not been seen to be a high priority. In contrast older plants will definitely require some management in this regard. At Bridestowe Lavender Estate in Australia the continual cropping of the lavender plantation is raising issues of sustainability of long term lavender plantings. Trials with rotational or lay phases and green manures are being conducted to restore organic matter levels and soil structure.

Weed control

One of the most important cultivation requirements is aimed at keeping the lavender plants free from weed contamination during the growing season especially in wet climates as UK. Even though the pest and disease control measures required for cultivating lavender are minimal compared to conventional agricultural crops, problems that do arise are generally site specific and seasonal in nature and can be controlled with conventional pest and disease eradication programs.

Nowadays the most commonly used method for the control of weeds in lavender fields is to use pesticides. The method of weed control by hand is no longer applied in lavender farms due to the high labour cost. Only organic essential oil producers will have no interest in pesticide unless it relates to biological pesticides and the control of the weed population will be by hand methods. At present relatively few herbicides are registered for application in lavender crops. In order to reduce the cultivated costs, farmers frequently use cheaper chemicals for the gaps between the bushes than the lavender rows where they use selective and consequently more expensive chemicals. The use of machinery to maintain the gaps between the lavender rows clean is also a way to control the weeds (Hunter, 2002). In some cases grass is sown between the rows to keep them free from weeds.

Another technique of weed control is by flame (Martini, 1996). Preliminary testing was performed on lavender field crops to test a prototype machine designed to control weeds by fire. The results indicated that except the high cost of this method flaming with this machine significantly reduced weeds but that the lavender plants were susceptible to damage if sufficient care was not taken.

Harvesting

Traditionally lavender harvest was by hand using a small sickle or knife. This method is still employed if the harvest is for bouquets that are dried and sold via florists or markets. On larger lavender farms where the plants are cultivated mainly for oil production, mechanical harvesting is required to achieve an acceptable productivity. The timing of harvest is critical and is determined by a combination of visual and aromatic criteria. The exact time of lavender harvest will depend on three factors: weather conditions, species and the intended use of the lavender flowers. Harvesting should not be carried out in hot temperatures >28°C as significant amounts of oil can be lost through evaporation is best undertaken in the morning once the dew has evaporated and before the hottest part of the day (Porter et al., 1982). However, in practice it is impossible to time exactly when large fields must be harvested, so on larger areas harvest procedures take place throughout the day. When harvest occurs for the fresh flower market, spikes are best cut when one quarter to one third of the flowers are open (McNaughton, 2000).

The optimum time to harvest for high quality oil depends upon the maturity of the flower head. This will range from mid season when 50% of the flowers are open to late season when 100% of the flowers are open (Lammerink et al., 1989). If lavender is harvested for dried flowers then the flower heads must remain intact. The cut must occur when the first flowers from the flower head have opened. It is very important to mention that the oil is so volatile that even a mist can influence the yield and for this reason when it rains the harvest procedure must stop immediately until the plants are dry again. The optimum harvest window is approximately 4-10 days so harvesting larger plantations needs to be carefully organized (Lammerink et al., 1989). Fine weather is also critical since free water in contact with the oil during the pre-heating stage of distillation reduces oil quality and extraction efficiency.

Oil Extraction

There are three common ways of extracting the oil from the lavender plant. Two of them namely hydro distillation and steam distillation used in large scale and solvent extraction in a smaller scale.

The hydro distillation method involves packing the crop into a container and adding cold water which then heated. The vapour (comprising of water and lavender oil) produced is then collected and passed into a condenser, which cools the blend, resulting in the separation of the oil from the water. The lavender oil has a lower density than the water and therefore floats to the surface.

Lavender is usually extracted by steam distillation. In modern production the lavender is packed into a container and steam is passed through the crop material. The steam produced separately. The steam as passes through the plant material traps the oil which then processed as described in hydro distillation method to derive the oil (Figure 3.2).

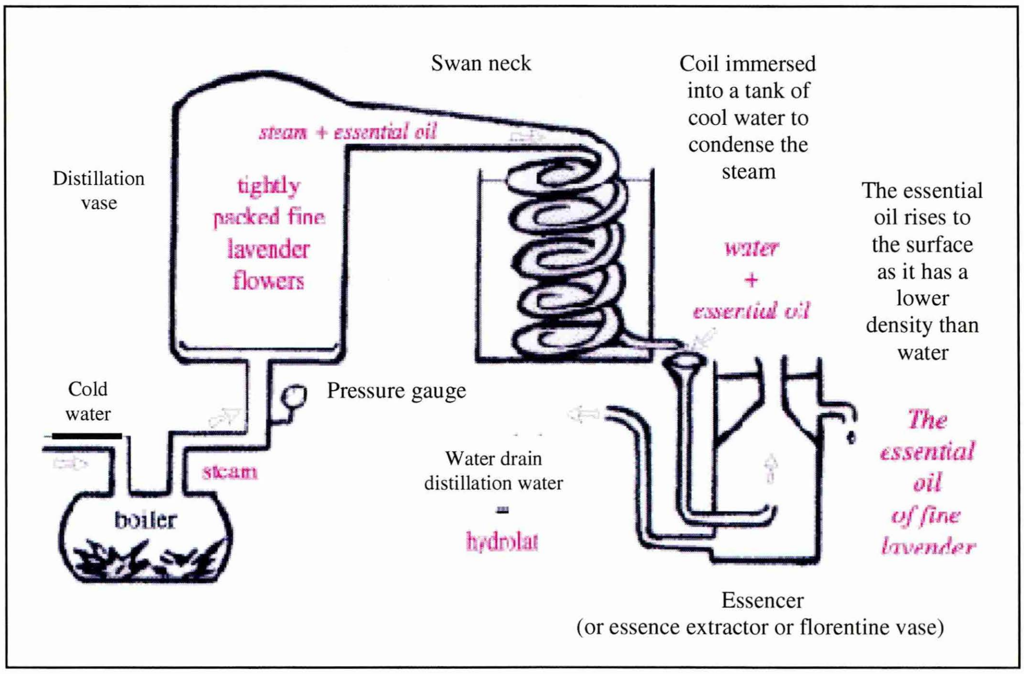


Figure 3.2: Steam distillation representation process for lavender oil extraction

Small quantities of lavender and lavandin concretes are produced in Southern France by solvent extraction. Concretes are extracted from fresh plant material using solvents such as toluene, hexane and petroleum ether. The solvents are evaporated off leaving residues called concretes. Concretes find uses in the perfumery industry (particularly soaps). As with the distilled product the yield of lavender is less than lavandin using solvent extraction. A further refinement is to mix concretes with ethanol. The mixture is then cooled and filtered, and then the ethanol is evaporated to produce a wax-free residue called an absolute. There is frequently a 50% yield loss from concrete to absolute. Absolutes are more widely used in fine perfumery.

Oil characteristics

The oil is concentrated in the glands situated chiefly on the calyx and corolla of the flower. The yield of the extracted oil is proportional to the number of essential oil glands and their size (Rabotyagov et al., 1980). A study from Venskutonis (1977) shows that when the flower and stem are distilled separately the oil quality from the flower is much higher than that of the stem and also the quantity of the oil extracted from dry flowers is thirty times more than the quantity extracted from the stem. The essential oils are also called volatile oils because their molecules evaporate rapidly. The very tiny molecular structure allows them to pass through the human skin (Encode, 2001).

Lavender essential oils are distilled from members of the genus *Lavandula* and have been used both cosmetically and therapeutically for centuries with the most commonly used species being *Lavandula angustifolia, Lavandula latifolia* and *Lavandula x intermedia.* Among the claims made for lavender oil are that is it antibacterial, antifungal, carminative (smooth muscle relaxing), sedative, anti-depressive and effective for burns and insect bites. Anti-oxidant and medicinal properties of the plant have been reported (Buchbauer et al., 1991). There are several types of lavender oil but for commercial use 3 oils are prevalent.

- "True" lavender oil is the first, the most highly prized, and comes from *Lavandula angustifolia.* The world production is approximately 200 ton per year and it is used in aromatherapy as a holistic relaxant and is described as having carminative, anti-flatulence and anti-colic properties

- "Spike" lavender oil is the second, derived from *Lavandula latifolia*, which has a world production of 150-200 ton per year.
- "Lavandin" oil that comes from *Lavandula x intermidia* has a world production about 1000 ton per year but with lower quality and price.

Very high quality essential oil of lavender is required for use in the alternative health practice of Aromatherapy. The purity of the lavender oil is determined by its chemical constituents. The variables that can affect these constituents are the soil conditions, climate, altitude, harvest time, harvest method, distillation process and the part or parts of the plant used for distillation. The British Pharmacopoeia directs that in making the most refined lavender oil (for medicinal use) it should be distilled from the flowers only after they have been separated (stripped) from their stalks (Grieve, 2001). Also the Department of Agriculture in Western Australia reports that the oil quality is affected by the amount of stem material included at the distillation process and in New Zealand no more than 15 cm stem length is recommended (Bulletin, 2003).
Samuel Perks and Charles Llewellyn who were lavender cultivators at Hitchin in England in 1877 used a specific process to produce higher quality and more pure oil. They removed the flowers from the stalks by hand after the harvest prior to the distillation process (Simmons, 1993).

Pruning

Keeping plants in shape is one of the best ways of maintaining a healthy and vigorous bush of lavender (McNaughton, 2000). Pruning should begin when the plant is still in the pot and continue for at least once a year for the rest of the life of the lavender bush. The plants must be pruned by one–third to one-half of the total annual growth. The rule is to cut back to three sets of leaves or three leaf nodes from the base (McNaughton, 2000). If the bush is trimmed any lower, the stems and maybe the whole bush will die.

3.3 Harvest technologies

3.3.1 Introduction

From earliest times people have built machines to help mechanise food production. Many different approaches for mechanization to accommodate the cultivation demands of a variety of crops have been developed over time. Although the progress made towards mechanising agriculture has been very large, the main principles remain the same. This chapter presents a review concerning the main principles of harvesting agriculture materials.

3.3.2 Cutting principles

The main functions into the harvest process according to Persson (1978) are:

- Feeding
- Compressing
- Cutting
- Removing

Cutting of cellular or fibrous materials of plant origin is a common basic process in agriculture and is a major process on most harvest machines. In order to have cutting to take place, a system of forces must occur upon the material in such a way as to cause it to fail. Persson (1978) in his study investigated the cutting process in general. After his research he has divided the cutting process into two sections. First section was with regard to the action of the cutting element and he has defined 11 types of cutting, namely: solid cut, chip-forming cut (brittle material), plastic cut, solid cut after compression, cut in local tension, wedging cut, chip-forming cut (ductile material), bending cut, tearing cut (squeezing), scraping cut and slicing cut. The second section was with regard to the nature of the support of the cutting material, namely: impact cut, peeling cut, countershear cut, scissors cut, clipper cut and anvil cut.

Most harvest mechanisms are based upon 2 principles namely:

- shear, using cutter mechanisms
- dynamic cut

These principles have been chosen for further investigation in this study.

3.3.2.1 Shearing force to cut the crop

Progress and research since 18th century produced reliable mechanisms for cutting agricultural crops. A common way of applying the cutting force is by means of two opposed shearing elements which meet and pass each other with little or no clearance between them. Either one or both of the elements may be moving. The cutting devices commonly used can be divided into three basic categories. Namely the devices in which knife edges perform reciprocating motion, the rotating knives and the cutting devices in which knife edges perform continuous plane motion (Kanofojski & Karwowski, 1976).
Persson (1978) in his book has done a vast research in basic mechanics of cutting agriculture crops. His book contains definitions and nomenclature related to cutting devices and the relationships between the physical variables involved such as: positions, velocities, forces, stresses and energies.
A cutting tool is characterised by a clearly defined edge (Koniger, 1953). Many cutting devices or tools can be used in the cutting operations applying a shear force. Mowing alfalfa or other hay or grain (as first part of combining) crops using double knifes or sickle bars are commonly used. Forage harvesters also use the shear force to cut the plant material in cylindrical or flywheel type of cutting mechanism. Rotary discs placed opposite for cutting corn stalks in row crop use also the shearing force (Persson, 1978).

3.3.2.2 Dynamic cut using different cutting elements

The first machine that applied the dynamic cut was the scythe. When this was exactly, remains shrouded in history. However, by the 18th century this machine became very popular. At the time of the industrial development at the end of the 17th century, inventors tried to build machines with rotary cutting mechanisms but with no success. Cutting elements in the form of differently shaped knife edges may rotate in the vertical or horizontal plane. Cutting with a rotary knife or hammer requires utilization of the inertia of the plants mass and requires appropriate peripheral speeds from the knife or hammer edges. This principle is often used on a variety of machines which deal with crops such as hay and alfalfa.

Another way to apply dynamic cut is by detach the valuable part of the crop. Different approaches have tried to improve this action via mechanical means. The first mention in world literature concerning a harvesting machine which detaches the valuable part of the plant comes from Pliny, a Roman Historian around 70 AD. It was a device for gathering ears of wheat or barley in Gaul known as the Gallic Vallus. The device builds in the form of a double wheeled cart to which a rake line was attached at the front. The cart was driven from behind using animal power. The rake line was set at such a level as to be able to detach the ears from the stalks (Quick & Buchele, 1978) as shown in Figure 3.3.

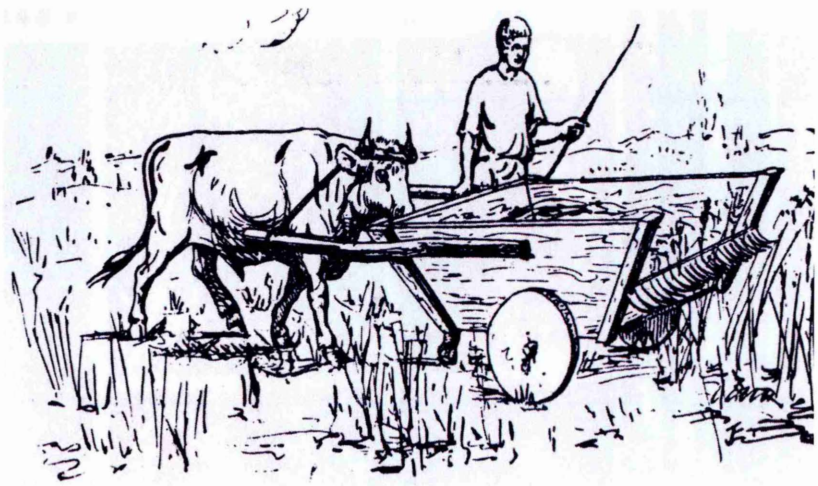


Figure 3.3: The Gallic Vallus harvester

In the late 1960's the International Rice Research Institute (IRRI) in Philippines developed a rice stripper harvester (Khan, 1972). Chowdhury in 1977 introduced the design of a power tiller-mounted stripper combine which threshed the ears inside the stripping unit by utilizing the technique of differential beating action of the stripping spikes (Chowdhury, 1977).

A self propelled machine *EC 60* cereal stripper was designed by France engineers of CIRAD-SAR in 1982. The stripping technique of the *EC 60* harvester was based on a longitudinal rotor principle. The stripping mechanism is composed of a divider-gathered system mounted on the front of the machine, and a threshing chamber with a drum studded with wire loops. In 1987 the machine was manufactured commercially by Rock International. (Martin, 1990).

The difficulty with stripping technology was always to get a detachment machine to work reliably over a range of crop conditions and on different crops with acceptable levels of loss. Most of these problems have been overcome with the system developed by Silsoe Research Institute which in 1984 introduced a new type of stripping element. The Silsoe system optimises the stripping technology for cereals and not for flowers. The machine uses the transverse rotor principle in which stripping of the crop takes place along the whole width of the rotor. The rotation of the stripping rotor is in the opposite direction from the ground wheels, so that the stripping elements comb upwards through the crop. The rotor is equipped with eight rows of flexible keyhole shaped stripping elements each one of which is mounted equidistantly on the periphery of the drum (Klinner et al., 1986a) Figure 3.4. This stripper method performed better than the cutter bar and manages to increase the combine capacity by 70 to 90% (Papesch et al., 1995). The straw intake was found to be about 30% lower than that of the cutter bar (Dammer & Lehman, 1997).

Although minimal straw intake has reduced the loss in the straw walkers, the increase in grain throughput caused an overloading in the sieving mechanism of the combine (Tado et al., 1998). Different crops were used to test the proposed stripping method and barley, grass seed, linseed, navy beans and oats all give an increase in output rate over the cutter bar (Stripper Harvesting, 1994).

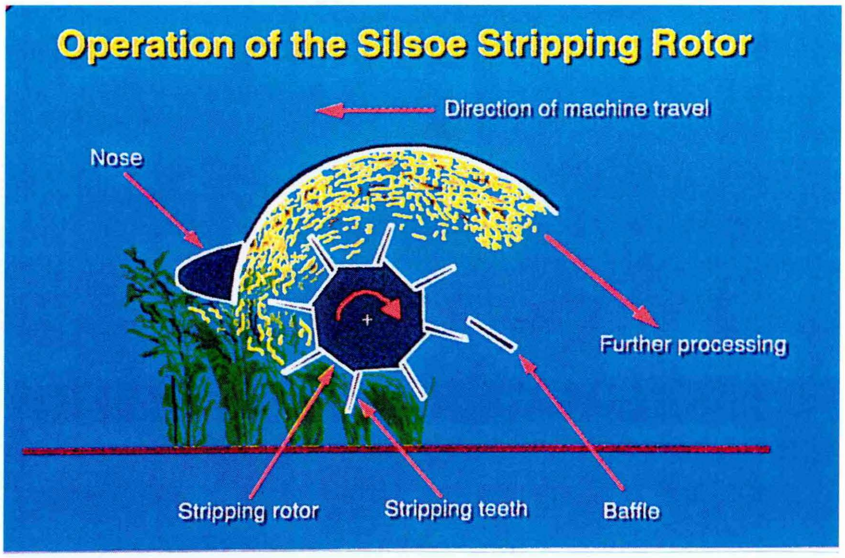


Figure 3.4: The Silsoe "stripper" harvester

At the Northeast Agriculture University in Habrin a track type, self propelled Chinese stripper combine was developed (Jiang Yiyuan, 1991). The prototype used a transverse mounted belt-type stripper to accommodate the variation in height of the rice plants. A second version employs a drum-type-stripper (Tado et al., 1998). The stripper system is essentially composed of a pick-up for harvesting lodged crop, a drum-type thresher to thresh the standing rice, and a pneumatic conveyor system to provide air suction for reducing grain losses.

3.3.3 Existing Lavender harvesting equipment

Since 1949 producers, entrepreneurs, engineers, processors, and manufacturers have been attempting to mechanize the harvest of lavender. Several types of lavender harvesting machines are used in different countries around the world, the majority of which are similar in working principle. All the types of harvesters use one of two cutting principles namely the dynamic or the shearing mechanism to accomplish the harvest.

McLeod (1989), reports that in 1949 at Bridestowe Lavender Estate in Australia the first mechanical lavender harvester was manufactured. Years of improvements and modifications produced a reliable machine to cover their demands. The machine cuts the flowers using a flail-type cutting mechanism like that of a forage harvester. Following the cutting procedure the flowers are guided and transported directly into a trailed cartridge which is then delivered direct to the distillery Plate 3.1. The latest version can cut 2 ½ ton of plant material every hour which is approximately 0.3 ha/h dependence upon the cultivar.

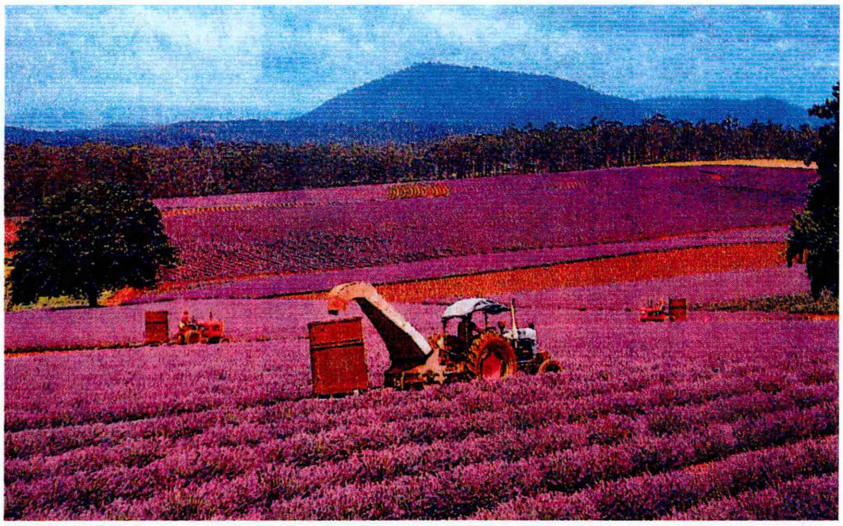


Plate 3.1: Lavender harvester (based on flail-type forage harvester)

In 1964 at Norfolk Lavender in the UK, a new mechanical lavender harvester was introduced (McLeod, 1989). The first machine was made using an old cultivator frame and an 8 hp engine (Norfolk Lavender, 2001). In 1970, an engineering company based in Norfolk built a lavender harvester for the Norfolk Lavender farm. The harvester was designed to draw the flower heads over the cutter bar, before carrying them along a conveyor belt into sacks (Simmons, 1993) (Plate 3.2). The present harvester built in 2002 is a one-row hedging-type harvester and is tractor mounted (Plate 3.3). The driver sits to the side of the elevator. The cut lavender is guided onto a conveyor via a belt which transfers the cut crop to a carrier cage at the rear of the machine. The harvester can cut 2 ton of plant material every hour which is approximately 0.25 to 0.30 ha/h depending upon the cultivar.

Plate 3.2: Old type lavender harvester (Norflok Lavender)

Plate 3.3: New type lavender harvester (Norflok Lavender)

In Bulgaria Todorov (1982) conducted experiments using two rotor blade disks fitted in a "v" shape (Figure 3.5). The two rotors were contra-rotated to cut and transport the crop to the rear of the container with the help of the air flow created from the cutting rotors and a fan. The machine was designed to be mounted on a tractor.

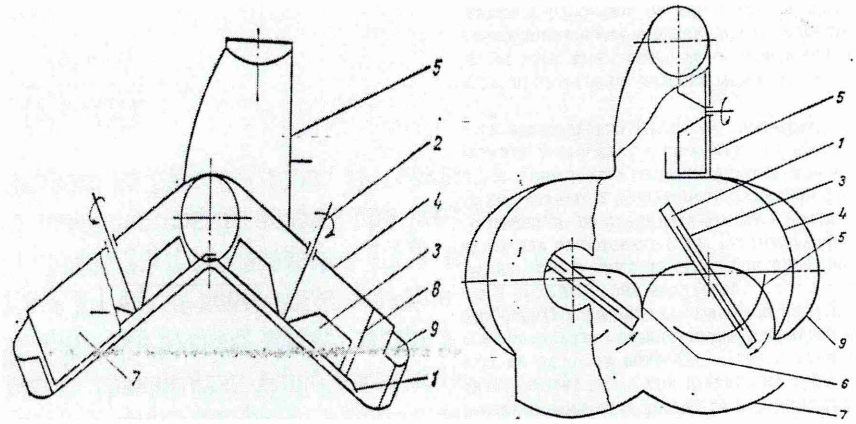


Figure 3.5: Side and top view of the experimental lavender harvester

Key:
1= cutting elements, 2= shaft of the cutting mechanism, 3= vanes, 4= cover
5= pneumatic transporters, 6= distributor, 7= rubber curtin, 8= vane shields

Baudinette (2001), describes a lavender harvester designed by Bernard Parker at Crossways in Dorchester UK. The machine is self propelled and is considered to be very manoeuvrable. It also has the ability to adjust the cutting height mechanism from 0.25 m to 0.6 m. The machine uses a double knife cutter bar with front lifters and beaters to take the cut material up an elevator to a container at the rear.

CLIER (2001), a French company specialising in harvesting machines produces a range of lavender harvesters. Four models of self propelled and tractor mounted are produced. The pick up and the cutting mechanism of all of the models are similar. The first model has two adjustable lifters at the front. The stalks are gathered by two chains equipped with rubber ridges which guide the crop to the cutter bar. The cut flowers are fed up a conveyor belt into a portable hopper (Plate 3.4).

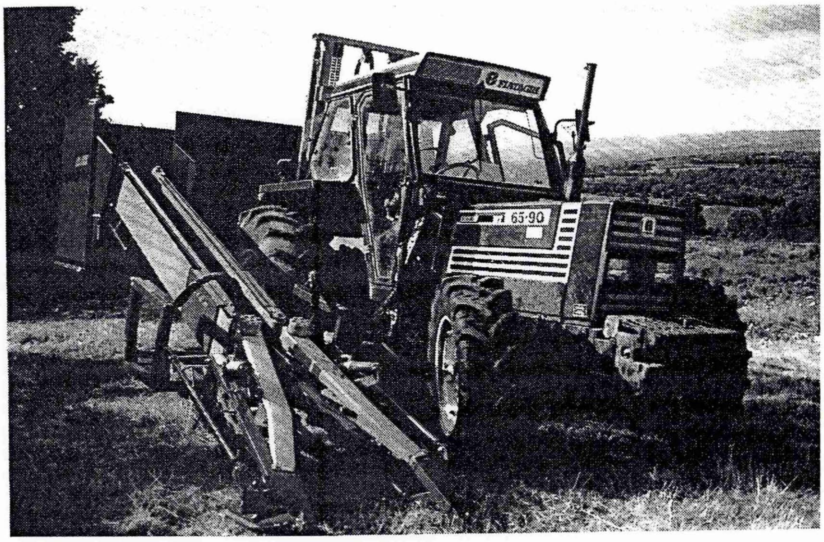


Plate 3.4: First type of tractor mounted CLIER lavender harvester

The same mechanisms for plant pick up and plant cutting are used for the second model. In this case the cut crop is transported into a portable hopper with a second cutting mechanism that chops and throws the plant material at the rear of the machine (Plate 3.5). The models are portable and mounted on one side of a tractor. The third model is a self propelled harvester using the same principles as the first model.

Plate 3.5: Second type of tractor mounted CLIER lavender harvester

The fourth model is a header specially designed and fitted in a silage machine. The header is fitted with three cutting units to harvest three rows at the same time. Each cutting unit is the same as this used in the second model. An auger at the back of the cutting mechanism guides the cut crop into an elevator that guides the crop into a multi knife cutting cylinder. This then delivers the chopped crop via an angular hose to a container at the rear of the machine.

In Japan a special hand held green tea harvester has been used with success. The harvester has a curved cutter bar and is powered from a two stroke light weight engine (Lavande Aromatiques, 2003) Plate 3.6.

Plate 3.6: Japanese Ochiai lavender harvester

In Australia another type of portable hand held herb harvester produced (Jenquip, 2004). The HT- Harvester (Plate 3.7) has been developed for cutting and pruning herbs or small plants, also for trimming hedges or shrubs. It is a very versatile machine and can perform a wide range of functions.

The Power head is mounted horizontally in the frame. It can cut down to ground level and up to 0.58 m high. Blade length is 0.75 m allowing it to cut bulky crops such as Lavender.

Plate 3.7: Portable hand held herb harvester

The sides of shrubs or low hedges can be cut or pruned by repositioning the power head. It can be mounted vertically or at an angle. The power head is fitted with a foot on the end of the cutter bar. This acts as a skid allowing the operator to cut right down to ground level. It picks up lower branches guiding them over the cutter bar. It can be used over weed matting and with the control handle the operator has fine control over cutting height.

Two prototypes herb harvesters namely HH 2000P and HH 2002C have also been developed in Australia (Jenquip, 2004). The herb harvester HH 2000P Plate 3.8 has been developed specially for harvesting herbs for oil production. Although designed initially for lavender, the harvester and options available for it are capable of harvesting a wide range of crops. The machine uses fingers and tines which lift and guide the flower heads to the cutter bar which can be set to a wide range of heights. The flower heads are cut at an optimum length. Using the pneumatic vacuum cleaner principle, the flower heads are sucked-blown up ducting into large bags mounted at the rear of the harvester. Raising the 3 point linkage above operating heights will lift the cutter/pickup head allowing easy turns at head lands. For moving through gateways and long distance travel the pick up head location arm is disconnected from the tractor, tubes disconnected and the head is rotated 180° to behind the implement, and lowered onto the tray.

Plate 3.8: Tractor mounted lavender harvester HH-2000P

The herb harvester HH 2000C has been developed for harvesting herbs. The conveyor feeds the product into vegetable bins or large bags. There is room on the machine for one or two people packing the cut crop. There are 3 models:

1. CT towed with hydraulic supply coming from a small tractor
2. CTP towed but with it's own hydraulic power pack
3. CSP self propelled and powered (Plate 3.9)

Plate 3.9: A self propelled lavender harvester

Two types of mechanical lavender stripper are available in Australia for growers who intend drying their product Plate 3.10. They have been displayed and demonstrated at recent TALGA conferences (Talga, 2001). The machines have been designed to strip hand-fed bunched herbs and are equipped with a single brush made from durable rolled formed steel.

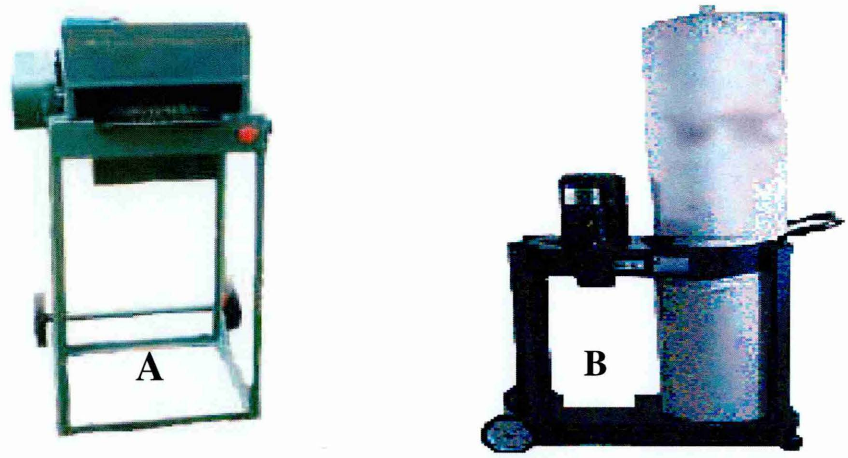


Plate 3.10: Portable hand fitted lavender stripper (type A and B)

3.4 Summary for the literature review

- Several lavender harvester machines exist but all remove both the stem and the flower.

- For oil production it has been shown (section 3.1, oil characteristics) that collection of the stem does not improve the quality of oil and only adds a very small amount (%) to the volume of the oil produced.

- The stripping technique has not been applied to lavender, even though there would appear to be a clear advantage for this technique for the production of oil.

- From the literature review (section 3.3.2.2) it can be said that a similar approach to that of the stripper concept used for cereals may be employed, but the physical characteristics of lavender are significantly different and unknown. Therefore the detachment force required to separate the flower from the stem and the aerodynamic properties of the plant required identification to enable the design process to be conducted efficiently.

4 Physical characteristics of the lavender plant

Design engineers working with plants need to know the structure and the properties in order to understand the in behaviour and interaction with the machine as a basis for improved designs (Stephens & Rabe, 1978). There is apparently no published research on factors affecting physical and mechanical properties of lavender plants such as the detachment force required to separate the flower from the stem and the aerodynamic properties of lavender flower, therefore laboratory tests were conducted. This chapter is divided in to two sections. Section one describes the selection criteria which was developed to identify the lavender cultivars that fulfil the demands for mechanical harvest. The second section describes the results of experimental work required to define the physical characteristics of the lavender plant.

Table 4.1: Botanical terms explanation

Botanical Term	***Explanation***
Bract	Modified leaf found at the base of a flower
Bracteole	Small bract borne on the flower stalk above the bract and below the calyx.
Calyx	An outer petal the calyces must open before the inner petals are revealed
Corolla	The whorl of petals that comprise the flower
Inflorescence	Flowering structure or head consisting of more than a single flower
Peduncle	The main stalk bearing flower heads and/or subordinate stalks
Pinnate	Having leaves on either side of the Peduncle
Rhombic	Diamond or rhomboid shaped
Spike	Flowers arranged along and attached to a stem with terminal flowers opening last
Tomentose	Densely covered with woolly hairs
Whorls	Ring of flowers

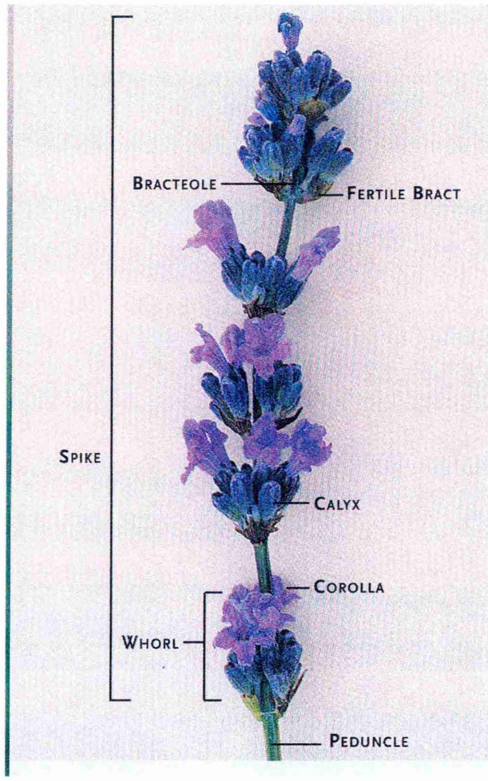


Figure 4.1: General outline of a lavender flower head

4.1 Cultivar(s) selection

Within the family Labiatae genus *Lavandula* is the most common commercially applied and grown for oil production. Two species are commonly used for their oil in UK, namely *Lavandula angustifolia* and *Lavandula x intermidia* and been selected for further research. According to McNaughton, (2000) there are 74 and 29 cultivars belonging in those two species respectively and they are presented in Tables A1.2 & A1.3 Appendix 1.

4.1.1 Selection procedure

To choose a cultivar(s) for experimentation a number of selection criteria were used to create plant specifications. A flow diagram shows the procedure followed for the selection of cultivar(s) (Figure 4.2).

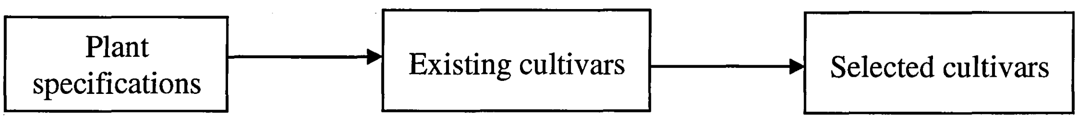


Figure 4.2: Research tactic flow diagram for cultivar(s) selection

The criteria list shown below was adopted taking into account the existing principles for mechanical harvest of crop material using a dynamic or shearing cut.

Selection criteria list:

- Cultivar availability
- Cultivar(s) must be grown for oil production
- Plant height 0.60-1.00 m (medium/high)
- Peduncles length 0.10-0.30 m (medium/long)
- Spikes length 0.07-0.16 m (medium/long)
- Peduncle alignment 40°-90° (semi-upright/upright)
- The cultivar(s) must be resistant to different environments

Using Table A2.1 and A2.2 from Appendix 2 and taking in to consideration the specification, a group of 20 cultivars were selected (Table 4.2).

Table 4.2: Selected cultivars using the developed criteria

N°	***Cultivar name***		
1	Lavandula angustifolia Amanda Carter	11	Lavandula angustifolia Heacham Blue
2	Lavandula angustifolia Avice hill	12	Lavandula angustifolia Hidcote
3	Lavandula angustifolia Backhouse Purple	13	Lavandula angustifolia Imperial Gem
4	Lavandula angustifolia Beechwood Blue	14	Lavandula Angustifolia London Blue
5	Lavandula angustifolia Blue Cushion	15	Lavandula angustifolia Maillette
6	Lavandula angustifolia Celestial Star	16	Lavandula angustifolia The Colour Purple
7	Lavandula angustifolia Egerton Blue	17	Lavandula angustifolia Tom Garbutt
8	Lavandula angustifolia Folgate	18	Lavandula x intermidia Alba
9	Lavandula angustifolia Foveaux Storm	19	Lavandula x intermidia Grosso
10	Lavandula angustifolia Gray Lady	20	Lavandula x intermidia "Bioregional"

The cultivars chosen for further study from the selected list were N° 8, 12, 15, 18, 19 and 20. These cultivars were chosen due to their widespread use in the UK and their availability.

4.1.2 General description for Lavender species used for oil production

Lavandula Angustifolia

"English Lavender" *Lavandula angustifolia*, is the most widely cultivated species and their cultivars are the hardiest and most fragrant of all lavender (McNaughton, 2000).

The stems are woody and often, but not always, branched. Stems are rectangular or square displaying occasional ribbing. Lateral branching of the peduncle is uncommon, compared to other cultivars belonging to Section *Lavandula*. When present, branching is mostly confined to semi-stalked (10-100 mm) or short-stemmed (10-20 mm) laterals with one to six flowers on the terminal end, none of which bears any resemblance to a spike. Most of the branching is single.

The leaves are opposite, blunt and linear or lance-shaped. When leaves are young they are white with dense stellate hairs on both surfaces with strongly revolute margins. When fully grown, leaves become greener and extend up to 75 mm long, with scattered hairs above, smooth or finely downy beneath, with the margins only slightly revolute.

Flowers are produced in terminating spikes from the young shoots, on long stems (Peduncles). Peduncles may be bent (wavy) or semi-bent rather than straight. The peduncle length is measured from the base of the bottom whorl to the main foliage line (excluding primary leaves). The spikes are composed of whorls or rings of flowers, each composed of six to ten flowers. In this group most spikes are interrupted, with obvious gaps between the whorls, and most have whorls a short distance from the main spike. Some, though, are only slightly interrupted and others are quite compact. Spike length is measured from the base whorl. The flowers themselves have very short stalks, three to five together in the axils of rhomboidal, brown, thin, dry bracts. Leaf like bracts are in an opposite arrangement below each whorl. They are usually shorter than the calyces. Calyces are tubular, 8, 13, or 15 nerved, and five toothed with the posterior tooth often enlarged. The five-toothed is hairy with shiny oil glands among the hairs visible with a hand lens.

The corolla size varies considerably between cultivars and can be a distinguishing feature. Corollas are tubular and extended by half their length beyond the calyx. Large corollas tend to give an inflorescence a much bolder look. The two-lipped corolla is a bluish-violet colour.

Lavandula angustifolia cultivars are very fragrant, and can be used for fresh or dried flowers, fragrant products, and ornamental, hedging or container purposes. It is one of the sweeter members of this group and is suitable for culinary purposes and oil production.

Lavandula x intermidia

Lavandula x intermidia or "Lavandins" cultivars are sterile hybrids between *Lavandula angustifolia* and *Lavandula latifolia.* The main foliage of the plants is 0.40 to 0.50 m high but in full season growth can reach 1.00 to 1.20 m high. Long lateral branching of the peduncle above the main foliage line is common, but not always present. Peduncles high vary from 190 to 360 mm depending upon the cultivar. In comparison to the *Lavandula angustifolia* plants of "Lavandins" are much taller. All cultivars have calyces and peduncles covered in hair to a greater or to a lesser extent with more hair sited on calyces than peduncles. Spikes are usually 15 to 20 mm wide having a length of 35 to 170 mm depending upon the cultivar. All bracts in "Lavandins" are fertile. Bracts at the base of the spike are often longer and narrower than the bracts immediately above.

All "Lavandins" can be used for fragrant purposes (McNaughton, 2000). The majority of them have a strong but less sweet fragrance than *Lavandula angustifolia* cultivars. The scent is generally sweeter towards the end of flowering when most of the flowers on the spike have withered. The strong fragrance in combination with the long peduncles made many of them ideal for crafts, fresh or dried flowers. Despite the lower oil quality, (AFNOR standards) the higher yield (Casabianca, 2001) in comparison to other lavender species made the "Lavandins" very popular for oil production.

Dimensional and appearance characteristics of lavender cultivars for oil production

The main dimensional and appearance characteristics for lavender species used for oil production are presented on Table 4.3, 4.4 and Figure 4.3.

Table 4.3: Lavender dimension characteristics after McNaughton (2000)

Dimensional characteristics	
Height of Plants	• Small: up to 0.50 m in flowers, bushes between 0.30 to 0.40 m *(L.angustifolia Lady)* • Medium: up to 0.70 m in flowers, bushes between 0.40 to 0.50 m *(L.angustifolia Hidcote)* • Semi –tall: up to 0.80 m in flowers, bushes between 0.50 to 0.60 m *(L.angustifolia Bosisto)* • Tall: 0.80 m to 1.00 m in flowers, bushes between 0.50 to 0.80 m *(L.×intermidia Grey Hedge)*
Peduncle Length	• Short: *L.angustifolia Lady(60-130 mm)* • Medium: *L.angustifolia Hidcote(120-220 mm)* • Long: *L.×intermidia Grey Hedge(160-280 mm)*
Peduncle width	• Narrow/thin: *L.angustifolia Lady(1mm)* • Medium: *L.angustifolia Hidcote(1.5 mm)* • Thick/broad: *L.angustifolia Twickel Purple(2-3 mm)*
Spike Length and Width	• Short: *L.angustifolia Lady(20-30mcm×20 mm)* • Medium: *L.angustifolia Hidcote(30-70 mm×20 mm)* • Long: *L.angustifolia Twickel Purple(80-190 mm×20 mm)*
Fertile Bracts Length and width	• Small and narrow: *L.angustifolia Lady(3-4 mm×3-4 mm)* • Intermediate: *L.angustifolia Hidcote(4-5 mm×4-5 mm)* • Broad: *L.angustifolia Twickel Purple(4-5 mm×3-7 mm)* • Long and Narrow: *L.×intermidia Grey Hedge(5-6 mm×3-4 mm)*
Bracteoles Length and width	• Insignificant, tiny or not present: *L.angustifolia Hidcote(if presnt 0.5 mm)* • Thin, small: *L.angustifolia Twickel Purple(0.5-1.5 mm×0.2-0.5 mm)* • Long, thin, plentiful: *L.×intermidia Grey Hedge(3-3 mm×0.2-1 mm)*

Table 4.4: Lavender appearance characteristics after McNaughton (2000)

Appearance characteristics		
Density of Foliage	• Open: • Semi –open: • Dense:	*L.angustifolia Twickel Purple* *L.×intermidia Alba* *L.×intermidia Grey Hedge*
Shape of Lavender plant in flower	• Spreading: • *Bushy:* • *Spherical/rounded:*	*L.angustifolia Lady* *L.angustifolia Munstead* *L.angustifolia Twickel Purple*
Growth Habit of Peduncles	• Upright: • Semi-upright: • Sprawling/Splayed:	*L.angustifolia Bosisto* *L.angustifolia Hidcote* *L.angustifolia Twickel Purple*
Inflorescence Shape (See Figure 4.2)	• Narrow-conical: • Broad-conical: • Truncate-conic: • Cylindric: • Fusiform: • Fusiform-conic:	*L.×intermidia Grey Hedge* *L.×intermidia Grosso* *L.×intermidia Hidcote Giant* *L.×intermidia Dutch White* *L.angustifolia Munstead* *L.×intermidia Yuulong*
Distance between Whorls	• Uninterrupted/compact: • Unevenly interrupted: • Interrupted/long:	*L.angustifolia Lady* *L.angustifolia Hidcote* *L.angustifolia Twickel Purple*

Cultivars from left to right:

L. ×i. Hidcote Giant

L. a. Munstead

L. ×i Grey Hedge

L. ×i Dunch Withe

L. ×i Yuulong

L. ×i Grosso

(McNaughton, 2000)

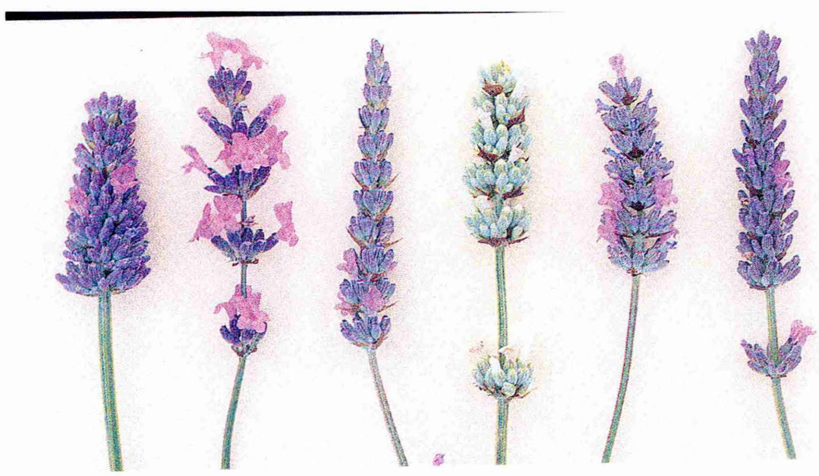


Figure 4.3: Inflorescence different shapes

4.2 Identification of the flower-head mechanical and aerodynamic properties

Three experiments were conducted with the aim of quantifying:

1. The typical level of flower/stem adhesion
2. The aerodynamic drag of a typical lavender flower head
3. The drag coefficient and the terminal velocity of a typical flower head

The instrument used to measure and record the force for the first two experiments was an Instron 1122. The basic instrument is comprised of two assemblies, the loading frame (Plate 4.1a) and the electronic control console (Plate 4.1b). The experiments were conducted in the Post Harvest Laboratory, at Cranfield University, Silsoe.

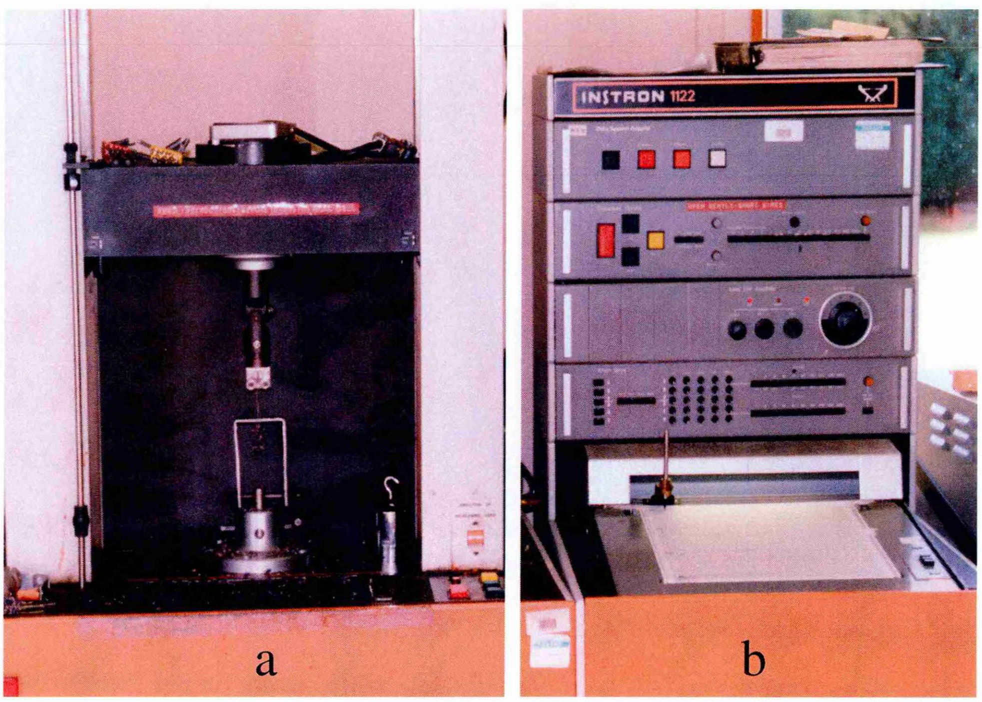


Plate 4.1: Instron 1122 test instrument

4.2.1 Flower detachment force identification

The aim of the experiment was to quantify the detachment force required to separate the flower from the stem and the UTS (Ultimate Tensile Strength) of the stem. Two tests were conducted. The first test was to quantify the measurement forces for the lavender flower at a typical harvest moisture content and the second test investigated the influence of the moisture content at these measurement forces. The results from this experiment was used to characterize the plant and help define the effectiveness of applying the detachment principle to harvest the lavender plant and predict the energy requirements of the stripping mechanism if this principle was selected for further development.

4.2.1.1 Quantification in measurement forces at harvest moisture content

The first test aimed to identify the detachment force required to separate the flower from the stem, the stem breaking force and the UTS of the stem at a typical harvest moisture content. This occurs when 50% of the flowers are open in each head flower.

Materials and methods

From the specification 3 *Lavandula angustifolia* and 3 *Lavandula intermidia* cultivars were chosen representing cultivars commonly cultivated in the UK. Those were:

- *L. angustifolia Folgate (Hitchin)*
- *L. angustifolia Hidcote (Silsoe + Swetsloots))*
- *L. angustifolia Maillette (Hitchin)*
- *L. x intermidia Alba (Swetsloots)*
- *L. x intermidia Grosso (Hitchin)*
- *L. x intermedia (Bioregional)*

The plant material for *L. angustifolia Hidcote (swetsloots)* and *L. x intermedia Alba (swetsloots)* cultivars were supplied from Swetsloots (2001) greenhouse on 17/10/01 & 20/10/01. The plants were 2 years old.

The plants for *L. angustifolia Hidcote (Silsoe)* and *L. x intermedia (Bioregional)* were supplied from the Silsoe ground on 04/10/01 & 21/07/04 and from the Bioregional field at Carlshalton in London on 02/08/01 & 27/07/04 respectively. The plants from Silsoe and from Bioregional were 3 years old in 2001 and 6 years old in 2004. The plant material for *L. angustifolia Maillette (Hitchin)*, *L. angustifolia Folgate (Hitchin)* and *L. x intermedia Grosso (Hitchin)* cultivars were supplied from Cadwell farm, Hitchin on 22/07/04. The plants from Hitchin were 2 years old for *L.angustifolia* cultivars and 3 years old for the *L.x intermidia* cultivar. All plants for all cultivars were collected randomly.

An experimental procedure was developed. All plants were cut with 100 mm length of peduncle and were placed upside-down in the instrument, as shown in Plate 4.2. The stem was fitted into the end of the load cell after being passed through a hole of 3 mm diameter fixed in a metal plate to the bottom of the instrument. The flower part was below the hole and as the cross head section moved upwards the stripping procedure was conducted. The test was stopped when the stem was completely clear of the metal plate.

Two treatments were examined for all cultivars. One treatment consisting of five replications for the flower detachment force identification and one treatment consisting of five replications for the stem breaking force measurement. When one experiment was complete the same procedure was followed for the next flower. The force was recorded using the recording part of the Instron 1122 instrument which was equipped with a chart drive unit. The cross head velocity and the chart speed of the Instron 1122 was selected at 50 mm/min. Greater detachment velocities were used but the results were inconsistent and exhibited a high degree of variation due to the collection of plant material around the hole within the metal fixture. Therefore 50 mm/min was chosen for all tests.

After the flower detachment experiments the same stems consisting of a 50 mm long peduncle were used to measure the stem break force and calculate the UTS. The procedure was the same as for the detachment experiment with the exception that both ends of the stem were attached to the Instron 1122 instrument as shown in Plate 4.3.

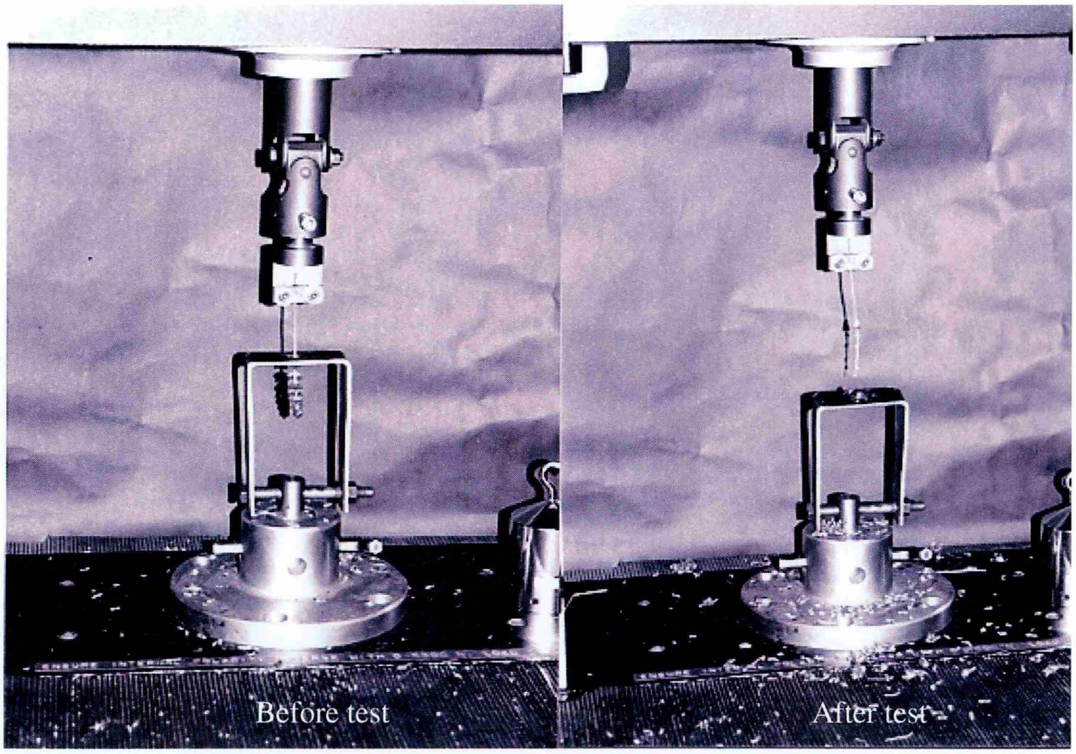


Plate 4.2: Experimental lay out for flower detachment test (LHS: before detachment-RHS: after detachment)

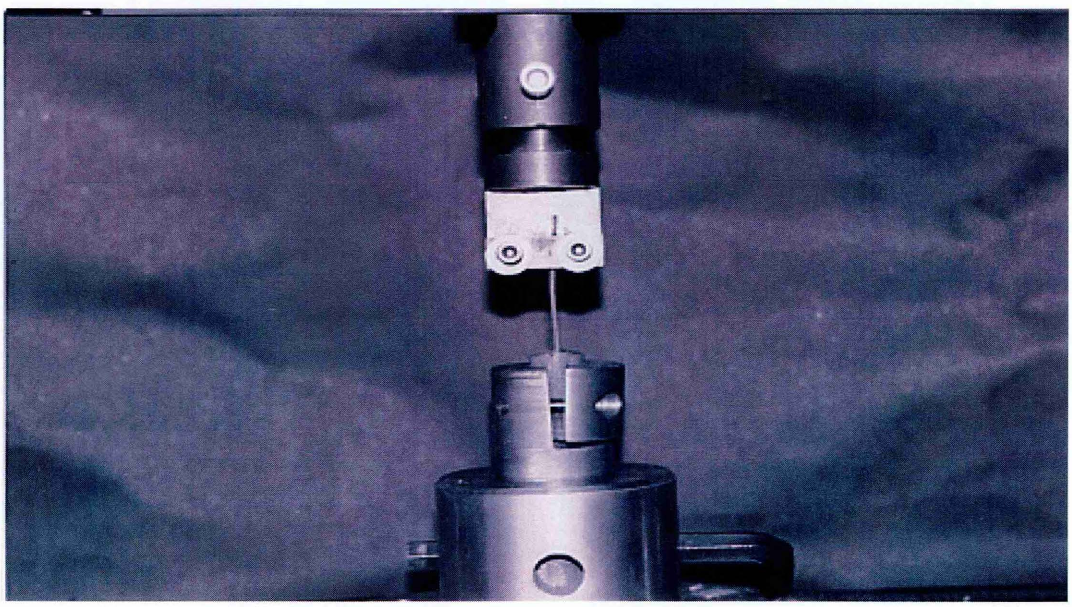


Plate 4.3: Experimental lay out for stem UTS test

Results

Table 4.5: Mechanical characteristics for lavender plant at 50 mm/min crosshead speed

N°	Variety	m/c[1] % w.b	Average flower Detachment force N	Average stem breaking force N	Stem U.T.S MPa
1	*L. angustifolia Hidcote (Silsoe)*	58.50*	8.64 (±0.872)	28.90 (±6.130)	12.13 (±0.284)
2	*L. angustifolia Hidcote(Swetsloots)*	72.00*	7.12 (±0.224)	39.60 (±2.271)	18.07 (±0.747)
3	*Lavandula x intermedia Alba (swetsloots)*	69.30*	11.72 (±1.123)	38.20 (±2.817)	16.25 (±2.727)
4	*L. angustifolia Hidcote (Silsoe)*	69.00*	9.22 (±0.480)	35.20 (±1.356)	17.77 (±1.615)
5	*L. angustifolia Maillette (Hitchin)*	67.30*	12.20 (±0.707)	36.20 (±1.655)	20.24 (±1.474)
6	*L. angustifolia Folgate (Hitchin)*	58.00*	9.96 (±0.224)	30.80 (±1.959)	23.12 (±2.932)
7	*Lavandula x intermedia Grosso (Hitchin)*	65.00*	15.04 (±0.150)	38.50 (±1.000)	13.05 (±0.344)
8	*Lavandula x intermedia (Bioregional)*	67.40*	15.56 (±0.917)	46.00 (±2.664)	17.93 (±1.251)

Term explanation: m/c= moisture content; w. b= wet basis; (±Standard Error)

Discussion

Table 4.5 demonstrates that for all cultivars the average force required to break the stem was considerably greater (2.6 to 5.6 times) than the average force required to detach the flower from the stem in harvest conditions for oil production.

[1] The samples for moisture content examination were taken when the inflorescence had 50% of the flower bloom and at this stage is suitable for harvest for oil production (Porter et al., 1982).

4.2.1.2 Quantification of measurement forces for a range of moisture content

In the second test the effect of moisture content on the forces measured was examined. The test was conducted to allow a comparison between the cultivars and the adjustment of the results from the previous experiments to a single moisture content.

Materials and methods

The same method as in the previous test was used to measure the detachment force and the stem breaking force. The difference was in the number of flower heads which were fifteen consisting of three sets of measurements (5+5+5 flowers) instead of one set which had been used for the 1st test. Each stem was used for the detachment and the braking measurement test. The number of replicates in each treatment was 5 and the samples were chosen randomly. The mean value from the replicates was used to plot the results assuming that the value represents the cultivar mean detach and breaking force. The number of cultivars tested was five instead of six used in the 1st test. Between each set of measurements the sample was allowed to dry for 4 hours at room temperature. The decline in the m/c was recorded by taking samples for each set of flowers which was tested. The recorded Relative Humidity during the test was 55% and the temperature 25°C.

Results

Figures 4.4 to 4.8 present the relationship between moisture content and measurement forces for each individual cultivar. This was to present the results in such a way that a comparison can be made between cultivars at the same moisture content considering the measurement forces.

Figure 4.9 presents a comparison between mean detachment force and mean stem breaking force for the same moisture content. Figure A2.3.1 at Appendix 2.3 presents the stem UTS for each cultivar tested.

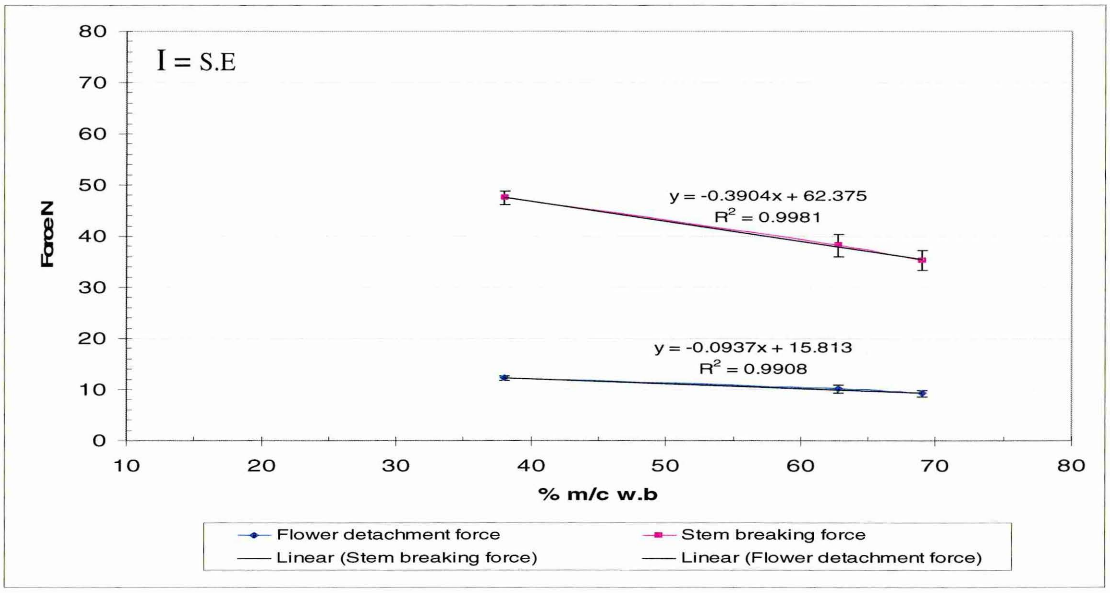


Figure 4.4: Plant force characteristics for Hidcote cultivar

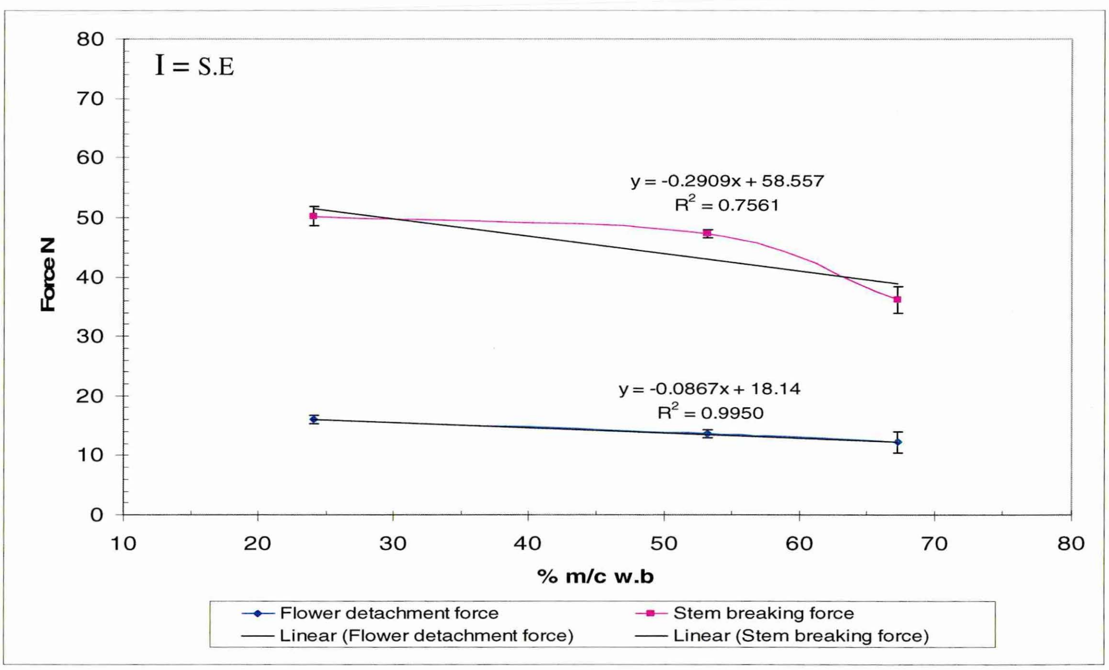


Figure 4.5: Plant force characteristics for Maillette cultivar

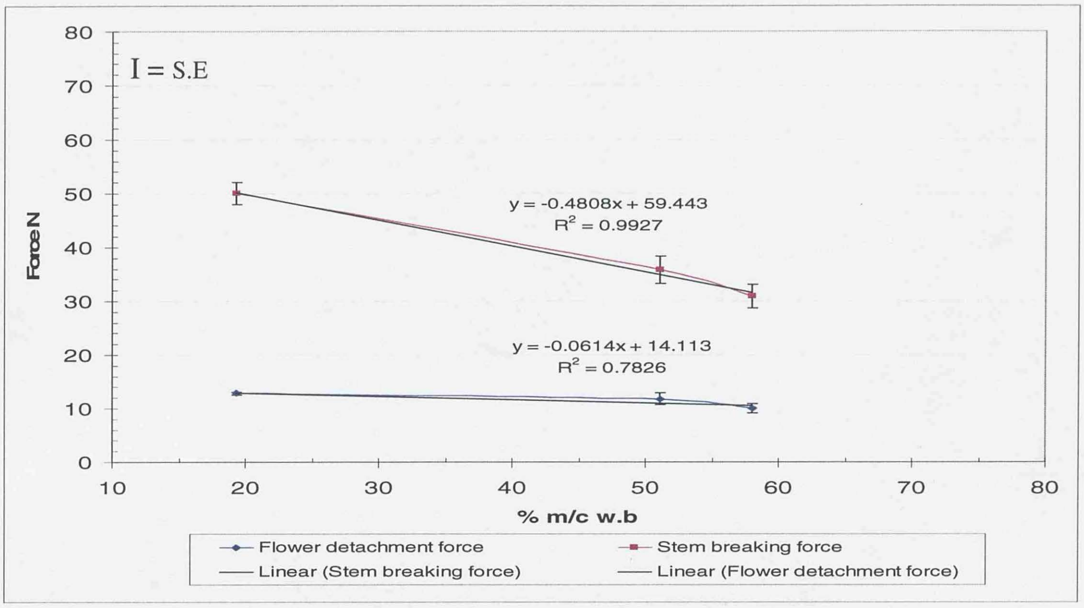


Figure 4.6: Plant force characteristics for Folgate cultivar

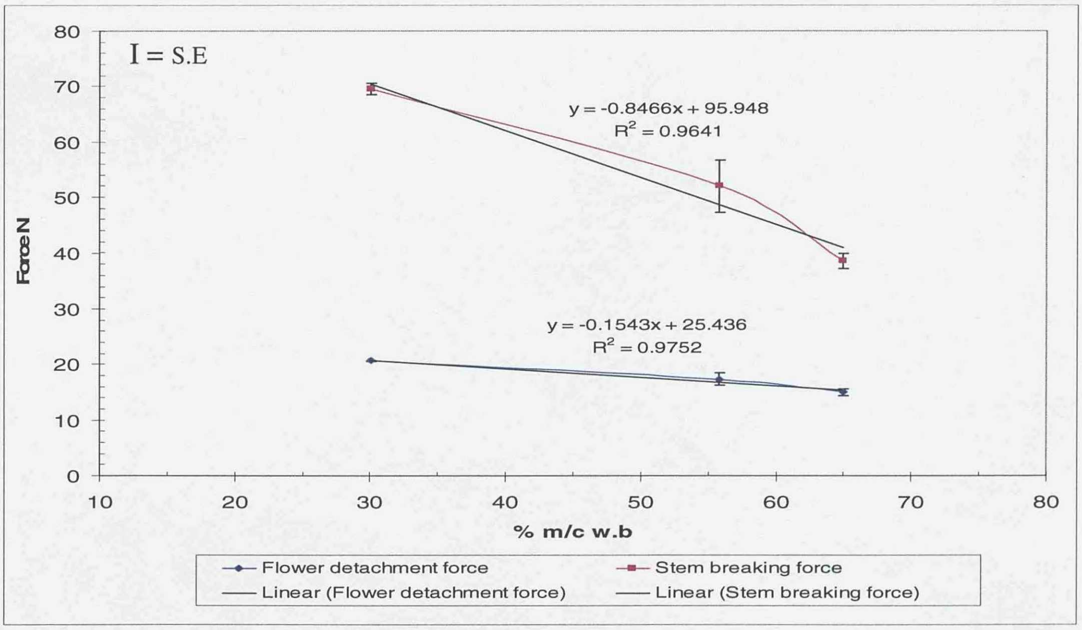


Figure 4.7: Plant force characteristics for Grosso cultivar

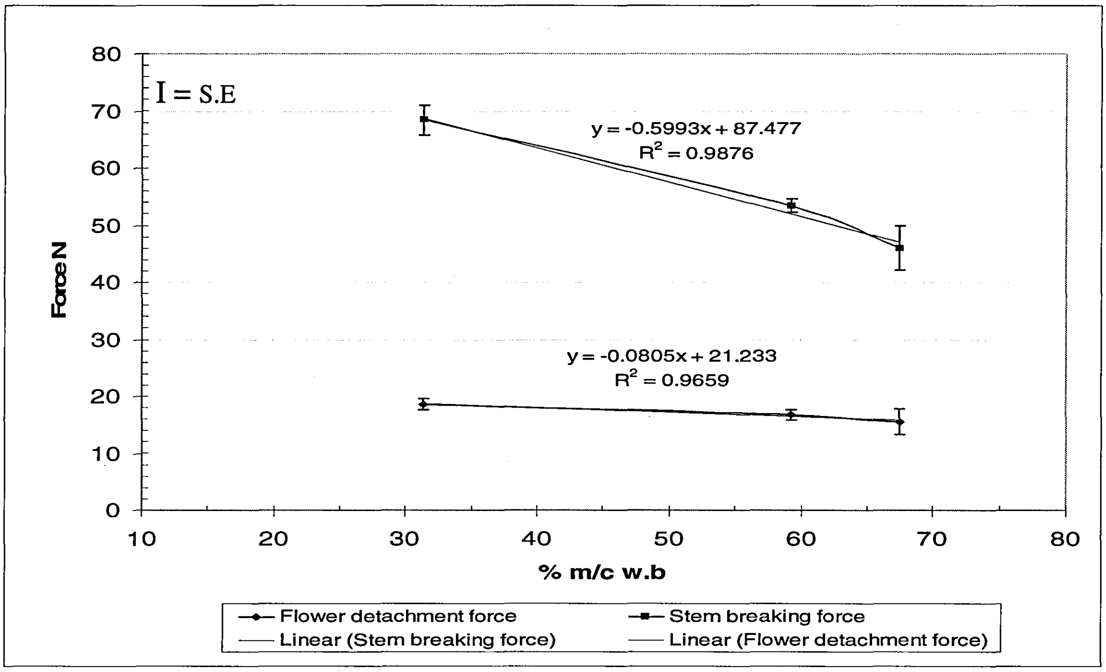


Figure 4.8: Plant force characteristics for "Bioregional" cultivar

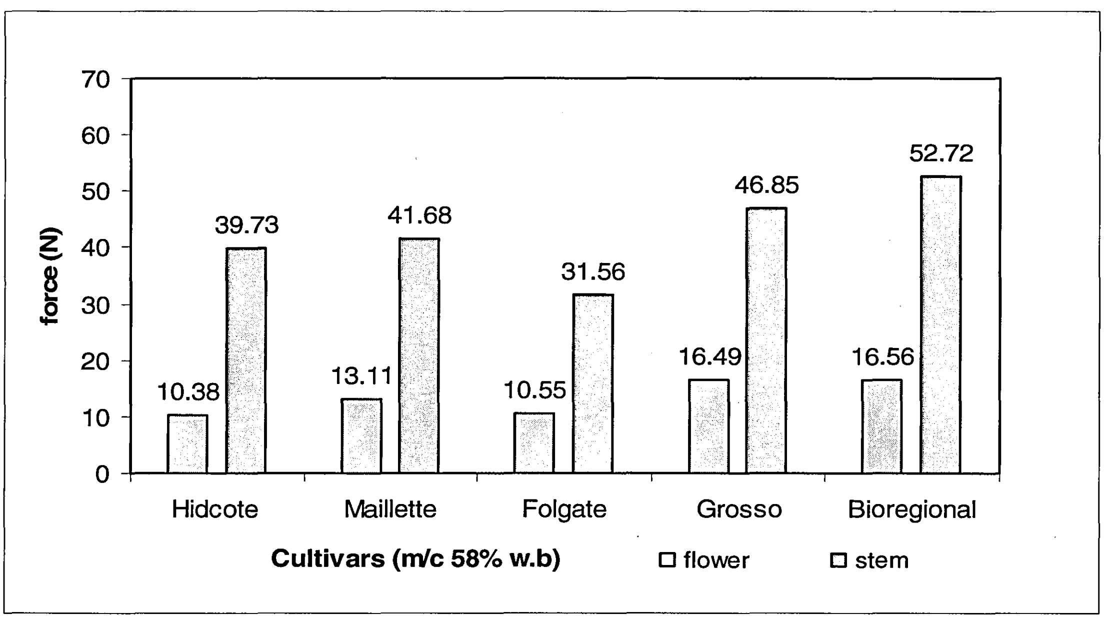


Figure 4.9: Histogram represents the mean value for flower detachment and stem break force adjusted to the same m/c

Discussion

Considering Figures 4.4 to 4.8 and extrapolating beyond the data set, there is a point at which the stem breaking force and flower stripping force becomes equal (the lines cross). In each case this represented a moisture content greater than 100% (101.8 to 197.9%) and is therefore not practical in reality. (so it is always possible to detach the flower from the stem).

Figure A2.3.1 in Appendix 2 shows the increase in stem UTS as the moisture content decreases for each cultivar. The shape for each curve is similar and the UTS for each cultivar more than double after 8 h of drying time. Figure 4.9 demonstrates a comparison for all cultivars tested between the average force required to break the stem and the average force required to detach the flower from the stem for oil harvest condition for the same moisture content of 58% w.b.. The selection of this moisture content to present the results was based on the lower harvest moisture content commonly found among the tested cultivars (*L.agustifolia Folgate)* in the UK. Plotting the results following the methodology developed it can be seen that the average force required to break the stem was found to be greater than the average force required to detach the flower from the stem and ranged from 2.8 to 3.8 times.

4.2.2 Flower aerodynamic properties identification

In handling and processing of agricultural products, air is often used as a carrier or as a helper to transport a product. In this case, air flow occurs around the transported particles and involves the action of the exerted forces by the fluid on these particles. Therefore it is necessary to have knowledge of some physical properties which affect the aerodynamic behaviour of the lavender as a transported particle, such as its drag coefficient and the terminal velocity.

4.2.2.1 Lavender flower terminal velocity

In free fall, an object will attain a constant terminal velocity at which the net gravitational accelerating force equals the resisting upward drag force (Hayden et all., 1968). If an air stream is applied to a particle, that is higher than its terminal velocity, then this particle would move in the direction of the air stream. Therefore it was necessary to determine the terminal velocity of the lavender flower so that the machine could be designed with sufficient airflow to move the crop in the desired manner if air was chosen as working principle for the final concept.

According to Mohsenin (1986) to find the terminal velocity of an irregular shape plant material is difficult, but using equation 4.1 below (adopted from Lapple (1956)) and estimating the cylindrical area of the plant shapes the terminal velocity can be estimated. According to Mohsenin experiments must be conducted to identify the terminal velocity for valid conclusions. Therefore both empirical and analytical approaches were used and the results compared.

Analytical determination of terminal velocity

Terminal velocity as derived by Lapple:

$$V_t^2 = g \; x \; dp \; x \; (pp - pf) \; / \; 2 \; x \; c \; x \; pf \quad \textit{(equation 4.1)}$$

Where:

V_t =Terminal velocity ($\frac{m}{s}$)

g = gravitational force ($\frac{m}{s^2}$) [9.81 m/s^2]

dp =particle diameter (m) [Mean diameter from 15 samples 15 mm = 0.015 m]

pp =mass density of the particle ($\frac{Kg}{m^3}$) [Measured mass density for Hidcote= 212 kg/m^3]

pf = fluid mass density ($\frac{Kg}{m^3}$) [Air density 1.21 kg/m^3]

c =overall drag coefficient – (Estimated as 0.8 (Crossley, 2001))

Assuming that the flower head of the lavender is a cylindrical shape it was found using the above equation that terminal velocity reaches the value of 4.0 m/s for the values shown.

Empirical determination of terminal velocity

Mueller, et al (1966) found the terminal velocity of black walnuts by placing the nut in a vertical air stream and adjusting the air velocity until the nut was suspended with little vertical movement. The above theory was used as a basis to find the terminal velocity of lavender flower head.

Materials and methods

To measure the terminal velocity of a lavender flower head a vacuum pump, a weight balance (resolution: 0.001 g), a variac, and three flower head samples were used. The flower samples were from *L.agustifolia Hidcote (silsoe)* cultivar and had a length of 15 cm including the stem. At the centre of the weight balance a small amount of blue tag (0.52 g) was attached and the instrument zeroed. A stem length equal to the sample was placed on the top of the weight balance and the instrument zeroed again, then the additional stem was removed and the test sample placed above instrument. The weight balance at this point measured the weight of the flower head only. The end of the stem from the flower sample was attached to the blue tag at 90° and a hose from the vacuum pump placed above the flower head. The hose had a 32 mm diameter and was lowered over the flower, completely covering it. The air velocity created from the air pump was controlled manually using the voltage controller (starting from 0 m/s). As the air velocity increased reduction of the flower head weight occurred. This was conducted to the point of zeroing the weight balance. At that moment the air speed was recorded and that number represented the terminal velocity (when a particle in free fall reaches it's terminal velocity the weight of it's mass is zero because an equal and opposite force is created by the air (Mohsenin, 1986)). Three samples and three replications in each sample were tested.

Results

Table 4.6 present the results from the terminal velocity test.

Table 4.6: Measurements in terminal velocity

Flower length mm	**Flower diameter mm**	**Flower weight g**	**Air velocity m/s**
50	11	0.53	4.5
60	11	0.66	5.9
50	13	0.68	4.8

Discussion

The terminal velocity was found from the tests (Table 4.6) exceed in a small amount those found using Lapple's equation. Taking into account the two approaches a range of 4 to 6 m/s as terminal velocity for the flower head can be used to determine the absolute lower limit of the air flow if air selected to be used in the final concept.

4.2.2.2 Flower aerodynamic drag resistance

An experiment was set up using *L. angustifolia Hidcote (Silsoe)* cultivar to identify the aerodynamic resistance of the flower head in an air stream.

Materials and methods

Inflorescences (including the stem) of 34 to 64 mm long were used for the experiments. A vacuum pump was used to create the air stream for the purpose of the experiment. Plate 4.4 shows the experiment set up. The plants were placed upside-down in the end of the vacuum hose. Into the end of the plastic hose, a clear plastic tube of 32 mm diameter was fitted. This permitted a clear view through the tube to record any reaction of the flower. At one end of the stem, a small diameter nylon line was attached. The other end of the nylon was attached to the load cell to measure the force as shown in Plate 4.5.

The test was conducted with air speeds of 24 m/s, 45 m/s and 65 m/s. Lower air speeds than 24 m/s weren't examined because the force created was very small and impossible to record with the Instron 1122 instrument (accuracy of the load cell 0.5% of indicated load). The air speed was measured using a vane anemometer. The force was marked using a pen and chart, on the recording part of the instrument. When one experiment was complete the same procedure was followed for the next flower. Fifteen treatments and three replications in each of the three different air speeds were examined and the results are shown in Table 4.7. Before each flower was tested measurements were taken of the length, width and weight of the inflorescences.

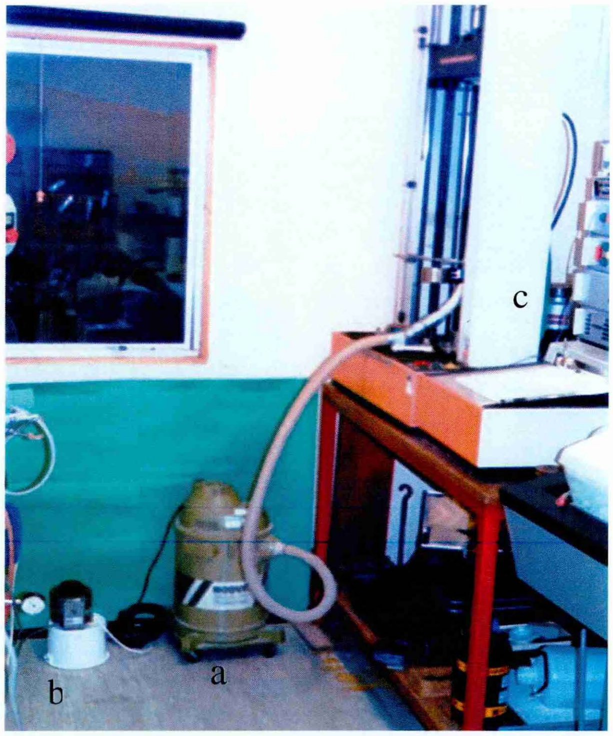


Plate 4.4: The equipment used for the airflow test
(a= vacuum pump, b= variac 0-240 Volt, c= load cell)

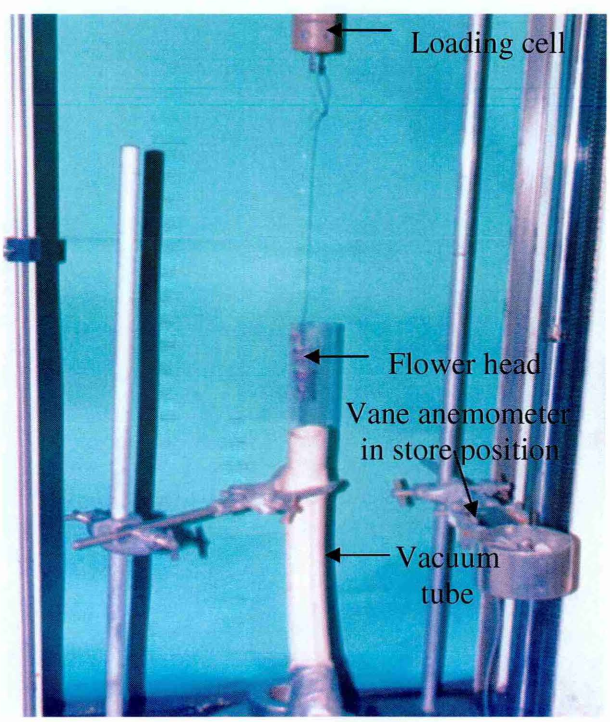


Plate 4.5: Flower drag measurement test lay out

Results

Table 4.7 and Figures 4.10 and 4.11 present the results from the flower head drag tests.

Table 4.7: Air resistance forces and dimensional data of the flower head shapes

Samples **N°**	**DRAG** **(N)** **Air speed 1** **24 m/s**	**DRAG** **(N)** **Air speed 2** **45 m/s**	**DRAG** **(N)** **Air speed 3** **65 m/s**	**Weight of flower** **g**	**Length of flower** **mm**	**Mean diameter of flower** **mm**	**Cylindrical Surface of the flower (estimated)** **mm²**
1	0.02	0.05	0.08	0.502	34	17	1814.9
2	0.02	0.05	0.08	0.530	47	13	1918.5
3	0.02	0.06	0.10	0.512	47	16	2361.3
4	0.02	0.04	0.07	0.542	38	14	1670.5
5	0.02	0.05	0.08	0.614	51	17	2722.4
6	0.02	0.04	0.08	0.674	60	17	3202.8
7	0.02	0.05	0.07	0.680	53	18	2995.6
8	0.03	0.07	0.12	0.650	64	16	3215.4
9	0.02	0.04	0.07	0.855	59	15	2778.9
10	0.02	0.05	0.08	0.591	36	17	1921.7
11	0.02	0.05	0.06	0.788	60	14	2637.6
12	0.02	0.04	0.06	0.528	55	13	2245.1
13	0.01	0.04	0.07	0.542	46	12	1733.3
14	0.01	0.03	0.05	0.503	56	12	2110.1
15	0.01	0.04	0.07	0.453	53	12	1997.0

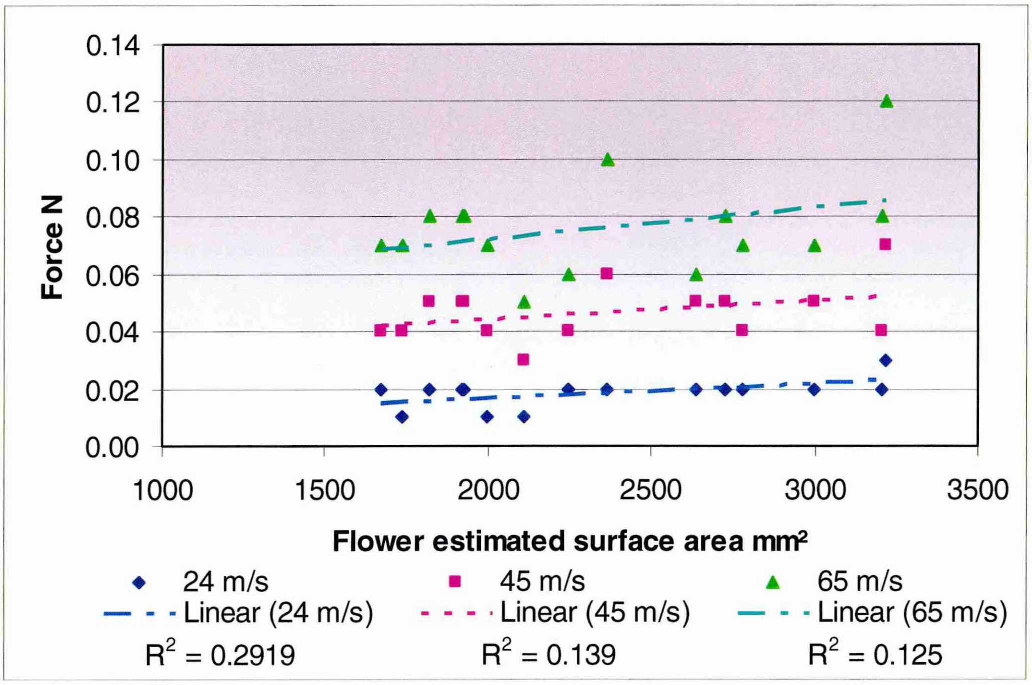


Figure 4.10: Air resistance flower force (N) and estimated surface area (mm²) for air stream velocities 24, 45 and 65 m/s

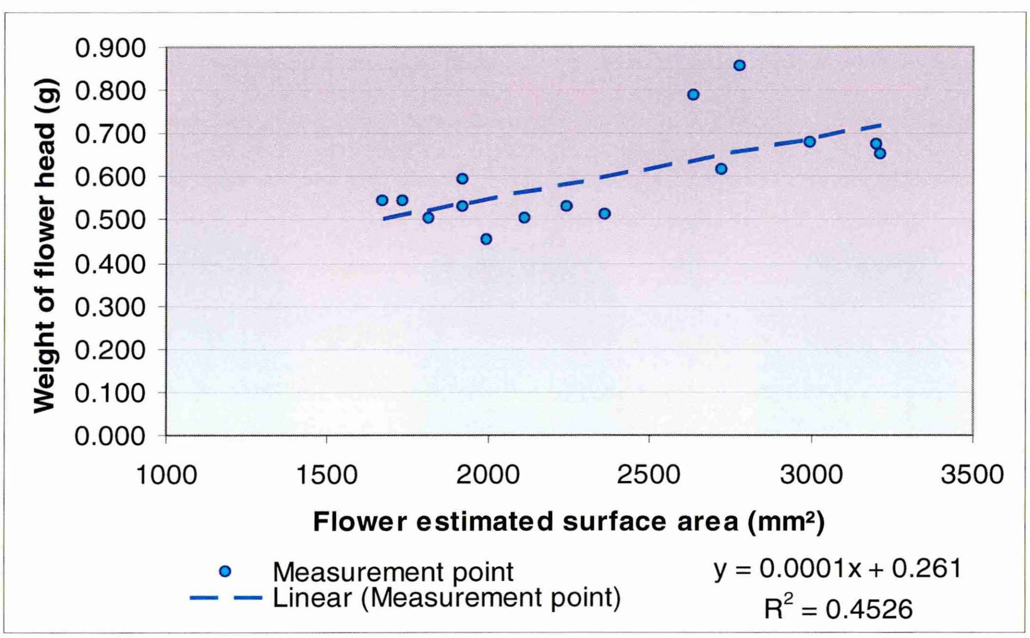


Figure 4.11: Relationship between weight (g) and surface area (mm²)

Discussion

Figure 4.10 shows that there is a trend for all air speeds which indicates an increase in the drag force required as the surface area increases. Differences have been expected to the real values of the measured force because the real shape of the flower head which is rhomboidal was taken as cylindrical for simplicity.

Figure 4.11 shows the relationship between estimated external surface area of the flower and the weight of the flower head.

4.3 Physical plant characteristics for the selected Lavender cultivars

Physical characteristics that describe common lavender cultivars are shown in Tables 4.8 & 4.9

Table 4.8: Lavender plant physical properties measured and calculated

No	Cultivar name	Flower average detachment force N	Stem average breaking force N	Stem average UTS MPa	Moisture content-flower detachment force relationship F= Force (N) MC= Moisture content (%)	Moisture content-stem break force relationship F= Force (N) MC= Moisture content (%)
1	*L. angustifolia Folgate (Hitchin)*	9.96	30.80	23.12	F = -0.0614MC + 14.113	F = -0.4808 MC + 59.443
2	*L. angustifolia Hidcote (Silsoe)*	8.64	28.90	12.13	F = -0.0937MC + 15.813	F = -0.3904 MC + 62.375
3	*L. angustifolia Hidcote (Swetsloots))*	7.12	39.60	18.07	–	–
4	*L. angustifolia Maillette (Hitchin)*	12.20	36.20	20.24	F = -0.0867MC + 18.14	F = -0.2909 MC + 58.557
5	*L. x intermidia Alba (Swetsloots)*	11.72	38.20	16.25	–	–
6	*L. x intermidia Grosso (Hitchin)*	15.04	38.50	13.05	F = -0.1543MC + 25.436	F = -0.8466 MC + 95.948
7	*L. x intermedia (Bioregional)*	15.56	46.00	17.93	F = -0.0805MC + 21.223	F = -0.5993 MC + 87.477

Table 4.9: Lavender plant specific physical characteristics measured and calculated for *Lavandula A. Hidcote* cultivar

Cultivar name	Flower head drag resistance relationship			Weight- estimated flower surface relationship	Terminal velocity m/s	
	24 m/s	45 m/s	65 m/s		Calculated	Empirical (max)
L. angustifolia Hidcote (Silsoe)	y= 5E-06x + 0.0064	y= 7E-06x + 0.0306	y= 1E-05x + 0.0498	y= 0.0001x + 0.261	4.0	5.9

Table 4.10: Lavender plant dimensional physical characteristics after McNaughton (2000)

		Lavender bush main dimensional characteristics			**Spikes (flowers)**			**Peduncles (stems)**	
N°	**Cultivar name**	B (cm)	H (cm)	H´ (cm)	Length (cm)	Width (mm)	Vertical alignment	Length (cm)	Width (mm)
1	*L. angustifolia Folgate (Hitchin)*	60-80	60-70	30-40	3.0-8.0	10-17	45°-90°	17-22	1.0-1.3
2	*L. angustifolia Hidcote (Silsoe)*	80-100	60-100	30-40	3.0-7.0	10-17	40°-90°	12-22	1.0-1.5
3	*L. angustifolia Hidcote (Swetsloots))*	80-100	60-100	30-40	3.0-7.0	10-17	40°-90°	12-22	1.0-1.5
4	*L. angustifolia Maillette (Hitchin)*	60-80	50-80	30-40	5.0-8.0	10-15	45°-90°	18-25	1.0-1.5
5	*L. x intermidia Alba (Swetsloots)*	80-120	80-100	40-50	4.0-5.0	13-18	30°-90°	25-32	1.3-1.8
6	*L. x intermidia Grosso (Hitchin)*	80-120	60-80	40-50	5.0-9.0	13-18	20°-90°	30-36	1.5-2.0
7	*L. x intermedia (Bioregional)*	80-120	80-120	50-60	5.0-8.0	15-18	45°-90°	20-30	1.5-2.0

Term explanation: B = Lavender bush width // H = Lavender bush height // H' = Lavender bush height after trimming (main bush height)

4.4 Summary for the physical characteristics of the lavender plant

Taking into account the results from the tests the following can be stated:

- Stem breaking force is always greater than flower detachment force for a given sample.

- The percentage moisture content of the plant affects the flower detachment force and the UTS. The results show that as the moisture content decreased the forces were increased.

- Terminal velocity was found to be at 6 m/s for *Lavandula a. Hidcote* cultivar.

5 Harvester design

In this Chapter the research strategy consisted of four main phases which are proposed by Pahl and Beitz (1999). The phases followed are explained here:

- The design of the harvester was started by classifying the requirements that the proposed solution should satisfy. The output of this phase was the product design specification (PDS) which includes the demands for matters such as safety, environment, performance, cost, manufacturing and maintenance.
- The conceptual design phase was the second step in which four different solutions (concepts) were developed and evaluated. At the end of this phase the concept scoring the highest value was selected for development.
- The third phase was the embodiment design during which the selected concept was analysed and the layout and shape of the many recessing components were developed and specified.
- Finally the detail design phase produced the drawings and material list required for the manufacture of the machine.

5.1 Product design specification (PDS)

The primary aim of the design was to create an improved machine for the harvest of lavender flowers for oil production for small scale enterprises. A secondary aim as requested by the client was to use recycled materials where possible in the design.
The PDS must be the main control criteria used during the design phases to help select the right solution from the different conceptual ideas. The following PDS was developed from measurements taken at the client's existing lavender field at Carlshalton. The PDS was developed to accomplish the lavender harvester requirements for small 1-2 ha enterprises.

Terrain

Usually lavender cultivation is on smooth slopes. The slope at the lavender field was found to be approximately 2% to 5%. Also the terrain can be rocky in lavender fields and a mean volume of stones at 160 cm^3 (approximate diameter of 67 mm ($\pi*d^3/6$)). Therefore an acceptable wheel radius would exceed 100 mm for adequate mobility.

Small overall size

The machine should be as small as possible to be able to turn at the edges of the field, because of the small field dimensions at small enterprises and the requirement to minimise the area of (unproductive) headlands. If the machine needs to be above the row the dimensions must be 1 m in width and 2.00 to 2.50 m in length. If the machine needs to be beside the row then the dimensions must be 2.00 m width and 1.50 to 2.00 m in length.

Ability to move on the ground between and over the rows

To achieve this goal the machine should be equipped with a power unit and propulsion system (either mechanical or human powered) to provide mobility on the ground. The operator will control the machine by driving or pushing it.

Ability to work at different heights above the rows of lavender

The width of the lavender rows was found to be 1 m. The bush stands (before harvest) 0.65 m to 1.00 m high. The width of the bushes varies dependants upon the year of growth and the cultivar and can reach a mean value 0.60 to 1.00 m for mature crops after the 3rd year of growth (under total canopy management regimes).

Operator safety and simple operation

The machine must move between and above the rows easily. Operator safety must be of primary importance, but all operations would be friend to use the machine in work and transport.

Plant

The product must be safe to operate and must ensure the plants are not damaged during the harvest operation. Pruning may be conducted as a secondly operation at the harvest if required.

Ergonomics

The operator interface should be at a suitable height and load. The container required for the collected lavender should be at a suitable height so that the worker can easily unload the machine.

Simple production and easy maintenance

Produce the machine using simple design solutions for the component parts so that maintenance will be logical and straight forward. Down time should also be minimized in the event of break down.

Harvesting capacity

The harvesting capacity must be more than 0.6 ha/day to ensure that it is considerably more than the hand harvesting method currently used by the client.

Volume of product to be transported

The volume of the collected lavender from the client's field of 1.2 ha for the 2000 harvest period was 40 m^3 using the hand harvest method. This volume yield was expected to be the same for 2001 harvest (Desai, 2001). If the field has 109 rows /40 m^3 = 0.367 m^3 per row. One row = 1.0 *110 m = 110 m^2 so from 110 m^2 we will collect 0.367 m^3. Therefore the container must be able to hold 0.367 m^3 of crop material and will need to be of minimum dimensions:

a) To collect the whole row: $\sqrt[3]{0.367}$= 0.72m*0.72m*0.72m

b) If half of the row is collected the volume will be $\sqrt[3]{0.183}$= 0.57m*0.57m*0.57m

c) If the collected crop can be emptied at any time, the dimensions can vary as the designer wishes.

However the utilization of stripping technology would be expected to reduce this volume at least 50%.

Machine forward speed

The machine must be designed around a field size of 1.2 ha as requested by the client. To find the forward velocity of the machine an assumption was made concerning the row lengths of the field. The row length was taken as 110 m. This was happen due the irregular shape of the field. The number of 110 m was found from measurements and represents the mean of those measurements. The field was 1.2 ha = 12,000 m² which approximately gives 110 m*110 m sides. The field must be harvested in two days (one day = 8 h of work). There are 109 rows, therefore 109/16 = 6.81 rows/h. Therefore the minimum forward velocity that the machine needs to attain is:

110 m*6.81rows/h = 749.1 m/h = 0.749 km/h / 0.95[2]= 0.788 km/h

Overall weight and component weight

The machine needs to be light for ease of transportation and ease of control during operation. A target weight of the final machine would be between 200 and 300 kg if a self propelled concept was used or 80 to 100 kg if a manually propelled concept was used to ensure good maneuverability.

Size of engine and fuel source

It was assumed that the power requirement for the engine must be 5 kW minimum (crop mechanism = 2 kW, machine movement = 2 kW, safety factor = 1 kW). The estimated power (5 kW) can be selected only if both movement (in two wheels) and cutting operation is to be considered. In any other case (e.g pushed instead of driven wheels), the power and the size of the engine could be smaller. Power sources, which are environmentally friendly and do not pollute the environment, should have priority. The type of fuel can be: direct current 12V or 24V electricity supplied by batteries, recharged via mains or solar, bottled gas, LPG, unleaded petrol, or diesel.

[2] 5% time losses to turn the machne at the edges and empty the container as best case scenario

5.2 Conceptual design

Conceptual design is part of the design process in which, by the identification of the essential problems, by establishment of functions structures and by the search for appropriate working principles and their combination the basic solution path is laid down through the elaboration of a solution principle (G. Pahl; W.Beitz, 1999).

5.2.1 Establishing Functions

A function analysis for the lavender harvester was used to guide the generation of alternative solutions. Figure 5.1 shows the function required by the machine.

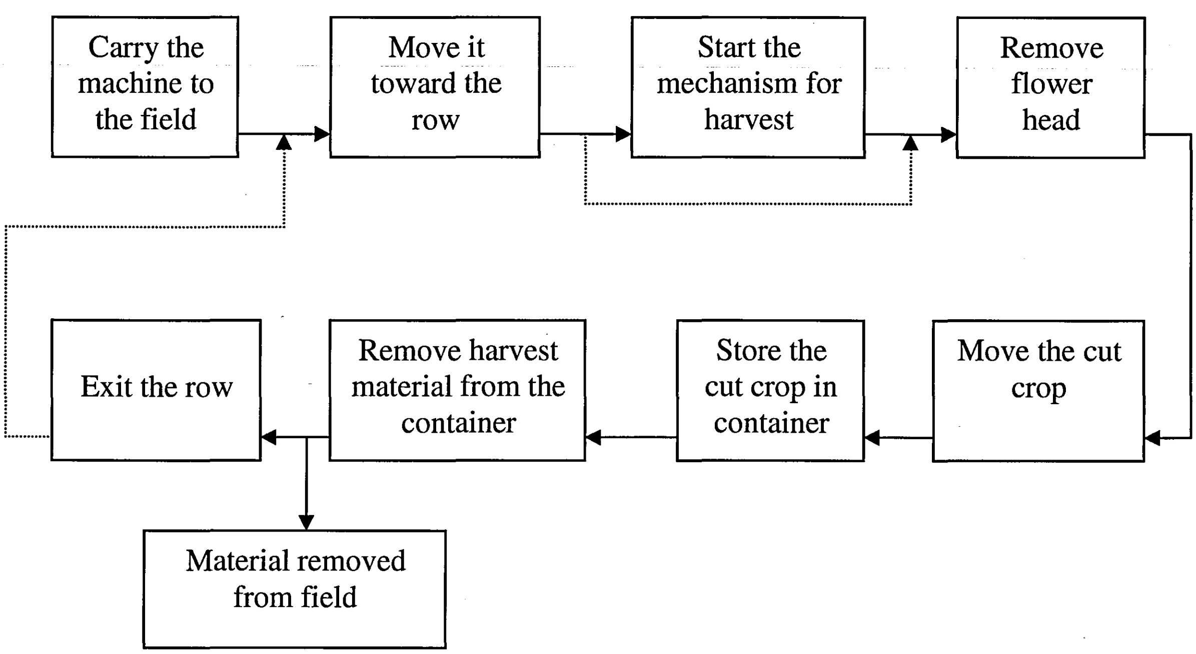


Figure 5.1: Function analysis of the lavender harvester machine

5.2.2 Concept Generation

It is important to generate a range of alternative design solutions for the machine, as it will help the researcher to identify new solutions. The concept solutions are shown in Table 5.1.

Table 5.1: Conceptual solutions

No	Function	Solutions					
		a	b	c	d	e	f
1	Support	Wheels	Skids	Tracks	Air Cushion		
2	Propulsion	Driven Wheels	Pushed	Air Thrust			
3	Power Source propulsion	Human power	Solar	Batteries	Gas	Petrol	Diesel
4	Power source crop mechanism	Land power	Petrol	Diesel	Gas	Electricity	
5	Transmiss-ion	Belts	Chains	Gears and shafts	Electric	Hydraulic	
6	Steering	Skid steer friction	Turning wheels	Free caster wheels			
7	Stopping	Brakes	Human power				
8	Parking Brake	Hydraulic	Human power	Mechanical	Transmiss-ion lock		
9	Cutting	Cutting bar	Disc cutter	Suction	Strip rotor	Internal Stripping Rotor	
10	Move the crop	Suction	Air flow	Belt conveyor	Chains conveyor		
11	Temporary storage of cut crop	Metallic container	Plastic container	Flexible sack	Plastic mesh	Metallic mesh	
12	Unload of the crop	By hand	Belt conveyor	Chain conveyor	Suction	Gravity	
13	Transport of cut crop	Metallic container	Plastic container	Plastic bags	On carriage		
14	Operator position	Standing at the rear	Walking	Seated at front	Seated at rear	Remote control	
15	Frame	Steel	Aluminum	Plastic	Wood		

5.2.3 Optimal proposal for the lavender harvester

From Table 5.1 the advantages of each solution shown are discussed in this section.

Support

Regarding the support function, Table 5.1 shows four different solutions. Air Cushion needs high power requirements and will increase the final cost of the machine so no interest was given to that solution. Tracks can be a solution but they are more complex and expensive elements than wheels. Skids are much cheaper than the other solutions but the friction on the ground is not suitable for hand or self-movement of the machine in the expected conditions. A wheel with a pneumatic tire is another alternative. These can be found in different sizes and provide a simple cost efficient mechanism to provide good mobility. From the above it is shown that the wheels are the most effective solution. Thus, this solution was selected.

Propulsion

For the propulsion function three different solutions are displayed in table 5.1. Air thrust will increase the final cost of the machine. Moving the machine by hand could be a solution but it would be difficult if the final weight of the machine exceeds 100 kg. A better solution is to use a drive mechanism which will give the operator the ability to steer the machine more easily than to push and steer at the same time. Wheels and a drive mechanism would be the preferred solution for the propulsion of the machine.

Power source propulsion

The machine can be powered either by an electric motor, human force or an internal combustion engine. When comparing these methods of powering the machine the use of electricity is better due to the simplicity of the power transfer. But has a disadvantage of high price and also during the harvest period it might need an extra stop to recharge the batteries which is not preferred. Petrol engine compared to diesel is cheaper, lighter and easier to use. The gas engine is almost the same as the Petrol but the stored gas needs special care and it will increase the total weight of the final machine.

The most reasonable solution to the selection of the power function is petrol due the purchase cost per kW being higher for a diesel engine of the same size. If the usage were expected to be much higher then the diesel option will be preferred due to its lower whole life costs.

Power source crop mechanism

To give power to the crop mechanism five different components are investigated. Land power is one of them. Using a fixed wheel in contact with the ground this movement can operate the mechanism that removes the head of the lavender plants. Rocky ground may affect the normal operation when the wheel hits a stone and changes the speed of the mechanism. The use of such a mechanism will add more components and is an inefficient way of transferring the energy due to frictional losses. This makes the maintenance of the machine more complicated. An alternative option is to use an engine. The engine can be petrol, diesel or gas. Also it can be said that the same engine can be used to operate functions of the propulsion and the rotation to the head removal mechanism. In that case the same petrol engine is the best solution. The use of electricity even though it is simple will increase the total cost and the total weight of the machine and may cause delays in the harvest procedure when batteries were used. In case the electricity produced by an internal combustion engine the cost will rise affecting the total cost of the machine.

Transmission

Gears and shafts can provide transmission. It is a very compact system compared to other systems for the same reduction ratio. Chains and belts are good when shafts are not close to each other and can tolerate more errors in shaft position. Hydraulic drives are more flexible but have a higher power requirement. Belts and chains are the cheapest concept. The belts to be used for high speeds and the chains in low speeds applications.

Steering

The machine can have fixed wheels, free caster wheels or operator controlled turning wheels. A combination of fixed and free caster wheels can give the required maneuverability at the edges of the client's field. In the case were the machine has fixed and free caster wheels and the operator walks behind the machine to control it, the fixed wheels must be at the front of the machine.

Stopping

Stopping the machine can be achieved by using brakes or human power. The use of human power to stop the machine is not a safe way to control a machine. A brake system can be placed on the driving axle, within the transmission system or at the wheel. Brakes at the wheels are safer than the other systems but add more parts to the machine which will add to the final cost. It should be noted that the forward speed of a machine whose operator walks with it will be low (min = 0.788 km/h, max = 3.0 km/h). Although Amitabha et all., (1992) in his research indicates a preferred walking speed of 5.0 km/h for agricultural operations, 3.0 km/h was chosen as being more suitable for safe control of the machine during harvest due to the characteristics of the ground (inclined and stony).

Parking brake

Parking brake is another function that needs to be considered. To achieve this goal a separate mechanism may need to be developed if the stopping brake mechanism cannot be used as a parking brake.

Cutting

A cutter bar can be used to remove the flower head from the plant. The disadvantage of this technique is that a percentage of stems from the plant will be collected with the flower head, which will increase the volume of the collected plant material. An increase in the volume of harvested material will affect the dimensions of the storage container and the costs of subsequent processing. Cutter bars use maximum knife speeds of 3 to 4 m/s and have a power requirement as low as 1-2 kW/m (O'Dogherty & Gale, 1986). The same function can be achieved using the impact cutting principle with disc cutters. The power requirement for disc cutters is 10 to 12 kW/m of mower width and knife speeds

80-90 m/s (O'Dogherty & Gale, 1986). Use of suction to remove the flower from the stem is another solution and may have good results but with high power demand and probably oil loss. Another solution is the use of a stripper rotor. The stripper uses a transverse rotor in which stripping of the crop takes place along the whole length of the rotor. The rotor, fitted with keyhole-slotted teeth, rotates opposite to the direction of travel and combs the plant from the stem as the rotor is propelled through the crop (Klinner et al., 1986b). The average maximum power requirement for the stripping rotor to harvest cereals is 3-5 kW/m (Hobson et al., 1988). The stripper rotor is capable of harvesting wheat, barley and rice efficiently and has been used to harvest different plants such as navy beans, oats, linseed and grass seeds although less efficiently (Hobson et al., 1988).

No previous research work has applied the rotor stripper to the harvest of lavender flower. The application of stripping technology to harvest other specialist crops as lavender is an area where potential for development exists. The use of a stripper rotor on a harvest machine for lavender could produce a smaller, lighter and cheaper solution. This harvesting method has the potential to be much more efficient for small-scale producers. The most reasonable solution is the use of a stripper rotor to collect the head of the lavender plant.

A similar approach to the stripping rotor for the lavender harvest could be the internal stripping rotor. A cardboard model was built as a concept based on an idea of the Author (Plate 5.1). Instead of having fixed stripping elements assembled at the drum of the stripping rotor, moving stripping elements were placed. The rotation of the rotor is opposite to the direction of travel. The stripping elements are attached with a joint at the surface of the drum and are capable to open and close the external surface of the drum which is cut at that area. The stripping elements are placed on the top of those cuts and they play a role of a guard. When the stripping element in its circular path is above the row it is open and detach the flower heads but when leaves the row closes and brings the stripped crop at the internal of the drum. Internally an auger (which is assembled with a half cylinder drum; the half cylinder is not rotating during operation) receives the cut plant material and guides it to the one side (right hand) of the machine.

Although the rotor could be used at a very low speed and appears to have design potential it was considered to be too impractical at this stage in the design process as it is a complex mechanism which will increase the total cost. This approach should only be serious considered should the stripping rotor not prove to be successful.

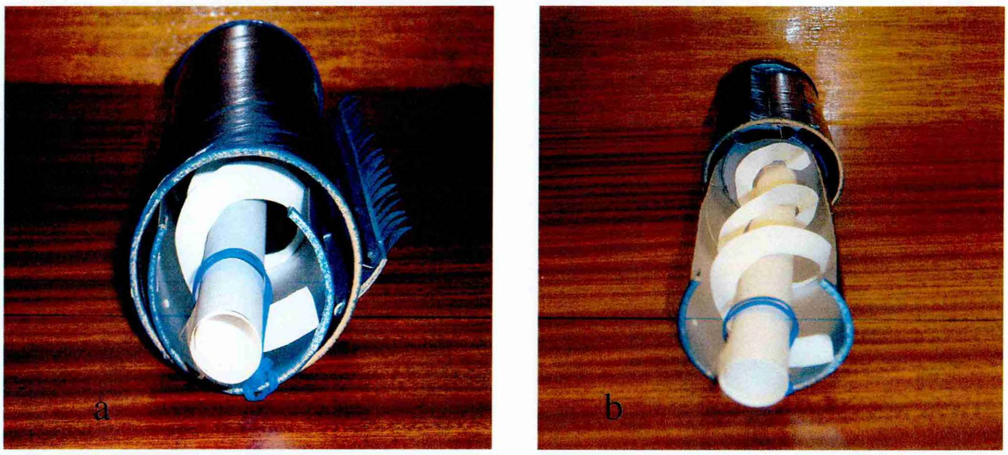


Plate 5.1: Cardboard model of ARTEMH concept (a = rotor at work position, b = the auger and half cylinder partially removed for illustration)

Move the crop

The movement of the cuttings or removed lavender plant could be achieved using belts or chains. This solution has the consequence of increasing the power demand of the machine and adds an extra mechanism to operate and maintain. Suction is an effective solution but it increases the power demand and requires a turbine to create the airflow. On the other hand the use of a stripper rotor can create airflow. Thus, the crop could be easily transported by air flow created by the stripping rotor. In the case that the airflow is not able to remove the plant head from the stripping elements (because the stripping rotor has been designed to strip cereals) a small fan could be used to promote a desirable air flow.

Storage of the cut crop

For the temporary storage of harvest material on the machine five different solutions are presented in Table 5.1. Harvest material can be stored in a metallic container or in a plastic container. Plastics need special preparation to give them shape but they are lighter and cheaper than metal. Metal, on the other hand is easier to form by welding and the use of recycled materials is much easier. The use of a flax sack is another solution that could be used.

Crop unload

To unload the crop from the temporary storage container three different concepts were studied. These concepts consist of unloading by hand, belts or chains. The most logical solution is to unload the machine by hand due to the cost of the other systems, for what is a small volume (0.367 m^3) of harvest crop.

Transportation of the cut crop

Transportation of the cut plant to the edge of the field each time the container is full could be done either by using a small carriage or by hand. However, using a small carriage will increase the total cost. Thus, the most reasonable solution for transporting harvested plant material from the field to the edge of the field is by hand using suitable container.

Operator position

The best position for the operator would be on the top of the machine but this would not be a cost effective solution for such a small machine and will decrease the stability of the machine due to the increase in the centre of gravity of the machine. Therefore the operator position is best located at the rear of the machine so that he can steer the rear of the machine and has a good view of the container and the machine movement.

Frame

With regards to ease of manufacture and cost constrains, the frame of the machine could be made of steel as weight is not of primary concern.

5.2.4 Concepts

5.2.4.1 Proposed Solutions

The concept for each function was selected from the morphological chart (Table 5.1) using the design objectives and specifications (PDS). Considering all of the proposals 4 solutions were selected employing different configurations of the conceptual solutions. Conceptual designs are presented in Table 5.2.

Table 5.2: Conceptual designs

		Conceptual design solution			
No	**Functions**	***ARTEMH***	***ARETH***	***ANDIGONH***	***ARETHOUSA***
1	**Support**	Wheels	Wheels	Wheels	Wheels
2	**Propulsion**	Driven Wheels	Pushed	Driven Wheels	Driven Wheels
3	**Power**	Petrol	Petrol	Batteries	Petrol
4	**Transmission**	Belts	Belts	Electro power	Belts
5	**Steering**	Free caster wheels	fixed wheels	Controlled wheels	Turning wheels
6	**Stopping**	Brakes	Human power	Brakes	Brakes
7	**Parking Brake**	Expander mechanism	Expander mechanism	Electro power	Electro power
8	**Cutting**	Strip rotor	Strip rotor	Cutting bar	Internal stripping rotor
9	**Move the crop**	Air flow	Belts	Belts	Air flow
10	**Storage of cut crop**	Metallic mesh	Plastic mesh	Metallic mesh	Plastic mesh
11	**Unload plant material**	By hand	Belts	Chains	On carriage
12	**Transport of cut crop to field edge**	Plastic bag	Plastic container	Metallic container	Plastic bag
13	**Operator position**	Walking	Walking	Walking	Walking
14	**Frame**	Steel	Steel	Steel	Aluminum

5.2.4.2 Conceptual Layout

The objective of this section is to describe the layout and spatial arrangement of the 4 concepts, using the elements from the morphological chart. Figures 5.2, 5.3, 5.4 and 5.5 illustrate the different solutions. Concepts were drawn by hand to scale were then scanned to provide the images shown. Orthographic views are shown in Figures A5.1-A5.4, Appendix 5.

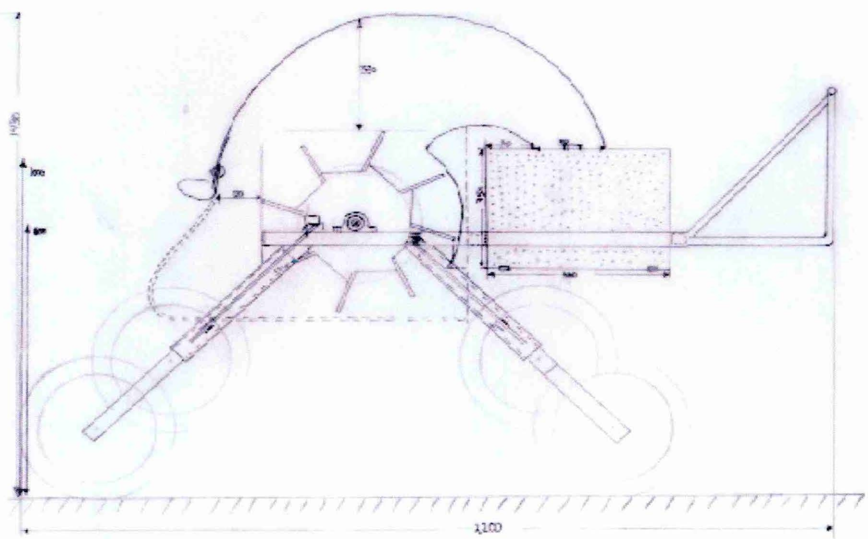


Figure 5.2: Proposal N^o 1 ARTEMH (side elevation, engine on far side)

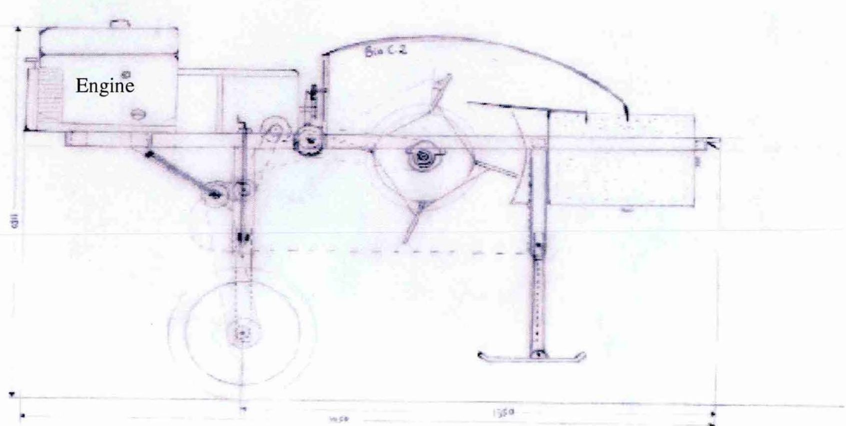


Figure 5.3: Proposal N^o 2 ARETH (side elevation)

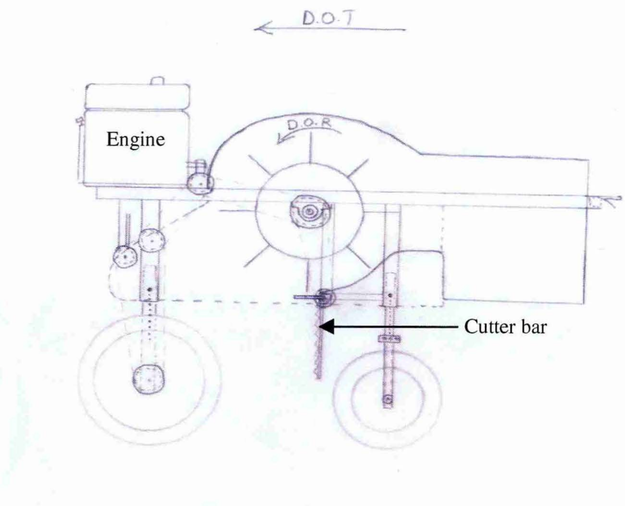


Figure 5.4: Proposal N° 3 ANDIGONH (side elevation)

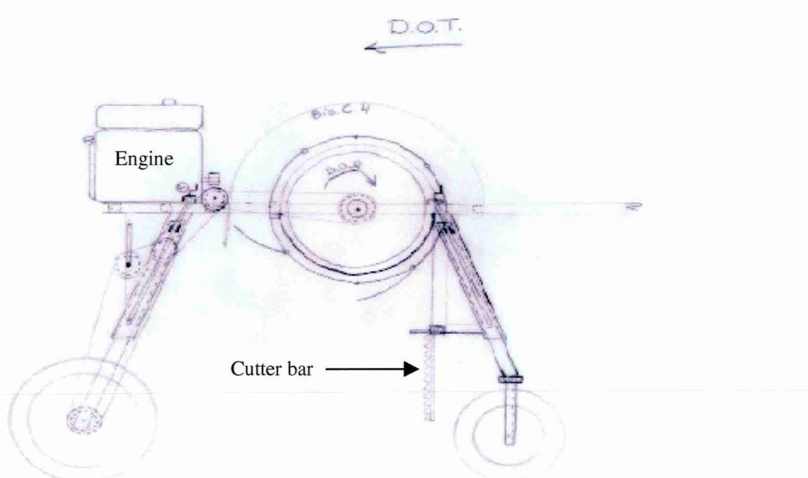


Figure 5.5: Proposal N° 4 ARETHOUSA (side elevation)

5.2.5 Evaluation

The 4 concepts were evaluated using ten factors each with an individual weighting. The results are shown in Table 5.3. The weighting subjectively chosen using the best information available at that time as discussed in the literature review.

Table 5.3: Tabular Matrix for the evaluation of the lavender harvester concepts

	Concepts											
	ARTEMH			*ARETH*			*ANDIGONH*			*ARETHOUSA*		
Evaluation criteria	**Weight (%)**	**Rating (1-10)**	**Score**	**Weight (%)**	**Rating (1-10)**	**Score**	**Weight (%)**	**Rating (1-10)**	**Score**	**Weight (%)**	**Rating (1-10)**	**Score**
Safety	20	5	1.00	20	5	1.00	20	5	1.00	20	4	0.80
Reliability	10	6	0.60	10	6	0.60	10	7	0.70	10	6	0.60
Performance	15	5	0.75	15	5	0.75	15	5	0.75	15	4	0.60
Ease of control	12	7	0.84	12	5	0.60	12	6	0.72	12	7	0.84
Ease of manufacture	5	5	0.25	5	6	0.30	5	3	0.15	5	3	0.15
Production cost	5	6	0.30	5	7	0.35	5	3	0.15	5	8	0.40
Crop losses	10	6	0.60	10	6	0.60	10	7	0.70	10	6	0.60
Durability	10	7	0.70	10	7	0.70	10	7	0.70	10	7	0.70
Low fuel consumption	8	6	0.48	8	7	0.56	8	5	0.40	8	7	0.56
Light weight construction	5	5	0.25	5	6	0.30	5	3	0.15	5	8	0.45
Total	100		5.77	100		5.76	100		5.42	100		5.70

A study of the concept evaluation table shows that all the concepts have quite similar scores but concept ARTEMH has the highest score of 5.77. Therefore ARTEMH was chosen as the basis for the embodiment design with consideration of the features of ARETH.
The difference in values from the evaluation of the 4 concepts was small. This was because the concepts all achieved high scores in the categories with the highest weight including safety, performance, reliability and durability.

5.2.6 Conclusions

The main conclusions from the conceptual design are:

- A secondary pruning operation will be necessary to ensure a more uniform crop height, which in turn will lead to a more efficient harvesting operation

- Four conceptual designs have been produced 2 of which satisfy the PDS to a greater extent and these were ARTEMH & ARETH.

ARTEMH should be used as the basis for the conceptual design with the advantageous features of ARETH included where possible.

5.3 Embodiment design

The design process, which develops concepts to the point where the subsequent detail design leads to the manufacture, is called embodiment design. The concept selected to be developed following the conceptual design was ARTEMH. Throughout the embodiment design different layouts of the shape and component orientation were explored.

Frame

The frame for the prototype was a rectangular 60 by 60 mm square steel tube of 4 mm wall thickness. Because all the mechanisms engaged to the frame special attention was given to its design and construction. The legs of the harvester were welded at 45° angle. This was made to allow the harvester to have a better stability when a higher height was used.

Engine and gearbox

The engine and the gear box were chosen from a small second hand cultivator provided from the client. The engine power was 7 kW and satisfied the power demands of the harvester which were estimated to be approximately 5 kW (section 5.1, size of engine and fuel source). The gear box had 3 forward and 2 reverse gears. The gear box was also suitable for the break function because a transmission break worm drive was used as the primary reduction therefore preventing reverse drive of the gearbox. The ratios of the three gears were measured and sprockets chosen to allow the harvester to move in a range of 0.3 to 3.0 km/h as required from the PDS and the experiments. A bespoke drive shaft was designed to be fitted to the tail of the gear box to provide the drive output to the stripping rotor. The gear box featured 2 additional outputs, one of which was used to provide the primary drive output for the wheels and the other was guarded and remained unused.

Rotor

The actual crop harvest height variation was measured at Carlshalton field and found to be 600 mm, (from 400 mm to 1000 mm) however the tallest plants were assumed to bend over before impact by the stripping rotor by 200 mm, caused by the hood nose. Therefore the minimum rotor radius was chosen to be 400 mm. For practical construction reasons a final diameter of 780 mm was chosen.

The work of Klinner et al., (1986c) found a peripheral speed of 21 m/s and 61 impacts/m performed well when harvesting spring barley and therefore this peripheral speed was adopted as a design constant, with the rotor speed and the number of stripping elements remaining as design variables. The density of lavender is considerably less compared to barley for which the original was designed. The approximate barley density was 600 plants/m² compared to the "Bioregional" cultivar at Carlshalton field of 280 plants/m². Therefore 30 impacts/m forward travel was chosen to prevent excessive lavender stem being harvested.

The calculated rotor speed to achieve the 30 impacts/m using the 3 km/h forward speed (taken as max limit from the PDS, section 5.2.3) and 780 mm rotor diameter was found to be 375 r.p.m with 4 stripping elements. Using standard components for the drive system a rotor speed of 360 r.p.m was selected. To allow optimisation of the machine the rotor speed was capable of being reduced to 210 r.p.m and increased to 510 r.p.m.

Hood cover and hood nose

The hood cover and the hood nose were made of metal sheet of 1 mm thickness. Its dimensions in relation to the rotor were derived from the previous research from Klinner at al., (1986d). One side of the hood cover was made of Perspex to allow a view of the internal components of the machine.

Differential and rotary motion delivery to the wheels and to the rotor

To deliver the rotary motion from the gear box to the drive wheels a differential and a system of sprockets and chains were used. The differential chosen was a second hand recycled unit from a Suzuki 500 cc 4WD quad bike. The differential was initially designed to be a front L.S.D. However the required torque to generate the differential action was far to high for this application. Therefore the differential was modified to standard differential by removing of the friction plates and ramps. The output from the differential was connected to the 2 drive wheels via chain and sprocket drive.

Side covers and dividers

Metal sheets of 1 mm thickness were used for the side covers. The dividers were modified units from a New Holland TX series combine.

Container

The container was designed to meet the PDS requirements, the volume being 0.367 m^3. For the frame of the container an angle metal of 3 mm thickness 20 by 20 mm was used. The bottom 1/3 of the container was covered with a metal sheet using pop rivets. The rest top of the container was covered with a copper mesh. The reason was to create a large pressure drop, therefore reducing the air velocity created by the stripping rotor, and make the crop fall out and separate from the air stream. Two drawers, one at the vertical left side of the machine and one at the bottom of the container were made to unload the harvest material.

Steering and controls

The steering handle and all the remote controls for the engine were taken from a small cultivator. The cables lengthened and levers modified to suit the new application.

Wheels

Two pneumatic agricultural trend pattern wheels were used as the fixed drive front wheels. The diameter of the wheels was 240 mm and satisfied the PDS requirement. Two axial shafts were designed to couple the wheels to the sprockets through to plammer block bearings. For the rear two caster wheels with pneumatic tyres were used to give the mobility into the harvester for easy turn (wheel diameter=100 mm, maximum load 100 kg per wheel).

Safety guards

All the exposed rotating parts from the harvester were covered with metal guards for the safety of the operator and bystanders.

5.4 Detail design

The detail design of the concept elements was conducted using the PDS and data generated from the study of the interaction between machine and lavender plant. The definitive layout provides a check of function, strength, and spatial compatibility. The main drawing was conducted using the Mechanical Desktop 4 software. The detail design is shown in Appendix 5.2. Figure 5.6 shows a side view of the prototype and Figure 5.7 shows a 3D view of the prototype.

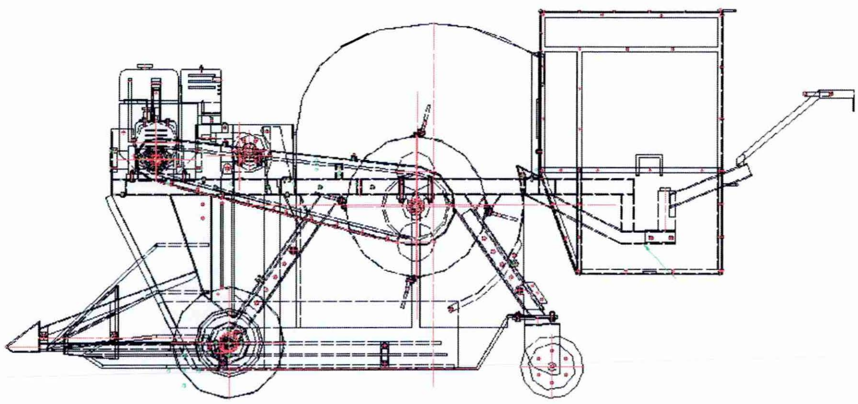


Figure 5.6: Side view of the prototype assembly

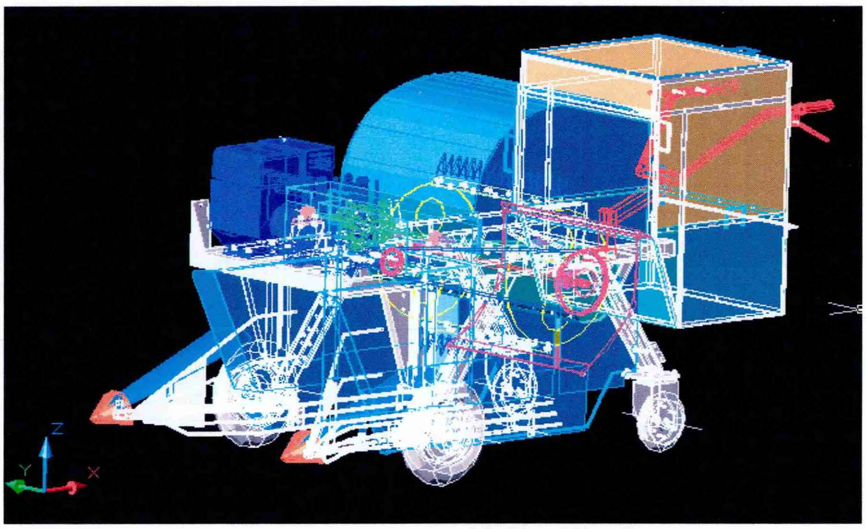


Figure 5.7: 3D rendered view of prototype with hidden lines shown

5.5 Prototype manufacture

The lavender harvester prototype shown in Plate 5.3 was manufactured in the workshop at Cranfield University, Silsoe (Plate 5.2). The machine construction required approximately 500 man hours.

Plate 5.2: Prototype under construction (from left to right: Christos I. Dimitriadis, Phil Trolley, Mick Cox, Dr. James Brighton, Dr. Terence Richards)

Plate 5.3: Isometric view of the produced prototype

6 Harvester evaluation

The prototype evaluation consisted of 3 separate test programs. Table 6.1 shows the test program list, which contains preliminary, laboratory and field evaluations to ensure that the design met the harvesting requirements by optimising forward and rotor speed together with the positions of the hood nose and operating height.

Table 6.1: Overview of prototype evaluation

Test program	*Test N^o*	*Date*	*Test purpose*	*Section*
Preliminary		August 2001	Prototype evaluation	6.1
Laboratory		March 2002	Air flow identification	6.2.1
		March 2002	Air flow improvement	6.2.2
Field	1	July 2002	Prototype evaluation	6.3.1.1
	2	July 2002	Prototype evaluation	6.3.1.2
	3	July 2002	Prototype evaluation	6.3.1.3
	4	July 2003	Prototype evaluation	6.3.1.4

6.1 Preliminary field tests (2001 harvest)

A preliminary test program was conducted to determine the general performance of the machine. In 2001 a 1.2 ha field at Carlshalton (South London UK) was used (Plate 6.1). The flower harvest was measured as numbers of flower heads. The plants had been planted at one meter spacing within the row and the mean width of each row was 0.80 m. The mean height was found to be 0.90 m. The mean moisture content of the plants was found to be 62% w.b.

Plate 6.1: Lavender harvester at first field trial (2001 harvest season)

Materials and Methods

To conduct the experiment the following equipment was used:

- The prototype Lavender harvester,
- An 1 m^2 quadrat,
- A Tachometer to measure the r.p.m of the rotor (tachometer resolution 1 r.p.m).

A split plot randomised design using 2 blocks was used. Each block consisted of nine treatments. Three different forward speeds and three different rotor speeds were examined. Two measurements conducted in each treatment using the quadrat to identify the number of lavender flowers existing before the harvester harvested the 50 m row. Those measurements were taken 15 m apart on each end of the row.

The flower heads remaining on the stalks and the flower head losses found on the ground after harvest were measured as numbers of flower heads and recorded giving the mean head losses.

Machine set up

The machine settings used for this preliminary trial were:

- Rotor shaft height from the ground 760 mm
- Hood nose below rotor shaft[3] 50 mm
- Angle of stripping elements 15°
- Rotor width 600 mm

These settings were chosen as a best estimate considering the size of the plant within the field to be harvested based on the previous work by Klinner et al (1986c) for the harvest of spring barley. These settings were chosen as being those of the cereal crop closer in form to lavender.

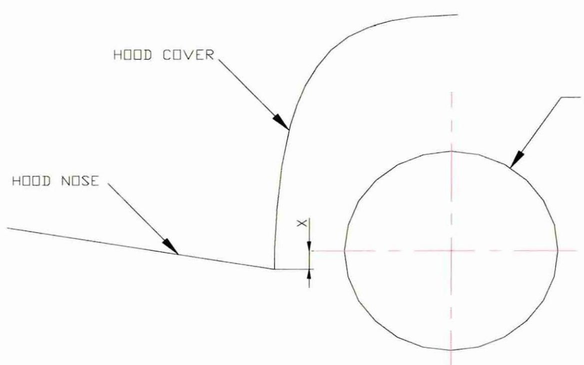


Figure 6.1: Main component explanation of the cutting mechanism (side view)

[3] Figure 6.1: x distance = 50 mm

Results

The 1.2 ha field area was harvested in 16 h (harvester work rate: 0.075 ha/h) and the machine consumed 5 litres of petrol. Two persons were used to conduct the harvest. Table 6.2 shows the results from the preliminary field test trials at Carlshalton area.

Table 6.2: Flower head harvest from preliminary field tests

Rotor speed r.p.m	Forward velocity km/h	Forward velocity m/s	Mean flower head harvest %
210	0.13	0.04	92.2
210	0.30	0.08	95.3
210	1.30	0.36	78.9
360	0.21	0.06	96.7
360	0.50	0.14	95.8
360	2.22	0.62	90.3
510	0.33	0.09	92.9
510	0.76	0.21	96.5
510	3.46	0.96	95.3

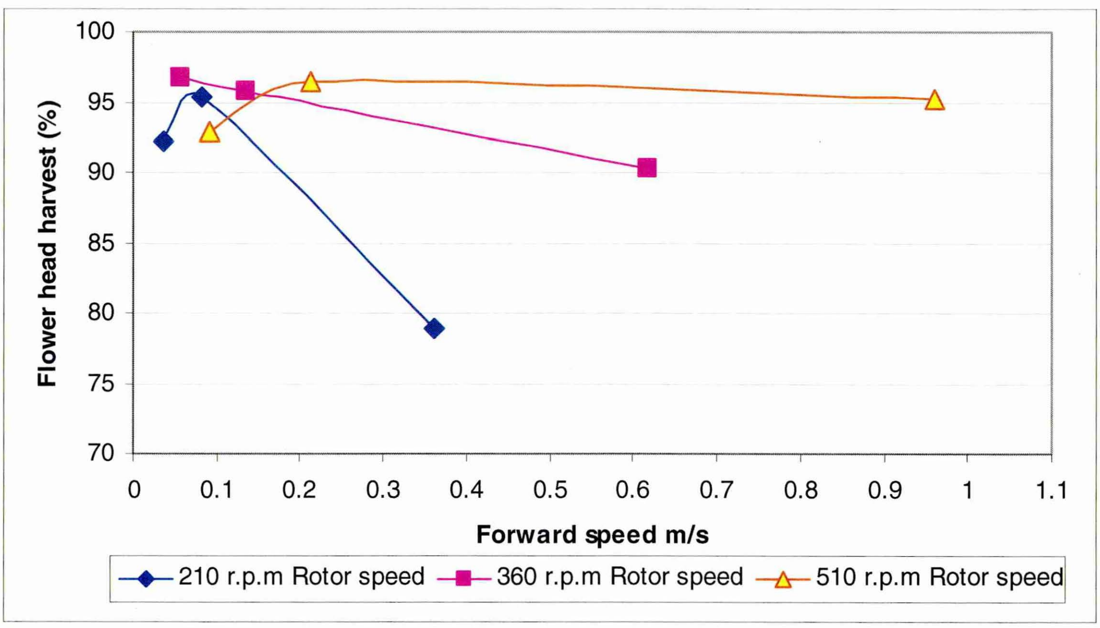


Figure 6.2: Flower harvest percent at different forward speeds (preliminary field trials 2001)

The mean flower head harvest ranged from 78.9% to 96.7% as shown in Table 6.2 and Figure 6.2. Figure 6.2 shows that the 210 r.p.m and the 510 r.p.m rotor speed exhibit a parabolic relationship. Starting at low values of harvest flower heads at low forward speed, reaching a maximum high value as the forward speed increased which then followed by a decline till forward speed reached its maximum value. The trend for the 360 r.p.m line was approximately linear demonstrating an increase in flower head harvest at lower forward speed with a decrease at higher forward speed. The data also show that at 360 r.p.m and 510 r.p.m, flower head harvest was less affected as the forward speed increased. It could therefore be assumed that higher velocities can be used to reduce the harvest period without sacrificing the efficiency of the machine in terms of flower head losses, and reducing the final cost of harvest if the quality of the harvested plant material is not reduced.

Further detailed research in which the quality of the harvest procedure was determined is presented in section 6.2.

6.2 Laboratory tests

Following the preliminary field trials two laboratory tests considering the airflow surrounding the machines stripping rotor were conducted to determine and optimise the effectiveness of the machine. In the first test the existing status of the air velocity and direction were recorded. In the second test improvements to the air flow direction and velocity were made.

The air flow from the rotor has an influence on the detached plant material which is transported from the point of stripping to the storage container. Flower head losses that were observed from the front entrance of the prototype during the preliminary harvest trials might be decreased if the air direction can be controlled.

6.2.1 Identification of the air flow surrounding the stripping rotor

The first measurements regarding the air's velocity and direction had the aim of mapping the air flow characteristics such as to identify areas that need to be improved for the optimum performance of the machine. In addition, the measurements were used as a basis from which to compare the differences in air flow when other modifications such as to the rotor, hood cover and hood nose were made.

Materials and methods

The materials used to conduct the air flow measurements are listed bellow:

- The lavender harvester machine,
- A pitot tube pressure measurement instrument,
- A Tachometer to measure the rotor speed (resolution 1 r.p.m),
- A 10 m measure tape,
- A stand to keep the pitot tube at a specific point,
- An air flow mesh for the determination of air flow direction.

The machine settings were the same as those used for the preliminary tests and the internal shape of the harvester remained the same during the experiment. The experiment was conducted at the Wind Tunnel Laboratories at Cranfield University. For the identification of the air-flow direction a mesh was used to which small length light strings were attached in each node of a 10 mm square grid. The grid can be seen in Plates 6.2 and 6.3.

To determine the velocity of air flowing though the harvester a Pitot tube instrument was used. The Pitot tube was a straight line tube and has a single facing hole to measure the total head and a ring of side holes that measure the static head, connected by concentric tubes to the end and side connectors at the tail. The two exits were connected with P.V.C. tubes to the main recording instrument, to measure the difference in pressure (total-static).

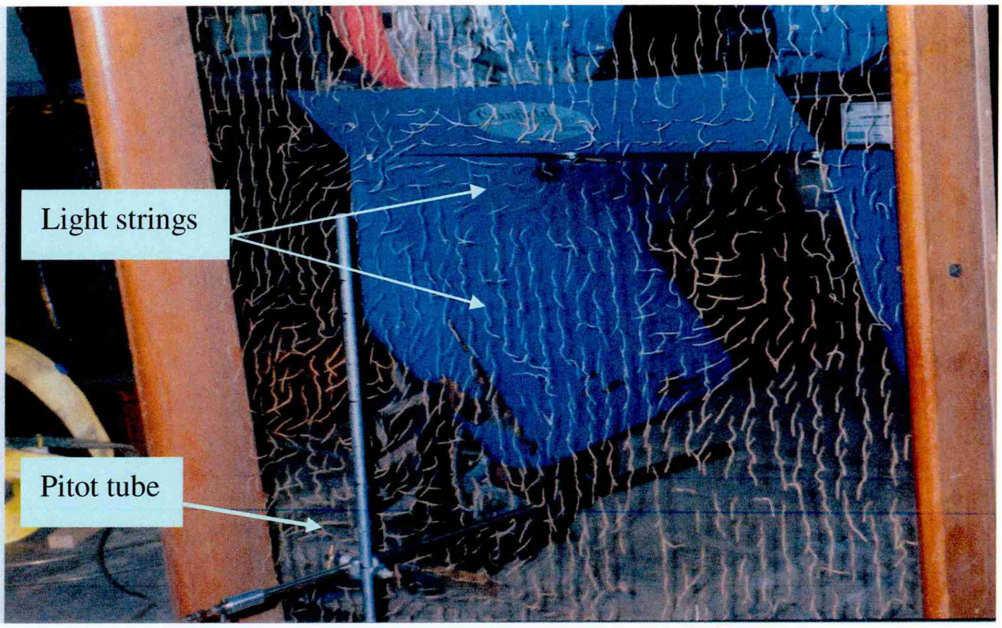


Plate 6.2: Air flow characteristics at crop intake

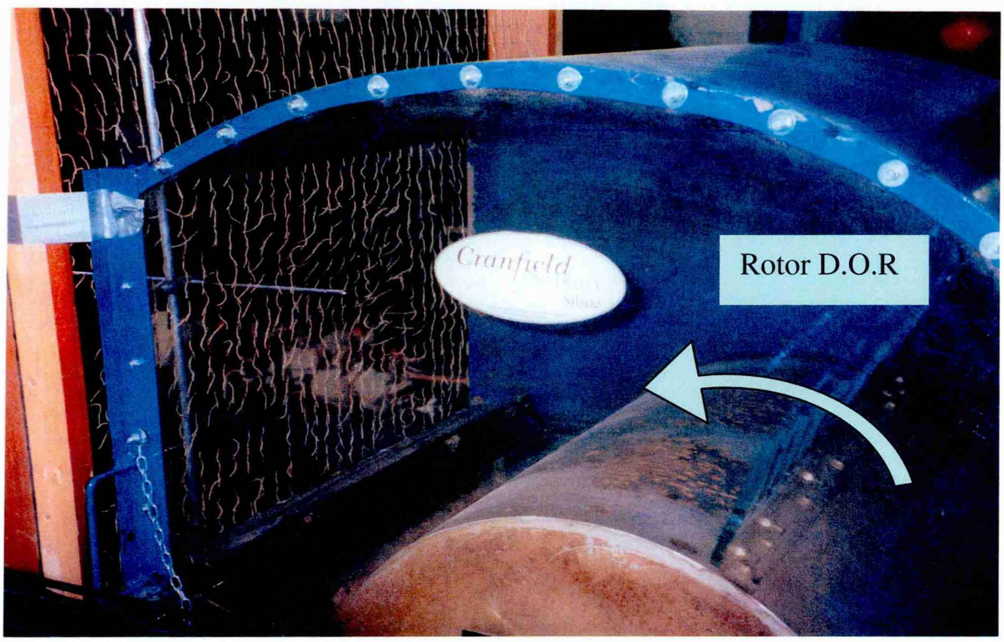


Plate 6.3: Air flow characteristics at crop Rear exit

To find the air velocity in m/s the following equation 6.1 was used:

$$\frac{1}{2} \times P_{air} \times \upsilon^2 = P_{liquid} \times g \times \Delta h \qquad \textit{(equation 6.1)}$$

υ = velocity of the measured air in m/s

P_{air} = density of the air 1.21 kg/m^3

P_{liquid} = the density of the liquid that the instrument used was 820 kg/m^3

g = gravitational force taken as 9.81 m/s^2

Δh= difference in pressure (total-static) measured from the instrument N/m^2

Therefore for this experiment $\upsilon^2 = 16.015\ \Delta h$ *and* $\upsilon = \sqrt{16.015\ \Delta h}$

The following procedure was developed to quantify the air velocity close to the rotor. Sixty three different measurement points were examined in each test. Two replications of each measurement point were made and the mean value of those two was recorded. Five tests were carried out using five different rotor speeds. Those speeds were 210, 310, 360, 410, 510 r.p.m.

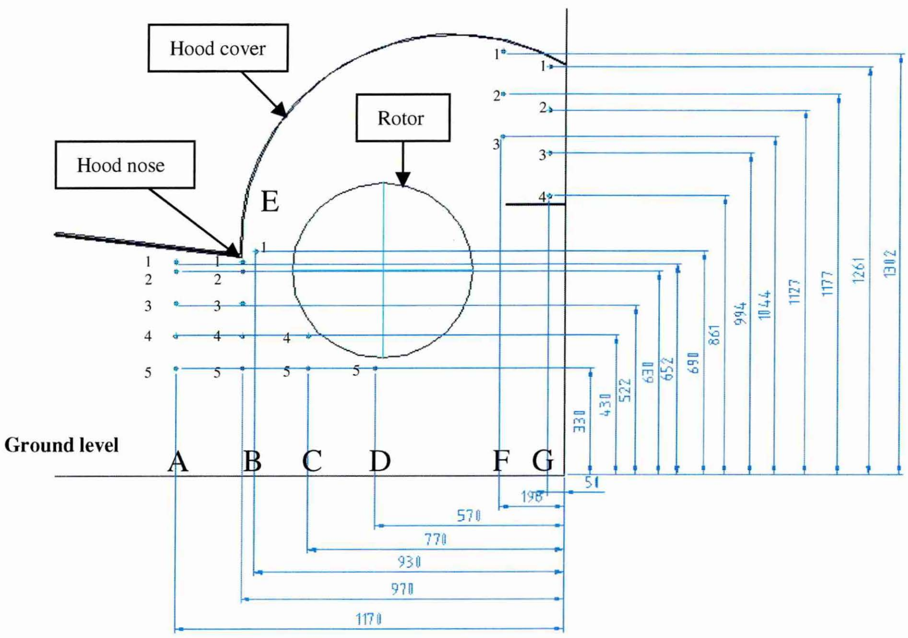


Figure 6.3: Measurement points of air flow (set “a”) (values in mm)

Figure 6.3 shows the set layer “a” with twenty one measurement points and the exact position of each point. It should be noted that there are two more set layers “b” and “c” hidden from the “a” layer at the present, each one having an equal number and spaced distribution of measurement points. The “a”, “b” and “c” sets belong to the same *Z* axis. The layer “b” was sited at the centre of the machines width on *Z* axis and layer “a” and “c” were equally distributed on both sides at 250 mm distance from the centre layer.
The measurement points were placed on a grid as shown on Figure 6.3 the spacing of the grid is not equidistant. The *X* axis gridlines are labelled with the letters A, B, C, D, E, F, G and the *Y* axis of the grid use numbers from 1 to 5.

Results

The results of the measurements are shown in Table 6.3. The findings from those tests indicate that the speed of the airflow surrounding the rotor varies between a negative “suction” value and a positive air speed of 15.2 m/s. Although there appeared to be an area of small negative velocities (< 0 m/s air speed) these could not be measured accurately using the pitot tube. To measure negative air flow using the pitot tube the duct must be placed to the opposite direction of the flow. For the tests it was found very difficult to place the duct inside the machine to take measurements because of its length.
Using the pitot tube instrument in air velocities lower than 1.3 m/s during the test decreased the accuracy of the measurement because the value showed at the recorded part of the instrument was unsteady. Therefore when the measurement reached a value lower than 1.3 m/s the x mark was used as a reading. When the air speed value reached the zero value into the recorded part of the instrument and stayed constant a negative air speed assumed to be present and the x- mark used as a reading.

Table 6.3: Data from air flow measurements (values in m/s)

Layer	210 r.p.m	A	B	C	D	E	F	G
a	1	x	x-			5.9	3.8	3.3
	2	1.3	x				3.1	2.9
	3	1.3	x				1.8	2.7
	4	1.3	1.3	x				3.1
	5	1.3	1.3	2.1	3.5			
b	1	2.2	x-			5.9	4	3.3
	2	2.2	x				3.3	2.8
	3	1.3	x				2.2	2.8
	4	2.5	2.8	3.8				3.1
	5	2.2	3.1	3.8	4			
c	1	2.2	x-			5.9	4	3.8
	2	2.2	x				3.3	3.3
	3	1.8	1.3				3.1	3.8
	4	2.5	2.5	x				4
	5	2.2	2.8	3.1	4			
Layer	**310 r.p.m**	**A**	**B**	**C**	**D**	**E**	**F**	**G**
a	1	2.2	x-			8.9	4.4	3.6
	2	x	x-				3.3	2.8
	3	1.3	x				3.6	4.4
	4	x	x	2.8				3.1
	5	1.3	x	3.8	4.5			
b	1	3.6	x-			8.9	4.2	4.2
	2	1.3	x-				3.8	3.1
	3	2.5	x				3.1	2.2
	4	x	3.1	4.5				3.1
	5	2.8	2.5	4	4.5			
c	1	4.2	x-			8.9	4.6	4.7
	2	2.8	x-				3.8	3.1
	3	3.1	x				4.9	4.4
	4	1.3	2.8	4.2				5.6
	5	2.8	3.6	3.8	4.7			

Cont'd

Key:

X (< 1.3) = reduced accuracy readings
X- = negative air flow (suction)

Layer	360 r.p.m	A	B	C	D	E	F	G
a	1	x	x-			10.2	5.5	3.8
	2	x	x-				2.5	2.5
	3	x	x				2.2	2.5
	4	x	x	1.8				3.5
	5	x	x	2.2	4.2			
b	1	3.6	x-			10.2	4.8	4
	2	1.3	x-				3.3	2.5
	3	1.3	x				3.5	2.8
	4	1.3	x	3.1				4.5
	5	2.2	3.1	3.6	5.5			
c	1	4	x-			10.2	5	3.8
	2	2.8	x-				3.3	2.8
	3	2.2	x				4.5	4.2
	4	2.2	2.8	3.1				5.2
	5	1.3	3.3	4.5	5.9			
Layer	**410 r.p.m**	**A**	**B**	**C**	**D**	**E**	**F**	**G**
a	1	x	x-			11.4	4.9	4.4
	2	x	x-				3.3	2.9
	3	x	x				x-	x
	4	x	x	x				4.4
	5	x	3.1	x	4.5			
b	1	4.4	x-			11.4	5.1	4.7
	2	3.1	x-				4.4	2.9
	3	x	x				x-	x
	4	1.3	x	5.3				4.2
	5	1.8	4.9	5.4	6.4			
c	1	4.9	x-			11.4	5.8	5.6
	2	3.3	x-				4.9	5
	3	1.3	x				6.9	5.6
	4	2.5	2.1	5				6.9
	5	1.3	3.3	5.3	6.9			
Layer	**510 r.p.m**	**A**	**B**	**C**	**D**	**E**	**F**	**G**
a	1	x	x-			15.2	7.7	6
	2	x	x-				3.3	3.3
	3	x	x-				x-	x
	4	x	x-	x				x
	5	x	x-	x	6.4			
b	1	4	x-			15.2	7.4	6.1
	2	2.5	x-				4.7	3.4
	3	x	x-				x-	x
	4	1.8	5.6	8.3				x
	5	x	4.5	6.5	8.9			
c	1	5.6	x-			15.2	8.1	7.6
	2	3.1	x-				5.4	5.6
	3	x	x-				9.8	8.5
	4	x	4.9	6.8				9.2
	5	x	5.8	5.6	8.3			

Discussion

From the three layer sets “a”, “b”, and “c”, the centre “b” layer set results are quite different than the others. The reason was the two metal plates on the two sides of the machine side covers which guide the crop to the stripping elements (Plate 6.4). These plates disturbed the airflow at sets “a” and “c” and caused the difference.

From the results it can be concluded that two areas needed further investigation. At “B” plane area (entrance of the crop into the hood cover) and “G” plane area (crop exit at the end of the hood cover) where the air was flowing in a highly turbulent manner.

Plate 6.4: Internal side to guide the crop at the centre of the rotor

6.2.1.1 Summary for the identification of the air flow surrounding the stripping rotor

- The rotor produces a forward airflow at its lowest point which promotes an air flow out of the front of the machine. This is an undesirable characteristic which was subsequently researched as described in the following chapter.

- The existing air flow was found to be highly turbulent especially at the front plane area "B" and at the rear plane area "G". Plane area "B" is an area of negative pressure (suction). At the rear exit plane area "G" it was noticed that there was significant air shear between two layers of air; one sited at the internal surface of the hood cover and the other closer to the stripping elements with lower air velocity between them. The bottom and the top layer had higher air velocities which caused the shear between air layers.

- From the results it can be concluded that the air flow needs to be improved relative to the path that the crop follows during harvest. An increase in negative air pressure (suction) at the entrance of the crop to the hood cover would help bring flower heads closer to the stripping elements and consequently make the detachment of the flower from the stem more efficient. Also an improvement to the air flow at the exit of the crop at the rear end of the hood cover can improve crop delivery into the container.

6.2.2 Machine airflow optimisation tests

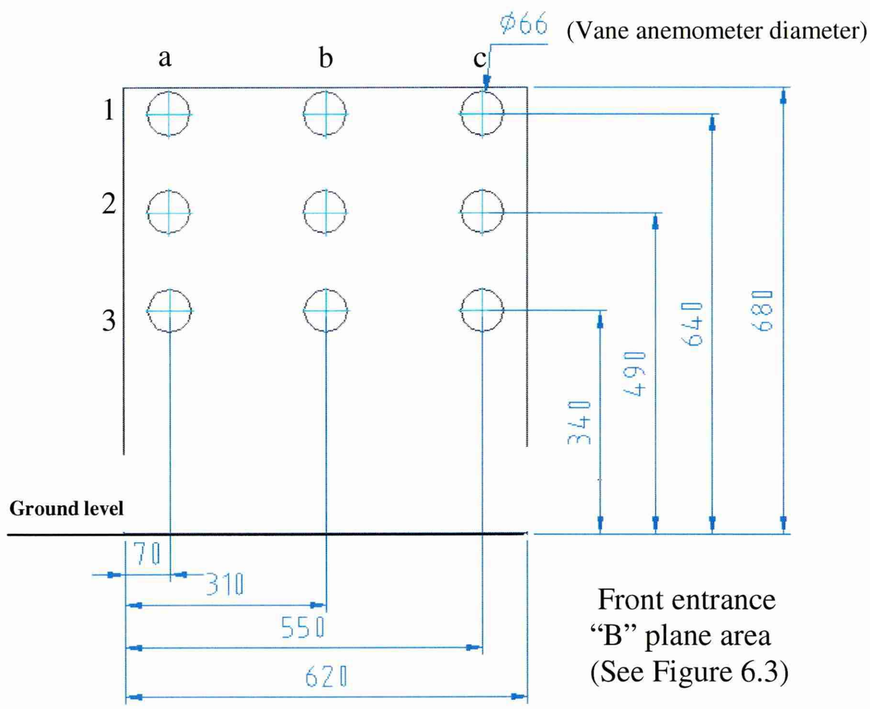
The preliminary measurement of air speed in the lavender harvester determined large variations in air velocity. This was considered to be undesirable and was a cause of a proportion of the flower loss during the 2001 year pilot field trials. Airflow above the terminal velocity of the flower 6 m/s (terminal velocity identification 4.2.3 section) can improve the harvest procedure by retaining the flower in the air stream. It was decided to investigate further the velocity profile of air as it entered at the front of the harvester and also at the exit at the rear of the rotor.

Materials and methods

The materials used to conduct the airflow optimisation measurements are listed bellow:

- The Lavender harvester machine,
- A tachometer to measure the rotor speed (resolution = 1 r.p.m),
- A clamp and retort stand to keep the anemometer in a specific reselected point,
- A vane anemometer (Rototherm Tempaflo MK11).

Due to the problems experienced using the pitot tube to measure small air velocities (<1.3 m/s) and difficulties when the instrument placed in the opposite direction to measure negative values inside the harvester, the use of the vane anemometer was chosen to recorded the air velocity. The anemometer was held at each specific position by the clamp and the retort stand. When the anemometer was steady its value was recorded. The machines rotor was run at five different velocities (210, 310, 360, 410, and 510 r.p.m). The use of a new length hood nose and a metal sheet (under cover) under the rotor were investigated. For each rotor speed three hood nose and three under cover positions were examined and gave a total of 45 different treatments. Two replications for each treatment gave a total number of 90 tests. Nine different measurement positions in each test were measured at the front entrance plane area "B" and other nine at the rear exit plane area "G" of the machine which gave a total number of 1620 measurements (exact measurement positions can be seen in Figure 6.4).



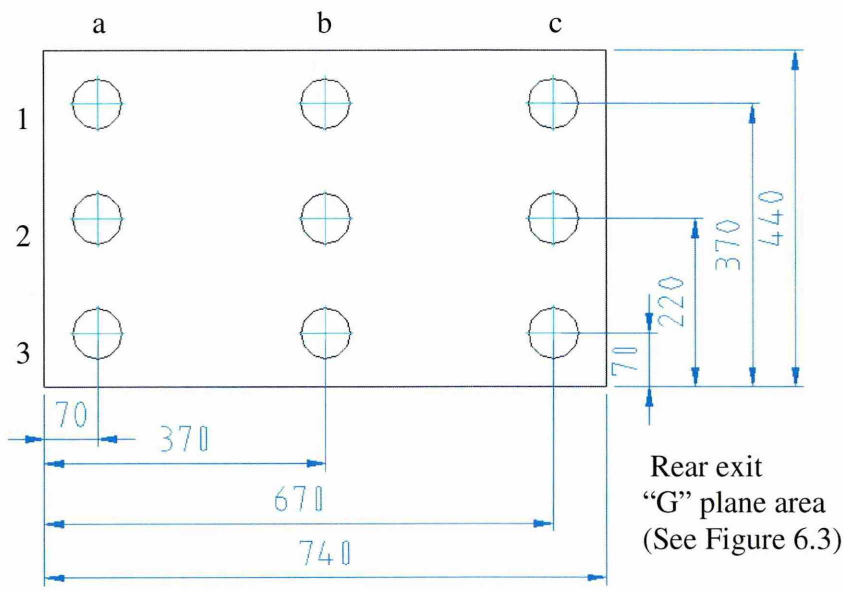


Figure 6.4: Measurement positions for air flow optimisation

(These can seen from the front of the machine, all values are in mm)

Results

The mean values for each arrangement from the air flow tests can be seen in Table 6.4. Full data are presented in Table A2.1, Appendix 2. Presentation of the air status can be seen in Figure 6.6a and 6.6b before and after the modifications using the Surfer 7 program. The colour scale bar at the top of the figures indicates the air velocity in m/s. The left hand column of graphs indicates the air status before modifications were made to the machine and the right hand column of graphs show how the air flow changed after the modifications.

Term explanation for under cover and hood nose for Table 6.4:

Under cover (U.c): 1= No U.c, 2= U.c 90°extend, 3= U.c 120°extend (see Figure 6.5)

Hood nose (H.n): 1= At Original position (O.p) (x = 50 mm), 2= 100 mm higher than O.p, 3= 100 mm lower than O.p.

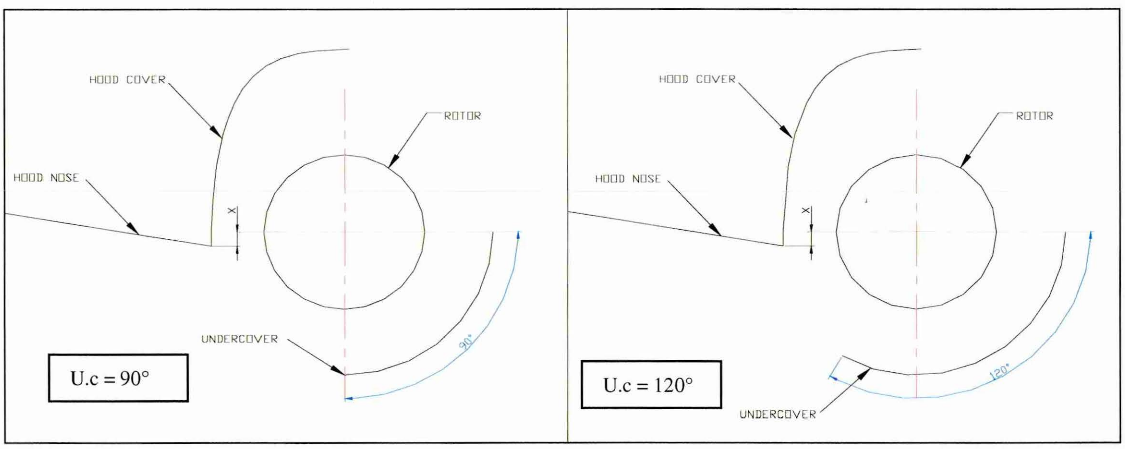


Figure 6.5: Explanation for Under cover and Hood nose placement

The number labelling at the right bottom on each graph at Figure 6.6a and 6.6b indicates:

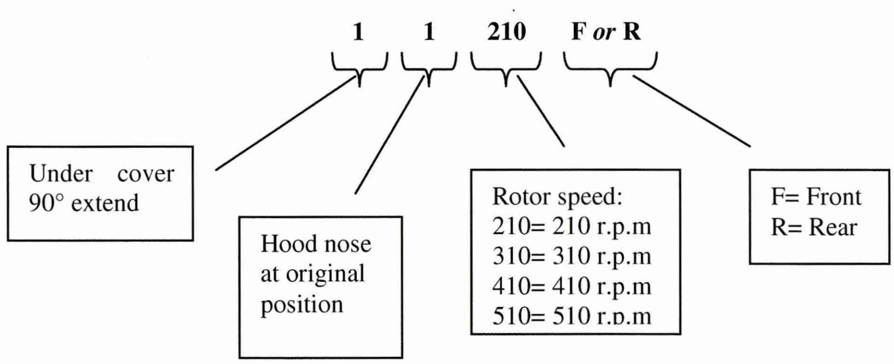


Table 6.4: Results from the optimization of the air flow tests

N°	Under Cover	Hood nose	Rotor speed (r.p.m)	Air velocity (plane area B) m/s	Air velocity (plane area G) m/s
1	1	1	210	-0.144	4.589
2	1	1	310	-0.400	6.333
3	1	1	360	-1.122	7.544
4	1	1	410	-1.700	8.667
5	1	1	510	-2.800	12.078
6	1	2	210	0.978	4.600
7	1	2	310	2.233	5.589
8	1	2	360	1.767	6.922
9	1	2	410	1.378	7.667
10	1	2	510	1.744	9.889
11	1	3	210	-1.467	4.578
12	1	3	310	-0.933	6.911
13	1	3	360	-2.844	7.922
14	1	3	410	-3.100	9.256
15	1	3	510	-4.622	12.233
16	2	1	210	-2.767	4.767
17	2	1	310	-4.244	6.000
18	2	1	360	-4.933	7.300
19	2	1	410	-5.500	7.833
20	2	1	510	-7.622	10.167
21	2	2	210	-0.567	4.300
22	2	2	310	-1.533	5.822
23	2	2	360	-2.978	6.844
24	2	2	410	-1.100	7.800
25	2	2	510	-1.522	9.433
26	2	3	210	-2.767	4.567
27	2	3	310	-3.933	6.733
28	2	3	360	-4.933	7.522
29	2	3	410	-5.800	8.211
30	2	3	510	-7.267	10.167
31	3	1	210	-2.356	3.733
32	3	1	310	-3.256	5.289
33	3	1	360	-4.322	5.811
34	3	1	410	-4.767	6.556
35	3	1	510	-6.233	8.600
36	3	2	210	-0.967	4.367
37	3	2	310	-1.378	5.378
38	3	2	360	-1.178	5.856
39	3	2	410	-1.411	7.278
40	3	2	510	-1.789	7.811
41	3	3	210	-2.256	3.911
42	3	3	310	-3.556	5.467
43	3	3	360	-4.611	6.689
44	3	3	410	-4.856	7.411
45	3	3	510	-6.178	8.889

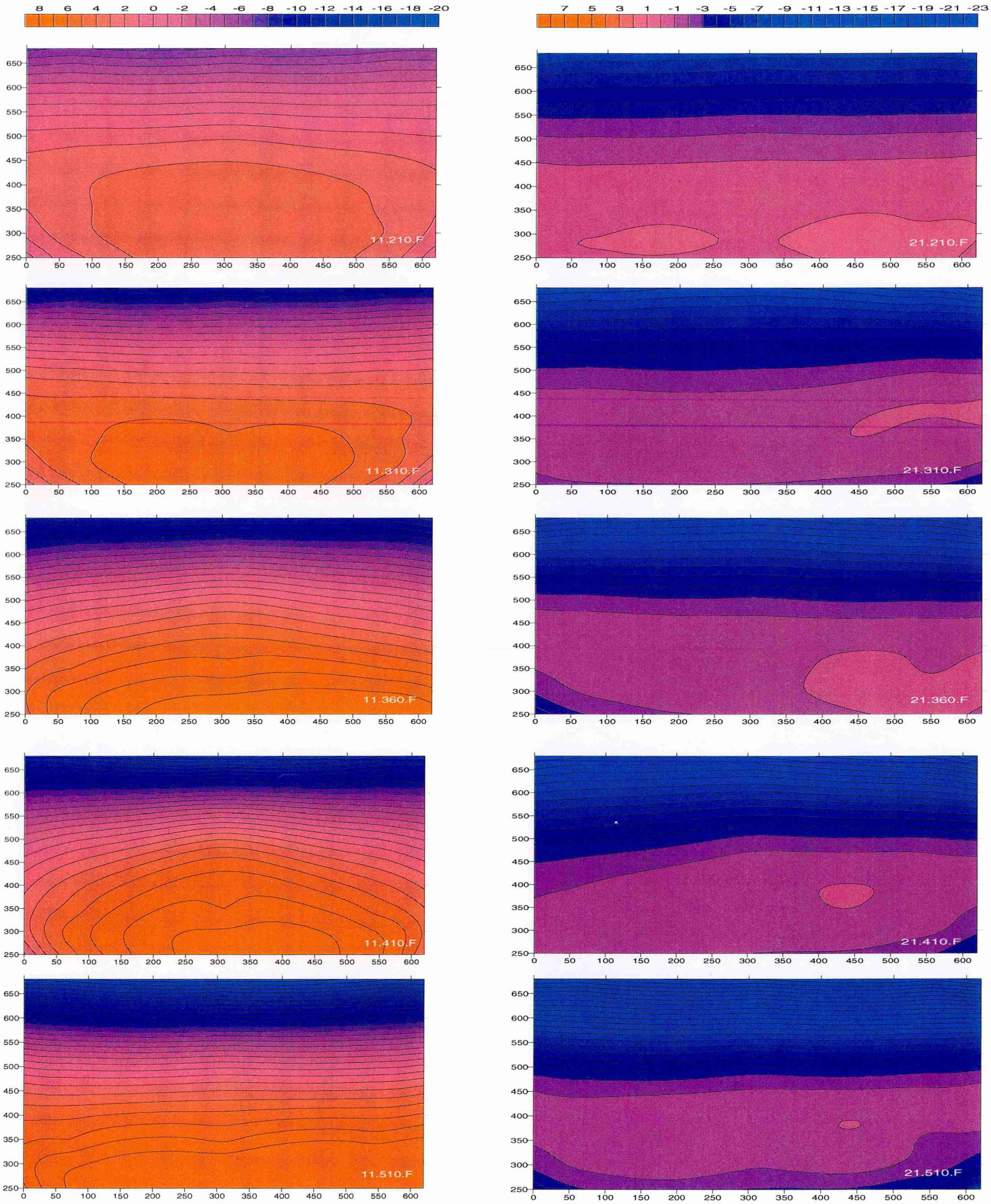


Figure 6.6a: Air flow characteristics for position "B"

Note: All values at "x" and "y" axis in Figures 6.6a & 6.6b are in mm

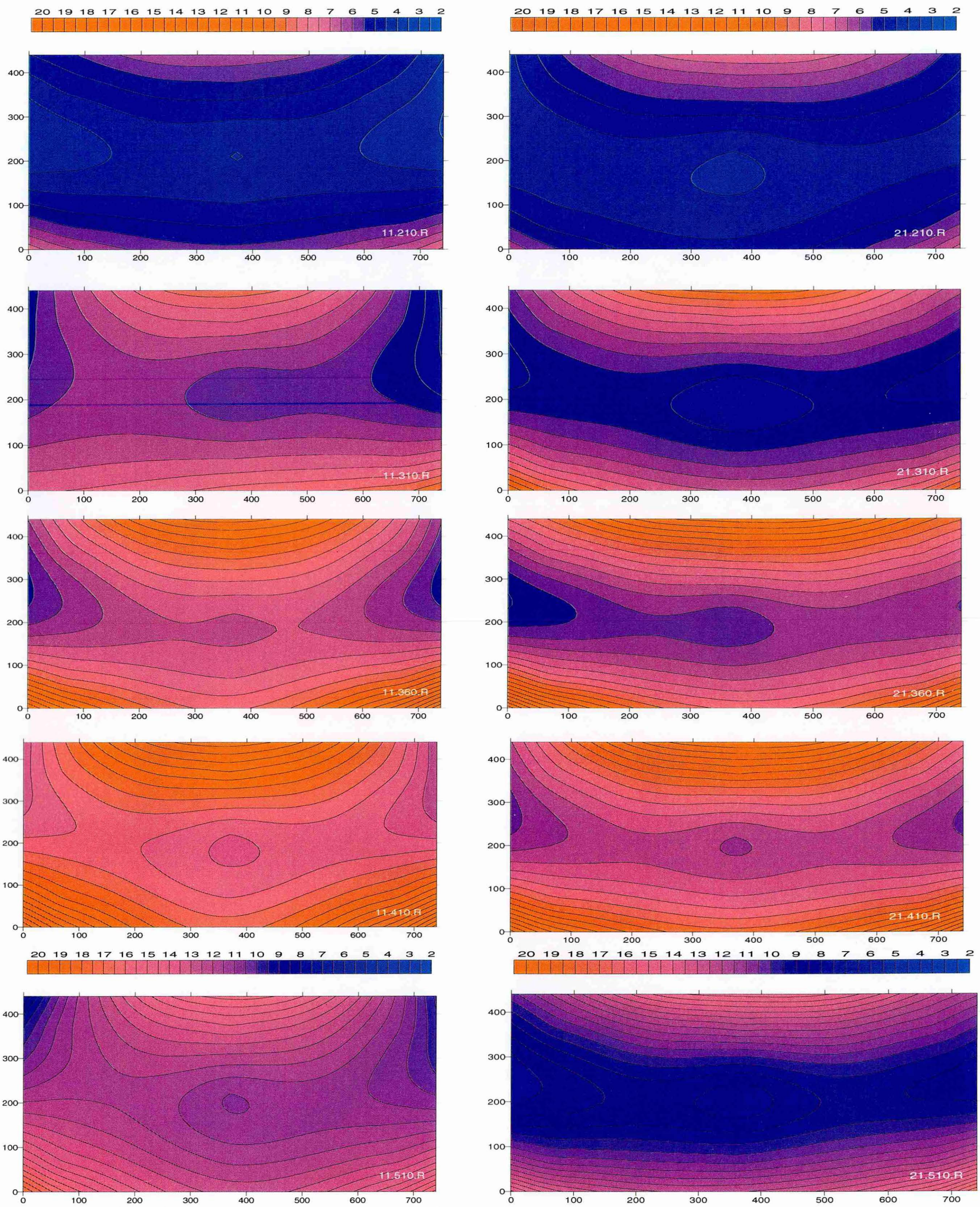


Figure 6.6b: Air flow characteristics for position "G"

Discussion

The changes of the internal shape of the harvester had a positive effect in the air flow surrounding the rotor. Best arrangements occur at number 16 to 20 of Table 6.4. The criterion was to find pair of "B" and "G" position treatments in which the suction in B position reaches the maximum value and in the mean time the air at the exit G position stay at mean values near the terminal velocity (6 m/s) of the flower head. At the selected treatment the under cover was "ON" at 90°, and the hood nose was at original position in all range of the rotor speeds. For this set up the analysis of variance shows that there was significant difference (5% level) between the mean values of suction from the front entrance of the machine in all range of rotor speeds and therefore this set up was chosen as the optimum set up to improve air flow.

6.2.2.1 Summary for the machine airflow optimisation tests

- The air flow into the internal area of the machine was improved. Especially at the front entrance where the air became sucked air. This phenomenon can be used to help the plants to come closer to the stripping elements resulting in a better stripping action.

- The most significant element that improved the air flow was the placement of the under cover.

- The best air values that can efficiently transport the detached flower particles were found at high rotor speeds especially at 510 r.p.m.

6.2.3 Harvester refinement after the preliminary field and laboratory tests (2001 year)

Following the laboratory experiments for the identification of the air flow surrounding the rotor and the preliminary field tests conducted in the 2001 harvest season, the harvester was modified. The modifications involved first an increase by 120 mm in width of rotor, container, hood cover and hood nose and secondly the placement of the under cover, the two side extensions inside the machine and the two dividers at the front of the machine (Figure 6.7). Changes were also made to the sprockets of the drive system due to the chain slipping during the harvest. The placement of bigger diameter sprockets with more teeth (23 instead of 19) in each wheel shaft was tested to combat the problem. At the front and rear, leg modifications were conducted to allow a further reduction in machine height.

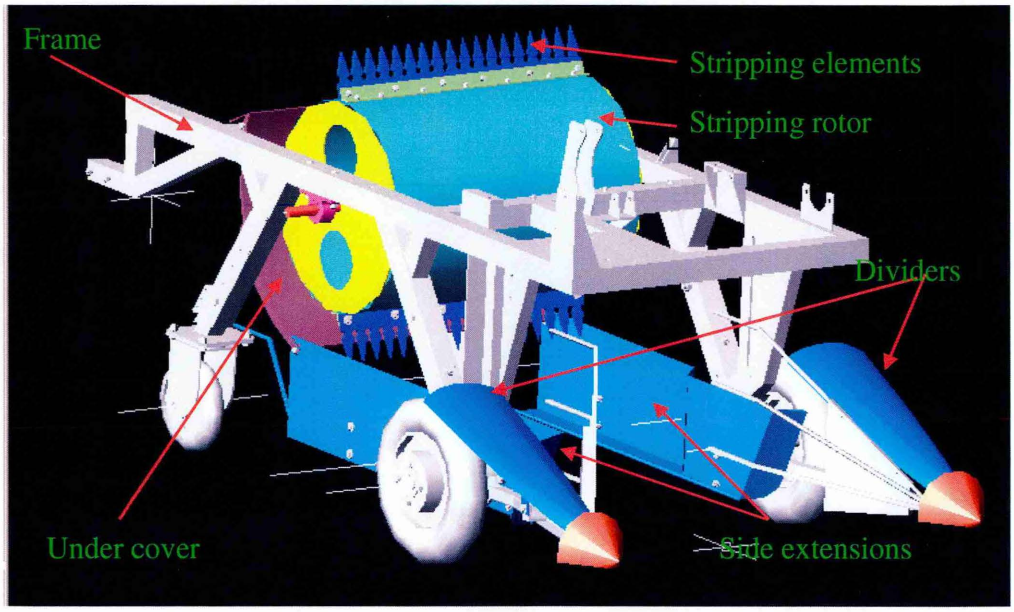


Figure 6.7: Harvester term explanations

6.3 Field tests for the optimisation of the harvester

Using the experimental findings concerning the air flow and the preliminary field test data, field trials were conducted to refine the performance of the harvester. Two field areas each of 1.2 ha were used for the experiment. One experimental field (same used for the preliminary tests) was at Carshalton in South London, UK and the other one at Hitchin in Hertfordshire, UK. The aim of this experimental programme was to identify the operating characteristics of the modified machine, such that the performance envelope could be determined and the optimum setting predicted for a given harvest requirement.

6.3.1 Determination of optimum machine settings for young and mature crop (2002 and 2003 harvest)

To determine the optimum machine settings for young and mature crops four tests were conducted. Three tests were conducted in July 2002 (test N° 1, 2, 3)[4] and one in July 2003 (test N° 4) during the lavender harvest period. Two of them took place at Hitchin UK, in a lavender field of 1.2 ha in which two different varieties were tested. First was the *Lavandula augustifolia Folgate* (N° 1 test, young crop) and second the *Lavandula x intermidia Lullingstone Castle* (N° 3 test, mature crop). One test was conducted at the Bioregional 1.2 ha Lavender field at Carshalton UK, the cultivar was *Lavandula x intermidia "Bioregional"* (N° 2 test, mature crop). One test was conducted at Yalding in South England UK, in a 5.6 ha field. The cultivar tested was *Lavandula augustifolia Folgate* (N° 4 test, mature crop). The aim of all the tests was to evaluate the performance of the lavender harvester in terms of flower and stem harvest. The cultivars tested were grown mainly for oil production.

[4] The test numbering indicates the chronological order in which the experiments were conducted

6.3.1.1 Test N° 1 *Lavandula augustifolia Folgate* test (2002 harvest)

Before the experiment

During the first few meters of harvest it was noticed that different harvester settings were required to meet the plants dimensional characteristics. The plants of *Lavandula augustifolia Folgate* cultivar were in their 2nd year of growth and they were very short. The average dimensions of the bush were 0.50 m high and 0.60 m wide and had a mean density of 110 plants per m² with a mean moisture content measured at 63.3% w.b. The machine was previously designed to harvest bushes of at least 0.65-1.00 m height and 0.80-1.00 m wide. The stripping elements that touch the flowers were not in the right position to detach the crop properly and forced many of the stripped flowers to follow a horizontal path out of the front of the machine causing high flower losses.

Design modifications were therefore conducted to enable the harvester to harvest these short and narrow plants. An analysis of the problem concluded that the following modifications were necessary:

- Reduce the machine's height.
- Lower the hood nose to trap the detached flowers in the required air flow.
- Change the angle of the stripping elements from 15° to 30°.
- Add internal side guides to compress the crop laterally and lift the edges so to present the whole crop to the rotor.

Conducting the experiment

Modifications were made to the harvester taking into account the problem analysis list. The original and the modified machine settings can be seen in Table 6.5. The new appearance of the machine can be seen in Plate 6.5.

Table 6.5: Harvester modifications

Machine set up		
Component	***Original***	***Test N°1***
Hood nose distance from the ground	710 mm	410 mm
Hood nose distance from the rotor shaft	50 mm	250 mm
Under cover (distance from the ground) ["ON" or "OFF"]	(380 mm) ["ON"]	(280 mm) ["ON" and "OFF"]
Angle of the stripping elements	15°	30°
Rotor width	720 mm	720 mm
Internal guides clear distance	No internal guides	400 mm

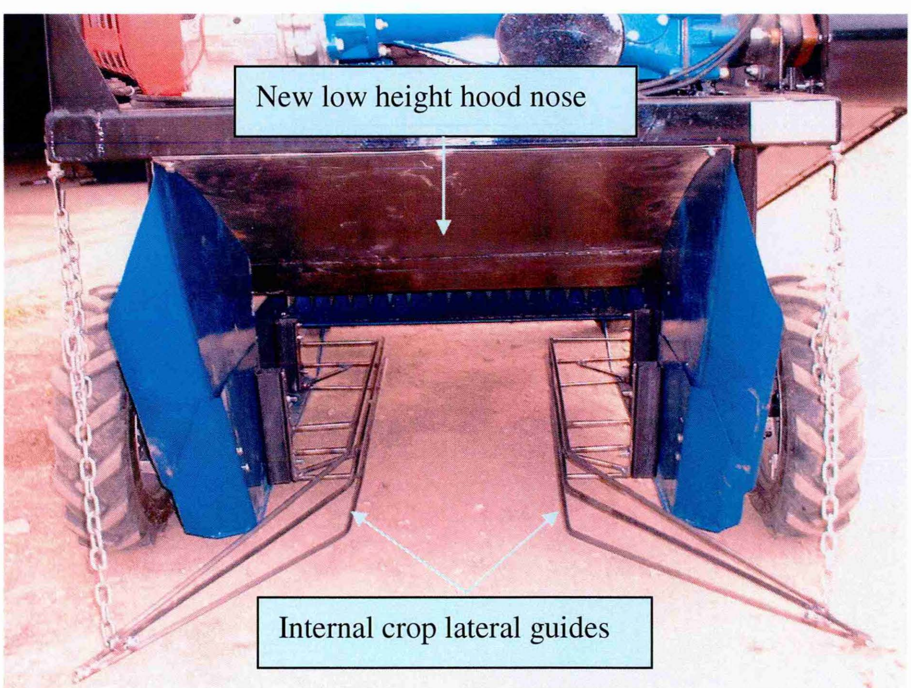


Plate 6.5: Modifications to meet young plant characteristics

Material and methods

The materials used to conduct the N° 1 test are listed below:

- The prototype harvester machine,
- A hedge trimmer,
- Six plastic buckets to collect the harvest material,
- A 30 m tape measure,
- Several point sticks to specify each treatment area,
- A tachometer to measure the r.p.m of the rotor speed (1 r.p.m resolution),
- A digital weight balance to weigh the collected plant material (0.01 g resolution).

To identify the optimum performance of the harvester a research methodology was developed to measure the harvested flower and stem so that comparisons could be made with a hand harvest method. For the purpose of the experiment 5 m long rows were used. Nine different treatments consisted of 3 rotor speeds and 3 forward speeds which were randomly tested. Originally the experimental design was to include 4 blocks of trials, however due to problems uncounted during the experiment which are described in the discussion section, only two were completed.

To measure the flower losses and the amount of stem harvest the following procedure was followed:

- Measure 5 m of the row length and mark the edges,
- Using a hedge trimmer randomly hand harvest 1 m row length and record the weight of the flowers and stems (hand harvest),
- Run the harvester for the selected 5 m row length and record the total weight of the harvested plant material. From the container randomly take three samples of 100 (g) and record the weight of flowers and stems (machine harvest),
- Bring the harvester 2 m back and clear the plant material up to the state of the next treatment at a height lower than the tip of the stripping elements,
- Run the next treatment.

For all treatments the free space of 2 m prior to the treatment harvest allowed the machine to reach a stable operating condition. The data from the 1 m row length for the hand harvest method was the total amount. The data from the container was derived from the mean value of 3 samples of 100 g randomly collected and measured by hand individually.

Because of the very small height of the bush and the minimum possible height the machine was capable of achieving the harvest occurred only above 280 mm for both hand harvest and machine harvest methods, below that height the plants were ignored and no data was recorded. Two different set ups were examined concerning the placement of the Under cover, one using it "ON" and one "OFF".

Results

The results from the N° 1 field trials are presented in Table 6.6. Figure 6.8 explains the treatment numbering.

Table 6.6: Results from N° 1 *Lavandula augustifolia Folgate* test

Treatment	Forward velocity		Hand harvest ratio per m² field area		Machine harvest ratio per m²field area		"Actual"[5] flower harvest	"Actual" stem harvest
			Flower	Stem	Flower	Stem		
N°	**km/h**	**m/s**	%	%	%	%	% of HH	% of HH
F1111	0.27	0.08	68.8	31.2	87.3	12.7	79.10	25.86
F1112	0.64	0.18	64.1	35.9	85.6	14.4	58.39	17.50
F1113	1.47	0.41	70.0	30.0	90.5	9.5	56.99	13.91
F1121	0.36	0.10	60.3	39.7	79.5	20.5	67.98	26.67
F1122	0.83	0.23	60.9	39.1	80.5	19.5	52.10	19.57
F1123	1.92	0.53	68.0	32.0	90.7	9.3	73.95	16.15
F1131	0.48	0.13	62.0	38.0	81.0	19.0	83.66	32.05
F1132	1.13	0.31	68.3	31.7	85.0	15.0	96.75	36.84
F1133	2.63	0.73	71.0	29.0	85.9	14.1	48.68	19.55
F1211	0.27	0.08	71.0	29.0	83.0	17.0	77.45	38.84
F1212	0.64	0.18	69.0	31.0	84.0	16.0	85.60	36.29
F1213	1.47	0.41	67.0	33.0	84.0	16.0	72.19	27.92
F1221	0.36	0.10	70.0	30.0	85.0	15.0	111.82	46.04
F1222	0.83	0.23	70.0	30.0	79.0	21.0	97.77	60.64
F1223	1.92	0.53	66.0	34.0	81.5	18.5	74.21	32.70
F1231	0.48	0.13	67.0	33.0	83.5	16.5	104.75	42.03
F1232	1.13	0.31	71.0	29.0	85.5	14.5	104.81	43.52
F1233	2.63	0.73	68.0	32.0	86.0	14.0	64.94	22.46

[5] "Actual"= how much flower and stem percentage of the existing plant (hand harvest) harvested using the machine

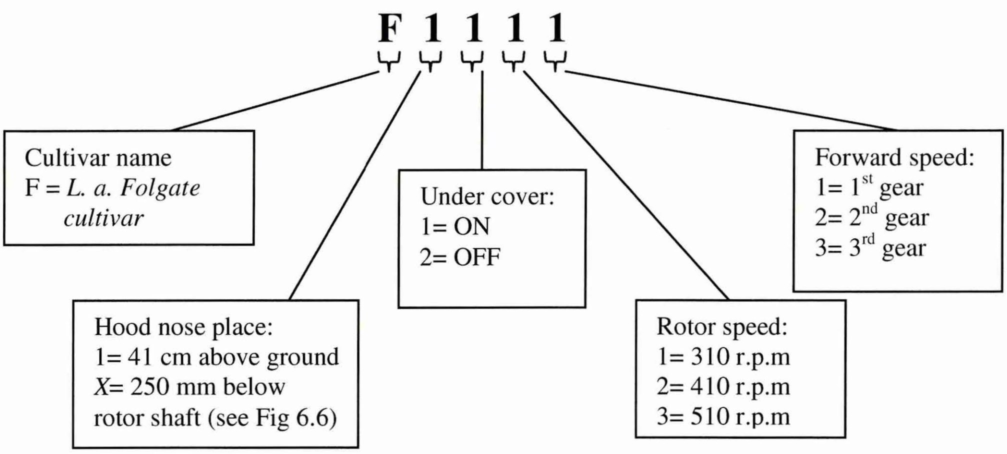


Figure 6.8: Treatment numbering key

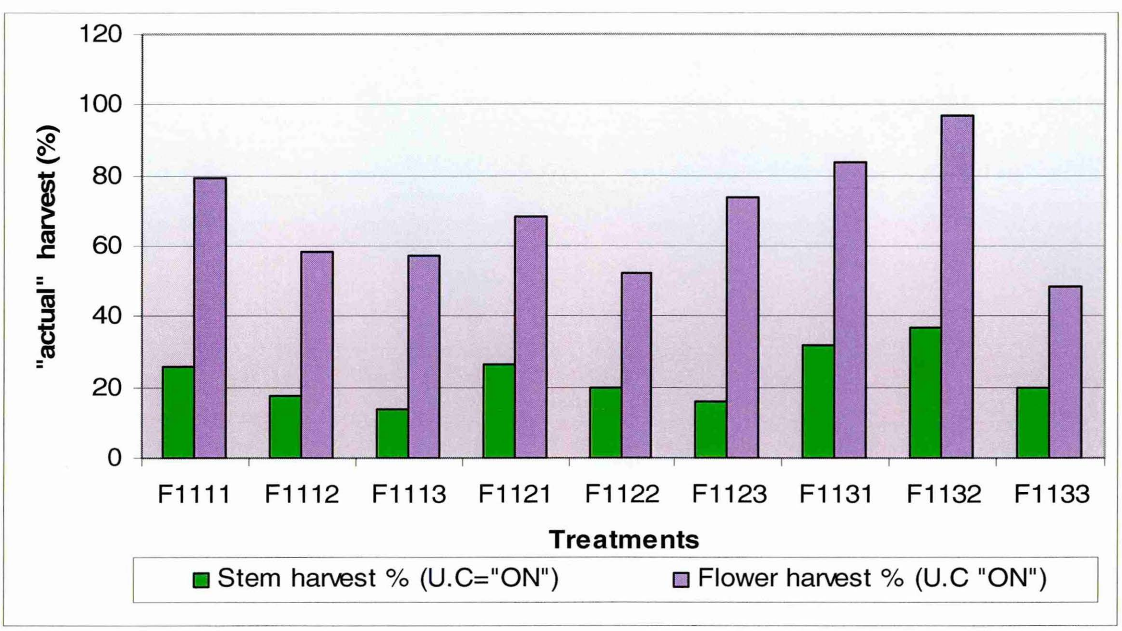


Figure 6.9: Flower and stem harvest comparison for Under cover "ON" (N° 1 test 2002)

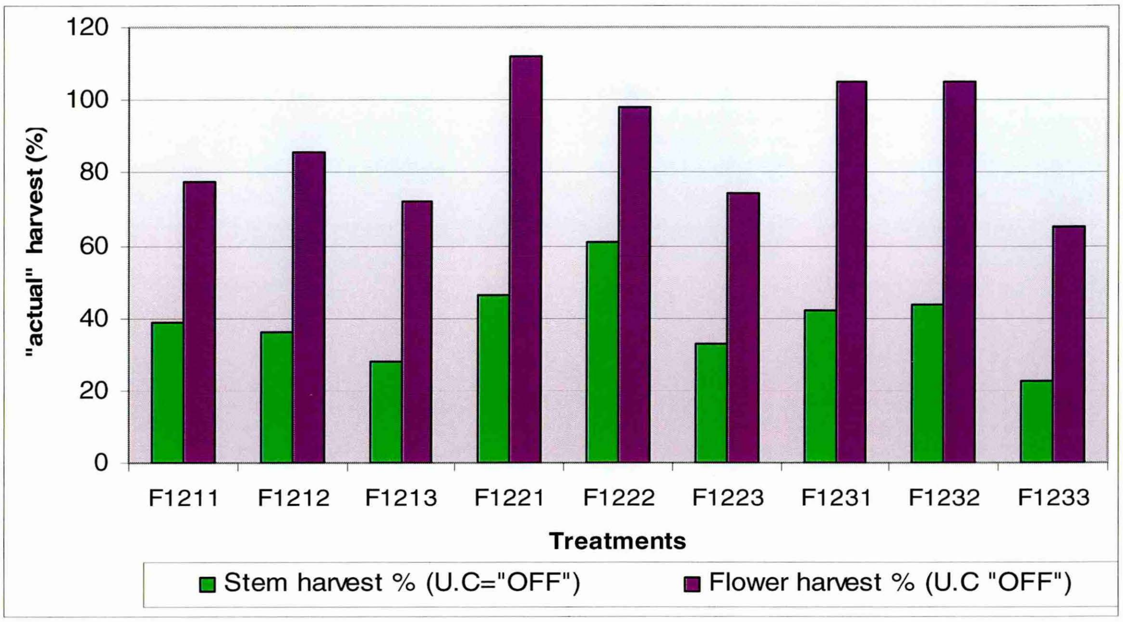


Figure 6.10: Flower and stem harvest comparison for Under Cover "OFF" (N° 1 test 2002)

Discussion

Two decisive criteria were developed concerning the final selection of the optimum settings of the machine. The first criterion follows the rule that the optimum harvest setting must have the maximum percentage in flowers and the minimum percentage of stems to find the best treatment for "quality" oil. This happens because the flower has better quality oil than that of the stem (Venskutonis, 1977), so the minimum amount of stem the better the quality. The second criterion follows the rule of maximum percentage of flower harvest with no interest in percentage stem harvest to find the treatment with the maximum flower yield. Concerning the identification of the treatment with maximum yield the selection was easy because the treatment with the maximum percentage flowers harvested was the one required. In contrast the identification of the best treatment for maximum quality was a procedure in which equation 6.2 below was developed and used.

$$S = (100-B) + A \qquad \textit{(equation 6.2)}$$

Were:

S = maximum value for quality

A = value % of actual flower harvest

B = value % of actual stem harvest

Adopting the above selection criteria, the results show that the machine performed well for the first set up (U.c "ON", Figure 6.9) in treatment F1132 for maximum "quantity" and "quality". In this treatment the "actual" % of flowers was 96.75 and the "actual" % of stems was 36.84. The second set up (U.c "OFF", Figure 6.10) treatment F1221 gave the maximum "quality" and "quantity". In this treatment the "actual" % of flowers was 111.82 and the "actual" % of stems was 46.04.

It is obvious that the values for the F1221, F1231 and F1232 treatments gave unanticipated results in which the values exceeded the 100%. A paradox was recognized concerning the real values for the "actual" % of flower and stem harvest. It is not possible for the machine to harvest more than the hand harvest. This was the reason that 2 of the 4 blocks of the experiment were not completed. Also statistical analysis was not performed due to missing treatments replication.

Two explanations were given and connected with this problem. The first reason was that the sample of hand harvest randomly chosen from the 5 m row wasn't accurate enough to represent the treatment because of the variation in shape and weight of the lavender flowers. Even when the hand harvest for the 1 m sample had been taken in five strips of 200 mm row length the results still exceeded 100%. The second and more logical reason was that of the exceptional performance of the dividers and the internal guides. During the hand harvest only the part of the bush that exceeds 280 mm of height could be collected by a person and the rest of the flowers were left on the bush. The edges of the row had stems which were lower than 280 mm, but when lifted up to vertical exceeded 280 mm height. When the machine passes above the bush the dividers picked these lower flower stems and guided them into the centre of the machine so that the rotor stripped them and added an extra proportion of plant material to the container.

Mention should be made at this point of the stem part of the plant. Comparing the two different tests and when the under cover was not in place ("OFF") the percentage stem harvested was in all treatments more than when it was "ON" (Table 6.6). The absence of the under cover gave the opportunity for the stripping elements to "hit" the plants more times per meter of forward trend and increase the final harvested material both in terms of flowers and stems.

Therefore the results should be analysed relative to each other and not as absolute readings. Looking at the data in this manner allows the following summary to be derived:

6.3.1.2 Summary for N° 1 test (young crop)

- The general trend that the results followed is very promising. The machine performs well on smaller immature bushes than the machine was originally designed for.

- The results indicate that the methodology used to asses the machines performance was only suitable for relative measurements and did not account adequately for field variability.

- For absolute field measurements a new method was required.

6.3.1.3 Test N^0 2 *Lavandula x intermidia "Bioregional" (2002 harvest)*

The plants of *Lavandula x intermidia "Bioregional"* cultivar were in the 4th year of growth. The average bush height and width was 1.00 m and 1.20 m respectively with a mean density of 250 plants per m². The plants mean moisture content for this test was at 66.9% w.b. The machine height was adjusted to meet the bushes requirements. Table 6.7 shows the machine set up for this test.

The angle of the stripping elements was returned to the original 15° degrees because the 30° angle did not release the plant properly in the mature crop and some of the flowers followed the circular direction of the elements forward. The under-cover contained residue which indicated plant material flow between under-cover and rotor.

The under cover was installed ("ON") for two reasons. First because the previous tests show that it's absence increases the percentage of stem in the collected material (Figure 6.9, 6.10) which might increase transportation and distillation cost (if a distillery is sited far away from the harvested field) and also there is a strong possibility the high percentage in stem to decrease the quality of the oil produced (Venskutonis, 1977). Second the air flow experiments showed that the under cover improves the air flow surrounding the rotor and contributes to the transportation of the detached flowers into the container (section 6.2.2).

Table 6.7: Harvester settings

Machine set up		
Component	***Test N°1***	***Test N°2***
Hood nose distance from the ground	410 mm	760 mm
Hood nose distance from the rotor shaft	250 mm	50 mm
Under cover (distance from the ground) ["ON" or "OFF"]	(280 mm) ["ON" and "OFF"]	(430 mm) ["ON"]
Angle of the stripping elements	30°	15°
Rotor width	720 mm	720 mm
Internal guides clear distance	400 mm	500 mm

Material and methods

The following equipment was used to conduct the experiment:

- The prototype harvester machine,
- A hedge trimmer,
- Hand shears,
- Six plastic buckets to collect the harvest material,
- A 30 m tape measure,
- Several point sticks to specify each treatment area,
- A tachometer to measure the rotor speed (1 r.p.m resolution),
- A digital balance to weigh the collected plant material (0.01 g resolution).

A new methodology was developed to avoid problems encountered during tests N° 1. The new research methodology had the aim of finding the exact performance of the machine by measuring the percentage of flowers harvested and the percentage of stems harvested from the selected area.

The total flower was the sum of the container flower percentage (which translated in weigh units g) the flowers left on the bush and those found on the ground. The total stem was calculated from the addition of the container stem percentage measured (which translated in weigh units g) and the hand harvest after the machine passed over each test row.

For the purpose of the experiment 5 m long rows were used. The restricted row length as a test area for each treatment was due to the limited field area provided by the owner of the field. Nine different treatments consisted of three rotor speeds and three forward speeds which were randomly tested in a two block experimental design. Two replicates for each treatment gave a total number of 36 measurements.

The research method was as follows:

- Divide the row in 5 m long sections and mark the edges with grass paint,
- Trim with the hedge trimmer 2 m prior the selected test area to a height of 0.43 m to avoid collecting unwanted plant material out side of the test row,
- Choose randomly 1 m from the test row and record the exact number of the existing lavender plants before harvest,
- Harvest the row with the harvester,
- Weigh the collected material from the container and then measure the percentage flower and percentage stem from three samples of 100 g each,
- Weigh the un-harvested flowers left on the stems and those left on the ground,
- Hand harvest the stems left on the bush and weigh them.

Results

The results from the N° 2 field trials are presented in Table 6.8. Figure 6.11 explains the treatment numbering.

Table 6.8: Results from N° 2 *Lavandula x intermidia "Bioregional"* test

Treatment	Forward velocity		Hand harvest ratio per m² field area		Machine harvest ratio per m² field area		Actual flower harvest	Actual stem harvest
N°	**km/h**	**m/s**	Flower %	Stem %	Flower %	Stem %	% of HH[6]	% of HH
B1111	0.27	0.08	50.0	50.0	78.4	21.6	87.14	24.07
B1112	0.64	0.18	40.8	59.2	65.5	34.5	92.66	33.72
B1113	1.47	0.41	55.1	44.9	76.8	23.2	85.62	31.83
B1121	0.36	0.10	59.0	41.0	76.5	23.5	93.18	41.13
B1122	0.83	0.23	39.4	60.6	50.6	49.4	95.38	60.58
B1123	1.92	0.53	37.0	63.0	48.9	51.1	91.46	56.14
B1131	0.48	0.13	60.7	39.3	66.7	33.3	95.09	73.45
B1132	1.13	0.31	50.9	49.1	60.6	39.4	96.14	64.87
B1133	2.63	0.73	41.0	59.0	53.0	47.0	92.06	56.69

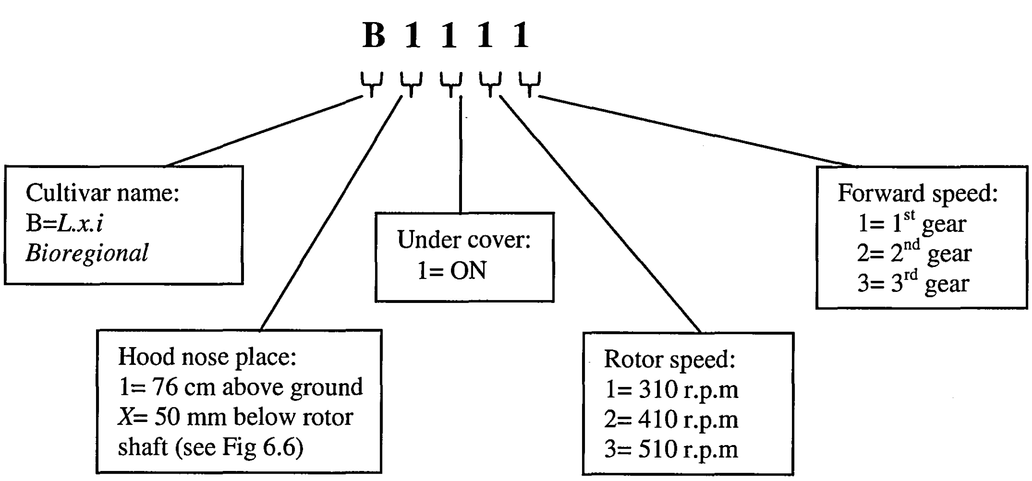


Figure 6.11: Treatment numbering key

[6] HH = Hand harvest

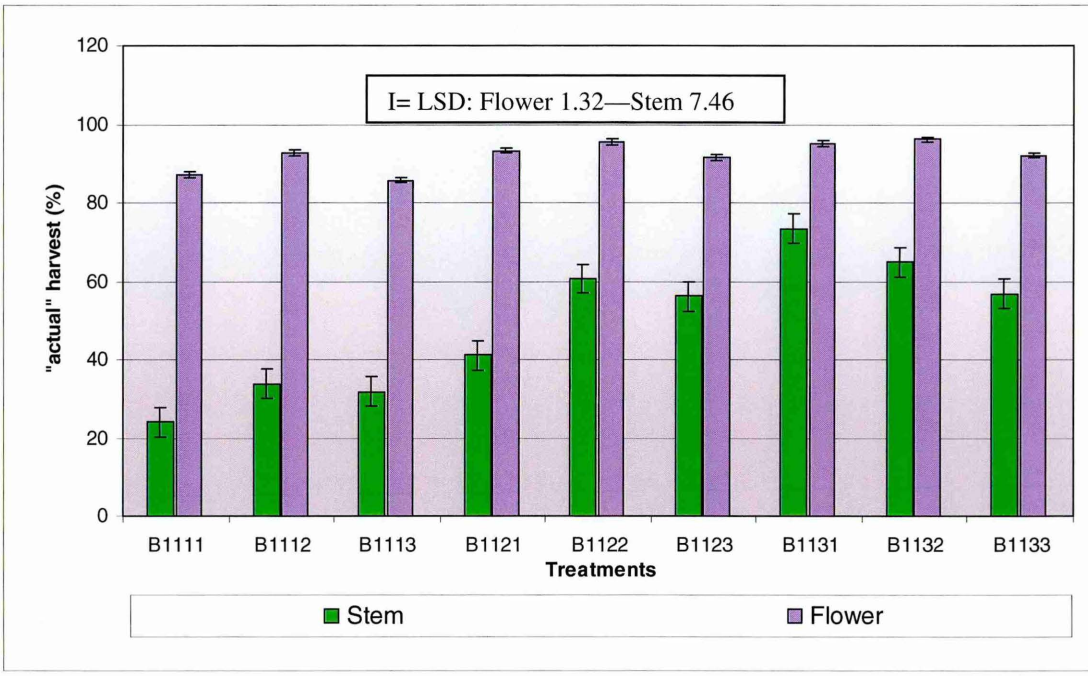


Figure 6.12: Flower and stem harvest percentage at different treatments (N° 2 test 2002) (LSD 5% level)[7]

Discussion

Adopting the selection criteria in terms of maximum "quality" and maximum "quantity" decided upon in section 6.3.1.1 (p. 125-126) N° 2 test indicated 2 treatments. In order to have the maximum "quality" oil yield, flower percentage with the minimum stem percentage needed and the machine should be operated in low rotor speed (310 r.p.m). In order to have the maximum "quantity" oil yield, flower percentage with no interest in stem percentage needed and the machine should be operated at high rotor speed (510 r.p.m). The results show (Figure 6.12) that the machine performed extremely well in treatment B1111 and B1132 for maximum "quality" and maximum "quantity" respectively. In the B1111 treatment for maximum "quality" the "actual" % of flowers was 87.14 and the "actual" % of stems was 24.07. At B1132 treatment for the maximum "quantity" the "actual" % of flowers was 96.84 and the "actual" % of stems was 64.87.

[7] There is a diagrammatic representation of the histogram in Appendix 2 Figure A2.4.1.

6.3.1.4 Test N° 3 *Lavandula x intermidia Lullingstone Castle (2002 harvest)*

The plants of *Lavandula x intermidia Lullingstone Castle* cultivar were in the 3rd year of growth. The average height and width of the bush was 1.00 m and 1.20 m respectively with a mean density of 346 plants per m². The moisture content for this cultivar was 63.7% w.b.. This 3rd and last field test for the 2002 harvest period had the aim of checking the influence of the hood nose and the under cover at selected machine set ups. From the results (Table 6.8) it was concluded that there were two optimum settings for the machine, one for maximum "quantity" (B1132) and one for maximum "quality" (B1111). Due to limited experimental area only one of the two set ups could be selected. In order to determine the maximum performance of the machine in terms of throughput B1132 (maximum "quantity") was selected. The machine set up is shown in Table 6.9. The rotor speed was 510 r.p.m and the forward speed 1.13 km/h. Table 6.10 shows the results.

Table 6.9: Harvester settings

Machine set up		
Component	***Test N°2***	***Test N°3***
Hood nose distance from the ground	760 mm	710 mm
Hood nose below rotor shaft	50 mm	1=50 mm (O.p.)[8] 2=100 mm (below O.p.) 1=150 mm (below O.p)
Under cover (distance from the ground) ["ON" or "OFF"]	(430 mm) ["ON"]	(380 mm) ["ON" and "OFF"]
Angle of the stripping elements	15°	15°
Rotor width	720 mm	720 mm
Internal guides clear distance	500 mm	500 mm

[8] O.p = Original position

Material and methods

Due to time and area constraints the experiment was simplified to measure only flower losses. The following equipment was used to conduct the experiment:

- The prototype harvester machine,
- A hedge trimmer,
- Hand shears,
- Six plastic buckets to collect the harvest material,
- A 30 m tape measure,
- Several point sticks to specify each treatment area,
- A tachometer to measure the rotor speed (1 r.p.m resolution),
- A digital balance to weigh the collected plant material (0.01 g resolution).

One row of 120 m was existed as experimental area at Hitchin to conduct the 3rd test. The row was divided by half in 2 blocks. Each treatment consisted of 10 m row length. Five treatments in each block (3 for Hood nose + 2 for Under cover) were tested. In each block the treatments were randomly selected. First the influence of the hood nose was examined. The optimum treatment from the 1st test was selected to run the 2nd test. Although the statistical analysis showed that there was no significant difference between L12 and L13 the L12 was chosen. The criterion for the selection was the possible affect of the hood nose at the "feeding" angle of the flower heads during harvest. An increase in the angle of the flower head could decrease the effectiveness of the stripping procedure. From Table 6.9 can be seen that although the final weight loss in flower at L13 treatment was lower than the L12 the flower left on the bush was a little higher than L12 meaning less effective stripping. Higher clearance means less bend and consequently faster recovery for the plants from the bending and thus the L12 treatment was selected for the 2nd test. At the 2nd test the influence of the under cover was investigated. The total flower loss in each case was the sum of the flowers left on the bush and those found on the ground.

The research method was as follows:

- Divide the row into 10 m sections and mark the edges with grass paint,
- Trim with the hedge trimmer 2 m prior to the selected test area to a plant height at 380 mm to avoid collecting unwanted plant material out side of the test row,
- Harvest the row,
- Choose randomly 1 m from the test row and record the exact weight of the existing lavender flowers on the bush and on the ground,
- Measure and record the number of stems left on the bush.

Results

The results from the N° 3 field test are presented in Table 6.10. Figure 6.13 explains the treatment numbering.

Table 6.10: Results from N° 3 *Lavandula x i. Lulingstone Castle* test

N°	Treatment N°	Plant Density per m^2	Bush flower losses g/m	Ground flower losses g/m	Total flower losses g/m	Total flower losses g/m^2
1	L11	357	2.25	23.25	25.50	21.25
2	L12	343	1.00	15.50	16.50	13.75
3	L13	341	1.10	14.40	15.50	12.92
4	L12	337	1.00	14.25	15.25	12.71
5	L22	352	1.25	22.25	23.50	19.58

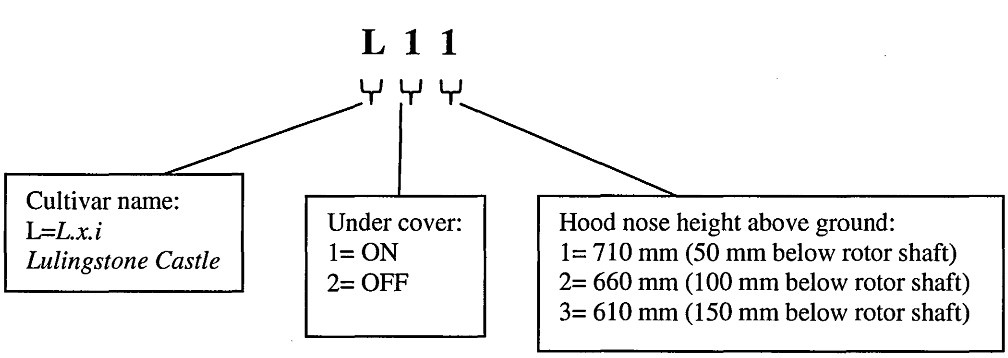


Figure 6.13: Treatment numbering key

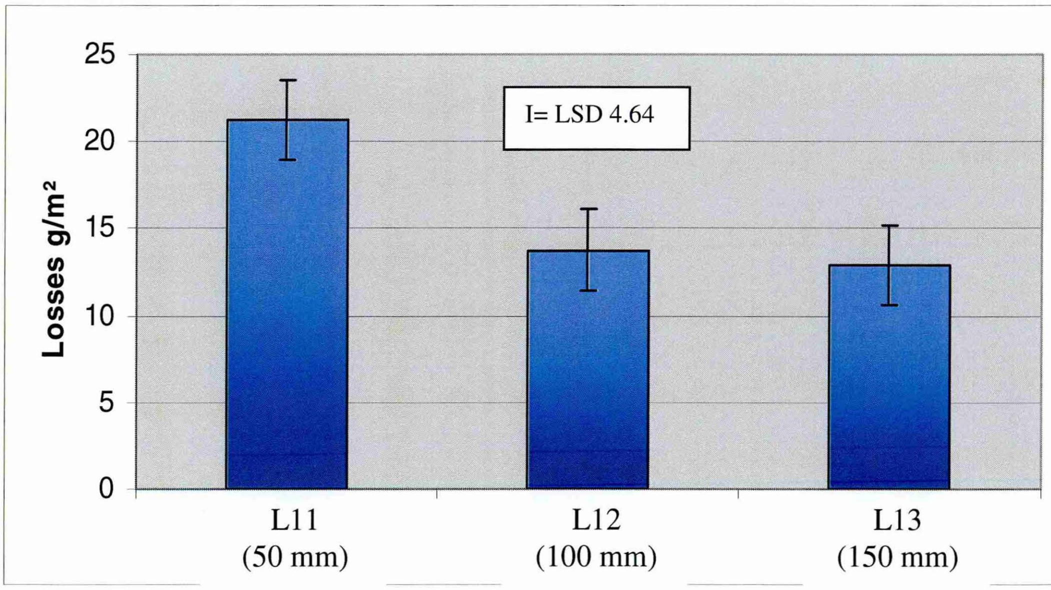


Figure 6.14: Flower losses at different hood nose heights below the rotor shaft
(LSD 5% level)

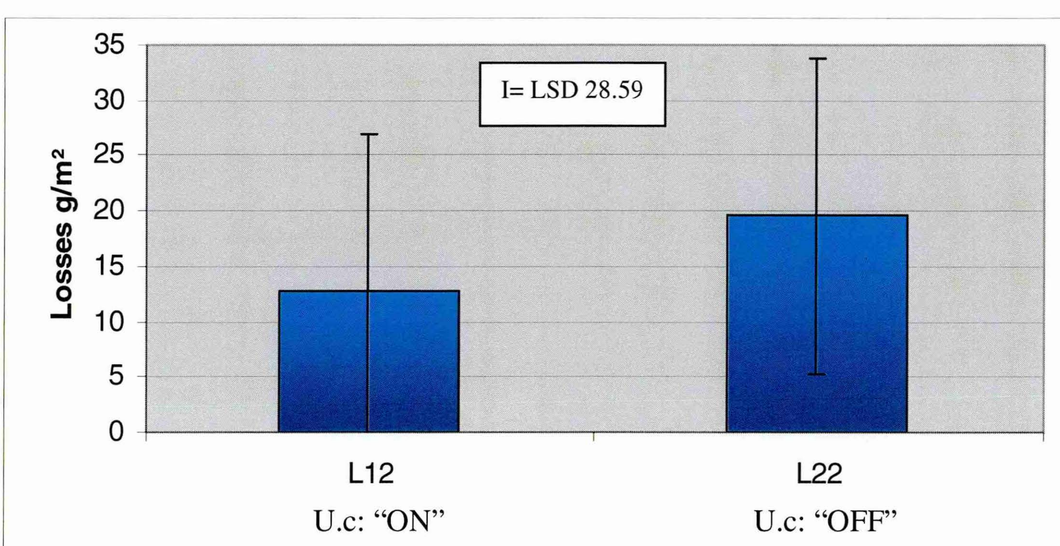


Figure 6.15: Flower losses at different Under Cover positions
(LSD 5% level)

Discussion

For treatment L11 the hood nose was kept at the 710 mm above ground. At the following L12 and L13 treatments the hood nose height was reduced by 50 mm and 100 mm respectively below the original placement. The results indicate that there is a difference at the 5% level in losses between L11 and the other two treatments L12 and L13 (Figure 6.14). It was observed that flower losses increased when the under cover was not fitted to the machine but there was no significant statistical difference at the 5% level Figure 6.15. Plate 6.6 demonstrates the effectiveness of the harvester for the N° 3 test.

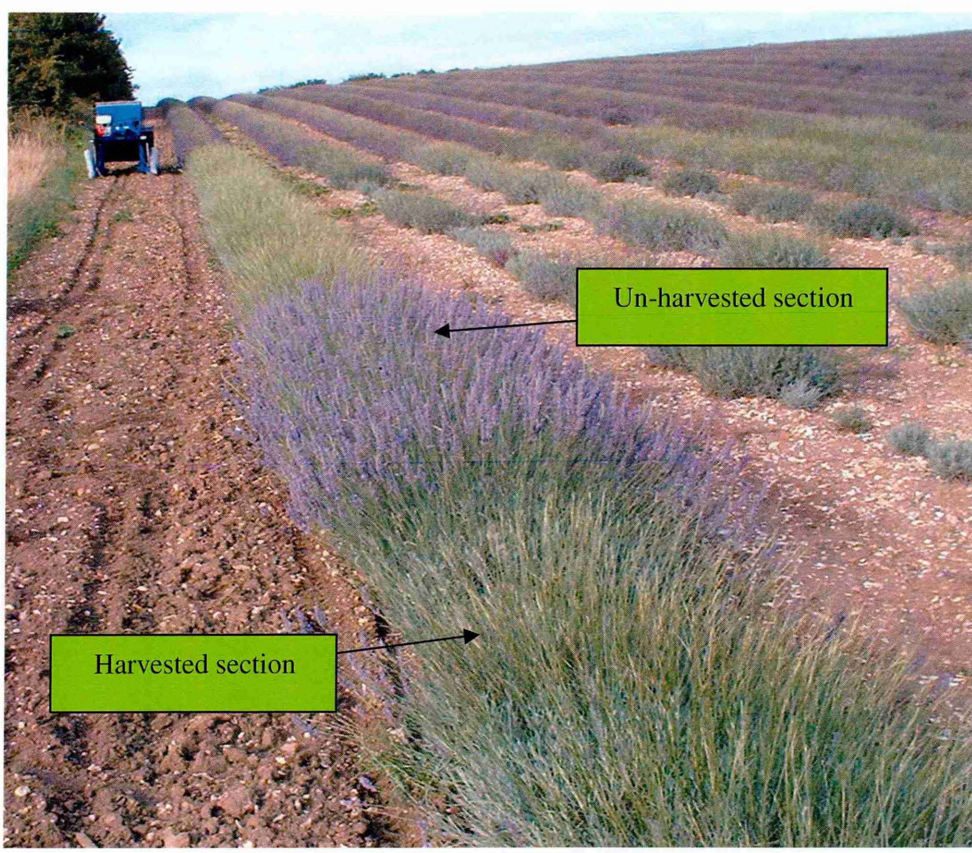


Plate 6.6: *Lavandula x intermidia Lullingstone Castle* cultivar test N° 3

6.3.1.5 Test N° 4 *Lavandula agustifolia Folgate (2003 harvest)*

Test N° 4 had the aim to determine the optimum machine settings for maximum harvest "quality" and "quantity" oil validating the results from previous field tests. The plants of *Lavandula angustifolia Folgate* cultivar were in the 3rd year of growth. The average bush height and width was 0.75 m and 0.90 m respectively with a mean density of 436 plants per m². The plants mean moisture content for this test was 65.9% w.b.. Table 6.11 shows the new machine set up. To determent which of the settings of the machine produced the best "quality" and "quantity" the criteria stated at section 6.3.1.1 was used.

Table 6.11: Harvester settings for Yalding evaluation test

Machine set up		
Component	***Test N°3***	***Test N°4***
Hood nose distance from the ground	710 mm	610 mm
Hood nose below rotor shaft	1=50 mm (O.p.) 2=100 mm (below O.p.) 1=150 mm (below O.p)	100 mm
Under cover (distance from the ground) ["ON" or "OFF"]	(380 mm) ["ON" and "OFF"]	(330 mm) ["ON"]
Angle of the stripping elements	15°	15°
Rotor width	720 mm	720 mm
Internal guides clear distance	500 mm	500 mm

Material and methods

The following equipment was used to conduct the experiment:

- The prototype harvester machine,
- A hedge trimmer,
- Hand shears,
- Six plastic buckets to collect the harvest material,
- A 30 m tape measure and several point sticks to specify each treatment area,
- A tachometer to measure the rotor speed (1 r.p.m resolution),
- A digital balance to weigh the collected plant material (0.01 g resolution).

The experiments were organised into 2 completely randomized block designs. An area of 336 m^2 consisting of 4 rows of 46 m length were used. Two different sets of measurements were taken from the same test area. The first set (which is the one described in this section) had the aim to determine the machine optimum settings. The second set had the aim to identify the work rate and the produced oil quantity and quality for three different harvest methods. The second set will be discussed in more details in Chapter 7 section 7.1. For the first set, six different treatments were replicated twice resulting in a total of 12 measurements. Each treatment consisted of a combination of rotor speed (310 and 510 r.p.m) and forward speed (0.6, 1.2, and 3.2 km/h). Between each treatment 2 m of row was left to allow the machine to reach its rotor speed and forward speed before harvesting the treatment.

The total flower incorporated at each treatment was the sum of the container material plus the flowers left on the bush and those found on the ground. The total stem was found from the addition of the container stem percentage and the hand harvest after the machine passes over each test row. In the same experiment 4 more treatments were examined to enable a comparison to be made between this harvester and existing methods. This is presented and explained in the next chapter.

To measure the percentage of flower harvest and stem harvest for each treatment the following procedure was followed:

- Measure 10 m of the row and mark the edges,
- Using a hedge trimmer clear 2 m of the row up to the marked row,
- Run the harvester for the selected 10 m and record the total weight of harvested plants from the container and then take three samples of 100 g each and record the weight of flowers and stems (machine harvest),
- After the harvest randomly choose 3 different 1 m length rows from 3 different positions from each 10 m harvested row weight and record the flowers left on the bushes, on the ground, and then hand harvest the stems count and weigh them.

Results

The results from N° 4 test at Yalding are presented in Table 6.12. Figure 6.16 explains the treatment numbering.

Table 6.12: Mean values from Yalding test

Treatment	m/c	Forward velocity		Hand harvest ratio per m² field area		Machine harvest ratio per m² field area		Actual flower harvest	Actual stem harvest
				Flower	Stem	Flower	Stem		
N°	%w.b	**km/h**	**m/s**	%	%	%	%	%	%
2F1111	65.7	0.60	0.17	70.1	29.9	93.5	6.5	95.86	15.91
2F1112	65.9	1.30	0.36	68.3	31.7	95.0	5.0	93.69	10.90
2F1113	65.6	3.20	0.89	61.6	38.4	96.5	3.5	80.56	4.74
2F1121	66.8	0.63	0.18	71.1	28.9	83.5	16.5	98.27	47.82
2F1122	65.3	1.50	0.42	67.1	32.9	87.5	12.5	96.08	28.02
2F1123	66.1	3.50	0.97	67.4	32.6	91.5	8.5	92.71	17.87

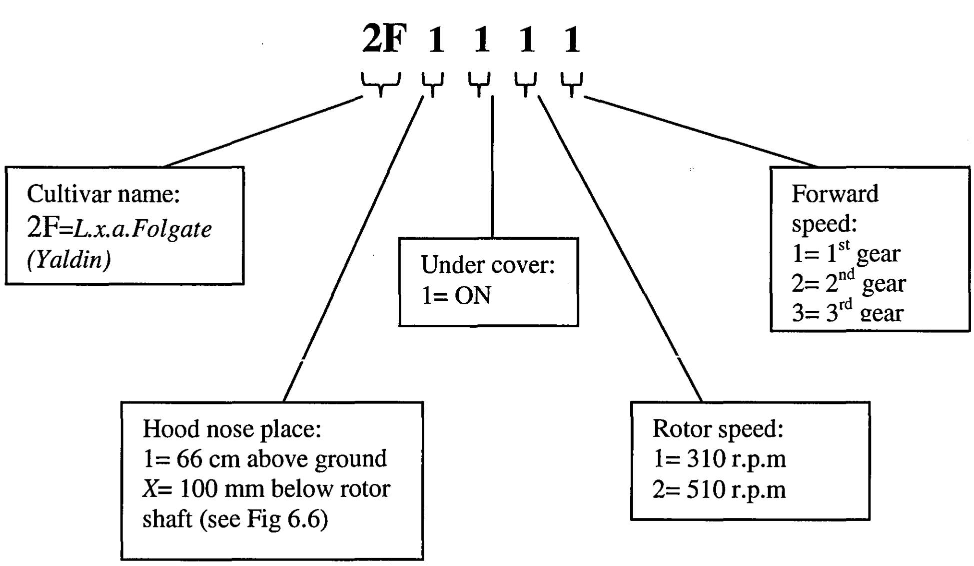


Figure 6.16: Treatment numbering key

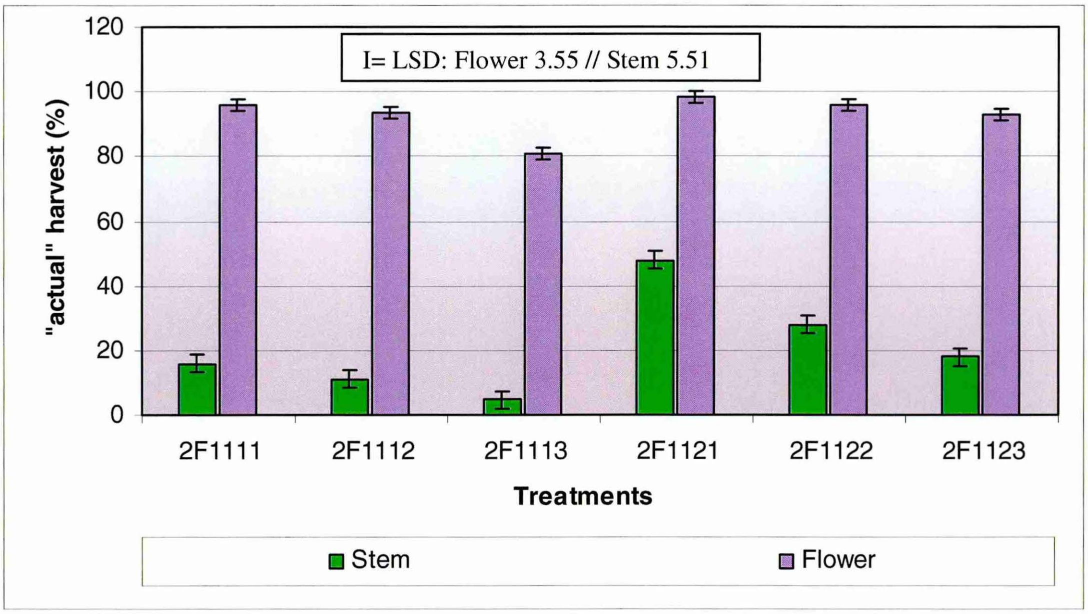


Figure 6.17: Flower and stem harvest for different treatments (N° 4 test 2003 harvest) (LSD 5% level)[9]

Discussion

The results show (Table 6.12 and Figure 6.17) that the machine performed very well in treatment 2F1112 for maximum "quality" and 2F1121 for maximum "quantity". This selection was based on the criteria developed in section 6.3.1.1. In the 2F1112 treatment the "actual" % of flowers was 93.69 and the "actual" % of stems was 10.90. At the 2F1121 treatment the "actual" % of flowers was 98.27 and the "actual" % of stems was 47.82.

The selection for maximum "quality" treatment 2F1112 was based firstly on criteria analysed in section 6.3.1.1. The statistical analysis followed, showed that there wasn't a significant difference with the 2F1111 treatment[10]. The final selection was also based on the fact that the 2F1112 treatment had a higher forward velocity which consequently had a better harvest efficiency compared to the 2F1111.

[9] There is a diagrammatic representation in Figure A2.4.2, Appendix 2

[10] To compare treatments between them using the statistical analysis decision was made only when both flower and stem was significant or not different to the compared.

6.3.1.6 Summary for N° 2, 3, 4 test (mature crop)

- Final methodology has worked very well to obtain accurate (± 1%) measurements.
- Of the hood nose settings investigated the best performance was found to be at 100 mm below rotor shaft.
- Two optimum settings were found to be one for maximum oil yield at 510 r.p.m rotor speed and a second one for maximum flower head with the minimum of stem at 310 r.p.m rotor speed.

6.3.2 Harvester refinement after field test N° 1, 2, 3, 4 (2002 and 2003 year)

Following the field tests during the 2002 harvest, the harvester was modified. The modifications involved the placement of two internal guides inside the machine to help hold the lavender plants laterally during the stripping operation. Changes were also made to the top of the container. A bee releaser was made to allow bees to escape prior to the harvester being unloaded. An extra hood nose was made to permit the machine to harvest young crops with low height reaching the 0.50 m from the ground and used only when young lavender plants were harvested. For the 2003 harvest no modifications were made.

6.3.3 Over all machine performance comparison

Table 6.13: Overall grand mean data for machine performance comparison after field tests

Test name	Cultivar name	Test site	Crop status[11]	Under cover position	Rotor speed[12] r.p.m	Flower harvest grand mean %	Stem harvest grand mean %
Preliminary	*Intermidia x "Bioregional"*	Carlshalton	Mature	"OFF"	210 360 510	92.65 in numbers of flower heads	–
1st	*Agustifolia Folgate*	Hitchin	Young	"ON"	310 510	70.59	24.28
1st	*Agustifolia Folgate*	Hitchin	Young	"OFF"	310 510	84.95	35.17
2nd	*Intermidia x Bioregional*	Carlshalton	Mature	"ON"	310 510	91.45	47.43
3rd	*Intermidia.x Lullington Castle*	Hitchin	Mature	"ON"	510	No data added because measurements was in terms of ground and bush losses	No data added because measurements was in terms of ground and bush losses
4th	*Agustifolia Folgate*	Yalding	Mature	"ON"	310 510	92.86	20.08

[11] Young < from 3 years growth, Mature > from 3 years growth

[12] For tests N° 1 and 2 the 410 r.p.m rotor speed excluded to allow a more representative comparison with test N° 4

7 Harvester comparison and economic analysis

This chapter focuses on the comparison of the new harvester (prototype) to current harvesting methods, hand harvesting and a conventional cutter bar harvester. This chapter is divided in two sections. In the first section, the work rate and the produced oil quantity and quality was measured and evaluated. In the second section an economical analysis was conducted to demonstrate the cost effectiveness of each harvest method.

7.1 Harvester comparison

Experiment location

The test to compare the work rate, the mass harvest yield and the oil yield for each method was conducted at Yalding area in South England. The hand harvest, prototype, and CLIER harvest methods were evaluated in a plot of 336 m^2. The same plot was used to conduct the 4^{th} test for the evaluation of the prototype harvester (see section 6.3.1.4). The total field area was 5.6 ha. The plants of *Lavandula angustifolia Folgate* cultivar were in the 3^{rd} year of growth. The average bush height and width was 0.75 m and 0.9 m respectively with a mean density of 436 plants per m^2. The mean moisture content was found at 65.9% w.b. The row width was 1.83 m (6 ft). The machine set up is described in Table 6.11 (section 6.3.1.4).

Harvest method specifications

For the hand harvest one adult person was used to harvest the chosen plot areas. Plate 7.1 shows the hand harvest operation. Plate 7.2 shows the prototype machine during test trials. Plates 7.3 to 7.5 show the prototype during harvest. Plate 7.6 shows the CLIER harvester and Plate 7.7 shows samples from each harvest method.

Plate 7.1: Hand harvest

Plate 7.2: The prototype harvester (Yalding area 2003 harvest)

Plate 7.3: Crop flow through the hood exit

Plate 7.4: View of the full container from the top

Plate 7.5: Machine after crop unloading

The CLIER was a portable one row harvester machine, and was mounted on the right hand side of the tractor. The tractor was a John Deere 2wheel drive 90 hp power. The CLIER machine had a pick up and a cutter bar mechanism with two adjustable lifters at the front. The stalks were gathered by two chains equipped with rubber ridges which guide the crop into the cutter bar where a second cutting mechanism is used to chop and throw the crop into a container on the rear of the machine.

Plate 7.6: The CLIER harvester mounted on the side of a John Deere 4040

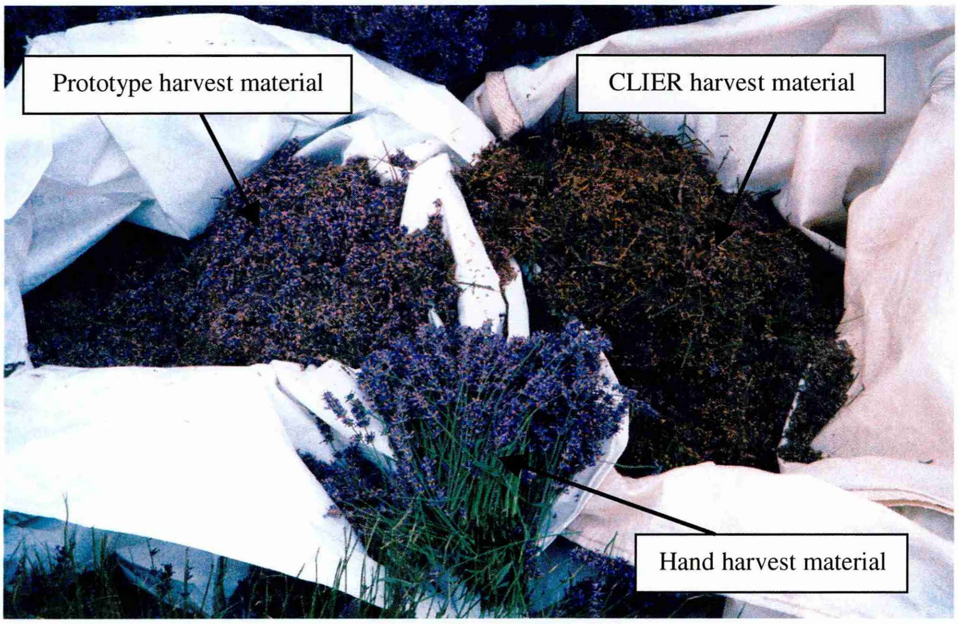


Plate 7.7: Harvest samples from each harvest method (photo taken 1 hr after harvest)

7.1.1 Performance comparison of the 3 different harvest methods

The aim of this experiment was to determine the work rate and the yield in terms of harvest mass and oil yield.

Material and methods

For the comparison of the 3 harvest methods a 2 block completely randomized design was used. Four rows (2 in each block) were used. The total number of treatments examined was four; the hand harvest, the CLIER and two different settings for qualitative and quantitative harvest for the Prototype. Four different treatments were replicated twice resulting in a total of 8 measurements. Plate 7.2 shows the field area used for the experiment and the prototype harvester.

The materials used for the test were:

<u>Hand harvest method:</u>

- Hand shears,
- 2 large plastic bags (1 m^3 volume),
- A stop watch,
- A 30 m measure tape,
- Several point sticks to specify each treatment area,
- A spring weight balance (10 g resolution).

For this method 10 m of row was harvested by hand. The harvested plant material was placed into a large plastic bag and weighed with the spring balance when the harvest was completed. A stop watch was used to record the time needed to harvest the selected row length.

Prototype and "CLIER" harvest method:

- 4 large plastic bags (1 m^3 volume),
- A spring weight balance (10 g resolution),
- A stop watch,
- A 30 m measure tape,
- Several point sticks to specify each treatment area.

To measure the yield using the prototype harvester the harvested material from the container of each treatment was placed into a large plastic bag and weighed. The stop watch was used to record the time needed to complete the 10 m row length harvest for the identification of the forward velocity.
To measure the yield using the CLIER harvester the large plastic bag was placed at the exit of the chute of the machine. The collected plant material was weighed and recorded. The time to complete each run was measured for the identification of the forward velocity.

Results
The performance results of each method are presented in Table 7.1. The supporting data is presented in Appendix 3 Table A3.1.

Table 7.1: Performance of the different harvest methods

Harvest method	Forward velocity km/h	Work rate ha/h	Harvest mass kg/ha	Oil quantity	
				L/ha	L/1000kg[13]
Hand harvest	0.0098	0.0018	8145.8	65.91	8.09
Prototype quality (310)	1.3	0.23	4140.4	51.89	12.53
Prototype quantity (510)	0.63	0.11	5445.5	54.45	10.00
CLIER	2.26	0.37	6615.6	40.34	6.09

[13] Litre per 1000 kg of harvested plant material for each method

7.1.2 Determination of volatile oil quality of the 3 different harvest methods

High quality oil will commonly be of greater market value and therefore it is important to consider the quality of the oil produced by each harvest method. To determine the oil quality for each treatment was a 3 stage process. First stage was to collect and store the samples into a container, the second stage was to freeze the samples using liquid nitrogen for storage in a freezer and the third was the analysis of the samples using a gas chromatography apparatus. For the analysis of the samples, Botanix Ltd laboratory was used due to their specialization in lavender oil (Botanix, 2003).

Material and methods

The materials and the methods used to take the measurements for each treatment were:

At the field:

- A digital weight balance to weigh the samples (0.01 g resolution),
- An insulated container with dry ice to keep the samples cool,
- Plastic bags.

From each treatment two samples of 100 g of harvest plant material was taken. The samples were placed in plastic bags and immediately placed into the container with the dry ice to keep them cool.

Cranfield Post harvest laboratory:

- A liquid nitrogen container,
- Two stainless steel cups of 500 cm^3 volume,
- A special box holder to hold the 2 cups,
- A special tool to take out the frozen plant material from the cups,
- plastic bags,
- A freezer.

Each sample was frozen using liquid nitrogen. The fresh sample was placed into the stainless steel cups and then liquid nitrogen added to the cup. When the cup was full the addition of the liquid nitrogen was stopped. The frozen plant material was then removed, marked and placed into plastic bags for storage in a freezer. Sixteen samples (4 treatments x 2 = 8 replicates x 2 samples per replicate = 16 samples) from the harvest material was taken and frozen for subsequent oil analysis.

Botanix Ltd laboratory:

The lavender samples were each weighed and then individually extracted for 1.5 hours by hydro-distillation using a Clevenger type apparatus. The yield was calculated by volume collected which was divided by the original weight and multiplied by 100 to achieve the data shown. For the quantitative Analyses the essential oils were analyzed by a Perkin Elmer automatic system. DB-1 column (30 m x 0.32 mm x 1 μm) was used with helium carrier gas (constant pressure 1.03 bars (15 psi)). The oven temperature was programmed from 60°C to 260°C at 4°C /60 s with a 90 s hold at 60°C and a 60 s at 260°C. The injector and detector temperatures were both set at 250°C. The samples (0.1 μl of oil concentrate) were injected by split injection. Temperature programmed retention indices of the compounds were determined relatively to the retention times of a series of n-alkanes. Quantification was determined by peak area normalisation without consideration of calibration factors. Figures 7.1 – 7.4 show the Gas Chromatography chromatograms complete with percentage peak area normalisation (PAN) and tentative identification of major peaks.

Garlick (1977) indicates that the principal criterion for quality in lavandin oil is its resemblance to "true" lavender oil. To evaluate the oil quality of the samples taken, the AFNOR standards (Table A3.2 Appendix 3) were selected to be used as a reference for the comparison. The differences between "true" lavender *(Lavandula angustifolia)* oil and lavandin *(Lavandula x intermidia)* oil are due to the percentage of the individual chemical components of their oil, which indicates their quality and determine the market price of the oil.

Lammerink et al., (1989) suggested that the high quality lavandin oil should contain relatively low levels of 1,8-cineole, camphor and borneol and high levels on linalyl acetate, terpinen-4-ol, and lavandulyl acetate. Lawrence (1993) mention that the linalyl acetate compound of lavender oil is used as a criterion of quality. Prager & Miskiewicz (1979) used as a basis for identification of lavender oil the criterion that lavender oils contain more linalyl acetate, β-caryophyllene, cis-β-ocimene and the lavandin oils contain larger amounts of 1,8-cineole, camphor, borneol and limonene. Rabotyagov & Akimov (1987) also mention the restricted spread of lavandin (although high yield) oils due to the lower quality compared with lavender oils because of the presence of large quantities of camphor, borneol, and cineole.

Considering the oil quality identification procedure from these Authors and the AFNOR standards a list of 10 compounds shown in Table 7.3 were established for comparison of the quality of the oil produced from each harvest method. The hand harvest was chosen as a control to compare the oil received from the other harvest methods.

Results

The results related to the oil analysis of the 3 harvest methods are presented in Table 7.2.

Table 7.2: Mean result values (component concentration in %)

Nº	Component	Hand harvest	Prototype quality 310	Prototype quantity 510	CLIER
	Volatile Oil % V/W	0.770	1.200	0.975	0.580
1	1,8-cineol / limonene	1.070	1.005	0.995	0.640
2	1-Octen-3-one	3.296	3.003	2.585	0.999
3	1-Octen-3-yl acetate	1.948	1.700	1.730	0.910
4	4-terpineol	14.290	14.335	14.370	15.975
5	alpha terpinyl acetate	0.984	1.009	0.936	1.495
6	alpha-humulene	1.125	1.140	1.410	0.885
7	alpha-terpineol	4.132	4.300	3.905	5.870
8	β -caryophyllene	0.978	1.175	0.260	0.500
9	borneol	1.476	1.445	1.700	3.295
10	cis ocimene	4.838	5.030	4.725	2.300
11	geraniol	2.167	2.350	0.000	3.349
12	germacrene D	0.466	0.455	0.535	0.000
13	lavandulyl acetate	3.664	3.235	3.455	1.465
14	linalool	24.755	25.090	24.020	34.040
15	linalyl acetate	24.996	24.895	29.895	19.050
16	myrcene	1.109	1.130	1.065	1.170
17	neo menthol	0.724	0.655	0.730	0.600
18	nerol	0.728	0.784	0.710	1.127
19	neryl acetate	1.892	1.936	1.796	2.895
20	trans ocimene	2.421	2.595	2.430	1.624

Figures 7.1-7.4 shown below for comparison see Table A3.1-A3.8 Appendix 3 for full size plots.

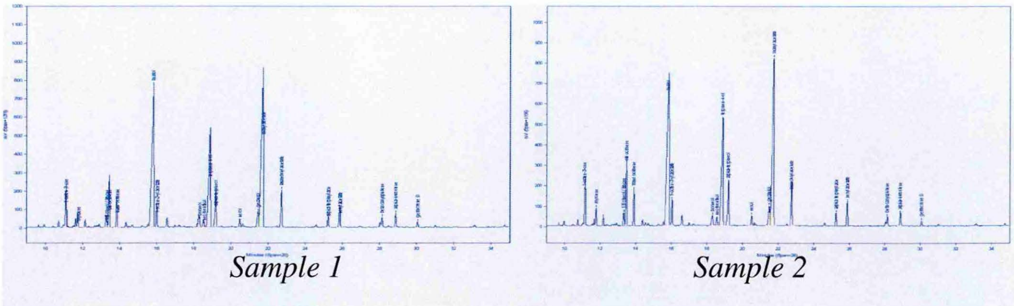


Figure 7.1: G.C. chromatogram for Hand harvest samples 1, 2

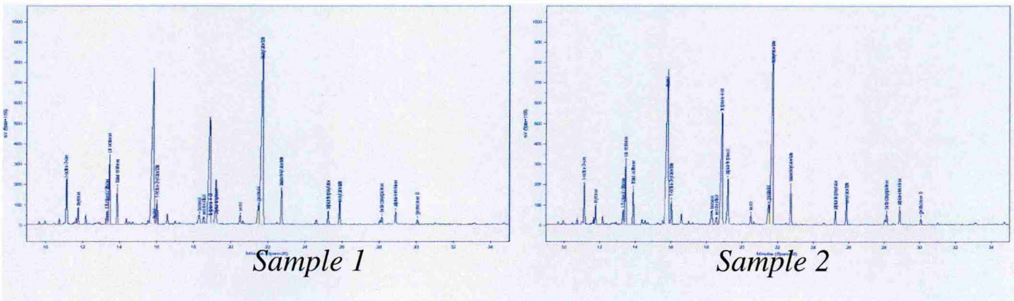


Figure 7.2: G.C chromatogram for Prototype "quality" samples 1, 2

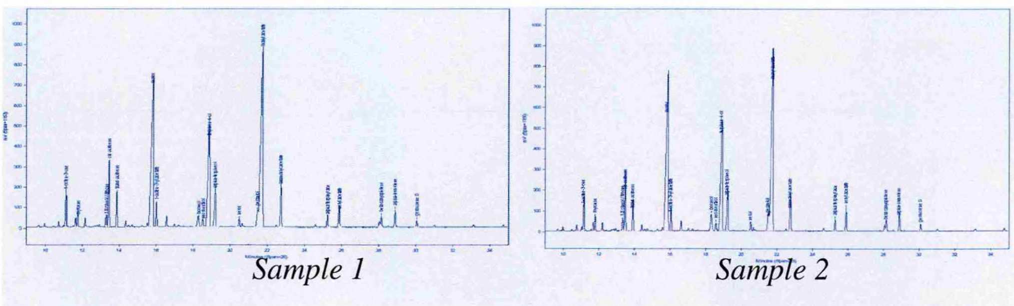


Figure 7.3: G.C chromatogram for Prototype "quantity" sample 1, 2

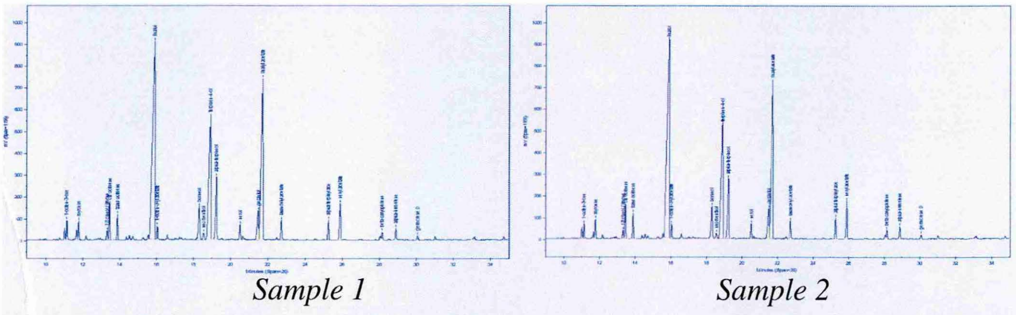


Figure 7.4: G.C chromatogram for CLIER sample 1, 2

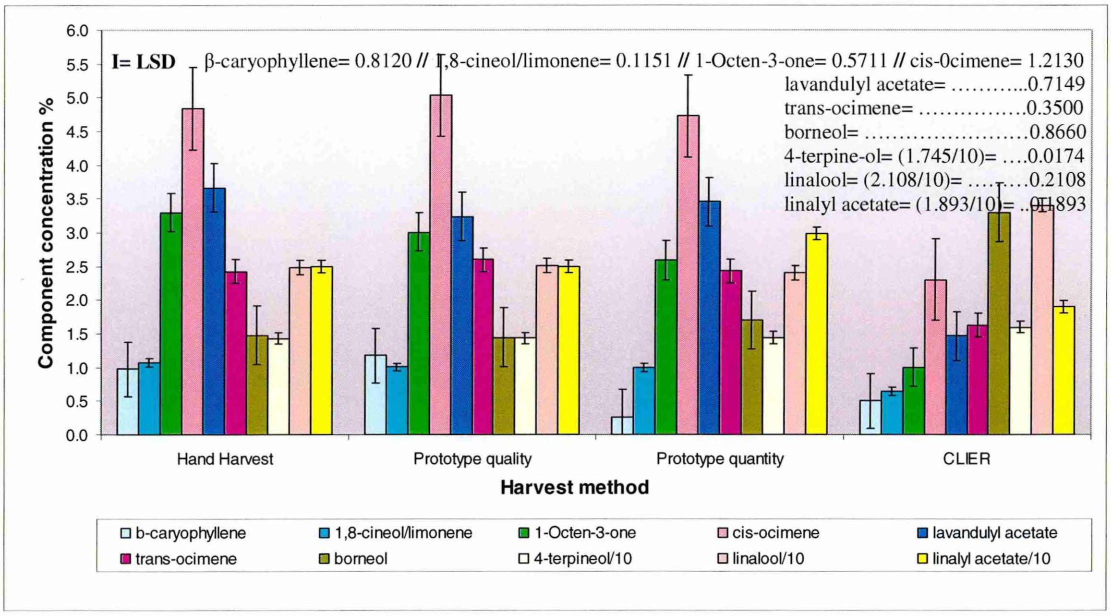


Figure 7.5: Main oil components for quality classification

The prototype "quality" setting produced very similar distribution of oil compounds to the hand harvest. "Quantity" had a slide variation and the CLIER was the most significant different.

Table 7.3: Significant difference of compounds at 5% level for each harvest method

No	Oil component	Hand harvest	Prototype quality	Prototype quantity	CLIER	Influence to the quality
1	1,8-cineol / limonene	C	NS	NS	S*	minimum as possible
2	borneol	C	NS*	NS*	S	minimum as possible
3	1-Octen-3-one	C	NS*	NS*	S	maximum as possible
4	cis-ocimene	C	NS*	NS*	S	maximum as possible
5	lavandulyl acetate	C	NS*	NS*	S	maximum as possible
6	linalyl acetate	C	NS*	S	S	maximum as possible
7	trans ocimene	C	NS*	NS*	S	maximum as possible
8	4-terpineol	C	NS*	NS*	NS*	maximum as possible
9	β-caryophyllene	C	NS*	NS*	NS*	maximum as possible
10	linalool	C	NS	NS	S*	maximum as possible

Term expl.: *(**C**= Control, **S**= sign. different to the control, **NS**= no sign. different to the control) *desirable*

Discussion

For the prototype "quality" method the analysis shows that from the 10 components examined none of them were significant different to the control.

For the prototype "quantity" method the analysis shows that from the 10 components examined only lynalyl acetate (N° 6) was significant different to the control in a greater amount.

For the CLIER method the analysis shows that 8 components were significant different to the control. Six of them were different in such a way that reduced the quality of the oil, and 2 of them to improve it, according to the AFNOR standards. The six components which decrease the oil quality were: *borneol* (N° 2), *1-Octen-3-one* (N° 3), *cis-ocimene* (N° 4), *lavandulyl acetate* (N° 5), *linalyl acetate* (N° 6), *trans ocimene* (N° 7). From those components N° 2, 3, 6 were significant different in a greater amount compared to the control and N° 4, 5, 7 in a lesser. The 2 compounds which increased the quality were *1,8-cineol / limonene* (N° 1) and *linalool* (N° 10). From those components N° 1 was significant different in a lesser amount and N° 10 in a greater amount compared to the control. Two compounds, *4-terpineol* (N° 8) and *β-caryophyllene* (N° 9) was not significant different to the control (Table 7.3).

The analysis shows that the cutting method has an influence into the quality of the produced oil. Therefore the effectiveness of the proposed method regarding the oil was established during the determination of the volatile oil quality for the 3 different harvest methods[14].

7.1.3 Summary for harvester comparison

- The best work rate from CLIER machine was found to be 0.37 ha/h
- The best setting for maximum oil yield from the prototype machine was at 510 r.p.m rotor speed and 0.63 km/h forward speed. This treatment gave an oil yield of 35% more than the conventional CLIER harvester and 21% less than the hand harvest.
- The oil quality was found to be better for both settings of the prototype compared with the CLIER.

[14] Assuming that the hand harvest had the best quality for the given field and experiment conditions

7.2 Economic analysis

An economic analysis was conducted to compare the production cost for each harvesting method considering the harvest operating cost.

7.2.1 Determination of the operating costs for the 3 different harvest methods

To determine the operating costs, findings of work rate, crop mass and oil yield were used from section 7.1. The annual costs for each method were divided into 2 categories, namely the fixed and the running costs. The fixed costs consisted of depreciation and insurance. The running costs included the fuel & oil, repair, maintenance and labour.
To calculate the hand harvest method the annual cost of the work rate and the cost per hour labour work was used.
To calculate the fixed costs an estimation of the prototype harvester price was required. The value of £15,000 was used. The value was estimated considering the materials price value (£5,000) and the labour (£10,000) to build the machine. For this method no insurance was calculated because the prototype was a test machine. For the running costs of the prototype the fuel consumption was measured during harvest and found to be 4.5 L/ha of petrol. For depreciation a 10% straight line reduction of the capital cost was used. For repairs & maintenance 1.5% of the capital cost was used. Two workers were needed to conduct the harvest using the prototype machine.
For the CLIER harvester the total annual cost was a combination of 2 machines. First was the tractor and second the mounted harvester. To evaluate the total mean annual cost of using a tractor for this operation a 100 hp tractor was used as a basis as these are common available in UK farming systems. The mean hourly cost (Nix, 2004) was multiplied by the harvest duration. The data reference used relates to a 4 wheel drive tractor as these are more commonly available at this engine size. To calculate the annual cost of the mounted harvester a capital cost of £20,000 was used (Alexander; Worley, 2003). For repairs & maintenance 1.5% of the capital cost was calculated and added to the final cost. One operator was needed to conduct the harvest. For the calculations the harvesters were assumed to work for 10 days (80 h) per season.

Results

Table 7.4 shows the operational costs for each harvest method regarding the fixed and the running costs. Detail calculations are presented in Table A3.3, Appendix 3.

Table 7.4: Harvest operation costs for each harvest method

Harvest method	Total operation cost (harvest) **£/ha**
Hand harvest	2425.5
Prototype "quality"	133.9
Prototype "quantity"	280.0
CLIER	120.2

7.2.2 Determination of the production oil cost for the 3 different harvest methods

To conduct the comparison of the produced oil cost from the 3 different harvest methods a scenario, based on real data supplied from Alec Hunter (Hunter, 2002) from a 0.8 ha plot area considering the 2002 harvest season were used. The data used to construct the analysis is show below:

- Distillery unit: Botanix Ltd. (110 miles (176 km) away from the harvest field).
- Lorry hire cost: £100/day (Plate7.8).
- Lorry fuel cost: £0.36/mile (£0.22/km).
- Distillation cost at Botanix distillery = £95/chamber[15].

Mass of material transported: 1460 kg and filled 1 ½ chambers ≈1000 kg/chamber

Results

Table 7.5 shows the final costs for each harvest method regarding the cost per ha and cost per litre of produced oil. Detail calculations are presented on Table A3.4, Appendix 3.

[15] 1 x Chamber ≈ 5.0 m^3 volume and requires 2 hours distillation time

Table 7.5: Overall total costs for each harvest method

Harvest method	Distance from the distillery miles	km	Harvest costs £/ha	Transportation & distillation costs £/ha	Total cost £/ha	Total cost £/L of prod. oil
Hand harvest	1	1.6	2425.5	870	3295.5	50.0
	66	105.6	2425.5	1004	3429.5	52.0
	110	176.0	2425.5	1200	3625.5	55.0
Prototype quality[16]	1	1.6	133.9	490	623.9	12.0
	110	176.0	133.9	600	733.9	14.1
Prototype quantity	1	1.6	280.0	585	865.0	15.9
	66	105.6	280.0	671	951.0	17.5
	110	176.0	280.0	835	1115	20.5
CLIER	1	1.6	120.2	775	895.2	22.2
	66	105.6	120.2	885	1005.2	24.9
	110	176.0	120.2	1065	1185.2	29.4

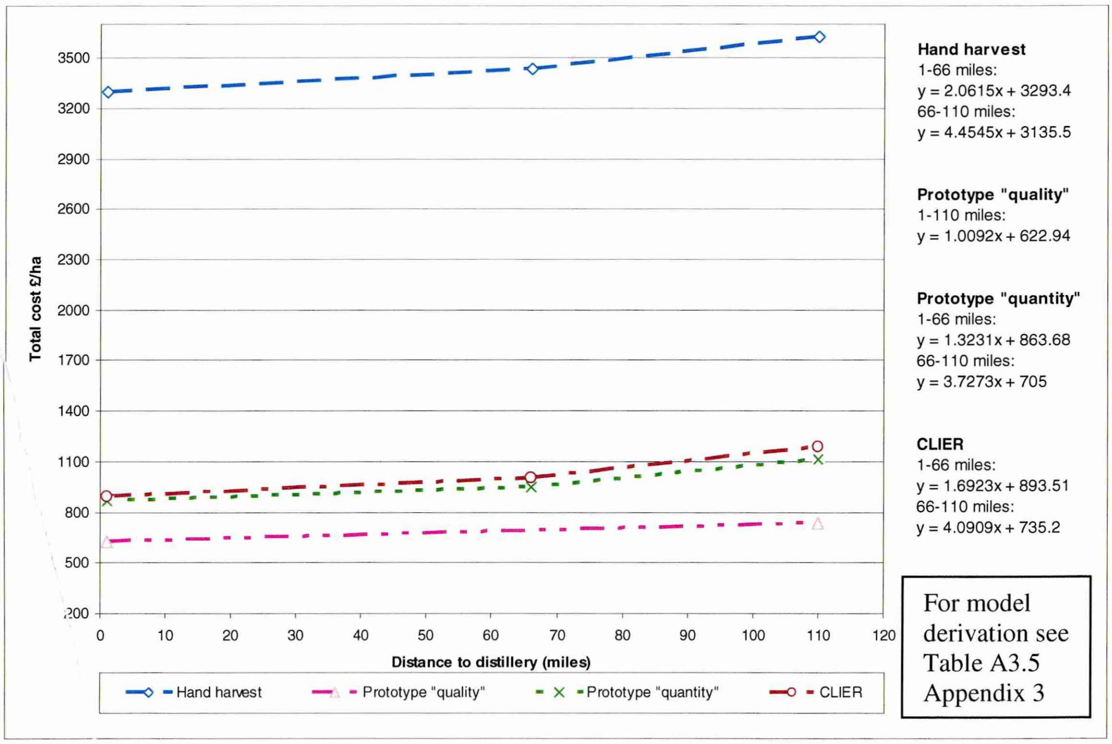


Figure 7.6: Total cost in relation to the area and distance from the distillery unit

[16] No 66 miles option taken because the harvested material was transported in the same working day

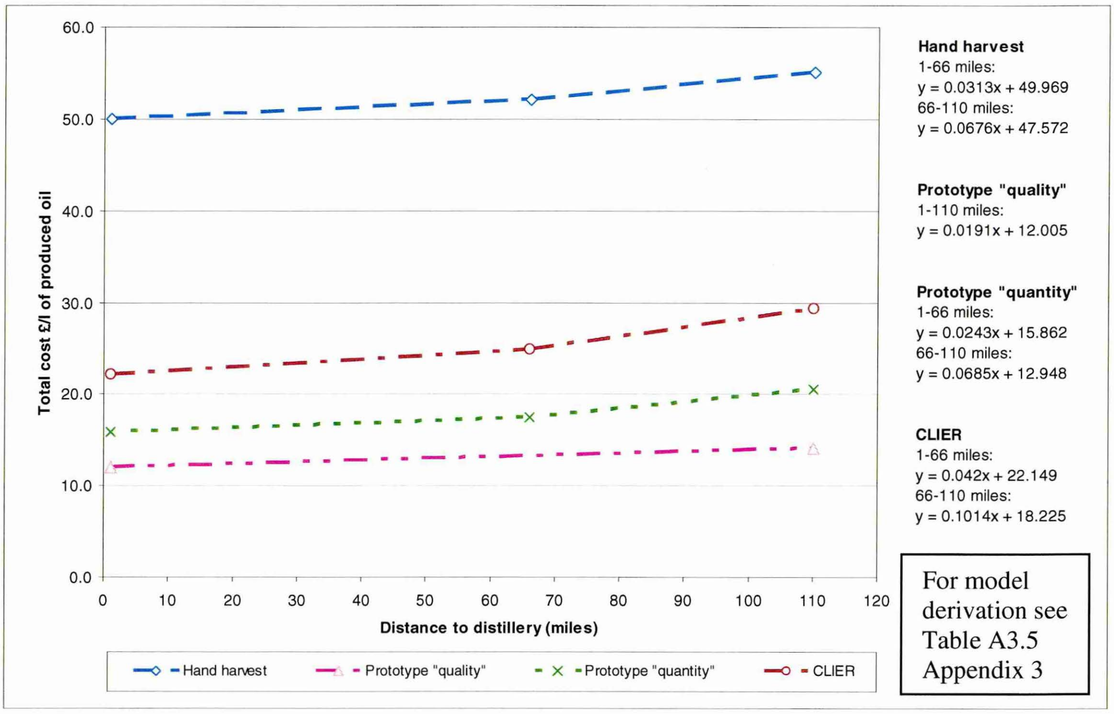


Figure 7.7: Production cost of oil in relation to the distance from the distillery

Discussion

The results show that the proposed method produced the minimum overall costs. Especially the prototype "quality" setting up which gave the lowest cost results (£623.9 /ha) (1 mile distance to still (D.T.STL)) and £733.9 /ha total cost (110 miles D.T.STL). The minimum production oil yield then must be 12.5 L/ha for the 1 mile (D.T.STL) and 15.7 L/ha for the 110 miles (D.T.STL) to cover the production costs (if a £50 /L take into account as market price (Alexander, 2003)). In the contrary the maximum total costs gave the hand harvest method with £3295.5 /ha (1 mile D.T.STL) and £3625.5 /ha (110 miles D.T.STL). Therefore the minimum production in oil yield for this method must be 65.9 L/ha for the 1 mile D.T.STL and 72.5 L/ha to cover the total costs. The distance has a great influence in to the total cost and is demonstrated in Figure 7.6. The costs per litre of produced oil (Figure 7.7) shown the effectiveness of the proposed harvest method compared to methods currently in use.

A comparison between the 2 mechanised harvest methods, Prototype "quality" and CLIER harvester showed that the prototype needs approximately half the costs to harvest the same field area for the given scenario. The prototype only harvests the flower and leaves the most of the stem. This provides the opportunity to conduct a second pass at a late stage with the purpose of harvesting late blooming flowers. This would only be economic if an 1891 kg /ha of flowers remaining after the first pass.

Plate 7.8: Rented lorry for the transportation of harvested lavender to the distillery

7.2.3 Summary for economic analysis

- Although the CLIER appears to have an advantage due to faster working speed the economic analysis shows that the prototype quality setting was the most cost efficient harvest method to use for the given scenario examined.

8 Discussion

The discussion covers three main areas, the physical characteristics of the plants, the harvester design and the harvester performance.

8.1 Physical characteristics of the plant

There has been very little research work related to the physical characteristics of the lavender plant in terms of the forces required for flower detachment and stem breakage. Therefore a new methodology to measure these forces was developed.

Chapter four showed that the force required to break the stem is always greater than the flower detachment force required. The mean stem breaking force, for each of the cultivars tested, ranged between 28.9 to 46.0 N. The mean detachment flower force, for each of the cultivars tested, ranged between 8.6 and 15.6 N depending upon the cultivars physical characteristics. Therefore it can be predicted that for these cultivars, the stripping method can always be applied. During the flower detachment force tests, a relationship between moisture content and measured forces was obtained. As the moisture content decreased the measured forces for flower detachment and stem breakage increased. This relationship was used to allow a comparison between tested cultivars at different moisture contents, over the typical harvest moisture content range of 58 to 69% w.b.. The force measurement data obtained from the Instron chart recorder (see plate 4.1b) showed a specific pattern for each cultivar. In the future, this may prove to be useful for the identification of cultivars because the trends appeared to be different for each cultivar tested and be a function of the flowering pattern. Although this was not investigated further the different trends produced can be seen in Figure A2.5a,b,c Appendix 2.5.

Due to time constraints the terminal velocity test was based on one cultivar. The use of the theoretical approach using Lapple's (1959) equation provided a basis for the analysis. During the prototype evaluation tests no problems of inadequate transportation of the detached flower to the container was noticed and therefore the design method achieved an acceptable level of performance.

8.2 Prototype design

The final harvester design was a compact and reliable one. In three years of harvest seasons the machine harvested a total of 4 ha of field area. Small problems arose occasionally; gear engagement was difficult when the engine was running at high revs and the chain slipped over the drive wheel shaft sprocket when the machine was fully loaded and moving on an incline. To solve the gear engagement problem, the revs of the engine were decreased prior to gear engagement. To prevent chain slippage, larger diameter drive shaft sprockets were used as described in section 6.2.3.

The time spent unloading the machine, especially when dense cultivars were harvested, could be improved. A larger volume container could be used to improve the field efficiency of the harvester, or a small towed carriage could be a solution to combat time loss due to unloading delays during harvesting. This would only be suitable where the headland size is sufficient to enable the harvester and carriage to turn around. However this may increase fuel costs and may also damage the soil due to a slight increase in compaction.

The rotor diameter was not optimal for young crops because the design was biased towards mature crops between 0.65 and 1.0 m height. Cultivars with a lower height would benefit from a smaller diameter rotor, which would be operated at a lower height in order to harvest the shortest plants.

8.3 Prototype performance

The evaluation of the prototype revealed two main areas for analysis; the performance measurement method and the optimum design settings.

Problems were found with the initial methodology used to measure the harvested flower and stem percentage which was corrected during the evaluation procedure as described below. The results from the field tests show that the prototype performed adequately in young crops and extremely well in mature crops.

8.3.1 Methods to determine performance

The difference between the total plant material available in the field and the harvested plant material was used as the indicator for the performance of the prototype. The initial methodology used measurements of the total weight of crop existing in the field before harvest. However when the crop density in the field is highly variable this creates errors, shown by some harvest percentages being in excess of 100. This was clearly not possible and therefore indicates that the initial experimental method did not adequately account for in field variability and could only be used for relative comparisons. Therefore a different methodology was applied in subsequent tests to provide an absolute measure of performance. This final methodology consisted of collecting the harvest material from the harvester, and the crop remaining in the field after the harvest to derive a crop total existing before harvest. This was a much more accurate methodology because it was independent of crop density, which could be accounted for by replicating the trial area.

The method was used at several test sites on the prototype machine and commercial machine and proved to be very effective.

8.3.2 Optimum performance settings

The rotor speed had a large influence on the percentage of harvested stem; higher rotor speeds increased the amount of stem harvested as shown in Plate 8.1. A change in rotor speed from 310 r.p.m to 510 r.p.m produced almost double the amount of harvested stem material due to the large increase in impacts per meter of forward travel.

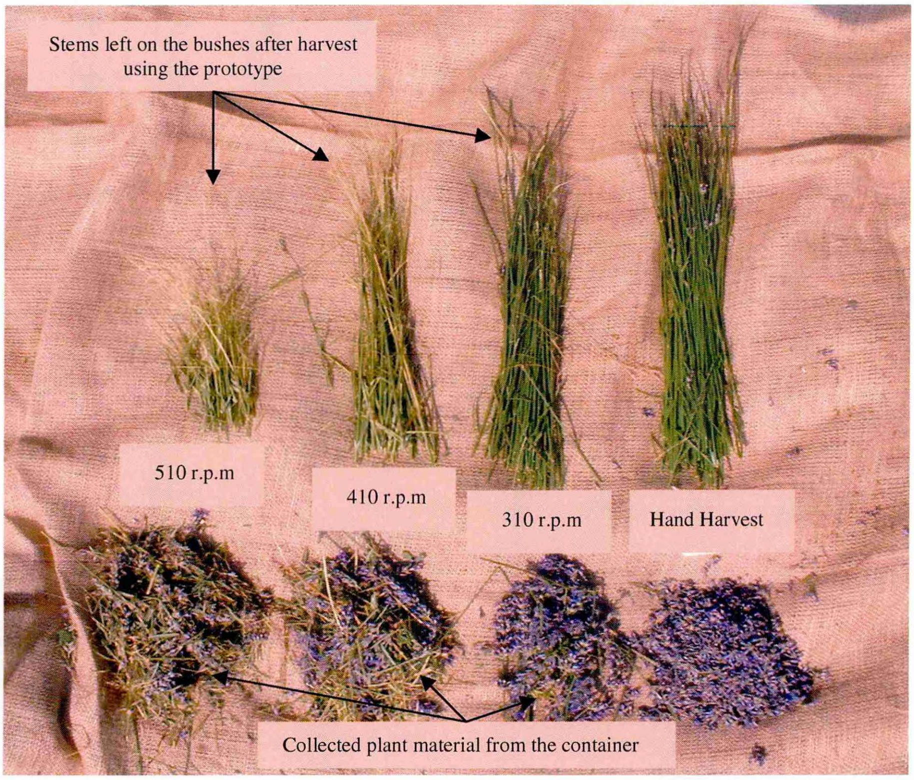


Plate 8.1: Effect of rotor speed on the amount of stem harvest[17]

[17] Hand harvest = Control

The results from the N° 4 field test showed that there is no single "optimum" setting for all harvest conditions. Table 8.1 demonstrates that for maximum quality (minimum stem) a low rotor speed (310 r.p.m) is always required and for maximum harvest volume (quantity) a high rotor speed of 510 r.p.m is required. Test N° 4 is more representative of commercial lavender oil production as the lavender had received full crop management, weeding and fertilisation and for this reason has been selected.

Table 8.1: The best performance achieved by the machine

Test	Plant density	m/c	Separating force		Test settings			Performance	
			Flower	Stem		Rotor speed	Forward speed	Flower harvest	Stem harvest
N°	**Plants/ m²**	**% w.b**	**N**	**N**		**r.p.m**	**km/h**	**%**	**%**
N° 4	436	65.9	10.55	31.56	quality	310	1.3	93.6	10.9
					quantity	510	0.63	98.3	47.8

For test N° 4, a "quality" harvest setting required a low rotor speed and a high forward speed. A "quantity" harvest setting required a high rotor speed and low forward speed.

The oil analysis shows that the prototype had a better oil quality and quantity per area of field than that of the conventional harvester. This is because the conventional harvester cuts the crop and collects the stem affecting the oil quality, volatile losses and total costs.

The economic analysis proves the effectiveness of the proposed method compared to existing machines and demonstrates that it is always more cost effective to set the machine up to harvest a minimum of stem ("quality" setting). This reduction in cost is predominantly due to the reduction in transportation and distillation costs and the extra oil yield per unit volume of harvested material.

Because no one setting is optimal, a rough guide to the set up of the machine for the most cost effective production of lavender oil (test N° 4 "quality") would be as follows:

- The rotor speed should be set at 310 r.p.m.
- The forward speed should then be increased to a level where the percentage stem is minimised without leaving flower in the field.
- If flower remains unharvested on the stem, the forward speed should be reduced.
- If excessive stem material is present in the container the forward speed should be increased.

The forward speed range will be between 0.3 and 1.3 km/h producing a spot work rate of 0.1 to 2.3 ha/day (1 harvest day = 10 h at peak season)

The machine is more cost effective than conventional harvesters on small scale (1-2 ha) enterprises. Section 7.2.2 shows a cost of £12/ L of oil produced versus £22.2/ L of oil produced for prototype "quality" and CLIER respectively when the distillery is sited on the field. When the distillery is 110 miles away from the field then the cost increases to £14.1/ L of oil produced versus £29.4/ L of oil produced for prototype "quality" and CLIER respectively.

Small scale enterprises of 1-2 ha can expand if a machine similar to the one used for this research is used.

9 Conclusions

- It is possible to detach the lavender flower head using stripping technology. The stripping technology can be applied to the harvest of lavender both for oil and pot-pouri production.

- Existing lavender harvesting machines use a cutter bar which collects the stem with the flower and decreases the amount of oil for a standard distillation volume of harvest material compared to a method which removes only the flower. This is a conceptually inefficient design because the volume of oil in the stem is 2.56% of the oil contained in the flower, and is of lower quality.

- The quality of the oil produced using the stripping principle to harvest lavender for oil production was significantly better (5% level) than that produced from the conventional mechanised harvest method (CLIER harvester) in 60% of the examined constituent essential oil components.

- Lower overall operational costs of the proposed harvest method compared to the existing conventional harvesting methods. The total cost per litre of the oil produced was reduced from £55.00 and £29.40 for the hand harvest and conventional mechanised harvest methods respectively to £14.10. These prices include the cost of transport assuming that the harvested field was 110 miles (175 km) away from the distillery.

- The UTS for the upper stem of the lavender plant was found to range from 12.13 MPa to 23.12 MPa. The force required to detach the flower from the stem was less than that required to break the stem in all cases tested. However, in the field it was not possible to reduce the amount of stem harvested to zero. The minimum amount of stem as a percentage of total stem for the most cost effective setting was 10.9% by weight when the machine was operated to yield the highest product quality at Yalding field. This was achieved by operating the rotor at a speed of 310 r.p.m (which is equivalent to a stripping element peripheral velocity of 11 m/s) for a range of forwards speeds dependant upon the physical characteristics of the cultivar.

- The optimum settings for the prototype in terms of oil quality and cost efficiency was as follows:
    - the rotor speed was at 310 r.p.m
    - the forward speed was 1.23 km/h
    - the Under cover was fitted
    - the rotor shaft was at 0.71 m above the ground
    - the hood nose was at 100 mm below rotor shaft

  The flower harvest efficiency reached 98.3% by weight using these settings. The plants height and width was 0.75 m and 0.90 m respectively with a mean density of 436 plants/m^2.

10 Recommendations for future research

- The time lost in emptying the plant material from the container was a problem which needs a further investigation. A small and very manoeuvrable harvester towing a 4 wheel carriage 1 m^3 volume could be a solution.

- Different shapes of striping elements should be tested to investigate the influence on the stripping action.

- In a new walking self propelled stripping lavender harvester special attention must be given to the capacity of the drive system, the ease of changing height and the type of the dividers (depending upon the physical characteristics of the cultivar grown).

- The internal rotor stripper could be a concept for future development using the knowledge gained from this research. Focus on reducing rotor speed may be beneficial as lower speed was shown to increase oil quality.

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APPENDICES

APPENDIX 1: LAVENDER PLANT GENERAL INFORMATIONS

Appendix Table A1.1. Most common names of lavender in different languages

Language		Language	
Albanian	Livandë e vërtetë	Icelandic	Lofnarblóm
Armenian	Հուսամ	Italian	Lavanda
Barmenian	Hoosam, Husam	Latvian	Šaurlapu lavanda, Lavandīna
Basque	Izpiliku; Belatxeta (Lavandula spicata); Esplikamin (Lavandula stoechas)	Lithuanian	Tikroji levanda
Bulgarian	Лавандула	Maltese	Lavandra
Catalan	Espígol	Norwegian	Lavendel
Croatian	Ljekovita lavanda	Polish	Lawenda wąskolistna
Czech	Levandule	Portuguese	Alfazema; Rosmaninho (Lavandula stoechas)
Danish	Lavendel, Hunlavendel	Provençal	Lavando
Dutch	Lavendel, Spijklavendel	Romanian	Levănțică
Esperanto	Lavendo	Russian	Лаванда
Estonian	Tähklavendel	Slovak	Lavandin, Levanduľa úzkolistá
Farsi	Ostukhudus	Slovenian	Lavendin, Sivka
Finnish	Tupsupäälaventeli	Spanish	Lavanda
French	Lavande	Swedish	Lavendel
Gaelic	Lus-na-tùise, An lus liath	Turkish	Lavânta çiçeği
German	Lavendel	Ukrainian	Лаванда
Greek	Λεβάντα	United Kingdom	Lavender
Hungarian	Levendula		

Appendix Table A1.2. Most common Cultivars of Lavandula Angustifolia

N°	*Cultivars*	N°	*Cultivars*
1	Lavandula Angustifolia Alba	38	Lavandula Angustifolia Lullaby
2	Lavandula Angustifolia Amanda Carter	39	Lavandula Angustifolia Lullaby Blue
3	Lavandula Angustifolia Ashdown Forest	40	Lavandula Angustifolia Maillette
4	Lavandula Angustifolia Avice hill	41	Lavandula Angustifolia Martha Roderick
5	Lavandula Angustifolia Backhouse Purple	42	Lavandula Angustifolia Mausen Dwarf
6	Lavandula Angustifolia Beechwood Blue	43	Lavandula Angustifolia Melissa
7	Lavandula Angustifolia Blue Bun	44	Lavandula Angustifolia Midhall
8	Lavandula Angustifolia Blue Cushion	45	Lavandula Angustifolia Miss Katherine
9	Lavandula Angustifolia Blue Mountain	46	Lavandula Angustifolia Mitcham Gray
10	Lavandula Angustifolia Bosisto	47	Lavandula Angustifolia Munstead
11	Lavandula Angustifolia Bowles Early	48	Lavandula Angustifolia Mystique
12	Lavandula Angustifolia Budakalaszi	49	Lavandula Angustifolia Nana
13	Lavandula Angustifolia Buena Vista	50	Lavandula Angustifolia Nana Alba
14	Lavandula Angustifolia Cedar Blue	51	Lavandula Angustifolia Nana Atropurpurea[I]
15	Lavandula Angustifolia Celestial Star	52	Lavandula Angustifolia Okamurasaki
16	Lavandula Angustifolia Coconut Ice	53	Lavandula Angustifolia Otago Haze
17	Lavandula Angustifolia Common	54	Lavandula Angustifolia Pacific Blue
18	Lavandula Angustifolia Crystal Lights	55	Lavandula Angustifolia Pacific Pink
19	Lavandula Angustifolia Egerton Blue	56	Lavandula Angustifolia Princess Blue
20	Lavandula Angustifolia Fiona English	57	Lavandula Angustifolia Purple Pixie
21	Lavandula Angustifolia Folgate	58	Lavandula Angustifolia Rosea
22	Lavandula Angustifolia Foveaux Storm	59	Lavandula Angustifolia Royal Velvet
23	Lavandula Angustifolia Fring	60	Lavandula Angustifolia Sachet
24	Lavandula Angustifolia Granny's Bouquet	61	Lavandula Angustifolia Sarah
25	Lavandula Angustifolia Gray Lady	62	Lavandula Angustifolia Sharon Roberts
26	Lavandula Angustifolia Heacham Blue	63	Lavandula Angustifolia South Pole
27	Lavandula Angustifolia Helen Batchelder	64	Lavandula Angustifolia Susan Belsinger
28	Lavandula Angustifolia Hidcote[I]	64	Lavandula Angustifolia Tarras
29	Lavandula Angustifolia Hidcote Pink	66	Lavandula Angustifolia Tasm
30	Lavandula Angustifolia Imperial Gem	67	Lavandula Angustifolia The Colour Purple
31	Lavandula Angustifolia Irene Doyle	68	Lavandula Angustifolia Thumbelina Leigh
32	Lavandula Angustifolia Jean Davis	69	Lavandula Angustifolia Tom Garbutt
33	Lavandula Angustifolia Lady	70	Lavandula Angustifolia Trolla
34	Lavandula Angustifolia Lavenite Petite	71	Lavandula Angustifolia Tucker's Early Purple
35	Lavandula Angustifolia Litle Lady	72	Lavandula Angustifolia Twickel Purple
36	Lavandula Angustifolia London Blue	73	Lavandula Angustifolia Violet Intrigue
37	Lavandula Angustifolia London Pink	74	Lavandula Angustifolia Winton

Note[I]: two plants, A and B

Appendix Table A1.3. Most common Cultivars of *Lavandula x intermidia*

N°	***Cultivars***
1	Lavandula x intermidia Abrialii
2	Lavandula x intermidia Alba
3	Lavandula x intermidia Arabian Night
4	Lavandula x intermidia Bogong
5	Lavandula x intermidia Chaix
6	Lavandula x intermidia Dilly Dilly
7	Lavandula x intermidia Dutch
8	Lavandula x intermidia Duch White
9	Lavandula x intermidia Fragrant Memories
10	Lavandula x intermidia Fred Boutin
11	Lavandula x intermidia Grappenhall
12	Lavandula x intermidia Grey Hedge
13	Lavandula x intermidia Grosso
14	Lavandula x intermidia Hidcote Giant
15	Lavandula x intermidia Impress Purple
16	Lavandula x intermidia Jaubert
17	Lavandula x intermidia Lullingstone Castle
18	Lavandula x intermidia Margaret
19	Lavandula x intermidia Miss Donnington
20	Lavandula x intermidia Nicoleii
21	Lavandula x intermidia Old English
22	Lavandula x intermidia Scottish Cottage
23	Lavandula x intermidia Seal
24	Lavandula x intermidia Sumian
25	Lavandula x intermidia Super[1]
26	Lavandula x intermidia Sussex
27	Lavandula x intermidia Walberton's Silver Edge
28	Lavandula x intermidia Wilson's Giant
29	Lavandula x intermidia Yuulong

Note[1]: Three plants, A, B and C

APPENDIX 2: AIR FLOW & LAVENDER PLANT PHYSICAL CHARACTERISTICS DATA

APPENDIX 2.1: *Air flow improvements data*

Appendix Table A2.1.1: Air flow test Replicate 1 data

1		111(210)			111(310)			111(360)			111(410)			111(510)	
	-4.8	-5.2	-5	-7.8	-7.6	-7	-10	-9.6	-10	-11	-12	-10.4	-14	-15	-13
Front (F)	1.8	2	1.6	2.4	1.6	2	2.6	1.6	2.4	3	1	3	2	3.6	3.6
	2.8	3	3.2	4.8	5.2	4.2	5	5.8	6	4.6	8	6	6	7.6	8.2
	4.4	4.8	4.6	6.4	8	5	7	10	7	8	11	8	11	14	11
Rear(R)	3.8	3.8	3.6	6	6.2	4.6	7.2	8	7	8	8	8	12	11	11
	5.4	4.6	4.6	5.6	7	6.2	9	8	9	11	8	11	14	12	13
		112(210)			112(310)			112(360)			112(410)			112(510)	
	-2	-2	-2	-3.2	-3.2	-3	-4	-3.2	-3	-5.6	-4.2	-5	-6.6	-6.2	-5.2
Front (F)	1.8	1.6	1	4	5	4.2	3	3.8	3.4	2	2.4	3	3.8	5	4.2
	3	3.6	3.4	4.6	6.4	5.8	4.8	5.6	6.2	6	6.2	7.2	7	7.6	7.8
	4	5.2	4	4.2	6.2	4.4	6	6.4	6.2	6.4	7.2	7	9.6	11	10
Rear(R)	4	4.2	5	5	4.8	6	5.6	6.2	6.4	5.8	7	7.6	8.4	8	8.2
	5	4	6	7.2	6	7	8	8.2	8.8	9.2	9	9.6	10.8	11	12
		113(210)			113(310)			113(360)			113(410)			113(510)	
	-6	-5	-6	-8.8	-8.4	-8	-10.8	-9	-10.6	-11.2	-12.4	-11.6	-16.2	-15.2	-15
Front (F)	-2.2	0.4	-2.4	-3.4	1.8	3.8	-3	-3	-2.8	-4	-2	-3	-5.6	-4	-4.6
	2	2.2	2.4	4	6.6	4.2	3.6	5	5.6	4.4	5.6	6.2	6.2	7	6.8
	4	5	4.4	7	7.6	6.8	7.8	9.2	9	9	10.4	9.4	11.6	13	12
Rear(R)	3.8	4.2	4	6	6.2	6.2	6	7	6.4	7.6	7.8	8.2	9.2	10.4	11
	5.4	5	5.4	7.6	7	8	8.6	8.8	9.2	10	9.6	11	14.2	13	15.6
		121(210)			121(310)			121(360)			121(410)			121(510)	
	-6.2	-6	-6.2	-9	-8.6	-9.6	-10.2	-10	-11	-11.6	-11.2	-13	-16.6	-17	-17.6
Front (F)	-1.8	-1.8	-1.6	-3	-2.8	-2	-2.8	-2.8	-3	-4	-2.8	-3	-4.2	-3.6	-3.6
	-0.6	-0.4	-0.2	-1.2	-1.2	-1	-1.8	-1.6	-1.2	-1.8	-1.6	-2	-2	-2	-2.4
	5	6	5.2	6	7.6	6.2	7.4	9.2	8.2	7.6	10	8	10	12.2	11
Rear(R)	4.2	4	4.4	5	4.6	5	5.4	5.8	6.2	6.2	6.4	6.2	8.2	8.4	9
	4.8	4.2	5	7	5.8	6.4	8.4	6.8	8.2	9	7.6	8.8	11	10.4	12
		122(210)			122(310)			122(360)			122(410)			122(510)	
	-0.4	-0.6	-0.4	-3.2	-3	-2.8	-4	-3.8	-3	-3.6	-3	-2.4	-5	-3.6	-4
Front (F)	-0.2	0.2	0.2	-1	-0.2	0.6	0.8	0.4	1.6	0.6	1.6	2	1.6	2	1
	-1.2	-1.4	-1.2	-1	-1	-1	-1	-0.6	-0.6	-2	-1.4	-1.6	-2	-1.6	-2
	3.8	5.6	5	5.8	6.2	6	7	8	7	8	9.4	9	10.2	11	8
Rear(R)	3.8	4.4	4	5	5.2	5.6	5	6	5.6	6.4	6	7	8	8.2	8
	4.2	3.8	4.2	6.2	6	7	7.8	7	8	8	9	7	11	9	11
		123(210)			123(310)			123(360)			123(410)			123(510)	
	-6	-6	-6	-8.4	-7.8	-9	-10.2	-10	-11	-11	-10.8	-11.6	-14.8	-14	-15.6
Front (F)	-1.4	-1.8	-2	-3	-2.8	-3	-3.4	-3.2	-3	-4	-3.4	-4	-4.2	-3.6	-5
	-0.6	-0.4	-0.2	-0.6	-0.6	-0.4	-1.6	-1	-1.6	-2.8	-2	-1.8	-3.2	-2	-2.4
	5	5.6	5	7.2	8.2	7.6	8.2	9.2	9	8.4	10	9	12.4	12	11
Rear(R)	3.6	4.2	3.8	5.6	6.2	6	6	6.4	7	7	7	7.6	8.6	8	9
	4.8	4.4	4.6	6.8	6.2	6.4	7.6	7	7.6	8.4	8.2	9	10.4	9.6	11

Table cont'd //

Table cont'd //

		131(210)			131(310)			131(360)			131(410)			131(510)	
	-5.8	-5.8	-6	-7.8	-7.8	-8	-10	-9.8	-10.2	-11.8	-11.2	-11	-14	-14.6	-14.2
Front (F)	-1	-1	-1.2	-1.4	-1.8	-1.8	-1.8	-2.2	-2	-2	-2.2	-2	-3	-3	-3
	-0.2	0	0	-0.4	-0.4	0.2	-1	-1	-1	-1.2	-1.2	-0.6	-1.2	-1.4	-1.6
	4	4	3.6	5.6	6	5.2	6.4	6.6	5.8	7.4	8	7	10	11	8.4
Rear(R)	3.4	2.8	3	4.8	4.2	3.8	6	5	4.8	6.2	5.6	5	9	6	5.2
	4.8	4.4	4	6.4	6	5	6.4	5	6	8.4	6.2	5	11	9	8
		132(210)			132(310)			132(360)			132(410)			132(510)	
	-2	-2.2	-2	-2.8	-3.2	-2.8	-2.4	-3	-2.8	-3.2	-3.4	-3.4	-3.6	-3.2	-2.8
Front (F)	-0.2	-0.4	-1	-1	-0.8	-1	-0.2	-1	-0.2	-0.2	-1.2	-0.6	-0.8	-1.2	-1.6
	-0.4	-0.2	0	-0.4	-0.2	0	-0.2	-0.4	-0.4	-0.4	-0.2	-0.2	-1.2	-1.2	-0.4
	4	4	3.6	4.6	5.6	5	6	6.2	5.8	7.6	8	7	9	8.4	8
Rear(R)	3	3.2	2.8	5	4.6	4	5.6	5	4.6	7	5	5.6	7	6	5.2
	6.2	6.2	6	7.2	6.8	6.2	7.8	6.2	5.6	9.6	6.4	8.4	11	8	9
		133(210)			133(310)			133(360)			133(410)			133(510)	
	-5.6	-5.6	-5.8	-8.8	-8.4	-8.2	-10.2	-9.8	-10.6	-10.8	-10.4	-11	-15	-14	-13.8
Front (F)	-1	-1.2	-1.2	-2	-1.6	-1.6	-2.6	-2.8	-2.6	-2.8	-3.2	-2.4	-2.8	-3.2	-3.4
	-0.2	-0.2	0	-0.4	-0.6	-0.2	-1.2	-0.8	-0.2	-2	-1.4	-0.2	-1.4	-1.2	-0.6
	4	4.4	4	6	6	5.2	7	7.6	6.4	8	9	7	9.6	10.4	8.2
Rear(R)	3	3	3	5	4	4.2	6	5	5.4	6.2	5	5.6	9.2	6.2	5.6
	5.8	4	4.4	6.4	5.6	7	8	6	8.2	9	6.2	10.4	11.6	7.6	11

Appendix Table A2.1.2: Air flow test Replicate 2 data

2		211(210)			211(310)			211(360)			211(410)			211(510)	
	-5.2	-4.8	-4.4	-8	-8.2	-7.8	-10	-9	-9	-12	-12.2	-12	-15.6	-15.8	-16
Front (F)	1.2	1.6	0.8	2	2	2	-3	2	-3	-3.6	5	-3	-3	-4	-4
	2.4	4.2	2.2	4	5	4	5	7	6	4	6	5	6	6	7
	5	6	4	6	7	6	7.4	9	7	9	10	8	11.4	13.8	11.2
Rear(R)	3.8	4.2	4	6	5	6	5	6	5.2	8	7	7	11.8	11	10.6
	5	5	6	8	7	8	8	7	9	9	8	9	14	11.8	12.8
		212(210)			212(310)			212(360)			212(410)			212(510)	
	-1.8	-1.8	-2	-3	-3	-2.6	-4.2	-3	-3	-5.2	-4	-4.6	-7.2	-6.4	-5.8
Front (F)	1.6	1.6	1.2	3.6	4.6	4.4	2.8	3.6	3.2	2.2	2.8	3.2	3	4.2	4
	3.2	3.8	3.4	4.2	6.2	5.2	4.4	5.4	6	5.6	6.2	6.6	6.8	7.6	7.8
	5	5.2	4.2	4.2	6	5	6	6.4	6	6.6	7.2	7	9.8	10.8	10.2
Rear(R)	4	4	5	4.6	4.8	5.8	5.8	6.6	6.6	6	7.2	7.8	8.2	8	8
	4.6	3.8	5.6	7	5.8	6.6	8.2	8.4	8.8	9	8.8	9.6	10.6	11	12.4
		213(210)			213(310)			213(360)			213(410)			213(510)	
	-6.6	-5.6	-6	-9.4	-8.4	-8.2	-11.4	-9.6	-10.2	-10.2	-12	-11.4	-18	-15.2	-15.8
Front (F)	-2	0.6	-2	-3.6	1.6	3.6	-3	-3.6	-3	-4	-3	-3	-5.4	-4.2	-4.2
	3	3.2	3.6	4.6	7	4.2	3.6	5.4	5.6	4.6	5.6	5.6	6.4	7	6.8
	4.2	5.2	4.2	6.4	7.4	7	8	9.2	8.8	9	10.2	9.6	11.8	13	12.2
Rear(R)	3.8	4.4	4	6	6.2	6.4	5.8	6.8	6.2	7.8	8	8.4	9.2	10.4	11
	5.2	5	5.2	7.6	7	8	8.2	8.8	8.8	10	10	10.6	14	13.2	15.4
		221(210)			221(310)			221(360)			221(410)			221(510)	
	-6.6	-6.2	-6	-8.8	-8.2	-9.2	-10.6	-10	-11.2	-11	-10.6	-12	-16.2	-17.2	-17.2
Front (F)	-2	-1.6	-1.8	-2.6	-3	-2.2	-2.4	-2.8	-3.2	-4.2	-2.6	-2.8	-4	-3.8	-3.6
	-0.2	-0.4	-0.2	-1.4	-1.2	-1.4	-1.8	-1.4	-1	-1.6	-1.6	-1.6	-2	-2	-2.2
	4.8	6.2	5.4	6.4	7.8	6.6	7.6	9.6	8.4	7.8	10.2	8.2	10.2	12.6	11
Rear(R)	4.2	4	4.4	5.2	4.6	4.8	5.2	5.8	6	6.6	6.6	6.4	8	8	8.8
	4.6	4.2	5.2	6.8	5.6	6.6	8.2	7	8	8.6	7.8	9	10.4	10.2	11.6
		222(210)			222(310)			222(360)			222(410)			222(510)	
	-0.4	-0.4	-0.6	-3.6	-3	-3.4	-4.2	-36	-3.2	-3.6	-3	-2.8	-4.6	-3.8	-4.2
Front (F)	-0.2	0.4	0.2	-1.2	-0.4	0.4	0.8	0.2	1.2	0.8	1.6	2.2	1.4	2.2	1.2
	-1.4	-1.4	-1.4	-1.2	-1.4	-1.2	-1.2	-0.6	-0.4	-2.2	-1.4	-1.6	-2.2	-1.8	-2
	4	5.2	5	5.6	6.2	6.2	7.2	8	7.4	8.2	9.6	8.8	10	11.2	8.2
Rear(R)	3.6	4.2	4	5	5.4	5.4	5.4	6.2	5.8	6.2	6.2	6.8	8	8.4	8.2
	4.2	4	4.4	6	5.6	6.4	7.6	6.6	7.6	8.2	9	7.6	10.8	9.4	11.2
		223(210)			223(310)			223(360)			223(410)			223(510)	
	-6.2	-6.4	-6.2	-8	-8	-8.8	-9.8	-9.8	-10.4	-11.2	-11	-11.6	-15	-14.2	-15
Front (F)	-1.6	-1.8	-2.2	-3.2	-2.8	-3	-3.6	-3.2	-2.8	-4.2	-3.8	-4.2	-4.2	-4	-5.6
	-0.4	-0.4	-0.2	-0.4	-0.6	-0.4	-1.4	-1.2	-1.6	-3	-2	-2	-3	-2.2	-2.8
	4.4	5.6	5	7.4	8.4	7.6	8.4	9	9.2	8.2	9.6	8.6	12.6	12.2	11.2
Rear(R)	3.8	4.4	4	5.8	6	6	6	6.6	7.2	7.4	7	7.2	8.2	8	8.4
	4.8	4.6	4.6	7	6.2	6.6	7.2	6.4	7.4	8.2	8.4	8.6	10	9.4	11

Table cont'd //

Table cont'd //

		231(210)			231(310)			231(360)			231(410)			231(510)	
	-5.6	-5.4	-6.2	-7.6	-7.8	-8.2	-9.4	-9.8	-10.4	-11.4	-11	-11	-13.8	-14.2	-14.6
Front (F)	-1.2	-1	-1.4	-1.4	-1.6	-1.8	-1.6	-2	-2.2	-2	-2.4	-2	-3	-3.2	-3
	-0.2	-0.2	-0.2	-0.4	-0.6	0	-1.2	-1	-1.2	-1	-1	-0.8	-1.4	-1.4	-1.6
	3.6	3.8	3.8	5.8	6.2	5.4	6	7	5.6	7	8.2	7.2	10.2	10.6	8.2
Rear(R)	3.2	2.8	2.8	5.2	4.4	4	5.6	5.6	4.8	6.2	5.6	5.2	8.6	6.4	5.6
	4.6	4.4	4.2	6.2	5.8	5.2	7	5.2	5.8	8	6.6	5.2	10.8	9	7.8
		232(210)			232(310)			232(360)			232(410)			232(510)	
	-2.2	-2.6	-2	-3	-3.4	-2.8	-2.4	-3.2	-3	-3.4	-3.4	-3.4	-3.8	-3.4	-3
Front (F)	-0.2	-0.2	-0.8	-1	-0.8	-1	-0.2	-0.8	-0.2	-0.2	-1	-0.4	-0.8	-1	-1.4
	-0.4	-0.4	-0.2	-0.2	-0.2	-0.2	-0.2	-0.4	-0.2	-0.4	-0.2	-0.2	-1	-1.2	-0.6
	4.2	4.4	3.8	4.4	5.4	5	6	6.6	5.6	8	8.2	7.2	9.2	8	8
Rear(R)	2.8	3.2	3	5	4.2	4	5.6	4.6	4.6	7	5.6	5.8	6.6	5.6	5
	6	6.2	6	7	6.8	6	7.6	6.2	5.8	9.4	6.6	8.6	10.2	7.8	8.6
		233(210)			233(310)			233(360)			233(410)			233(510)	
	-5.6	-5.2	-5.6	-9	-8.4	-8.2	-10.8	-10	-10.6	-10.2	-10.2	-10.4	-15.6	-14.4	-13.8
Front (F)	-0.8	-1	-1.2	-2.2	-1.8	-1.6	-2.6	-3	-2.6	-2.8	-3	-2.6	-3	-3	-3.2
	-0.2	-0.2	0	-0.4	-0.4	-0.2	-1.2	-1	-0.4	-2	-1.6	-0.4	-1.2	-1	-0.6
	4.2	4.4	4	6.2	6	5	7.4	7.6	6.6	8	9	7.6	9.8	11	8.8
Rear(R)	3	2.8	3	5.2	4.2	4.4	5.8	5	5.4	6	5.4	5.8	9	6	6
	5.6	3.8	4	6	5.4	6.6	8.2	6.4	8.4	8.6	6.4	10.2	11.4	7.8	10.8

APPENDIX 2.2: *Lavender plant physical characteristics test data*

Appendix Table A2.2.1: Bioregional intermidia

Bioregional samples — tests as concern harvest conditions********* m/c between 58-72%w.b

27/07/2004

Pulling speed at Instron 1122=50 mm/min ,chart speed 50 mm/min

Samples= Intermidia "Old English" Bioregional

For each cultivar =1 treatments and 5 replicates(flowers)at m/c A &1treatment and 5replicates for m/c B,C

For each cultivar =1 treatments and 5 replicates(stems)at m/c A &1treatment and 5replicates for m/c B,C

Harvest condition (lab conditior 25°C, RH 50%d.b)

	Flower strip force: Bioregional			Stem break: Bioregional					
No	N force	mm flower leng	mm flower diametre	N	mean width	Area mm²	UTS MPa N/mm²		
1	17.20	66.80	17.50	48.00	1.60	2.56	18.75		
2	18.00	76.20	16.40	53.00	1.67	2.79	19.00		
3	15.40	67.10	16.90	38.00	1.71	2.92	13.00		
4	13.10	69.80	17.20	49.00	1.61	2.59	18.90		
5	14.10	73	18.20	42.00	1.45	2.10	19.98		
SUM	77.8	352.9	86.2	230.0	8.04	12.97	89.6		
MEAN	15.56	70.58	17.24	46.00	1.61	2.59	17.93	Stem UTS	17.93 Mpa

					UTS
	STDEV	2.052559	STDEV	5.958188	STDEV 2.797778
A	SQRT	2.236068	SQRT	2.236068	SQRT 2.236068
A	Stand.Erro	0.917932	Stand.Erro	2.664583	Stand.Erro 1.251204
A m/c	Bioregiona 67.4%w.b				

After 4 hours (lab conditior 25°C, RH 50%d.b)

	Flower strip force: Bioregional			Stem break: Bioregional					
No	N force	mm flower leng	mm flower diametre	N	mean width	Area mm²	UTS MPa N/mm²		
1	19.20	81.00	14.90	52.00	1.48	2.19	23.74		
2	16.00	71.50	13.30	53.00	1.43	2.04	25.92		
3	16.50	70.40	13.90	57.00	1.47	2.16	26.38		
4	14.20	69.20	14.20	55.00	1.38	1.90	28.88		
5	18.00	63.30	12.70	50.00	1.44	2.07	24.11		
SUM	83.9	355.4	69	267.0	7.20	10.37	129.0		
MEAN	16.78	71.08	13.80	53.40	1.44	2.07	25.81	Stem UTS	25.81 Mpa

					UTS
	STDEV	1.916246	STDEV	2.701851	STDEV 2.057187
B	SQRT	2.236068	SQRT	2.236068	SQRT 2.236068
B	Stand.Erro	0.856971	Stand.Erro	1.208305	Stand.Erro 0.920002
B m/c	Hidcote sil 59.2%w.b				

After 20 hours (lab conditior 25°C, RH 50%d.b)

	Flower strip force: Bioregional			Stem break: Bioregional					
No	N force	mm flower leng	mm flower diametre	N	mean width	Area mm²	UTS MPa N/mm²		
1	14.80	53.50	9.80	64.00	1.15	1.32	48.39		
2	24.00	85.90	14.70	72.00	1.53	2.34	30.76		
3	15.00	59.00	8.70	61.00	1.28	1.64	37.23		
4	24.50	64.80	11.50	82.00	1.35	1.82	44.99		
5	14.90	86.20	11.60	63.00	1.30	1.69	37.28		
SUM	93.2	349.4	56.3	342.0	6.61	8.81	198.7		
MEAN	18.64	69.88	11.26	68.40	1.32	1.76	39.73	Stem UTS	39.73 MPa

					UTS
	STDEV	5.124744	STDEV	8.677557	STDEV 6.99131
C	SQRT	2.236068	SQRT	2.236068	SQRT 2.236068
C	Stand.Erro	2.291855	Stand.Erro	3.880722	Stand.Erro 3.126609
C m/c	Hidcote sil 31.3%w.b				

			m/c	N
		a	67.4	15.56
	Mean strip forse	b	59.2	16.78
		c	31.3	18.64
Bioregional			m/c	UTS
		a	67.4	17.93
	Mean stem UTS	b	59.2	25.81
		c	31.3	39.73
			m/c	N
		a	67.4	46.00
	Mean stem breaking fc	b	59.2	53.40

Bioregional		UTS	
m/c	flower	stem	stem break force
67.4	15.56	17.93	46.00
59.2	16.78	25.81	53.40
31.3	18.64	39.73	68.40

flower

$y = -0.0805x + 21.233$

stem UTS

$y = -0.577x + 58.195$

break stem force

$y = -0.5993x + 87.477$

Appendix Table A2.2.2: Hitchin Grosso

Grosso Hitchin samples — tests as concern harvest conditions********* m/c between 58-72%w.b

22/07/2004
Pulling speed at Instron 1122=50 mm/min ,chart speed 50 mm/min
Samples= Grosso Hitchin
For each cultivar =1 treatments and 5 replicates(flowers)at m/c A &1treatment and 5replicates for m/c B,C
For each cultivar =1 treatments and 5 replicates(stems)at m/c A &1treatment and 5replicates for m/c B,C

A — harvest condition; lab conditior 25°C; m/c 50%d.b

Flower strip force — Grosso

No	N force	mm flower leng	mm flower diametre
1	15.50	87.70	13.70
2	14.60	82.80	14.00
3	15.00	83.50	13.60
4	15.20	81.00	14.30
5	14.90	91	15.10
SUM	75.2	426	70.7
MEAN	15.04	85.20	14.14

STDEV 0.336155
A SQRT 2.236068
A Stand.Erro 0.150333
A m/c Grosso 65%w.b

Stem break — Grosso

N	mean width	Area mm²	UTS MPa N/mm²		
38.00	1.72	2.96	12.84		
41.00	1.75	3.06	13.39		
39.50	1.67	2.79	14.16		
35.00	1.70	2.89	12.11		
39.00	1.75	3.06	12.73		
192.5	8.59	14.76	65.2		
38.50	1.72	2.95	13.05	Stem UTS	13.05 Mpa

		UTS	
STDEV	2.236068	STDEV	0.770916
SQRT	2.236068	SQRT	2.236068
Stand.Erro	1	Stand.Erro	0.344764

B — after 4 hours; lab conditior 25°C; m/c 50%d.b

Flower strip force — Grosso

No	N force	mm flower leng	mm flower diametre
1	18.80	85.60	13.90
2	20.10	82.80	15.60
3	17.10	75.90	12.50
4	13.40	58.80	13.20
5	17.20	60.90	11.50
SUM	86.6	364	66.7
MEAN	17.32	72.80	13.34

STDEV 2.51734
B SQRT 2.236068
B Stand.Erro 1.125789
B m/c Grosso 55.8%w.b

Stem break — Grosso

N	mean width	Area mm²	UTS MPa N/mm²		
48.00	1.62	2.62	18.29		
70.00	1.65	2.72	25.71		
42.00	1.53	2.34	17.94		
49.00	1.40	1.96	25.00		
51.00	1.40	1.96	26.02		
260.0	7.60	11.61	113.0		
52.00	1.52	2.32	22.59	Stem UTS	22.59 Mpa

		UTS	
STDEV	10.6066	STDEV	4.105394
SQRT	2.236068	SQRT	2.236068
Stand.Erro	4.743416	Stand.Erro	1.835988

C — After 8 hours; lab conditior 25°C; m/c 50%d.b

Flower strip force — Grosso

No	N force	mm flower leng	mm flower diametre
1	20.40	80.10	11.10
2	20.10	83.30	14.80
3	21.30	89.80	12.60
4	19.00	66.50	12.80
5	22.50	84.30	14.60
SUM	103.3	404	65.9
MEAN	20.66	80.80	13.18

STDEV 1.316435
SQRT 2.236068
C Stand.Erro 0.588727
C
C m/c Grosso 30.1%w.b

Stem break — Grosso

N	mean width	Area mm²	UTS MPa N/mm²		
73.00	1.50	2.25	32.44		
65.00	1.58	2.50	26.04		
71.00	1.55	2.40	29.55		
68.00	1.44	2.07	32.79		
71.00	1.56	2.43	29.17		
348.0	7.63	11.66	150.0		
69.60	1.53	2.33	30.00	Stem UTS	30 MPa

		UTS	
STDEV	3.130495	STDEV	2.754987
SQRT	2.236068	SQRT	2.236068
Stand.Erro	1.4	Stand.Erro	1.232068

Grosso			m/c	N
	Mean strip forse	a	65.0	15.04
		b	55.8	17.32
		c	30.1	20.66
			m/c	UTS
	Mean stem UTS	a	65.0	13.05
		b	55.8	22.59
		c	30.1	30.00
			m/c	N
	Mean stem breaking f(	a	65.0	38.50
		b	55.8	52.00

Grosso	UTS		
m/c	flower	stem	stem break force
65.0	15.04	13.05	38.50
55.8	17.32	22.59	52.00
30.1	20.66	30.00	69.60

flower
y = -0.1543x + 25.436
stem UTS
y = -0.443x + 44.165
break stem force
y = -0.8466x + 95.948

Appendix Table A2.2.3: Swetsloots Hidcote

Hidcote Swetsloots samples — tests as concern harvest conditions********* m/c between 60-70%w.b

17&18/10/2001
Pulling speed at Instron 1122=50 mm/min
Samples= Swetchlooch::::Hidcote
For each cultivar =2 treatments and 5 replicates(flowers)at m/c A &1treatment and 5replicates for m/c B,C
For each cultivar =1 treatments and 5 replicates(stems)at m/c A &1treatment and 5replicates for m/c B,C

Flower strip force — Hidcote (A)

No	N	mm flower leng	mm flower diametre
1	6.80		
2	7.40		
3	6.40		
4	7.60		
5	7.40		
SUM	35.6		
MEAN	7.12		

		STDEV	0.501996
A		SQRT	2.236068
A		Stand.Erro	0.224499
A m/c	Hidcote	72%w.b	

Stem break — Hidcote (A)

N	Area mm²	UTS MPa N/mm²		
40.50	2.25	18.00		
33.50	1.96	17.09		
40.50	1.96	20.66		
47.00	2.56	18.36		
36.50	2.25	16.22		
198.0	10.98	90.3		
39.60	2.20	18.07		
39.60	2.20	18.07	Stem UTS	18.07 MPa

		UTS	
STDEV	5.07937	STDEV	1.672178
SQRT	2.236068	SQRT	2.236068
Stand.Erro	2.271563	Stand.Erro	0.747821

Flower strip force — Hidcote (B, after 4hours)

No	N	mm flower leng	mm flower diametre
1	7.80		
2	8.10		
3	7.30		
4	7.60		
5	7.00		
SUM	37.8		
MEAN	7.56		

		STDEV	0.427785
B		SQRT	2.236068
B		Stand.Erro	0.191311
B m/c	Hidcote	63.5%w.b	

Stem break — Hidcote (B)

N	Area mm²	UTS MPa N/mm²		
46.00	2.56	17.97		
34.00	1.69	20.12		
28.50	1.44	19.79		
41.50	1.96	21.17		
51.00	2.25	22.67		
201.0	9.90	101.7		
40.20	1.98	20.34	Stem UTS	20.34 MPa

		UTS	
STDEV	9.045717	STDEV	1.737858
SQRT	2.236068	SQRT	2.236068
Stand.Erro	4.045368	Stand.Erro	0.777194

Flower strip force — Hidcote (C, after 8 hours)

No	N	mm flower leng	mm flower diametre
1	8.40		
2	8.00		
3	9.00		
4	8.90		
5	10.30		
SUM	44.6		
MEAN	8.92		

		STDEV	0.870057
		SQRT	2.236068
C		Stand.Erro	0.389102
C			
C m/c	Hidcote	51.9%w.b	

Stem break — Hidcote (C)

N	Area mm²	UTS MPa N/mm²		
47.00	1.44	32.64		
36.00	1.21	29.75		
31.50	1.00	31.50		
49.00	1.44	34.03		
38.00	1.21	31.40		
201.5	6.30	159.3		
40.30	1.26	31.86	Stem UTS	31.86 MPa

		UTS	
STDEV	7.446476	STDEV	1.587912
SQRT	2.236068	SQRT	2.236068
Stand.Erro	3.330165	Stand.Erro	0.710136

			m/c	N
		a	72.0	7.12
	Mean strip forse	b	63.5	7.56
		c	51.9	8.92
Hidcote			m/c	UTS
		a	72.0	18.07
	Mean stem UTS	b	63.5	20.34
		c	51.9	31.86
			m/c	N
		a	72.0	39.6
	Mean stem breaking fc	b	63.5	40.2

Hidcote	UTS		
m/c	flower	stem	stem break force
72.0	7.12	18.07	39.6
63.5	7.56	20.34	40.2
51.9	8.92	31.86	40.3

flower
y = -0.0912x + 13.563
stem UTS
y = -0.7041x + 67.409
break stem force
y = -0.0333x + 42.112

Appendix Table A2.2.4: Hitchin Folgate

Folgare Hitchin samples tests as concern harvest conditions********* m/c between 60-70%w.b

22/07/2004

Pulling speed at Instron 1122=50 mm/min ,chart speed 50 mm/min

Samples= folgate

For each cultivar =1 treatments and 5 replicates(flowers)at m/c A &1treatment and 5replicates for m/c B,C

For each cultivar =1 treatments and 5 replicates(stems)at m/c A &1treatment and 5replicates for m/c B,C

harvest condition — lab conditior 25°C, m/c 50%d.b

Flower strip force

	Folgate N	mm	mm
No	force	flower leng	flower diametre
1	9.80	64.70	15.80
2	10.80	61.20	16.20
3	9.70	42.40	16.40
4	10.00	57.00	18.00
5	9.50	52.00	16.00
SUM	49.8	277.3	82.4
MEAN	9.96	55.46	16.48

	STDEV	0.502991
A	SQRT	2.236068
A	Stand.Erro	0.224944
A m/c	Folgate	58%w.b

Stem break — Folgate

N	mean width	Area mm²	UTS MPa N/mm²
25.00	1.25	1.56	16.00
37.00	1.05	1.10	33.56
32.00	1.20	1.44	22.22
31.00	1.25	1.56	19.84
29.00	1.10	1.21	23.97
154.0	5.85	6.88	115.6
30.80	1.17	1.38	23.12

Stem UTS 23.12 Mpa

			UTS
STDEV	4.38178	STDEV	6.556897
SQRT	2.236068	SQRT	2.236068
Stand.Erro	1.959592	Stand.Erro	2.932333

after 4 hours — lab conditior 25°C, m/c 50%d.b

Flower strip force

	Folgate N	mm	mm
No	force	flower leng	flower diametre
1	9.60	62.20	14.80
2	15.80	92.00	17.50
3	10.80	58.60	16.60
4	10.30	85.10	15.80
5	12.00	74.70	15.70
SUM	58.5	372.6	80.4
MEAN	11.70	74.52	16.08

		STDEV	2.453569
B		SQRT	2.236068
B		Stand.Erro	1.097269
B m/c	Folgate	51.1%w.b	

Stem break — Folgate

N	mean width	Area mm²	UTS MPa N/mm²
28.00	1.14	1.30	21.55
32.00	1.30	1.69	18.93
40.00	1.00	1.00	40.00
38.00	1.10	1.21	31.40
41.00	1.11	1.23	33.28
179.0	5.65	6.43	145.2
35.80	1.13	1.29	29.03

Stem UTS 29.03 Mpa

			UTS
STDEV	5.585696	STDEV	8.688339
SQRT	2.236068	SQRT	2.236068
Stand.Erro	2.497999	Stand.Erro	3.885543

After 8 hours — lab conditior 25°C, m/c 50%d.b

Flower strip force

	Folgate N	mm	mm
No	force	flower leng	flower diametre
1	10.80	57.10	15.50
2	12.20	68.20	14.30
3	12.90	61.30	12.90
4	16.10	67.10	14.90
5	12.00	50.30	12.90
SUM	64	304	70.5
MEAN	12.80	60.80	14.10

		STDEV	1.99374
		SQRT	2.236068
C		Stand.Erro	0.891628
C			
C m/c	Folgate	19.3%w.b	

Stem break — Folgate

N	mean width	Area mm²	UTS MPa N/mm²
53.00	1.25	1.56	33.92
42.00	1.17	1.37	30.68
51.00	1.22	1.49	34.26
55.00	1.12	1.25	43.85
49.00	1.05	1.10	44.44
250.0	5.81	6.78	187.2
50.00	1.16	1.36	37.43

Stem UTS 37.43 MPa

			UTS
STDEV	5	STDEV	6.289712
SQRT	2.236068	SQRT	2.236068
Stand.Erro	2.236068	Stand.Erro	2.812845

			m/c	N
Folgate	Mean strip forse	a	58.00	9.96
		b	51.10	11.70
		c	19.30	12.80
			m/c	UTS
	Mean stem UTS	a	58.00	23.12
		b	51.10	29.03
		c	19.30	37.43
			m/c	N
		a	58.00	30.80
	Mean stem braking fo	b	51.10	35.80

Folgate		UTS	
m/c	flower	stem	stem break force
58.00	9.96	23.12	30.80
51.10	11.70	29.03	35.80
19.30	12.80	37.43	50.00

flower
y = -0.0614x + 14.113

stem UTS
y = -0.3371x + 44.286

break stem force
y = -0.4808x + 59.443

Appendix Table A2.2.5: Hitchin Maillette

Maillette Hitchin samples — tests as concern harvest conditions********* m/c between 60-70%w.b

21/07/2004

Pulling speed at Instron 1122=50 mm/min ,chart speed 50 mm/min

Samples= Maiette

For each cultivar =1 treatments and 5 replicates(flowers)at m/c A &1treatment and 5replicates for m/c B,C

For each cultivar =1 treatments and 5 replicates(stems)at m/c A &1treatment and 5replicates for m/c B,C

harvest condition; lab conditior 25°C; m/c 50%d.b

Flower strip force	Maiette		
	N	mm	mm
No	force	flower leng	flower diametre
1	11.80	67.00	13.80
2	14.40	79.00	13.40
3	11.60	85.00	11.00
4	13.00	68.00	14.30
5	10.20	60.2	12.00
SUM	61	359.2	64.5
MEAN	12.20	71.84	12.90
		STDEV	1.581139
A		SQRT	2.236068
A		Stand.Erro	0.707107
A m/c	Maiette	67.3%w.b	

Stem break	Maiette				
	mean	Area	UTS MPa		
N	width	mm²	N/mm²		
32.00	1.42	2.02	15.87		
41.00	1.45	2.10	19.50		
38.00	1.25	1.56	24.32		
37.00	1.28	1.64	22.58		
33.00	1.32	1.74	18.94		
181.0	6.72	9.06	101.2		
36.20	1.34	1.81	20.24	Stem UTS	20.24 Mpa
		UTS			
STDEV	3.701351	STDEV	3.296681		
SQRT	2.236068	SQRT	2.236068		
Stand.Erro	1.655295	Stand.Erro	1.47432		

after 4 hours; lab conditior 25°C; m/c 50%d.b

Flower strip force	Maiette		
	N	mm	mm
No	force	flower leng	flower diametre
1	16.00	78.30	10.20
2	14.20	79.00	14.30
3	13.00	78.60	11.50
4	12.10	81.60	13.70
5	13.10	71.00	11.40
SUM	68.4	388.5	61.1
MEAN	13.68	77.70	12.22
		STDEV	1.49566
B		SQRT	2.236068
B		Stand.Erro	0.66888
B m/c	Maiette	53.2%w.b	

Stem break	Maiette				
	mean	Area	UTS MPa		
N	width	mm²	N/mm²		
47.00	1.35	1.82	25.79		
47.00	1.30	1.69	27.81		
49.00	1.40	1.96	25.00		
45.00	1.25	1.56	28.80		
48.00	1.35	1.82	26.34		
236.0	6.65	8.86	133.7		
47.20	1.33	1.77	26.75	Stem UTS	26.75 Mpa
		UTS			
STDEV	1.48324	STDEV	1.539817		
SQRT	2.236068	SQRT	2.236068		
Stand.Erro	0.663325	Stand.Erro	0.688627		

After 8 hours; lab conditior 25°C; m/c 50%d.b

Flower strip force	Maiette		
	N	mm	mm
No	force	flower leng	flower diametre
1	20.00	67.80	12.80
2	13.00	88.80	10.80
3	10.80	69.00	8.20
4	20.20	82.80	11.20
5	16.00	88.00	11.90
SUM	80	396.4	54.9
MEAN	16.00	79.28	10.98
		STDEV	4.173727
		SQRT	2.236068
C		Stand.Erro	1.866548
C			
C m/c	Maiette	24.1%w.b	

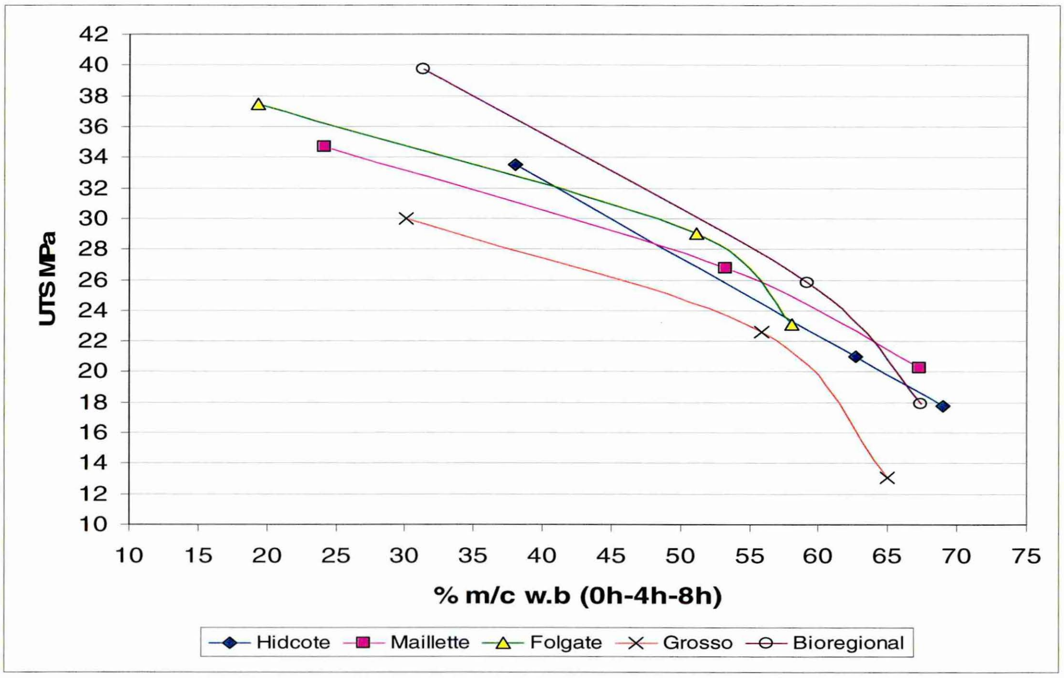
Stem break	Maiette				
	mean	Area	UTS MPa		
N	width	mm²	N/mm²		
46.00	1.33	1.77	26.00		
51.00	1.35	1.82	27.98		
57.00	1.00	1.00	57.00		
45.00	1.27	1.61	27.90		
52.00	1.23	1.51	34.37		
251.0	6.18	7.72	173.3		
50.20	1.24	1.54	34.65	Stem UTS	34.65 MPa
		UTS			
STDEV	4.868265	STDEV	12.88742		
SQRT	2.236068	SQRT	2.236068		
Stand.Erro	2.177154	Stand.Erro	5.763428		

			m/c	N
		a	67.3	12.20
	Mean strip forse	b	53.2	13.68
		c	24.1	16.00
Maiette			m/c	UTS
		a	67.3	20.24
	Mean stem UTS	b	53.2	26.75
		c	24.1	34.65
			m/c	N
		a	67.3	36.2
	Mean stem Braking fo	b	53.2	47.2
		c	24.1	50.2

Maiette		UTS	
m/c	flower	stem	m break force
67.3	12.20	20.24	36.2
53.2	13.68	26.75	47.2
24.1	16.00	34.65	50.2

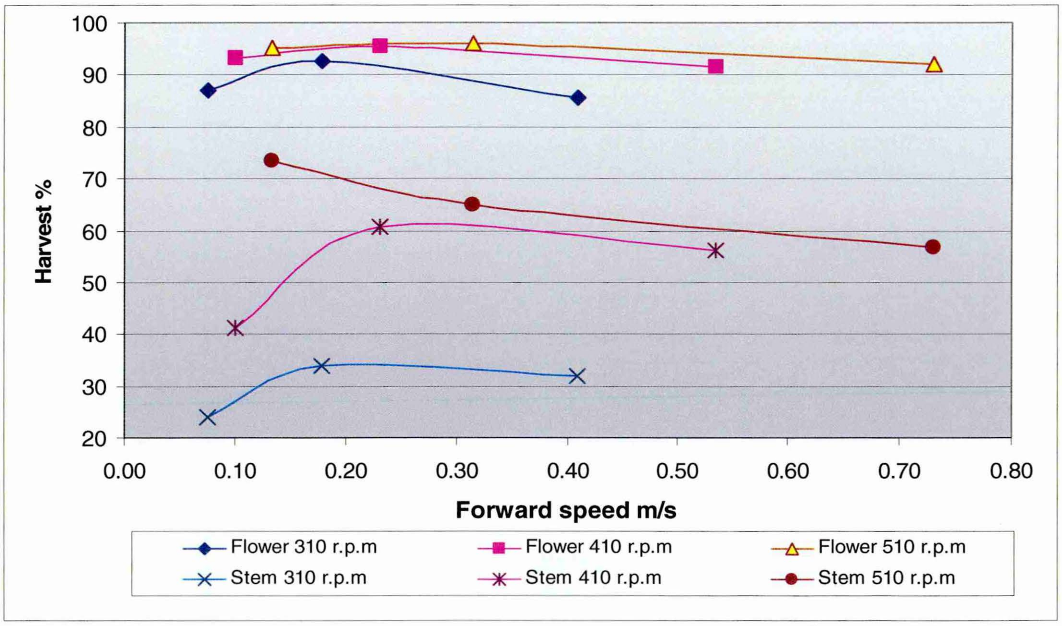
flower
$y = -0.0867x + 18.14$
stem UTS
$y = -0.3243x + 42.843$
break stem force
$y = -0.2909x + 58.557$

APPENDIX 2.3: ***Stem UTS characteristics***

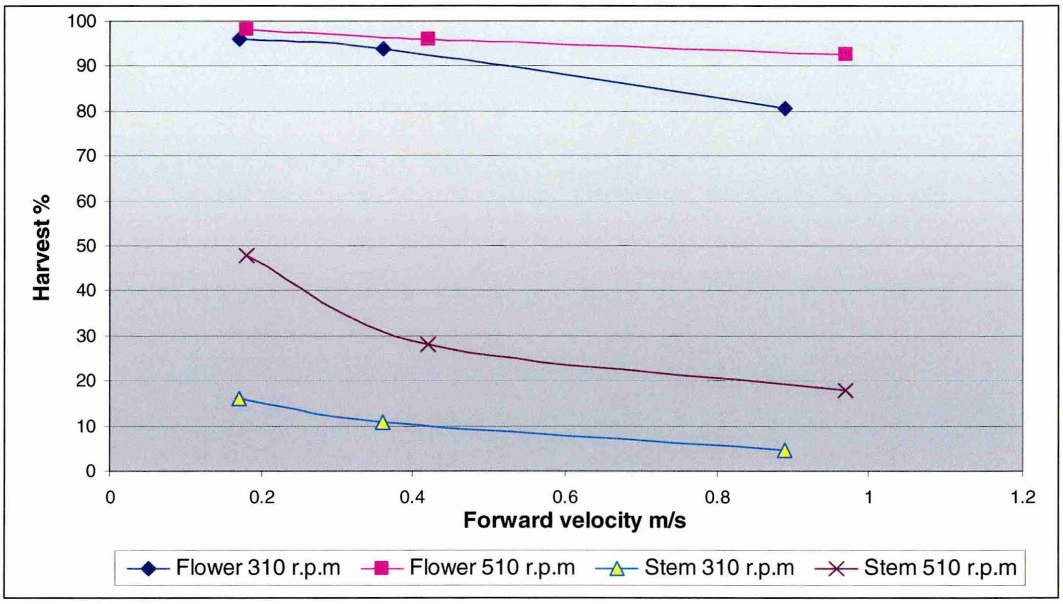


Appendix Figure A2.3.1: Stem UTS versus moisture content for tested cultivars

APPENDIX 2.4: ***Diagrammatic representation of flower and stem harvest percentage for test N° 2 (Carlshalton area) and N° 4 (Yalding area).***

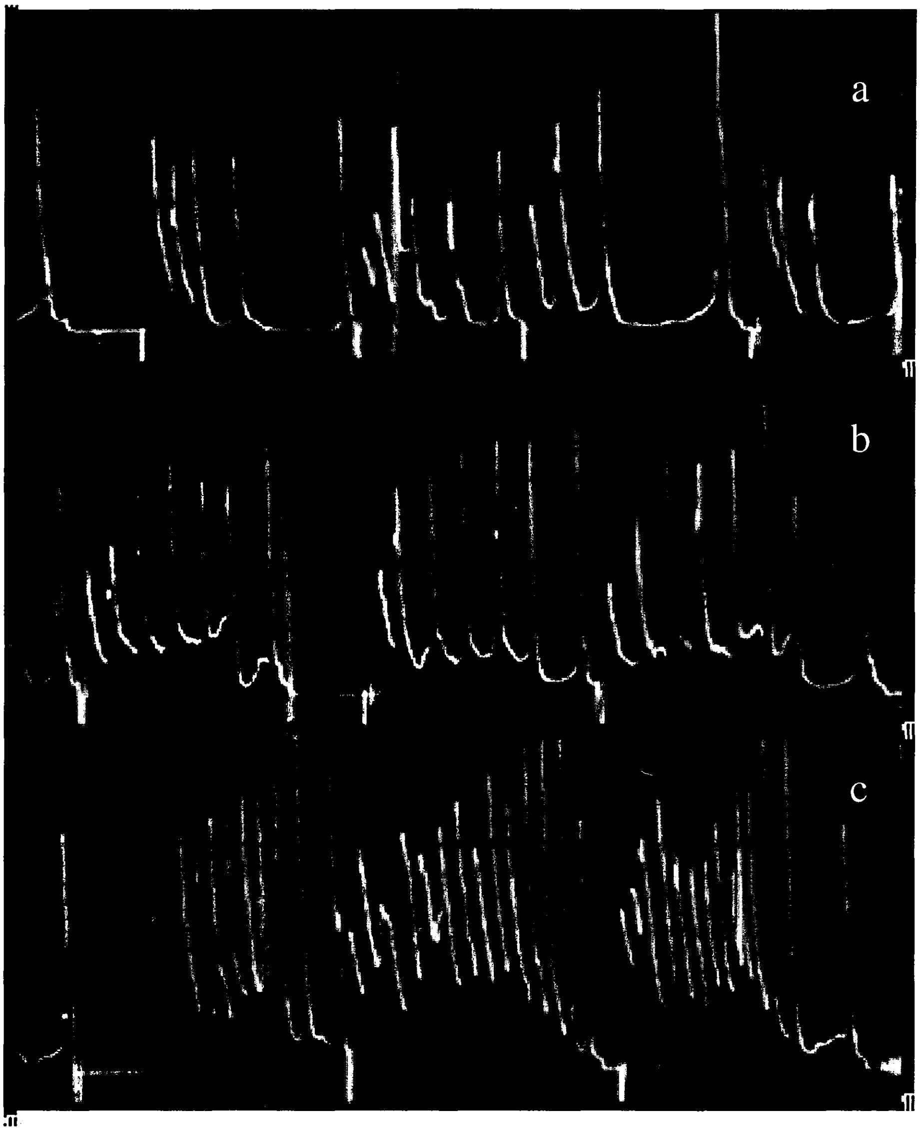


Appendix Figure A2.4.1: Diagrammatic representation for test N° 2 (Lavandula x intermidia "Bioregional" cultivar) at different rotor and forward speeds



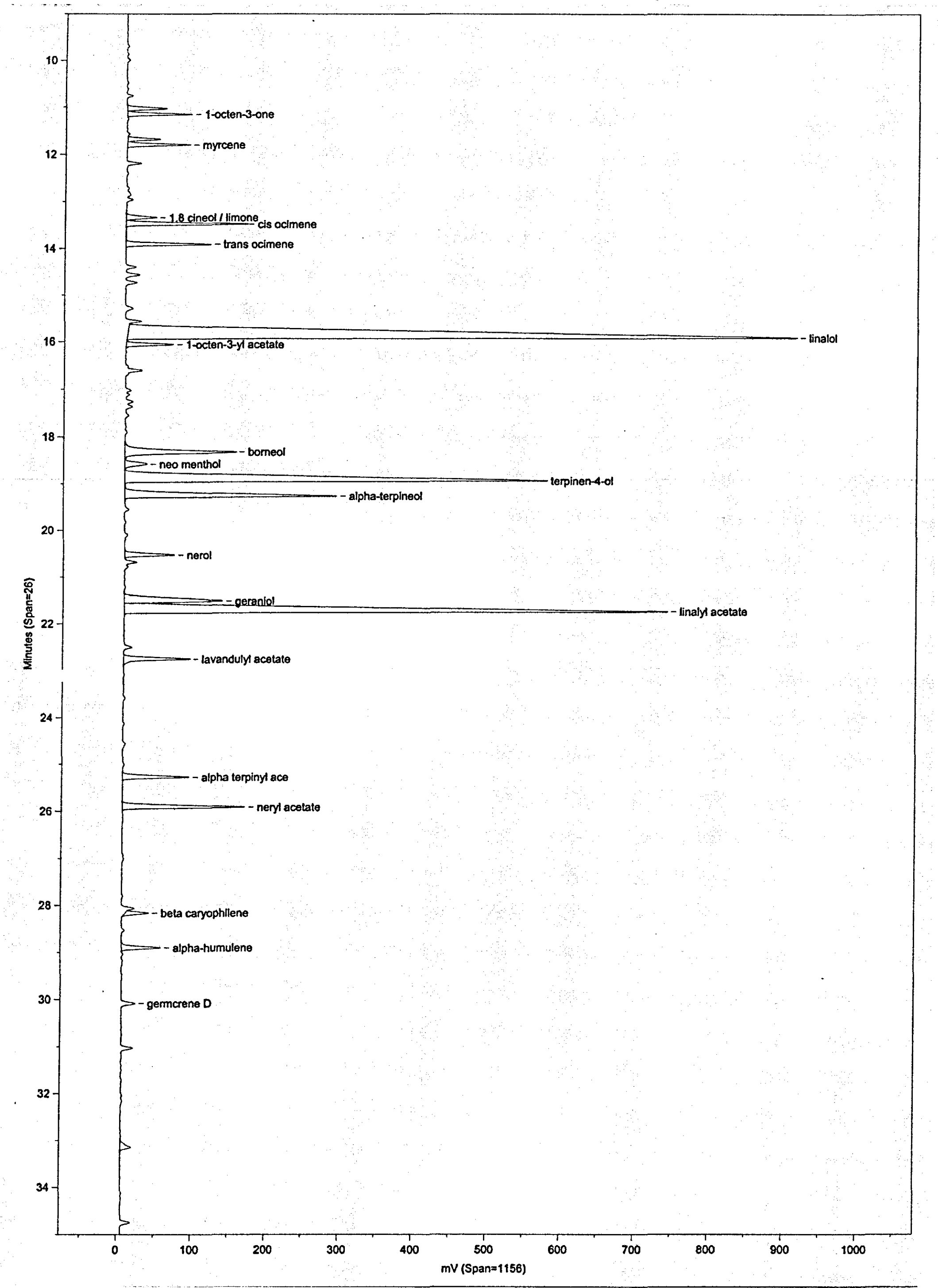
Appendix Figure A2.4.2: Diagrammatic representation for test N° 4 (Lavandula angustifolia Folgate cultivar) at different rotor and forward speeds

APPENDIX 2.5: ***Diagrammatic representation of flower detachment measured forces.***

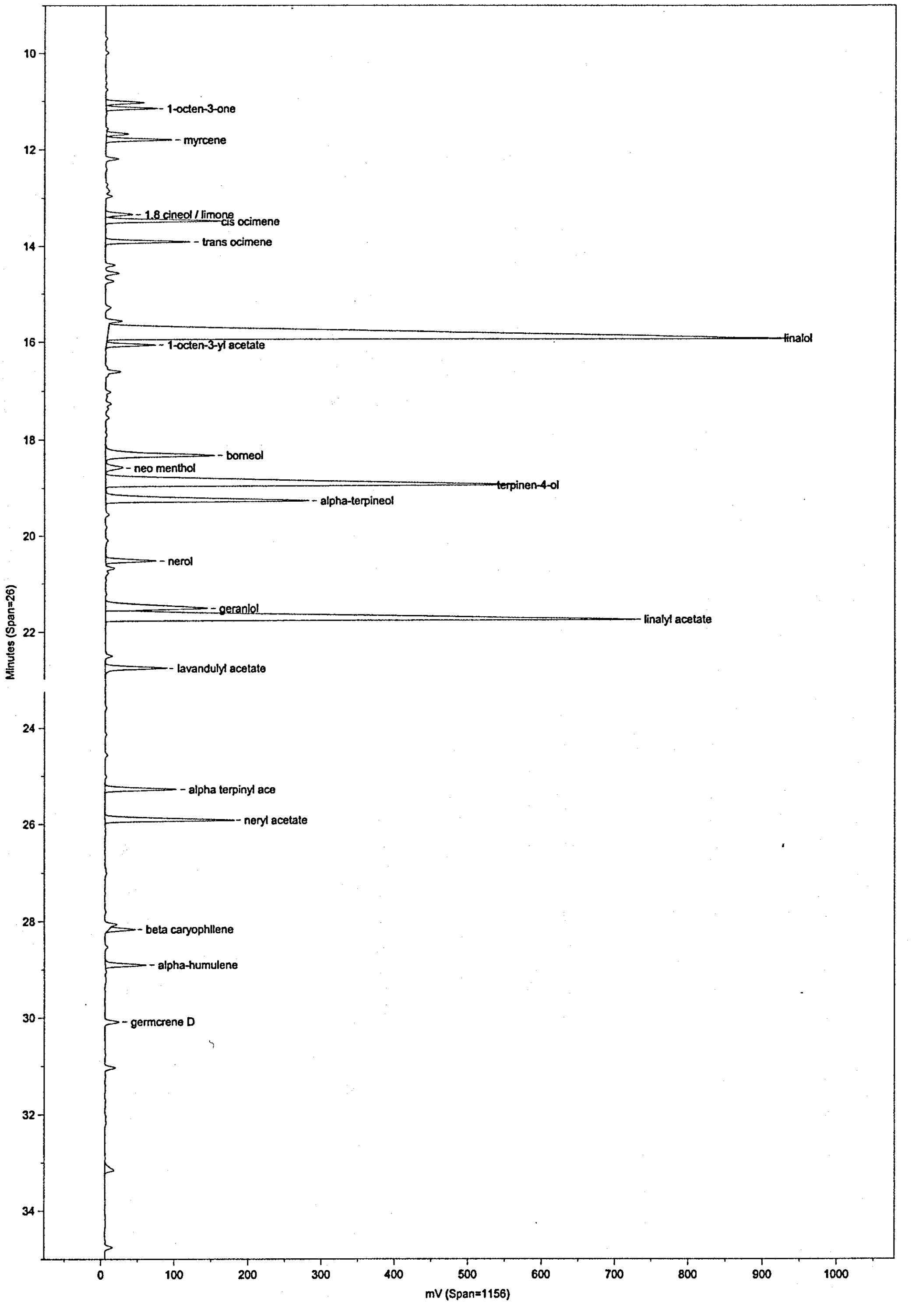


Appendix Figure A2.5a,b,c : Diagrammatic representation from Instron chart for *Lavandula Augustifolia Folgate* cultivar (a), *Lavandula Augustifolia Mailette* cultivar (b), *Lavandula x intermidia Grosso* cultivar (c)

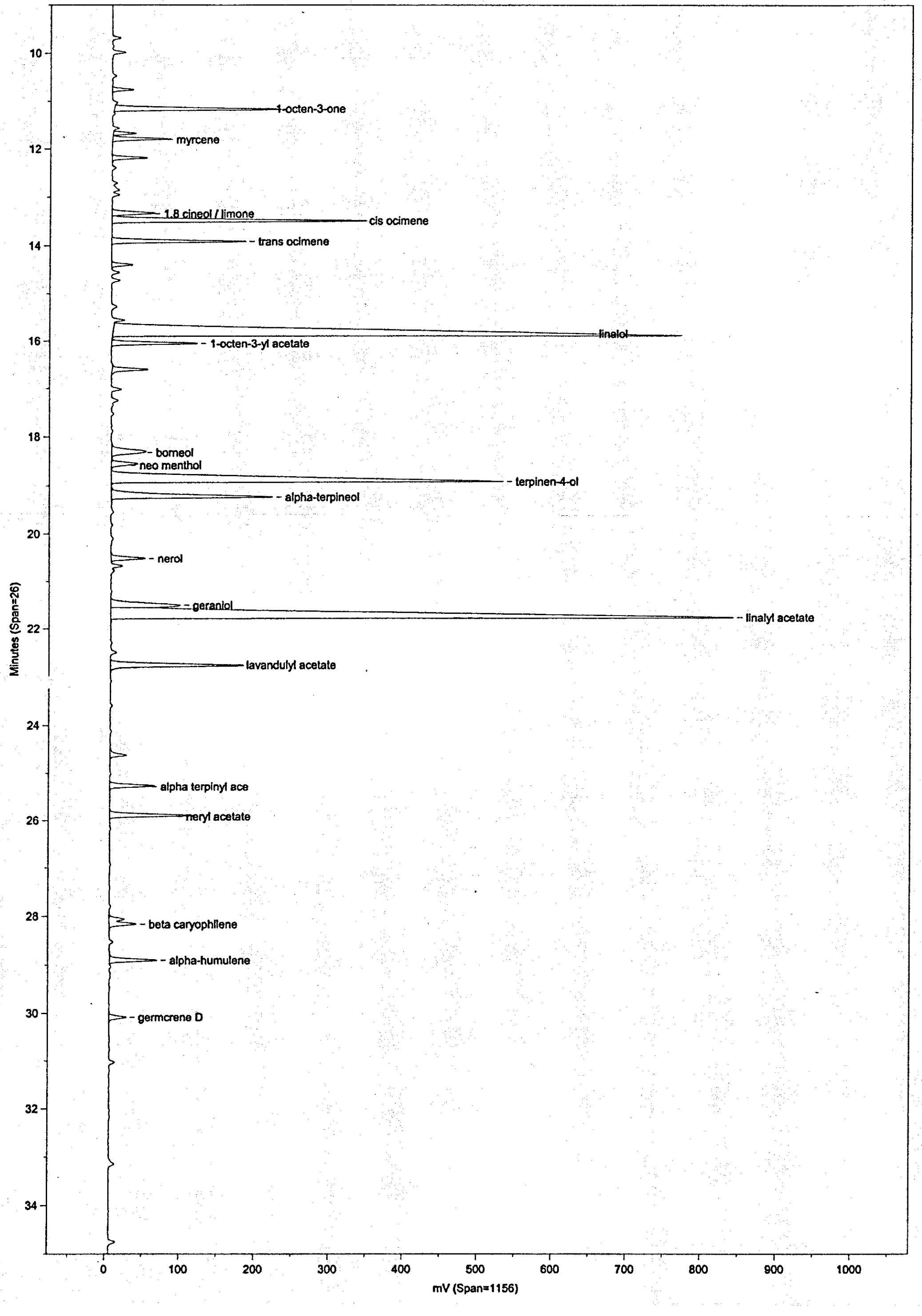
APPENDIX 3: OIL ANALYSIS & COST IDENTIFICATION



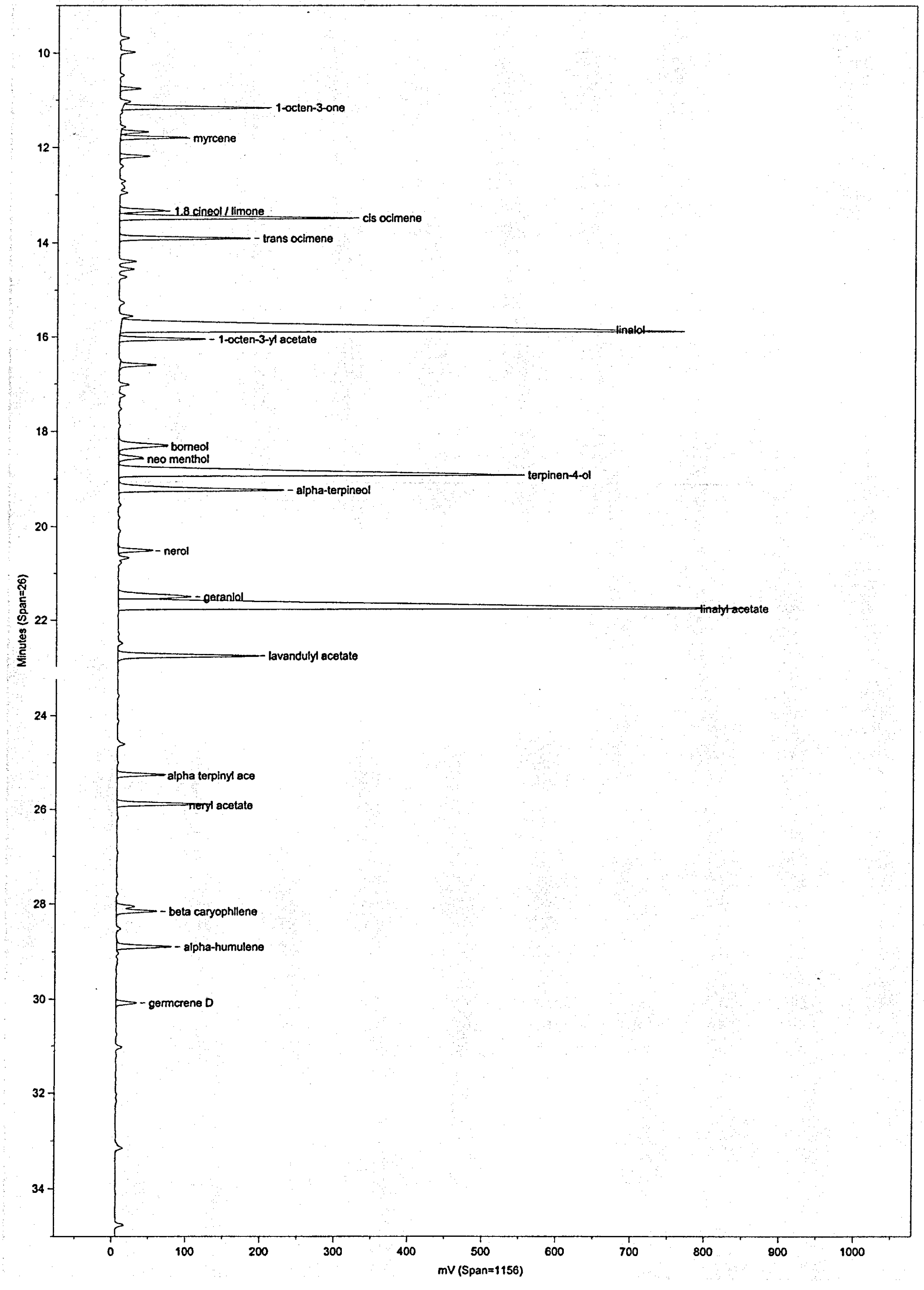
Appendix Figure A3.1: Gas chromatography chromatogram from CLIER sample 1



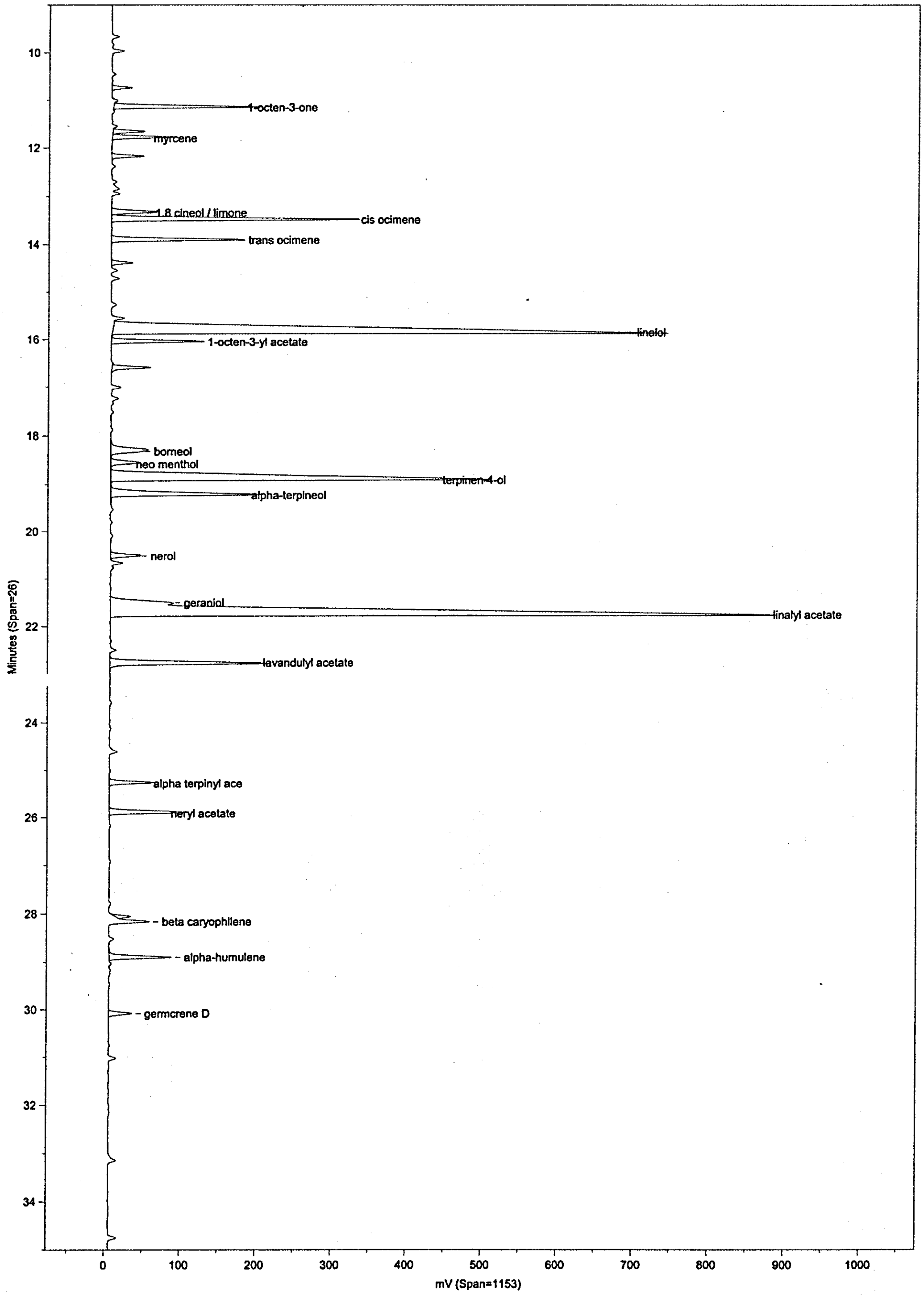
Appendix Figure A3.2: Gas chromatography chromatogram from CLIER sample 2



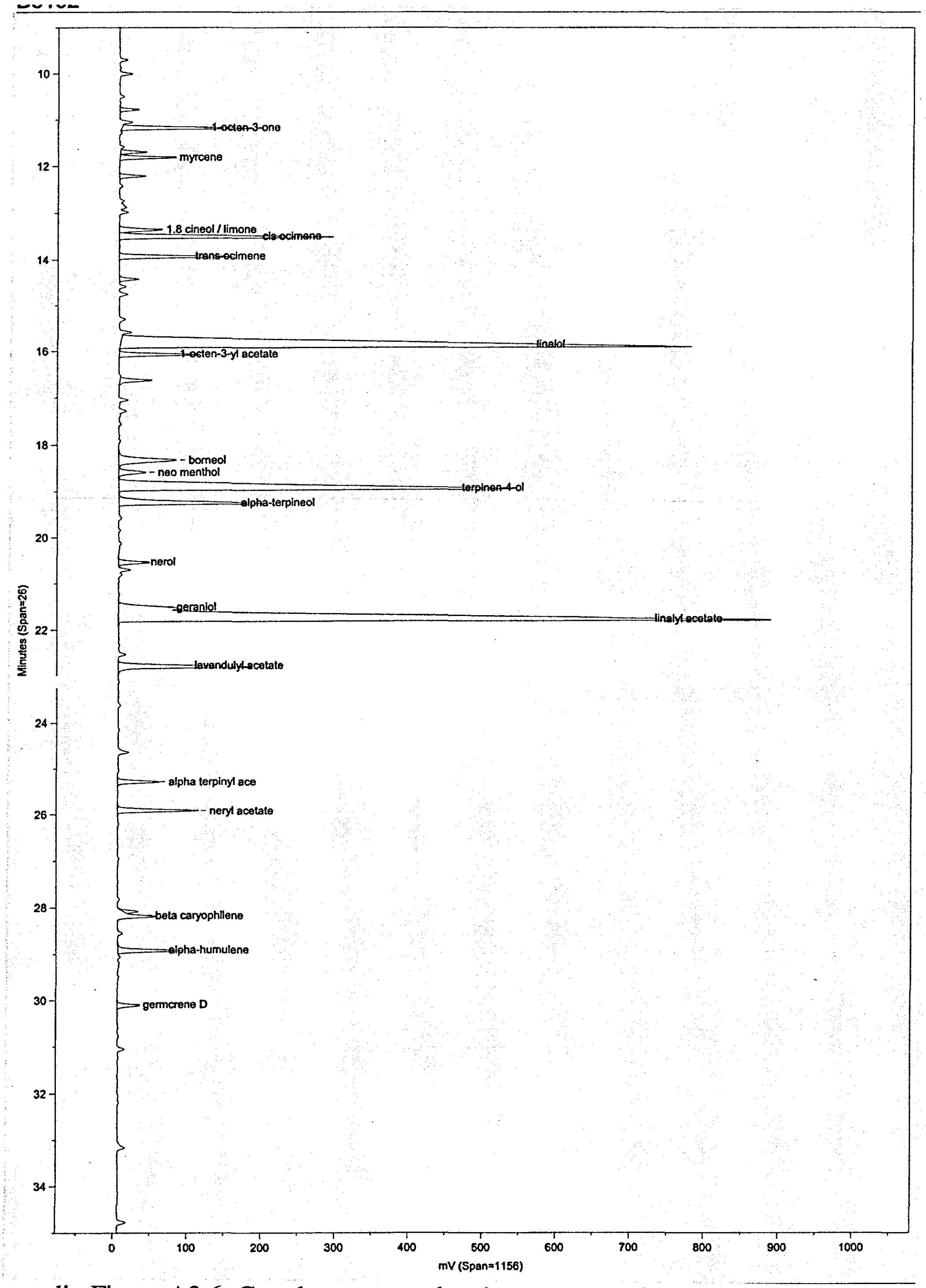
Appendix Figure A3.3: Gas chromatography chromatogram from prototype "quality" sample 1



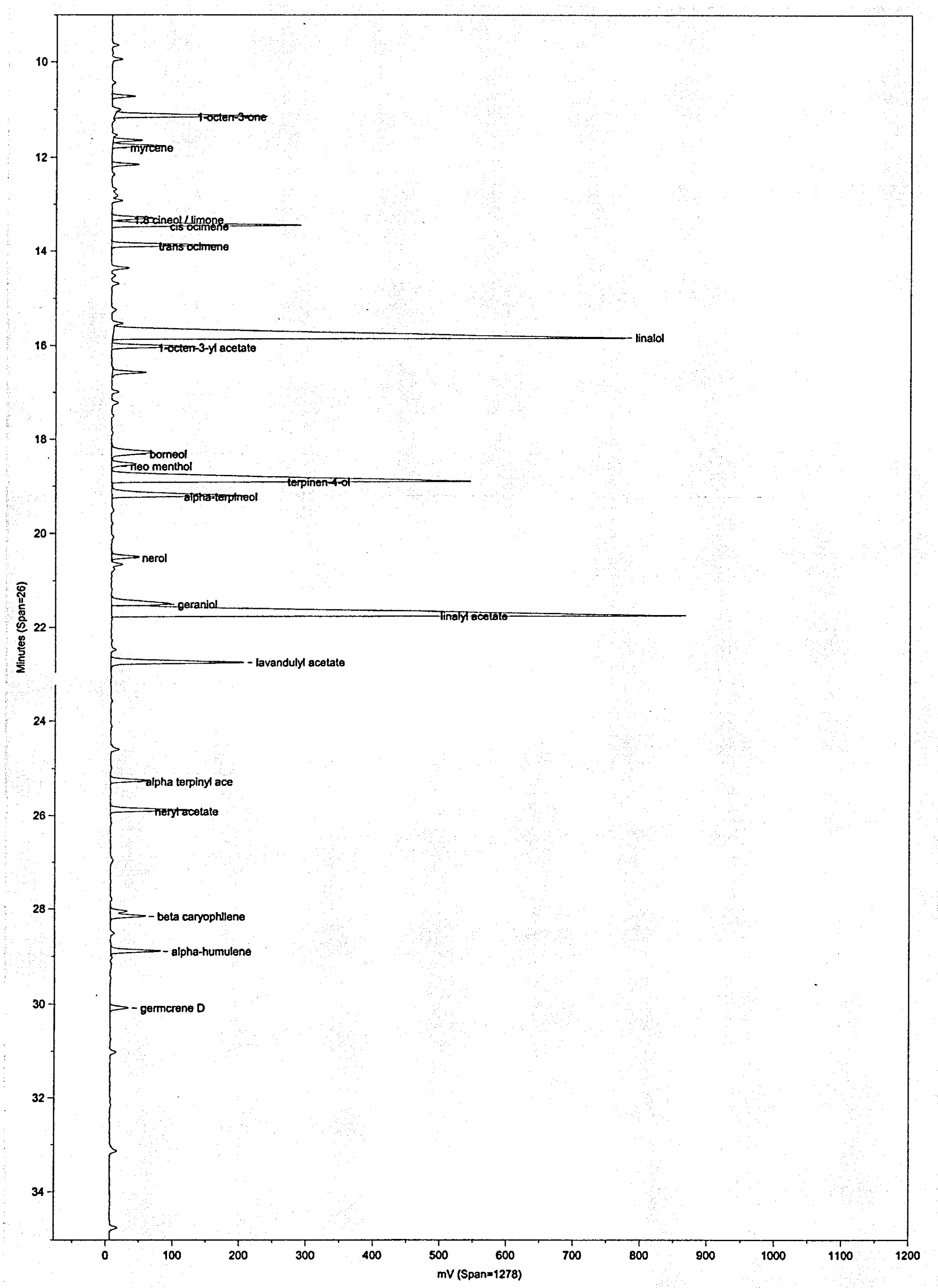
Appendix Figure A3.4: Gas chromatography chromatogram from prototype "quality" sample 2



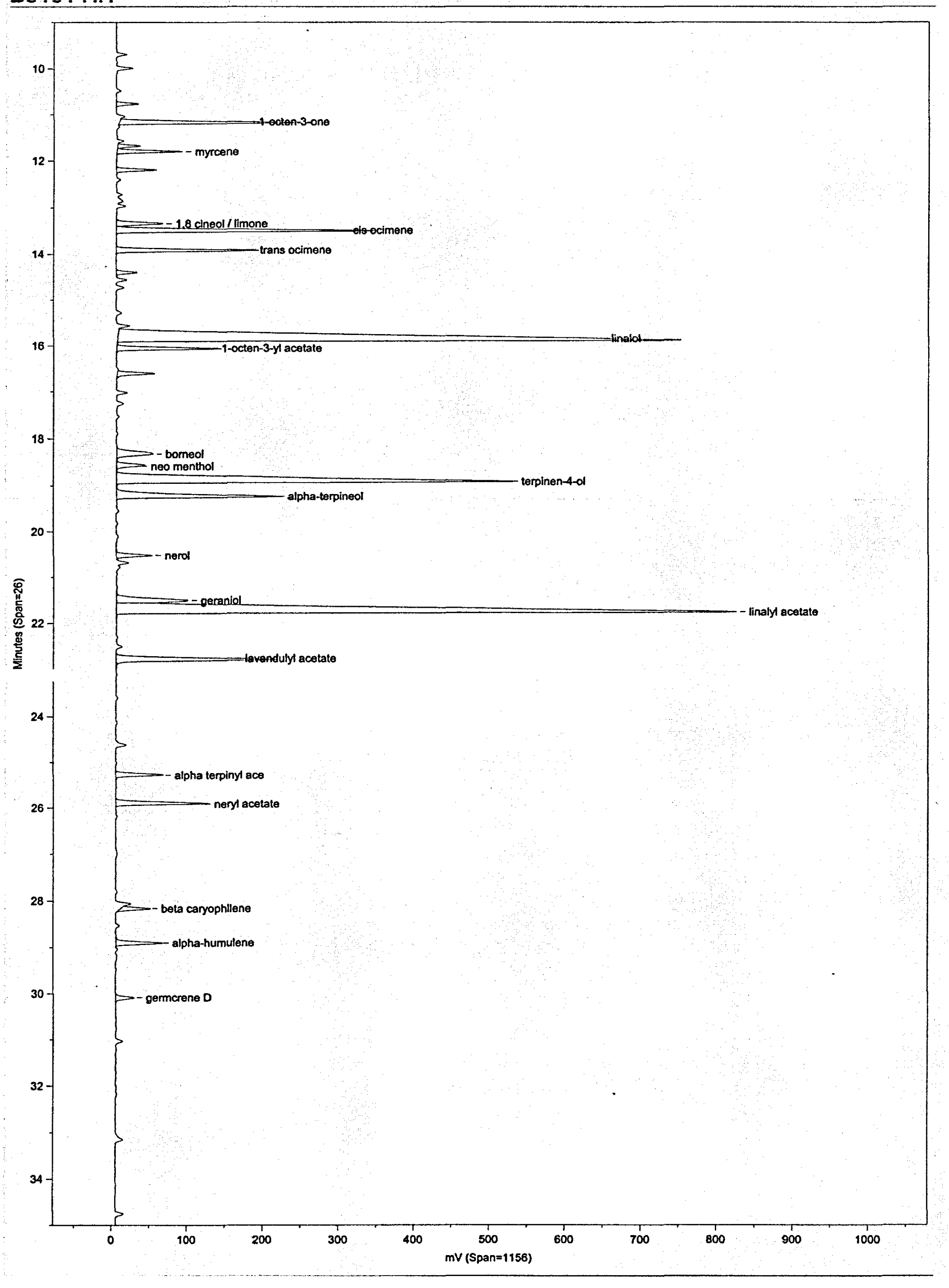
Appendix Figure A3.5: Gas chromatography chromatogram from prototype "quantity" sample 1



Appendix Figure A3.6: Gas chromatography chromatogram from prototype "quantity" sample 2



Appendix Figure A3.7: Gas chromatography chromatogram from hand harvest sample 1



Appendix Figure A3.8: Gas chromatography chromatogram from hand harvest sample 2

Appendix Table A3.1: Data collected from Yalding field trials

Harvest method	Row length m	Row Width m	Distance between rows m	Mean harvest time per plot s	Mean harvested mass from each plot kg	Mean oil quantity **ml/100g mass**
Hand harvest	10	0.9	1.83	1940	9.05	0.77
Prototype quality (310)	10	0.9	1.83	27	4.6	1.20
Prototype quantity (510)	10	0.9	1.83	57	6.05	0.97
CLIER	10	0.9	1.83	10	7.35	0.58

Appendix Table A3.2: Oil standards configuration (McGimpsey & Porter, 1999)

	Lavender cultivar			
	Lavandula Agustifolia		Lavandula x Intermidia	
Component	ISO	AFNOR	ISO	AFNOR
1,8-Cineole	0 - 15	trace - 0.5	4- 7	4 - 7
Limonene	0 - 0.5	0 - 0.5	ns	0.5 - 1.5
trans-β-Ocimene	2- 6	1.5 -6	ns	trace - 1
cis-β-Ocimene	4- 10	4- 10	ns	0.5 - 1.5
3-Octanone	0 - 2	trace - 2	ns	ns
Camphor	0 - 0.5	trace - 0.5	6 - 8	6 - 8
Linalool	25 - 38	25 - 38	25 - 36	24 - 35
Linalyl acetate	25 - 45	25 - 45	28 - 38	28 - 38
Terpinen-4-ol	2- 6	2 - 6	2 - 4	1.5 - 5
Borneol	ns	ns	1.5 - 3	1.5 - 3
Lvandulol	min 0.3	min 0.3	0.3 - 0.5	0.2 - 0.8
lavandulyl acetate	min 2	min 2	1.5 - 3	1.5 - 3
α-terpineol	0 - 1	0 - 1	ns	ns

Appendix Table A3.3: Harvest operation costs calculation for 3 harvest methods (Based on 10 days (80 h) harvest work per season)

Hand harvest		The hours needed to harvest by hand one hectare was measured during tests and found 539 h. John Nix (2004) indicates that each hour of field work costs £4.5. So the total cost would be :…………………539 h/ha*£4.5 = £2425.5
Prototype	Prototype quality	Depreciation: £1,500/80h (harvest window) =………………£18.75 /h Repairs & Maintenance: 1.5% (of the capital cost) £225/80 h (harvest window) =……………………………….£2.81 /h Fuel & oil : 4.5 L/14 h (harvest time) = 0.32 L/h 0.32 L/h * £0.78/L[1] =……………………………………….£0.25 /h Labour : £4.5 /h *2 workers =………………………………..£9.00 /h *Total : £30.81 /h* £30.81 /h / 0.23 ha/h (work rate) = **£133.9 /ha**
	Prototype quantity	Depreciation: £1,500/80h (harvest window) =………………£18.75 /h Repairs & Maintenance: 1.5% (of the capital cost) £225/80 h (harvest window) =……………………………….£2.81 /h Fuel & oil : 4.5 L/14 h (harvest time) = 0.32 L/h 0.32 L/h * £0.78/L =………………………………………….£0.25 /h Labour : £4.5 /h *2 workers =………………………………..£9.00 /h *Total : £30.81 /h* £30.81 /h / 0.11 ha/h (work rate) = **£280.00 /ha**
CLIER	Tractor	From John Nix (2004) tractor 100 hp 2 wheel drive operation cost =……………………………………………….£11.23 /h
	Mounted harvester	Depreciation: £2,000/80 h (harvest window) =……………£25.00 /h Repairs & Maintenance: 1.5% (of the capital cost) £450/80 h (harvest window) =……………………………….£3.75 /h Fuel & oil :…………………………………………………….£0.00 /h Labour : £4.5 /h *1 worker =………………………………..£4.50 /h *Total : £44.48 /h* 44.48 £/h / 0.37 ha/h (work rate) = **£120.21 /ha**

[1] Price taken at 2004 year

Appendix Table A3.4: Determination on produced oil cost (for the calculations the running hours of the distillery was taken as 12 hours per day for peak harvest season)

Hand harvest Mass: 8,145.8 kg/ha Oil yield: 65.91 L/ha	<u>Distillation :</u> 8,145.8 kg/1000 kg (of 1 chamber) = 8.14 chambers ≈ 8 runs *95 £/run = ...£760 <u>Transportation :</u> 8,145.8 kg/1460 kg (max van fill) = 5.58 van fills (110 miles) ≈ 6 trips/3 trips per day = 2 days hire *100 £/day =..........£200 (66 mile) ≈ 6 trips/6 trips per day = 1.0 days hire *100 £/day =..........£100 (1 mile) ≈ 6 trips/6 trips per day = 1.0 day hire *100 £/day =..........£100 <u>Fuel :</u> (110 miles) 40£/trip * 6 trips =..........£240 (66 miles)...66 miles *0.36 £/mile = 24 £/trip *6 trips =..........£144 (1 mile)..........£10 *Total cost = distillation + Lorry hire + Fuel* ***(1 mile distance to still) T.C=D +L.H +F = 760+100+10 =.......£870*** ***(66 miles distance to still) T.C=D +L.H +F = 760+100+144 =.....£1004*** ***(110 miles distance to still) T.C=D +L.H +F = 760+200+240 = ...£1200***
Prototype quality Mass: 4,140.4 kg/ha Oil yield: 51.89 L/ha	<u>Distillation :</u> 4,140.4 kg/1000 kg (of 1 chamber) = 4.14 chambers ≈ 4 runs *95 £/run = ...£380 <u>Transportation :</u> 4,140.4 kg/1460 kg (max van fill) = 2.8 van fills (110 miles) ≈ 3 trips/3 trips per day = 1.0 day hire *100 £/day =..........£100 (1 mile) ≈ 3 trips/6 trips per day = 0.5 ≈ 1 day hire *100 £/day =..........£100 <u>Fuel :</u> (110 miles) 40£/trip * 3 trips =..........£120 (1 mile)..........£10 *Total cost = distillation + Lorry hire + Fuel* ***(0 miles distance to still) : T.C=D +L.H +F = 380+100+10 =........£480*** ***(110 miles distance to still) : T.C=D +L.H +F = 380+100+120 = ...£600***
Prototype quantity Mass: 5,445.5 kg/ha Oil yield: 54.45 L/ha	<u>Distillation :</u> 5,445.5 kg/1000 kg (of 1 chamber) = 5.44 chambers ≈ 5 runs *95 £/run = ...£475 <u>Transportation :</u> 5,445.5 kg/1460 kg (max van fill) = 3.72 van fills (110 miles) ≈ 4 trips/3 trips per day = 1.33 ≈ 2 days hire *100 £/day =......£200 (66 miles) ≈ 4 trips/6 trips per day = 0.66 ≈ 1.0 days hire *100 £/day =.........£100 (1 mile) ≈ 4 trips/6 trips per day = 0.66 ≈ 1 day hire *100 £/day =..........£100 <u>Fuel :</u> (110 miles) 40£/trip * 4 trips =..........£160 (66 miles)...66 miles *0.36 £/mile = 24 £/trip *4 trips =..........£96 (0 miles)..........£10 *Total cost = Distillation + Lorry Hire + Fuel (T.C=D +L.H +F)* ***(0 miles distance to still) : T.C=D +L.H +F = 475+100+10 =........£585*** ***(66 miles distance to still) : T.C=D +L.H +F = 475+100+96 =........£671*** ***(110 miles distance to still) : T.C=D +L.H +F = 475+200+160 = ...£835***
CLIER Mass: 6,615.6 kg/ha Oil yield: 40.34 L/ha	<u>Distillation :</u> 6,615.6 kg/1000 kg (of 1 chamber) = 6.61 chambers ≈ 7 runs *95 £/run = ...£665 <u>Transportation :</u> 6,615.6 kg/1460 kg (max van fill) = 4.53 van fills (110 miles) ≈ 5 trips/3 trips per day = 1.66 ≈ 2.0 days hire *100 £/day =......£200 (66 miles) ≈ 5 trips/6 trips per day = 0.83 ≈ 1.0 days hire *100 £/day =.........£100 (1 mile) ≈ 5 trips/6 trips per day = 0.83 ≈ 1.0 days hire *100 £/day =..........£100 <u>Fuel :</u> (110 miles) 40£/trip * 5 trips =..........£200 (66 miles)...66 miles *0.36 £/mile = 24 £/trip *5 trips =..........£120 (0 miles)..........£10 *Total cost = Distillation + Lorry Hire + Fuel (T.C=D +L.H +F)* ***(0 miles distance to still) : T.C=D +L.H +F = 665+100+10 =........£775*** ***(66 miles distance to still) : T.C=D +L.H +F = 665+100+24 =........£885*** ***(110 miles distance to still) : T.C=D +L.H +F = 665+200+200 = ...£1065***

Appendix Table A3.5: Data used to determine Figure 7.6 and 7.7.

A	B	C	D	E	F	G
Harvest method	**Distance to still**	**Harvest operation cost**	**Distillation & transportation cost**	**Total cost**	**Oil yield**	**Total cost**
				(C+D)		**(E/F)**
	miles	*£/ha*	*£/ha*	*£/ha*	*L/ha*	*£/L of prod. oil*
Hand Harvest	1	2425.5	870	3295.5	65.91	50.0
Hand Harvest	66	2425.5	1004	3429.5	65.91	52.0
Hand Harvest	110	2425.5	1200	3625.5	65.91	55.0
Prototype "quality"	1	133.9	490	623.9	51.89	12.0
Prototype "quality"	110	133.9	600	733.9	51.89	14.1
Prototype "quantity"	1	280.0	585	865.0	54.45	15.9
Prototype "quantity"	66	280.0	671	951.0	54.45	17.5
Prototype "quantity"	110	280.0	835	1115.0	54.45	20.5
CLIER	1	120.2	775	895.2	40.34	22.2
CLIER	66	120.2	885	1005.2	40.34	24.9
CLIER	110	120.2	1065	1185.2	40.34	29.4

APPENDIX 4: EXPERIMENTS STATISTICAL ANALYSIS

APPENDIX 4.1: *Air flow improvement test*

The analysis of Variance (ANOVA) for Air flow improvement test was done using a randomised complete block design.

Appendix Table A4.1.1: Air flow test "Analysis of variance" Values_m/s

Source of variation	d.f	s.s	m.s	v.r	F pr
Replicate stratum	1	6.55	6.55	2.28	
Replicate Wholeplots stratum					
Under_cover	2	1300.53	650.26	226.14	<.001
hood_noze	2	673.69	336.84	117.15	<.001
Under_cover.hood_noze	4	31.55	7.89	2.74	0.105
Residual	8	23.00	2.88	0.24	
Replication Wholeplots *Units* stratum					
Rotor r.p.m	4	367.99	92.00	7.60	<.001
Position	1	37480.48	37480.48	3096.27	<.001
Under_cover.Rotor_speed	8	105.56	13.20	1.09	0.367
hood_noze.Rotor_speed	8	68.95	8.62	0.71	0.681
Under_cover.Position	2	463.30	231.65	19.14	<.001
hood_noze.Position	2	1372.97	686.48	56.71	<.001
Rotor_speed.Position	4	3112.96	778.24	64.29	<.001
Under_cover.hood_noze.Rotor_speed	16	39.50	2.47	0.20	1.000
Under_cover.hood_noze.Position	4	68.23	17.06	1.41	0.229
Under_cover.Rotor_speed.Position	8	56.24	7.03	0.58	0.794
hood_noze.Rotor_speed.Position	8	240.62	30.08	2.48	0.011
Under_cover.hood_noze.Rotor_speed. Position	16	27.78	1.74	0.14	1.000
Residual	1521	18411.79	12.11		
Total	1619	63851.70			

Appendix Table A4.1.2: Air flow test "Table of means" Values_m/s

Under cover	1	2	3		
	3.458	1.667	1.464		
Hood nose	1	2	3		
	1.770	3.108	1.711		
Rotor r.p.m	210	310	360	410	510
	1.506	2.029	2.070	2.435	2.943
Position	A	G			
	-2.614	7.006			
Under cover. Hood nose	1	2	3		
1	3.304	4.277	2.793		
2	1.100	2.650	1.250		
3	0.906	2.397	1.091		
Under cover. Rotor r.p.m	210	310	360	410	510
1	2.189	3.289	3.365	3.694	4.754
2	1.256	1.474	1.470	1.907	2.226
3	1.072	1.324	1.374	1.702	1.850
Hood nose. Rotor r.p.m	210	310	360	410	510
1	1.304	1.620	1.713	1.848	2.365
2	2.119	2.685	2.872	3.602	4.261
3	1.094	1.781	1.624	1.854	2.204
Under cover.Position	B	G			
1	-0.736	7.652			
2	-3.831	7.164			
3	-3.274	6.203			
Hood noze.Position	B	G			
1	-3.478	7.018			
2	-0.421	6.637			
3	-3.941	7.364			

Table cont'd

Table cont'd

Rotorspeed.Position		B	G				
210		-1.368	4.379				
310		-1.889	5.947				
360		-2.795	6.935				
410		-2.984	7.853				
510		-4.032	9.919				
Under cover. hood_noze. Rotor_speed		210	310	360	410	510	
1	1	2.222	2.967	3.211	3.483	4.639	
1	2	2.789	3.911	4.344	4.522	5.817	
1	3	1.556	2.989	2.539	3.078	3.806	
2	1	1.000	0.878	1.183	1.167	1.272	
2	2	1.867	2.144	1.933	3.350	3.956	
2	3	0.900	1.400	1.294	1.206	1.450	
3	1	0.689	1.017	0.744	0.894	1.183	
3	2	1.700	2.000	2.339	2.933	3.011	
3	3	0.828	0.956	1.039	1.278	1.356	
Hood nose		1		2		3	
Under cover.Position		B	G	B	G	B	G
1		-1.233	7.842	1.620	6.933	-2.593	8.180
2		-5.013	7.213	-1.540	6.840	-4.940	7.440
3		-4.187	5.998	-1.344	6.138	-4.291	6.473

Table cont'd

Table cont'd

Under cover. Rotor r.p.m. Position		B	G				
1	210	-0.211	4.589				
1	310	0.300	6.278				
1	360	-0.733	7.463				
1	410	-1.141	8.530				
1	510	-1.893	11.400				
2	210	-2.033	4.544				
2	310	-3.237	6.185				
2	360	-4.281	7.222				
2	410	-4.133	7.948				
2	510	-5.470	9.922				
3	210	-1.859	4.004				
3	310	-2.730	5.378				
3	360	-3.370	6.119				
3	410	-3.678	7.081				
3	510	-4.733	8.433				
Hood nose. Rotor r.p.m. Position		B	G				
1	210	-1.756	4.363				
1	310	-2.633	5.874				
1	360	-3.459	6.885				
1	410	-3.989	7.685				
1	510	-5.552	10.281				
2	210	-0.185	4.422				
2	310	-0.226	5.596				
2	360	-0.796	6.541				
2	410	-0.378	7.581				
2	510	-0.522	9.044				
3	210	-2.163	4.352				
3	310	-2.807	6.370				
3	360	-4.130	7.378				
3	410	-4.585	8.293				
3	510	-6.022	10.430				

Table cont'd

Table cont'd

Under cover.Hood nose.. Rotor r.p.m. Position			B	G			
1	1	210	-0.144	4.589			
1	1	310	-0.400	6.333			
1	1	360	-1.122	7.544			
1	1	410	-1.700	8.667			
1	1	510	-2.800	12.078			
1	2	210	0.978	4.600			
1	2	310	2.233	5.589			
1	2	360	1.767	6.922			
1	2	410	1.378	7.667			
1	2	510	1.744	9.889			
1	3	210	-1.467	4.578			
1	3	310	-0.933	6.911			
1	3	360	-2.844	7.922			
1	3	410	-3.100	9.256			
1	3	510	-4.622	12.233			
2	1	210	-2.767	4.767			
2	1	310	-4.244	6.000			
2	1	360	-4.933	7.300			
2	1	410	-5.500	7.833			
2	1	510	-7.622	10.167			
2	2	210	-0.567	4.300			
2	2	310	-1.533	5.822			
2	2	360	-2.978	6.844			
2	2	410	-1.100	7.800			
2	2	510	-1.522	9.433			
2	3	210	-2.767	4.567			
2	3	310	-3.933	6.733			
2	3	360	-4.933	7.522			
2	3	410	-5.800	8.211			
2	3	510	-7.267	10.167			

Table cont'd

Table cont'd

3	1	210	-2.356	3.733			
3	1	310	-3.256	5.289			
3	1	360	-4.322	5.811			
3	1	410	-4.767	6.556			
3	1	510	-6.233	8.600			
3	2	210	-0.967	4.367			
3	2	310	-1.378	5.378			
3	2	360	-1.178	5.856			
3	2	410	-1.411	7.278			
3	2	510	-1.789	7.811			
3	3	210	-2.256	3.911			
3	3	310	-3.556	5.467			
3	3	360	-4.611	6.689			
3	3	410	-4.856	7.411			
3	3	510	-6.178	8.889			
Grand mean		2.196					

Appendix Table A4.1.3: Air flow test "Standard errors of means" Values_m/s

Table	Under cover	Hood nose	Rotor r.p.m	Position
rep.	540	540	324	810
d.f.	8	8	1521	1521
e.s.e	0.0730	0.0730	0.1933	0.1222
Table	Under cover Hood nose	Under cover Rotor r.p.m	Hood nose Rotor r.p.m	Under cover Position
rep.	180	108	108	270
d.f.	8	1021.86	1021.86	198.62
e.s.e	0.1264	0.3082	0.3082	0.1666
Table	Hood nose Position	Rotor r.p.m Position	Under cover Hood nose Rotor r.p.m	Under cover Hood nose Position
rep.	270	162	36	90
d.f.	198.62	1521	1021.86	198.62
e.s.e	0.1666	0.2734	0.5338	0.2885
Table	Under cover Rotor r.p.m Position	Hood nose Rotor r.p.m Position	Under cover Hood nose Rotor r.p.m Position	
rep.	54	54	18	
d.f.	1414.95	1414.95	1414.95	
e.s.e	0.4551	0.4551	0.7882	

Appendix Table A4.1.4: Air flow test "Standard errors of differences of means"
Values_m/s

Table	Under cover	Hood nose	Rotor r.p.m	Position
rep.	540	540	324	810
d.f.	8	8	1521	1521
s.e.d	0.1032	0.1032	0.2734	0.1729
Table	Under cover Hood nose	Under cover Rotor r.p.m	Hood nose Rotor r.p.m	Under cover Position
rep.	180	108	108	270
d.f.	8	1021.86	1021.86	198.62
s.e.d	0.1787	0.4359	0.4359	0.2355
Table	Hood nose Position	Rotor r.p.m Position	Under cover Hood nose Rotor r.p.m	Under cover Hood nose Position
rep.	270	162	36	90
d.f.	198.62	1521	1021.86	198.62
s.e.d	0.2355	0.3866	0.7550	0.4080
Table	Under cover Rotor r.p.m Position	Hood nose Rotor r.p.m Position	Under cover Hood nose Rotor r.p.m Position	
rep.	54	54	18	
d.f.	1414.95	1414.95	1414.95	
s.e.d	0.6435	0.6435	1.1147	

Appendix Table A4.1.5: Air flow test "Least significant differences of means (5% level)" Values_m/s

Table	Under cover	Hood nose	Rotor r.p.m	Position
rep.	540	540	324	810
d.f.	8	8	1521	1521
l.s.d	0.2380	0.2380	0.5362	0.3391
Table	Under cover Hood nose	Under cover Rotor r.p.m	Hood nose Rotor r.p.m	Under cover Position
rep.	180	108	108	270
d.f.	8	1021.86	1021.86	198.62
l.s.d	0.4122	0.8553	0.8553	0.4645
Table	Hood nose Position	Rotor r.p.m Position	Under cover Hood nose Rotor r.p.m	Under cover Hood nose Position
rep.	270	162	36	90
d.f.	198.62	1521	1021.86	198.62
l.s.d	0.4645	0.7583	1.4814	0.8045
Table	Under cover Rotor r.p.m Position	Hood nose Rotor r.p.m Position	Under cover Hood nose Rotor r.p.m Position	
rep.	54	54	18	
d.f.	1414.95	1414.95	1414.95	
l.s.d	1.2624	1.2624	2.1866	

Appendix Table A4.1.6: Air flow test "Stratum standard errors and coefficients of variation" Values_m/s

Stratum	d.f	s.e	cv%
Replication	1	0.0899	4.1
Replicate. Wholeplots	8	0.1787	8.1
Replicate.Wholeplots.*Units*	1521	3.4792	158.4

APPENDIX 4.2: ***Bioregional test***

The analysis of Variance (ANOVA) for Air flow improvement test was done using a randomised complete block design.

Appendix Table A4.2.1: Bioregional test "Analysis of variance" for % flowers

Source of variation	d.f	s.s	m.s	v.r	F pr
Replication stratum	1	1.3210	1.3210	14.93	
Replication Forward speed stratum					
Forward speed	2	76.3760	38.1880	431.65	0.002
Residual	2	0.1769	0.0885	0.21	
Replication Forward speed *Units* stratum					
Rotor r.p.m	2	120.3113	60.1556	141.17	<.001
Forward speed-Rotor r.p.m	4	12.3225	3.0806	7.23	0.018
Residual	6	2.5568	0.4261		
Total	17	213.0646			

Appendix Table A4.2.2: Bioregional test "Table of means" for % flowers

Forward speed	1	2	3
	91.82	94.74	89.72
Rotor r.p.m	1	2	3
	88.49	93.36	94.44
Forward speed . Rotor r.p.m	1	2	3
1	87.17	93.19	95.10
2	92.69	95.39	96.15
3	85.62	91.48	92.06
Grand mean	92.10		

Appendix Table A4.2.3: Bioregional test "Standard errors of means" for % flowers

Table	Forward speed	Rotor r.p.m	Forward speed-Rotor r.p.m
rep.	6	6	2
d.f.	2	6	7.08
e.s.e	0.121	0.266	0.396

Appendix Table A4.2.4: Bioregional test "Standard errors of differences of means" for % flowers

Table	Forward speed	Rotor r.p.m	Forward speed.Rotor r.p.m
rep.	6	6	2
d.f.	2	6	7.08
s.e.d	0.172	0.377	0.560

Appendix Table A4.2.5: Bioregional test "Least significant differences of means (5% level)" for % flowers

Table	Forward speed	Rotor r.p.m	Forward speed.Rotor r.p.m
rep.	6	6	2
d.f.	2	6	7.08
l.s.d	0.739	0.922	1.321

Appendix Table A4.2.6: Bioregional test "Stratum standard errors and coefficients of variation" for % flowers

Stratum	d.f	s.e	cv%
Replication	1	0.383	0.4
Replication.Forward speed	2	0.172	0.2
Replication.Forward speed.*Units*	6	0.653	0.7

Appendix Table A4.2.7: Bioregional test "Analysis of variance" for % stems

Source of variation	d.f	s.s	m.s	v.r	F pr
Replication stratum	1	13.27	13.27	1.23	
Replication Forward speed stratum					
Forward speed	2	145.48	72.74	6.74	0.129
Residual	2	21.59	10.80	1.08	
Replication Forward speed *Units* stratum					
Rotor r.p.m	2	3714.19	1857.10	185.39	<.001
Forward speed-Rotor r.p.m	4	670.21	167.55	16.73	0.002
Residual	6	60.10	10.02		
Total	17	4624.85			

Appendix Table A4.2.8: Bioregional test "Table of means" for % stems

Forward speed	1	2	3
	46.20	53.06	48.64
Rotor r.p.m	1	2	3
	30.29	52.61	65.00
Forward speed . Rotor r.p.m	1	2	3
1	24.02	41.11	73.45
2	33.74	60.59	64.87
3	33.10	56.14	56.69
Grand mean	49.30		

Appendix Table A4.2.9: Bioregional test "Standard errors of means" for % stems

Table	Forward speed	Rotor r.p.m	Forward speed-Rotor r.p.m
rep.	6	6	2
d.f.	2	6	7.59
e.s.e	1.341	1.292	2.267

Appendix Table A4.2.10: Bioregional test "Standard errors of differences of means" for % stems

Table	Forward speed	Rotor r.p.m	Forward speed.Rotor r.p.m
rep.	6	6	2
d.f.	2	6	7.59
s.e.d	1.897	1.827	3.206

Appendix Table A4.2.11: Bioregional test "Least significant differences of means (5% level)" for % stems

Table	Forward speed	Rotor r.p.m	Forward speed.Rotor r.p.m
rep.	6	6	2
d.f.	2	6	7.59
l.s.d	8.162	4.471	7.462

Appendix Table A4.2.12: Bioregional test "Stratum standard errors and coefficients of variation" for % stems

Stratum	d.f	s.e	cv%
Replication	1	1.214	2.5
Replication.Forward speed	2	1.897	3.8
Replication.Forward speed.*Units*	6	3.165	6.4

APPENDIX 4.3: ***Hitchin test***

The analysis of Variance (ANOVA) for Air flow improvement test was done using a randomised complete block design.

Appendix Table A4.3.1: Hitchin test "Analysis of variance" for total loss (Hood nose height)

Source of variation	d.f	s.s	m.s	v.r	F pr
Replication stratum	1	0.667	0.667	0.57	
Replication *Units* stratum					
Hood nose height	2	121.333	60.667	52.00	0.019
Residual	2	2.333	1.167		
Total	5	124.333			

Appendix Table A4.3.2: Hitchin test "Table of means" for total loss

Hood nose height	1	2	3
	25.50	16.50	15.50
Grand mean	19.17		

Appendix Table A4.3.3: Hitchin test "Standard errors of differences of means" for total loss

Table	Hood nose height
rep.	2
d.f.	2
s.e.d	1.080

Appendix Table A4.3.4: Hitchin test "Least significant differences of means (5% level)" for total loss

Table	Hood nose height
rep.	2
d.f.	2
l.s.d	4.647

Appendix Table A4.3.5: Hitchin test "Stratum standard errors and coefficients of variation" for total loss

Stratum	d.f	s.e	cv%
Replication	1	0.471	2.5
Replication *Units*	2	1.080	5.6

Appendix Table A4.3.6: Hitchin test "Analysis of variance" for total loss
(Under cover "ON" "OFF")

Source of variation	d.f	s.s	m.s	v.r	F pr
Replication stratum	1	0.563	0.563	0.11	
Replication *Units* stratum					
Under cover	1	68.063	68.063	13.44	0.170
Residual	1	5.062	5.062		
Total	3	73.688			

Appendix Table A4.3.7: Hitchin test "Table of means" for total loss

Under cover	1	2
	15.3	23.5
Grand mean	19.4	

Appendix Table A4.3.8: Hitchin test "Standard errors of differences of means" for total loss

Table	Under cover
rep.	2
d.f.	1
s.e.d	2.25

Appendix Table A4.3.9: Hitchin test "Least significant differences of means (5% level)" for total loss

Table	Under cover
rep.	2
d.f.	1
l.s.d	28.59

Appendix Table A4.3.10: Hitchin test "Stratum standard errors and coefficients of variation" for total loss

Stratum	d.f	s.e	cv%
Replication	1	0.53	2.7
Replication *Units*	2	2.25	11.6

APPENDIX 4.4: ***Yalding test***

The analysis of Variance (ANOVA) for Air flow improvement test was done using a randomised complete block design.

Appendix Table A4.4.1: Yalding test "Analysis of variance" for % flowers

Source of variation	d.f	s.s	m.s	v.r	F pr
Replication stratum	1	2.168	2.168	1.13	
Replication *Units* stratum					
Forward speed	2	233.670	116.835	60.96	<.001
Rotor r.p.m	1	90.233	90.233	47.08	0.001
Forward speed-Rotor r.p.m	2	66.811	33.405	17.43	0.006
Residual	5	9.584	1.917		
Total	11	402.465			

Appendix Table A4.4.2: Yalding test "Table of means" for % flowers

Forward speed	1	2	3
	96.81	94.89	86.64
Rotor r.p.m	1	2	
	90.04	95.52	
Forward speed . Rotor r.p.m	1	2	
1	95.86	97.76	
2	93.69	96.08	
3	80.56	92.71	
Grand mean	92.78		

Appendix Table A4.4.3: Yalding test "Standard errors of means" for % flowers

Table	Forward speed	Rotor r.p.m	Forward speed-Rotor r.p.m
rep.	4	6	2
d.f.	5	5	5
e.s.e	0.692	0.565	0.979

Appendix Table A4.4.4: Yalding test "Standard errors of differences of means" for % flowers

Table	Forward speed	Rotor r.p.m	Forward speed.Rotor r.p.m
rep.	4	6	2
d.f.	5	5	5
s.e.d	0.979	0.799	1.384

Appendix Table A4.4.5: Yalding test "Least significant differences of means (5% level)" for % flowers

Table	Forward speed	Rotor r.p.m	Forward speed.Rotor r.p.m
rep.	4	6	2
d.f.	5	5	5
l.s.d	2.516	2.055	3.559

Appendix Table A4.4.6: Yalding test "Stratum standard errors and coefficients of variation" for % flowers

Stratum	d.f	s.e	cv%
Replication	1	0.601	0.6
Replication.*Units*	5	1.384	1.5

Appendix Table A4.4.7: Yalding test "Analysis of variance" for % stems

Source of variation	d.f	s.s	m.s	v.r	F pr
Replication stratum	1	20.955	20.955	4.55	
Replication *Units* stratum					
Forward speed	2	851.774	425.887	92.51	<.001
Rotor r.p.m	1	1282.426	1282.426	278.57	<.001
Forward speed-Rotor r.p.m	2	192.973	96.486	20.96	0.004
Residual	5	23.018	4.604		
Total	11	2371.145			

Appendix Table A4.4.8: Yalding test "Table of means" for % stems

Forward speed	1	2	3
	31.80	19.46	11.31
Rotor r.p.m	1	2	
	10.52	31.19	
Forward speed . Rotor r.p.m	1	2	
1	15.91	47.69	
2	10.90	28.02	
3	4.74	17.87	
Grand mean	20.86		

Appendix Table A4.4.9: Yalding test "Standard errors of means" for % stems

Table	Forward speed	Rotor r.p.m	Forward speed-Rotor r.p.m
rep.	4	6	2
d.f.	5	5	5
e.s.e	1.073	0.876	1.517

Appendix Table A4.4.10: Yalding test "Standard errors of differences of means" for % stems

Table	Forward speed	Rotor r.p.m	Forward speed.Rotor r.p.m
rep.	4	6	2
d.f.	5	5	5
s.e.d	1.517	1.239	2.146

Appendix Table A4.4.11: Yalding test "Least significant differences of means (5% level)" for % stems

Table	Forward speed	Rotor r.p.m	Forward speed.Rotor r.p.m
rep.	4	6	2
d.f.	5	5	5
l.s.d	3.900	3.184	5.515

Appendix Table A4.4.12: Yalding test "Stratum standard errors and coefficients of variation" for % stems

Stratum	d.f	s.e	cv%
Replication	1	1.869	9.0
Replication *Units*	5	2.146	10.3

APPENDIX 4.5: ***Oil components analysis test***

The analysis of Variance (ANOVA) for Air flow improvement test was done using a complete randomised design.

Appendix Table A4.5.1: Oil test "%1_8_cineol_limonene" compound

"Analysis of variance" for 1_8_cineol_limonene compound					
Source of variation	d.f	s.s	m.s	v.r	F pr
Treatment	3	0.226765	0.075588	43.94	0.002
Residual	4	0.006881	0.001720		
Total	7	0.233646			
"Tables of means" for 1_8_cineol_limonene compound					
Treatment	CLIER	Hand harvest	Prototype "quality"	Prototype "quantity"	
	0.640	1.070	1.005	0.995	
Grand mean	0.927				
"Standard errors of means" for 1_8_cineol_limonene compound					
Table	Treatment				
rep.	2				
d.f.	4				
e.s.e	0.0293				
"Standard errors of differences of means" for 1_8_cineol_limonene compound					
Table	Treatment				
rep.	2				
d.f.	4				
s.e.d	0.0415				
"Least significant differences of means (5% level)" for 1_8_cineol_limonene compound					
Table	Treatment				
rep.	2				
d.f.	4				
l.s.d	0.1151				
"Stratum standard errors and coefficients of variation" for 1_8_cineol_limonene compound					
Stratum	d.f	s.e	cv%		
Replication	4	0.0415	4.5		

Appendix Table A4.5.2: Oil test "%borneol" compound

"Analysis of variance" for borneol compound					
Source of variation	d.f	s.s	m.s	v.r	F pr
Treatment	3	4.69572	1.56524	16.09	0.011
Residual	4	0.38901	0.09725		
Total	7	5.08474			
"Tables of means" for borneol compound					
Treatment	CLIER	Hand harvest	Prototype "quality"	Prototype "quantity"	
	3.29	1.48	1.44	1.70	
Grand mean	1.98				
"Standard errors of means" for borneol compound					
Table	Treatment				
rep.	2				
d.f.	4				
e.s.e	0.221				
"Standard errors of differences of means" for borneol compound					
Table	Treatment				
rep.	2				
d.f.	4				
s.e.d	0.312				
"Least significant differences of means (5% level)" for borneol compound					
Table	Treatment				
rep.	2				
d.f.	4				
l.s.d	0.866				
"Stratum standard errors and coefficients of variation" for borneol compound					
Stratum	d.f	s.e	cv%		
Replication	4	0.312	15.8		

Appendix Table A4.5.3: Oil test "%1_Octen_3_one" compound

"Analysis of variance" for 1_8_cineol_limonene compound					
Source of variation	d.f	s.s	m.s	v.r	F pr
Treatment	3	6.28957	2.09652	49.55	0.001
Residual	4	0.16923	0.04231		
Total	7	6.45880			
"Tables of means" for 1_8_cineol_limonene compound					
Treatment	CLIER	Hand harvest	Prototype "quality"	Prototype "quantity"	
	0.998	3.296	3.003	2.585	
Grand mean	2.470				
"Standard errors of means" for 1_8_cineol_limonene compound					
Table	Treatment				
rep.	2				
d.f.	4				
e.s.e	0.1454				
"Standard errors of differences of means" for 1_8_cineol_limonene compound					
Table	Treatment				
rep.	2				
d.f.	4				
s.e.d	0.2057				
"Least significant differences of means (5% level)" for 1_8_cineol_limonene compound					
Table	Treatment				
rep.	2				
d.f.	4				
l.s.d	0.5711				
"Stratum standard errors and coefficients of variation" for 1_8_cineol_limonene compound					
Stratum	d.f	s.e	cv%		
Replication	4	0.2057	8.3		

Appendix Table A4.5.4: Oil test "%cis_ocimene" compound

"Analysis of variance" for cis_ocimene compound					
Source of variation	d.f	s.s	m.s	v.r	F pr
Treatment	3	9.9576	3.3192	17.38	0.009
Residual	4	0.7641	0.1910		
Total	7	10.7216			
"Tables of means" for cis_ocimene compound					
Treatment	CLIER	Hand harvest	Prototype "quality"	Prototype "quantity"	
	2.30	4.84	5.03	4.72	
Grand mean	4.22				
"Standard errors of means" for cis_ocimene compound					
Table	Treatment				
rep.	2				
d.f.	4				
e.s.e	0.309				
"Standard errors of differences of means" for cis_ocimene compound					
Table	Treatment				
rep.	2				
d.f.	4				
s.e.d	0.437				
"Least significant differences of means (5% level)" for cis_ocimene compound					
Table	Treatment				
rep.	2				
d.f.	4				
l.s.d	1.213				
"Stratum standard errors and coefficients of variation" for cis_ocimene compound					
Stratum	d.f	s.e	cv%		
Replication	4	0.437	10.3		

Appendix Table A4.5.5: Oil test "%lavandulyl_acetate" compound

"Analysis of variance" for lavandulyl_acetate compound					
Source of variation	d.f	s.s	m.s	v.r	F pr
Treatment	3	6.10236	2.03412	30.68	0.003
Residual	4	0.26518	0.06630		
Total	7	6.36754			
"Tables of means" for lavandulyl_acetate compound					
Treatment	CLIER	Hand harvest	Prototype "quality"	Prototype "quantity"	
	1.465	3.664	3.235	3.455	
Grand mean	2.955				
"Standard errors of means" for lavandulyl_acetate compound					
Table	Treatment				
rep.	2				
d.f.	4				
e.s.e	0.1821				
"Standard errors of differences of means" for lavandulyl_acetate compound					
Table	Treatment				
rep.	2				
d.f.	4				
s.e.d	0.2575				
"Least significant differences of means (5% level)" for lavandulyl_acetate compound					
Table	Treatment				
rep.	2				
d.f.	4				
l.s.d	0.7149				
"Stratum standard errors and coefficients of variation" for lavandulyl_acetate compound					
Stratum	d.f	s.e	cv%		
Replication	4	0.2575	8.7		

Appendix Table A4.5.6: Oil test "%linalyl_acetate" compound

"Analysis of variance" for linalyl_acetate compound					
Source of variation	d.f	s.s	m.s	v.r	F pr
Treatment	3	118.0717	39.3572	84.62	<.001
Residual	4	1.8604	0.4651		
Total	7	119.9321			
"Tables of means" for linalyl_acetate compound					
Treatment	CLIER	Hand harvest	Prototype "quality"	Prototype "quantity"	
	19.05	25.00	24.90	29.89	
Grand mean	24.71				
"Standard errors of means" for linalyl_acetate compound					
Table	Treatment				
rep.	2				
d.f.	4				
e.s.e	0.482				
"Standard errors of differences of means" for linalyl_acetate compound					
Table	Treatment				
rep.	2				
d.f.	4				
s.e.d	0.682				
"Least significant differences of means (5% level)" for linalyl_acetate compound					
Table	Treatment				
rep.	2				
d.f.	4				
l.s.d	1.893				
"Stratum standard errors and coefficients of variation" for linalyl_acetate compound					
Stratum	d.f	s.e	cv%		
Replication	4	0.682	2.8		

Appendix Table A4.5.7: Oil test "%trans_ocimene" compound

"Analysis of variance" for trans_ocimene compound					
Source of variation	d.f	s.s	m.s	v.r	F pr
Treatment	3	1.14270	0.38090	23.31	0.005
Residual	4	0.06535	0.01634		
Total	7	1.20805			
"Tables of means" for trans_ocimene compound					
Treatment	CLIER	Hand harvest	Prototype "quality"	Prototype "quantity"	
	1.624	2.421	2.595	2.430	
Grand mean	2.268				
"Standard errors of means" for trans_ocimene compound					
Table	Treatment				
rep.	2				
d.f.	4				
e.s.e	0.0904				
"Standard errors of differences of means" for trans_ocimene compound					
Table	Treatment				
rep.	2				
d.f.	4				
s.e.d	0.1278				
"Least significant differences of means (5% level)" for trans_ocimene compound					
Table	Treatment				
rep.	2				
d.f.	4				
l.s.d	0.3549				
"Stratum standard errors and coefficients of variation" for trans_ocimene compound					
Stratum	d.f	s.e	cv%		
Replication	4	0.1278	5.6		

Appendix Table A4.5.8: Oil test "%4_terpineol" compound

"Analysis of variance" for 4_terpineol compound					
Source of variation	d.f	s.s	m.s	v.r	F pr
Treatment	3	4.0572	1.3524	3.42	0.133
Residual	4	1.5795	0.3949		
Total	7	5.6367			
"Tables of means" for 4_terpineol compound					
Treatment	CLIER	Hand harvest	Prototype "quality"	Prototype "quantity"	
	15.97	14.29	14.34	14.37	
Grand mean	14.74				
"Standard errors of means" for 4_terpineol compound					
Table	Treatment				
rep.	2				
d.f.	4				
e.s.e	0.444				
"Standard errors of differences of means" for 4_terpineol compound					
Table	Treatment				
rep.	2				
d.f.	4				
s.e.d	0.628				
"Least significant differences of means (5% level)" for 4_terpineol compound					
Table	Treatment				
rep.	2				
d.f.	4				
l.s.d	1.745				
"Stratum standard errors and coefficients of variation" for 4_terpineol compound					
Stratum	d.f	s.e	cv%		
Replication	4	0.628	4.3		

Appendix Table A4.5.9: Oil test "%β_caryophyllene" compound

"Analysis of variance" for β_caryophyllene compound					
Source of variation	d.f	s.s	m.s	v.r	F pr
Treatment	3	1.06663	0.35554	4.16	0.101
Residual	4	0.34202	0.08550		
Total	7	1.40865			
"Tables of means" for β_caryophyllene compound					
Treatment	CLIER	Hand harvest	Prototype "quality"	Prototype "quantity"	
	0.50	0.98	1.18	0.26	
Grand mean	0.73				
"Standard errors of means" for β_caryophyllene compound					
Table	Treatment				
rep.	2				
d.f.	4				
e.s.e	0.207				
"Standard errors of differences of means" for β_caryophyllene compound					
Table	Treatment				
rep.	2				
d.f.	4				
s.e.d	0.292				
"Least significant differences of means (5% level)" for β_caryophyllene compound					
Table	Treatment				
rep.	2				
d.f.	4				
l.s.d	0.812				
"Stratum standard errors and coefficients of variation" for β_caryophyllene compound					
Stratum	d.f	s.e	cv%		
Replication	4	0.292	40.2		

Appendix Table A4.5.10: Oil test "%linalool" compound

"Analysis of variance" for linalool compound					
Source of variation	d.f	s.s	m.s	v.r	F pr
Treatment	3	134.2557	44.7519	77.65	<.001
Residual	4	2.3055	0.5764		
Total	7	136.5612			
"Tables of means" for linalool compound					
Treatment	CLIER	Hand harvest	Prototype "quality"	Prototype "quantity"	
	34.04	24.76	25.09	24.02	
Grand mean	26.98				
"Standard errors of means" for linalool compound					
Table	Treatment				
rep.	2				
d.f.	4				
e.s.e	0.537				
"Standard errors of differences of means" for linalool compound					
Table	Treatment				
rep.	2				
d.f.	4				
s.e.d	0.759				
"Least significant differences of means (5% level)" for linalool compound					
Table	Treatment				
rep.	2				
d.f.	4				
l.s.d	2.108				
"Stratum standard errors and coefficients of variation" for linalool compound					
Stratum	d.f	s.e	cv%		
Replication	4	0.759	2.8		

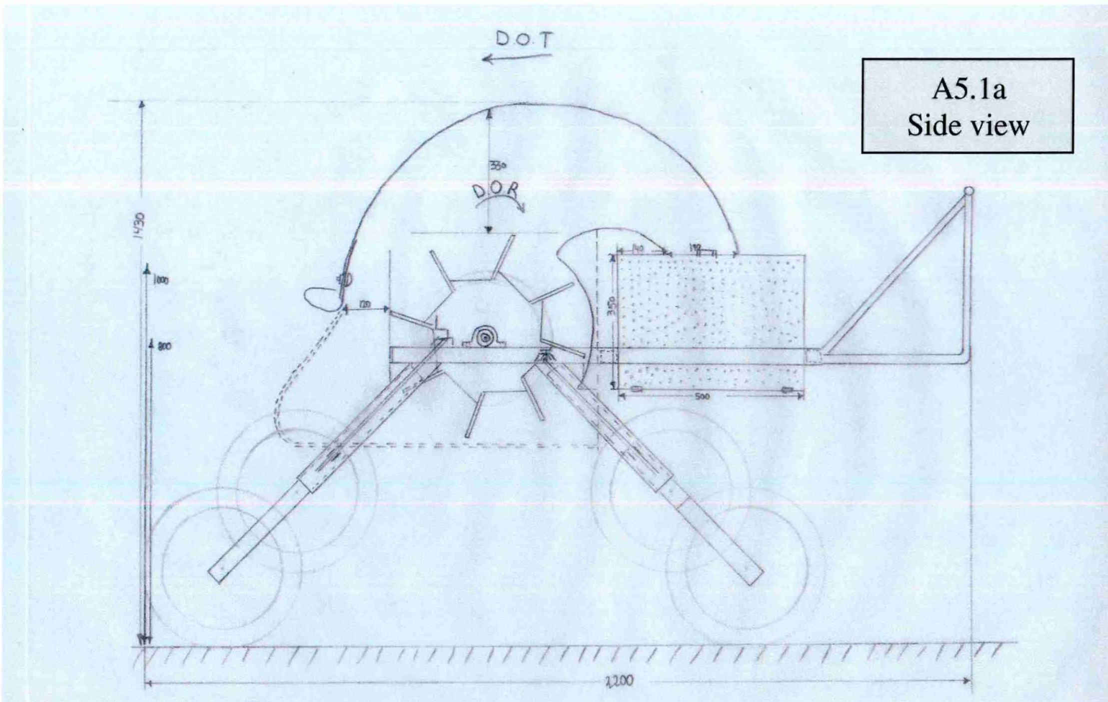
Appendix Table A4.5.11: Oil test "Volatile_Oil_%_VW"

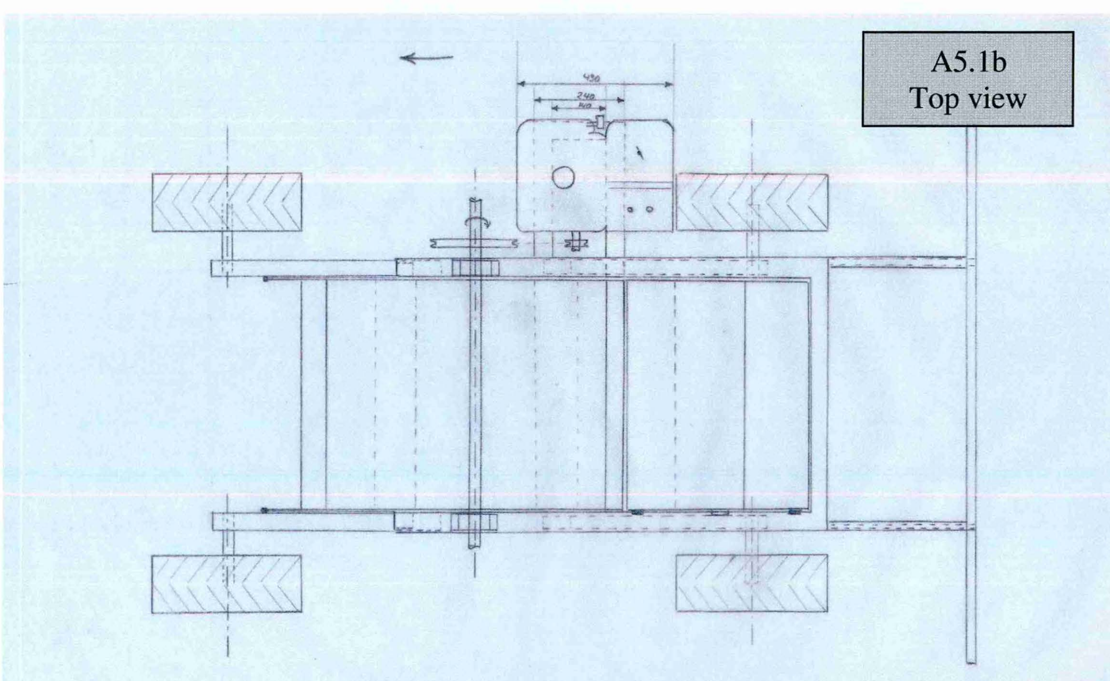
"Analysis of variance" for Volatile_Oil_%_VW					
Source of variation	d.f	s.s	m.s	v.r	F pr
Treatment	3	0.427037	0.142346	17.88	0.009
Residual	4	0.031850	0.007962		
Total	7	0.458887			
"Tables of means" for Volatile_Oil_%_VW					
Treatment	CLIER	Hand harvest	Prototype "quality"	Prototype "quantity"	
	0.580	0.770	1.200	0.975	
Grand mean	0.881				
"Standard errors of means" for Volatile_Oil_%_VW					
Table	Treatment				
rep.	2				
d.f.	4				
e.s.e	0.0631				
"Standard errors of differences of means" for Volatile_Oil_%_VW					
Table	Treatment				
rep.	2				
d.f.	4				
s.e.d	0.0892				
"Least significant differences of means (5% level)" for Volatile_Oil_%_VW					
Table	Treatment				
rep.	2				
d.f.	4				
l.s.d	0.2477				
"Stratum standard errors and coefficients of variation" for Volatile_Oil_%_VW					
Stratum	d.f	s.e	Cv%		
Replication	4	0.0892	10.1		

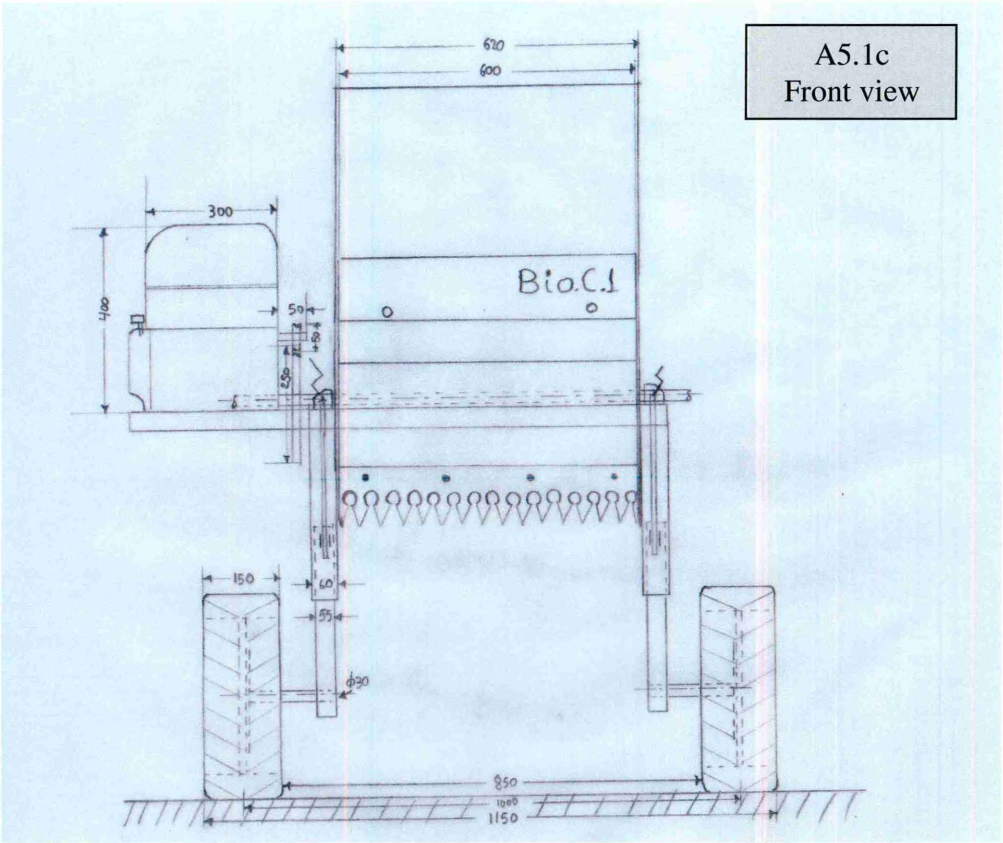
APPENDIX 5: MACHINE DRAWINGS

Appendix 5.1: *Preliminary Drawings*

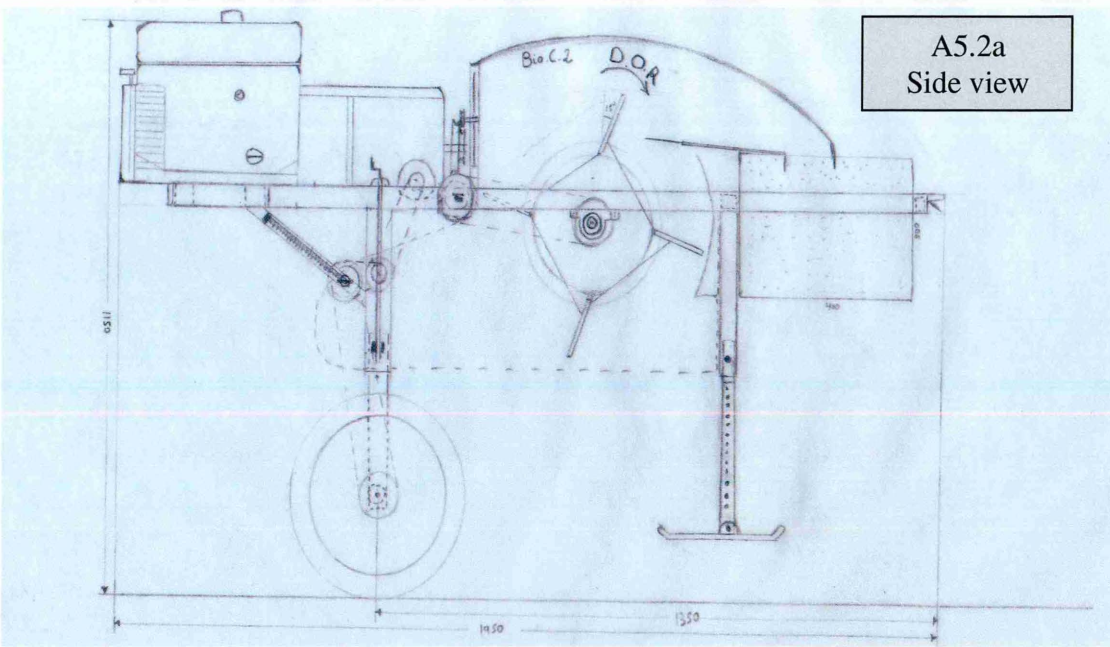
Appendix Figure A5.1a,b,c: Conceptual layout drawing details. Concept ARTEMH

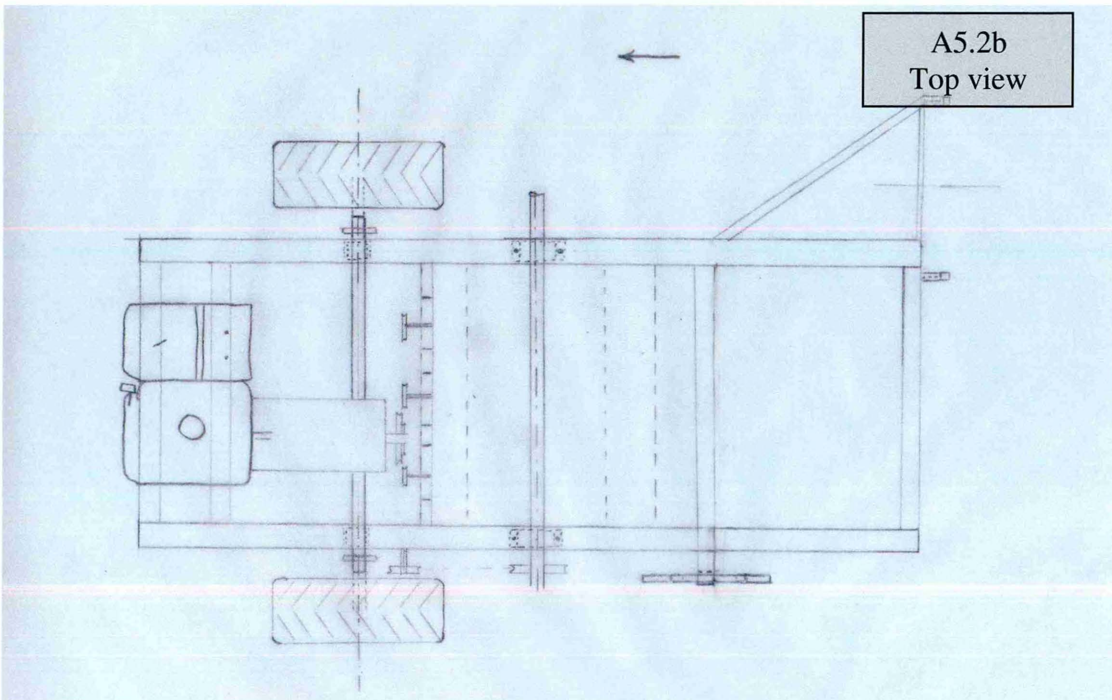


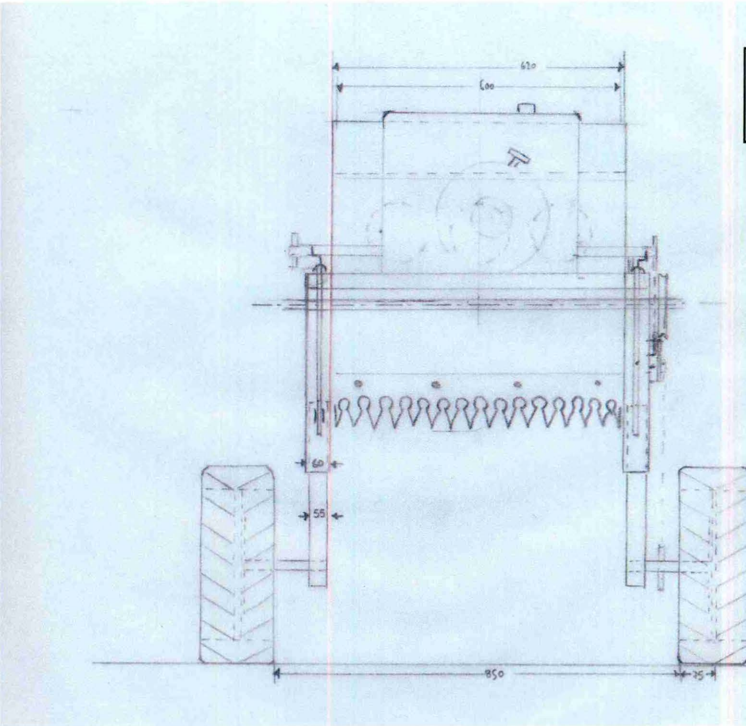



A5.1c
Front view
620
600
300
400
Bio.C.1
850
1000
1150
150
60
55
250
50
ϕ30

Appendix Figure A5.2a,b,c: Conceptual layout drawing details. Concept ARETH

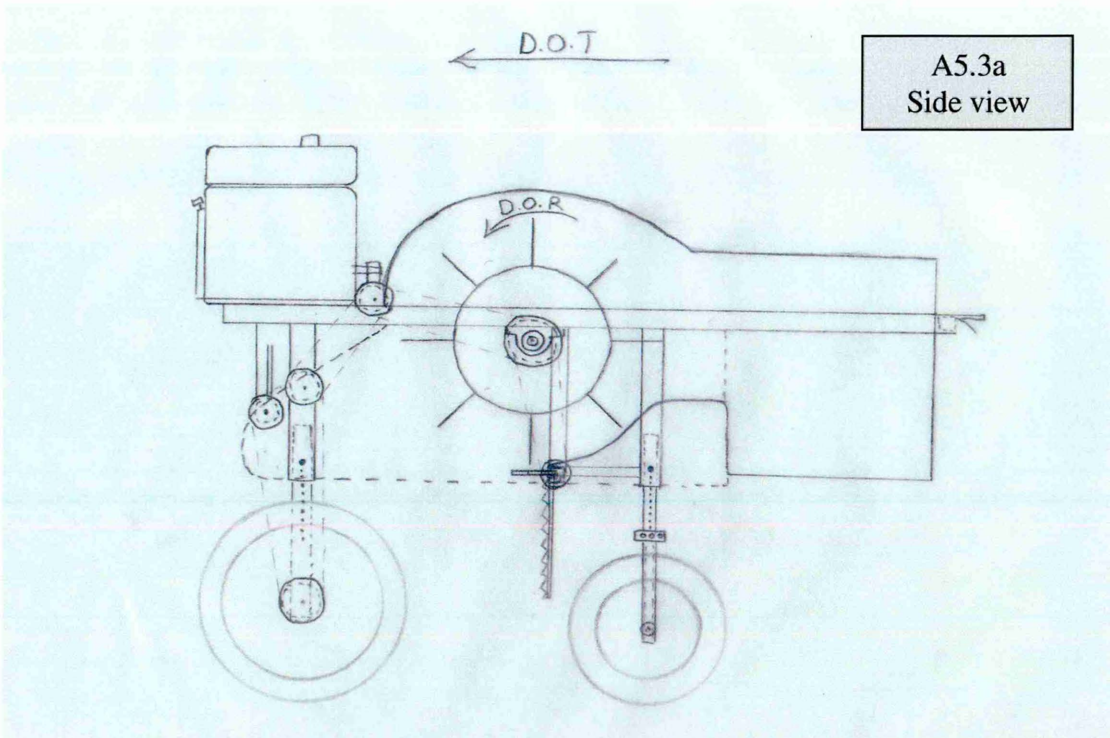


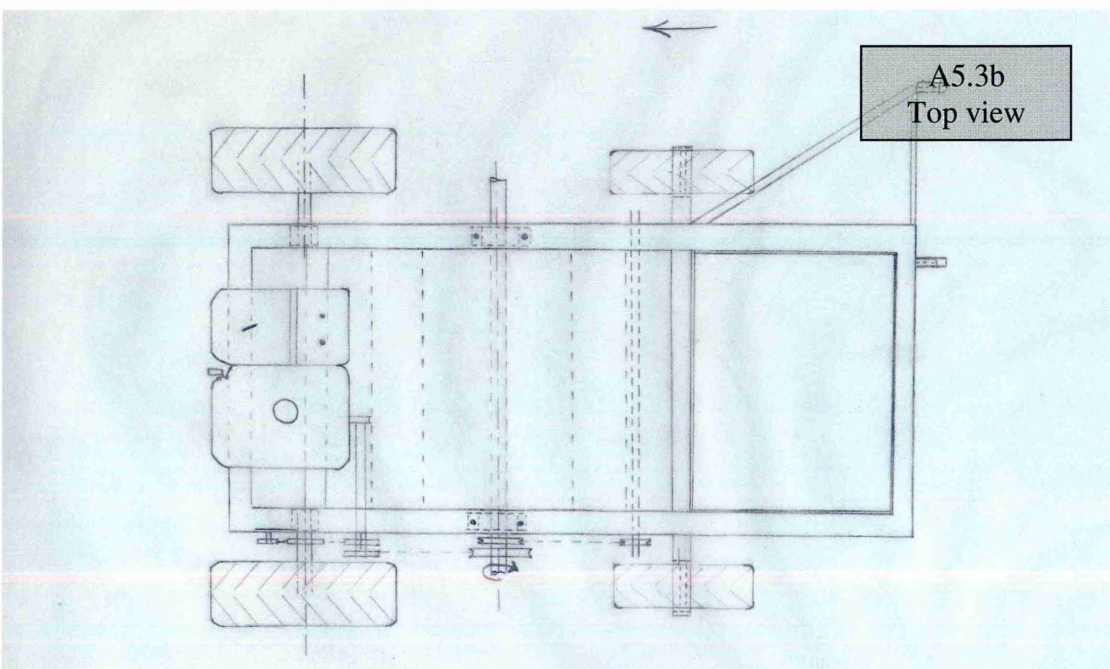


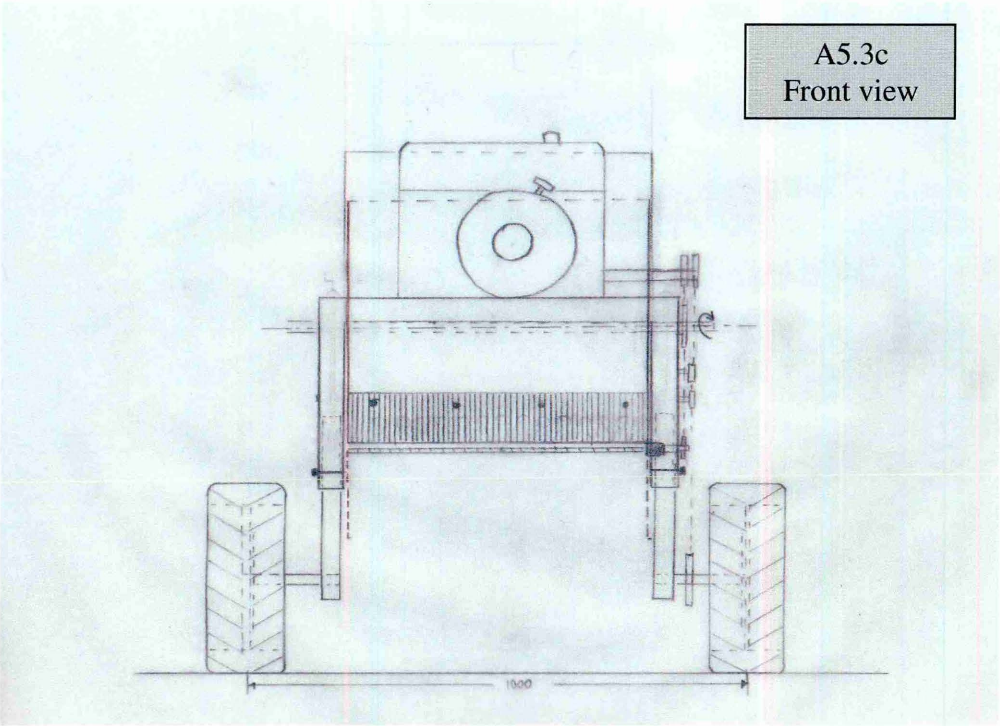


A5.2c
Front view

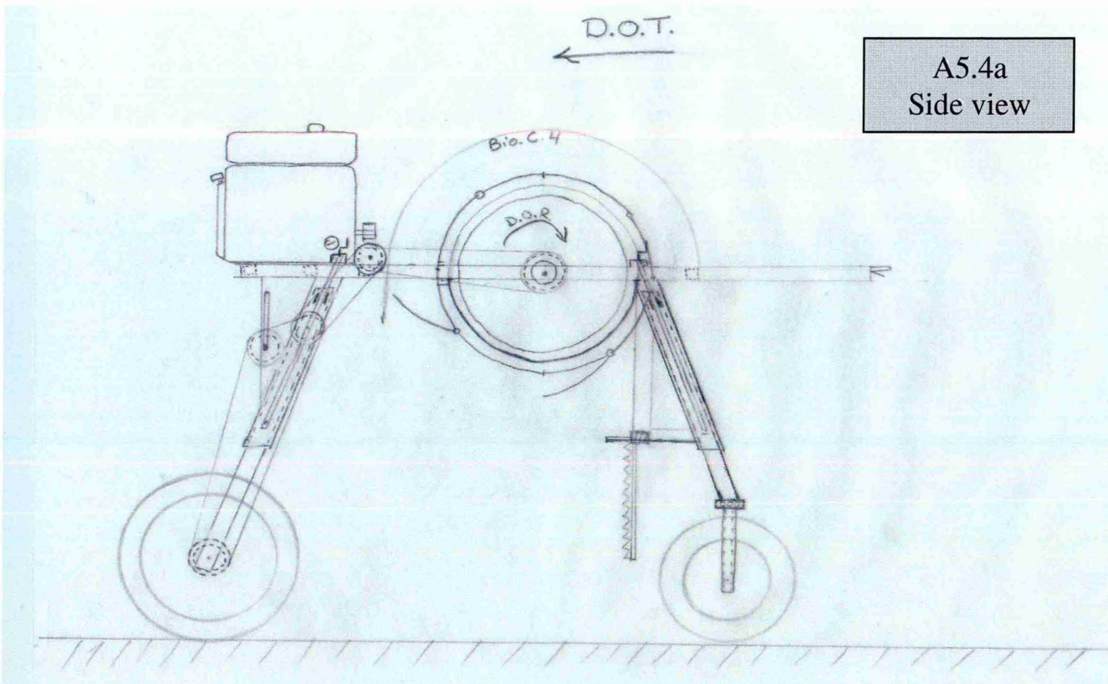
Appendix Figure A5.3a,b,c: Conceptual layout drawing details. Concept ANDIGONH

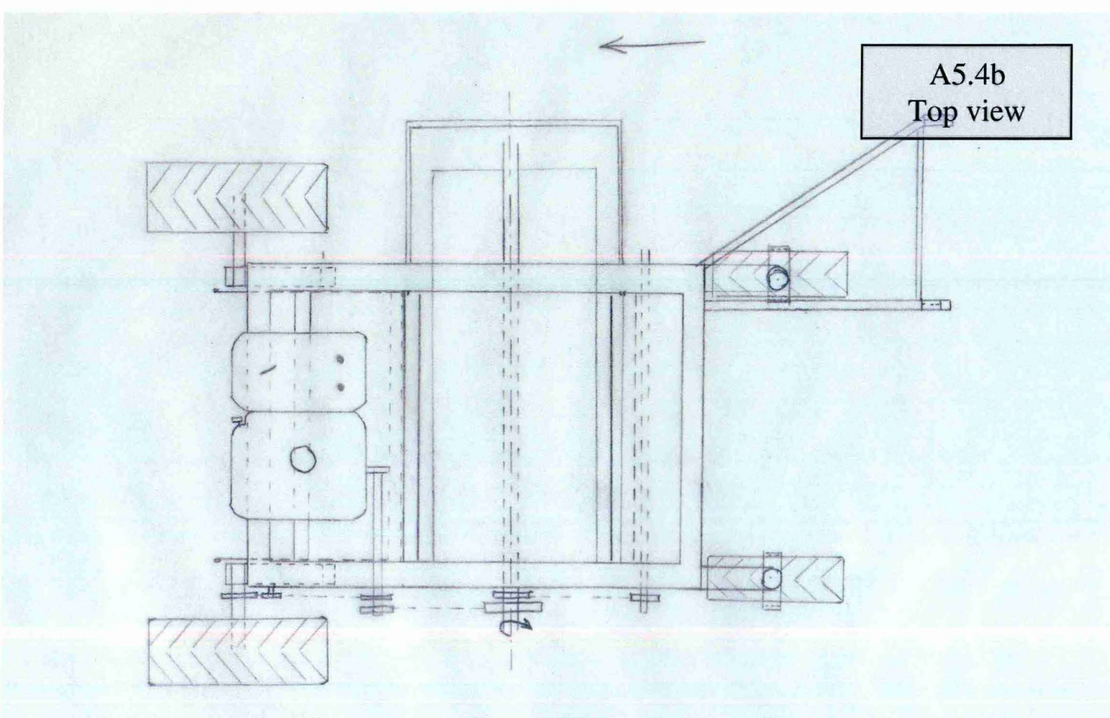


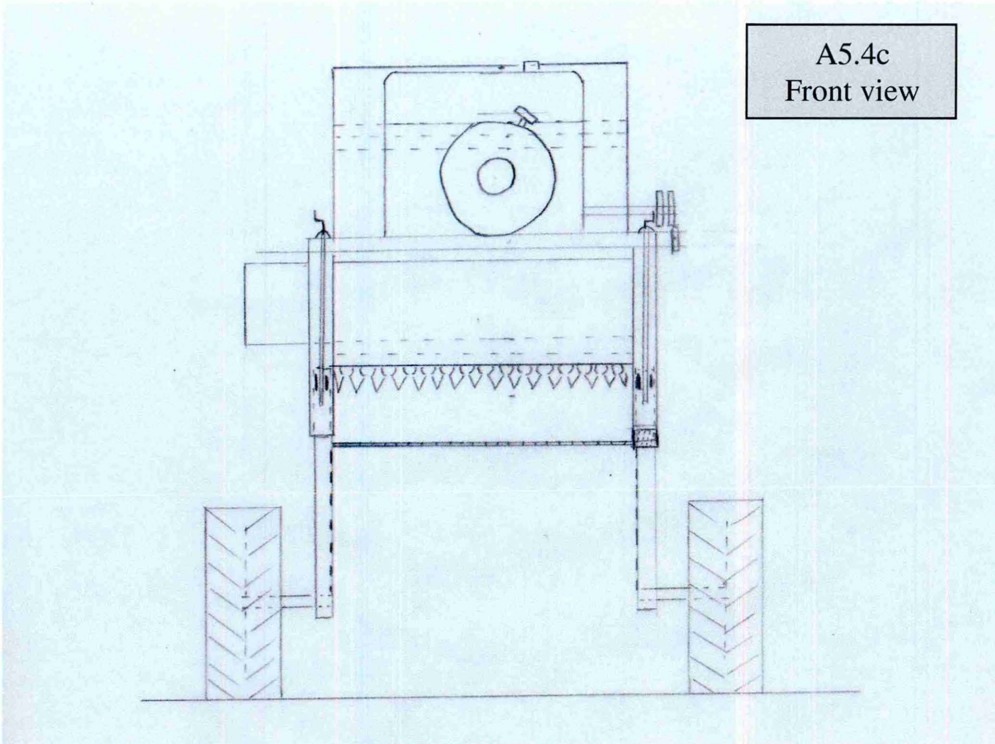



A5.3c
Front view
1000

Appendix Figure A5.4a,b,c: Conceptual layout drawing details. Concept ARETHOUSA







Appendix 5.2: ***Detail design Drawings***

Project 720

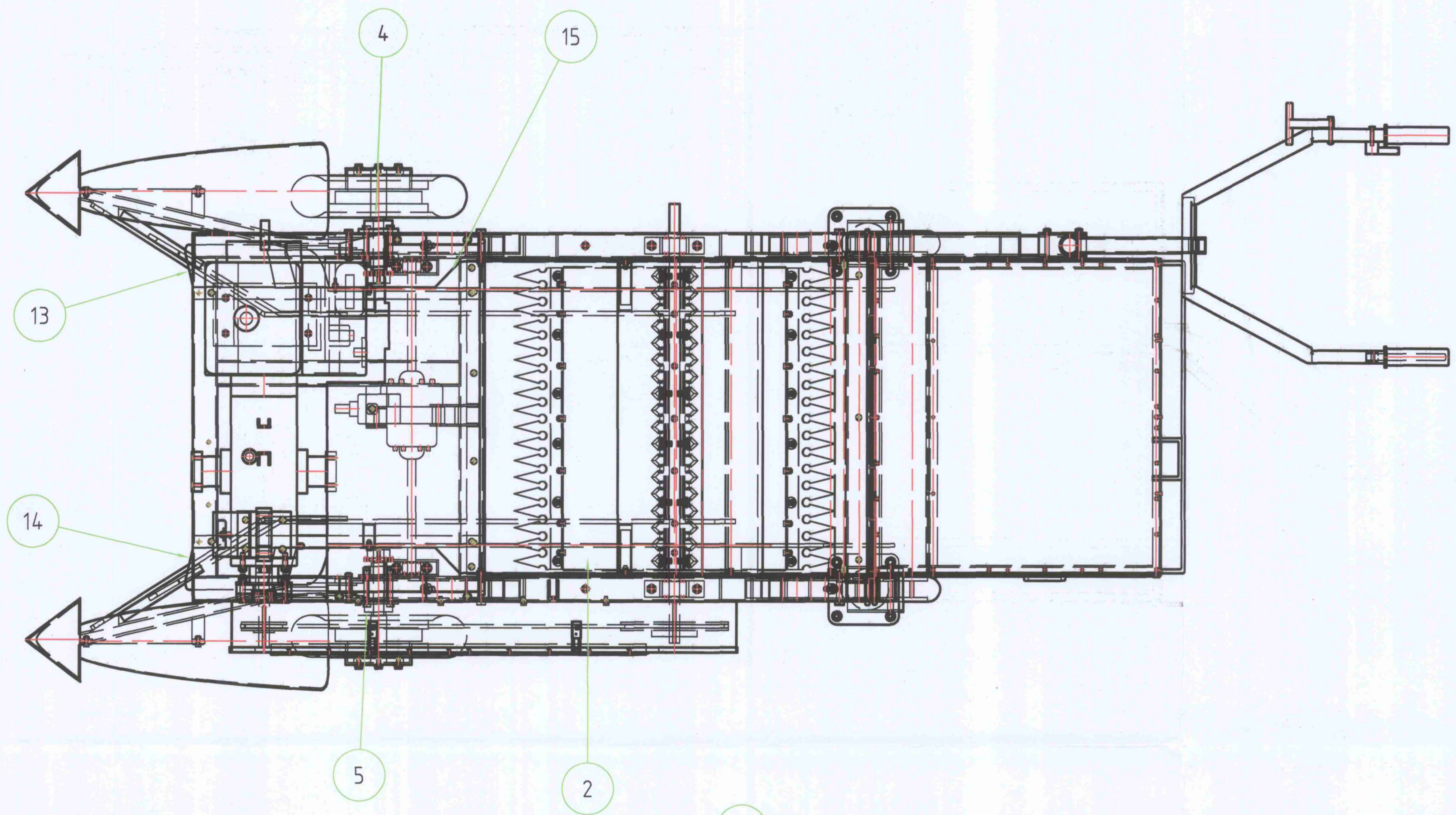
Drawing Number Allocation:

Drawing Number	Description	Number	Comment
720000A01	Lavender Harvester Master Assembly	1	
720001A01	Rotor Assembly	1	
720002A01	Container Assembly	1	
720003A01	Front right Leg Assembly	1	
720004A01	Front left Leg Assembly	1	
720005A01	Rear Leg Assembly	2	
720006A01	P.T.O shaft Assembly	1	
720007A01	Violin guard Assembly	1	
Rotor Assembly			
720100P01	Drum	1	
720101P01	Rotor shaft	1	
720102P01	Angle bracket	4	
720103P01	Stripping element	4	
720104P01	Bearing PNP 25 CR (RS cat* N° 232-8625)	2	
720105P01	Shaft Key 8 x 8 x 40 mild steel	1	
720106P01	Bolt M 1.5 x 8 x 30- M 1.5 x 8 x 12 nut	44	
Container Assembly			
720200P01	Container frame	1	
720201P01	Bottom cover	1	
720202P01	Side drawer	1	
720203P01	Side cover	1	
720204P01	Angle cover	1	
720205P01	Bee releaser frame	1	
720206P01	Bee releaser mesh (ø 0.5 copper)	1	
720207P01	Container mesh (ø 0.5 copper)	1	
720208P01	Pop rivet (ø 4 x 10)	≈300	
Front Leg Assembly (R.)			
720300P01	Leg insert (Front Right)	1	
720301P01	Wheel drive shaft	1	
720302P01	Housing of the Wheel drive shaft	1	
720303P01	Shaft Key 8 x 8 x 20 mild steel	1	
720304P01	Bearing of the wheel shaft PSFT 25 CR (RS cat* N° 232-8710)	2	
720305P01	Bolt M 1.5 x 10 x 140- M 1.5 x 10 x 15 nut	2	
720306P01	Pin bolt ø 14 x 70 mild steel	1	
Front Leg Assembly(L.)			
720400P01	Leg insert (Front Left)	1	
720401P01	Wheel drive shaft	1	
720402P01	Housing of the Wheel drive shaft	1	
720403P01	Shaft Key 8 x 8 x 20 mild steel	1	
720404P01	Bearing of the wheel shaft (RS cat* N° 232-8710)	2	
720405P01	Bolt M 1.5 x 10 x140- M 1.5 x 10 x 15 nut	2	
720406P01	Pin bolt ø 14 x 70 mild steel	1	
Rear Leg Assembly			
720500P01	Leg insert	2	
720501P01	Custer wheel 100 mm diameter (RS cat* N° 393-661)	2	
720502P01	Bolt M 1.5 x 12 x 30 -M 1.5 x 12 x 20 nut	8	
720503P01	Pin bolt ø 14 x 70 mild steel	2	

P.T.O shaft Assembly			
720600P01	P.T.O shaft	1	
720601P01	P.T.O housing	1	
720602P01	P.T.O ring	1	
720603P01	P.T.O shaft key 8 x 8 x 30 mild steel	1	
720604P01	Bolt M 1.5 x 12 x 40 -M 1.5 x 12 x 20 nut	2	
Violin guard Assembly			
720700P01	Case	1	
720701P01	Cover	1	
720702P01	Hintch	1	
720703P01	Catcher (RS cat* N° 687-051)	2	
720704P01	Bolt M 1.5 x 4 x 10 -M 1.5 x 4 x 5 nut	18	
Parts			
720800P01	Frame	1	
720801P01	Hood cover	1	
720802P01	Hood nose	1	
720803P01	Under cover	1	
720804P01	Side internal (Right)	1	
720805P01	Side internal (Left)	1	
720806P01	Side internal extension (Right)	1	
720807P01	Side internal extension (Left)	1	
720808P01	Lateral guide (Right)	1	
720809P01	Lateral guide (Left)	1	
720810P01	Divider (Right) (Second hand from TX series New Holland combine)	1	
720811P01	Divider (Left) (from TX series New Holland combine)	1	
720812P01	Engine (petrol 7 kW Honda) & gear box (small cultivator)	1	
720813P01	Differential (from quote bike 4WD Suzuki 500 front differential)	1	
720814P01	Steering handle (from small cultivator)	1	
720815P01	Gear box sprocket 38 teeth (RS cat* N° 678-524)	1	
720816P01	Differential sprocket 11 teeth	1	
720817P01	Differential drive shaft taper bush sprocket 23 teeth (RS cat* N° 678-192)	2	
720818P01	Shaft sprocket 23 teeth	2	
720819P01	P.T.O Pulley	1	
720820P01	Rotor Pulley	1	
720821P01	Chain 08B1 (RS cat* N° 329-4135)	5 m	
720822P01	Pneumatic wheel 240 mm diameter (from small cultivator)	2	
720823P01	Differential guard	1	

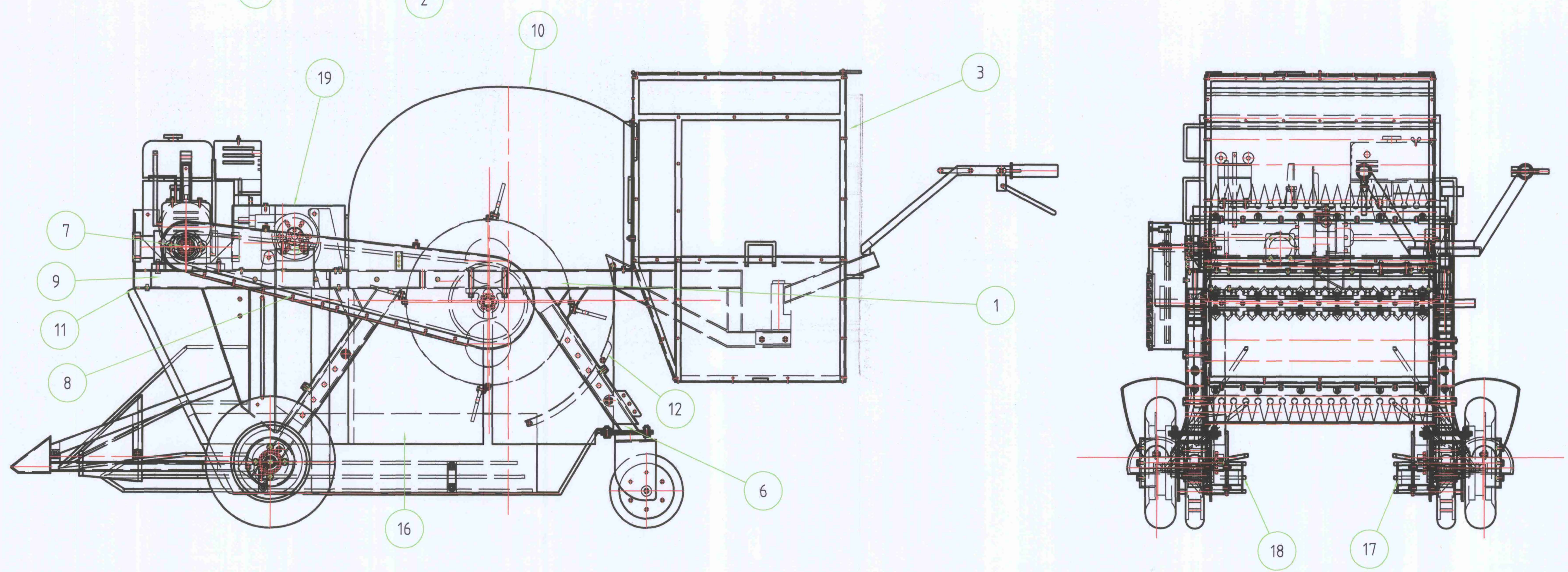
*RS catalogue: 5. Mechanical 2000-2001

PART No.	720000A01	
ISSUE	CHANGE RECORD DATE+AUTHY	
1	PRODUCTION REL.	CD01



ITEM	DESCRIPTION	PART#	QTY
19	DIFFERENTIAL GUARD PART	720823P01	1
18	LEFT LATERAL GUIDE PART	720809P01	1
17	RIGHT LATERAL GUIDE PART	720808P01	1
16	LEFT SIDE INTERNAL EXTENT.PART	720807P01	1
15	RIGHT SIDE INTERNAL EXTENT.PART	720806P01	1
14	LEFT SIDE INTERNAL PART	720805P01	1
13	RIGHT SIDE INTERNAL PART	720804P01	1
12	UNDER COVER PART	720803P01	1
11	HOOD NOSE PART	720802P02	1
10	HOOD COVER PART	720801P01	1
9	FRAME PART	720800P01	1
8	VIOLIN GUARD ASSEMBLY	720001A01	1
7	P.T.O ASSEMBLY	720006A01	1
6	REAR LEG ASSEMBLY	720005A01	2
5	FRONT LEFT LEG ASSEMBLY	720004A01	1
4	FRONT RIGHT LEG ASSEMBLY	720003A01	1
3	CONTAINER ASSEMBLY	720002A01	1
2	ROTOR ASSEMBLY	720001A01	1
1	LAVENDER HARVESTER ASSEMBLY	720000A01	

NOTES:



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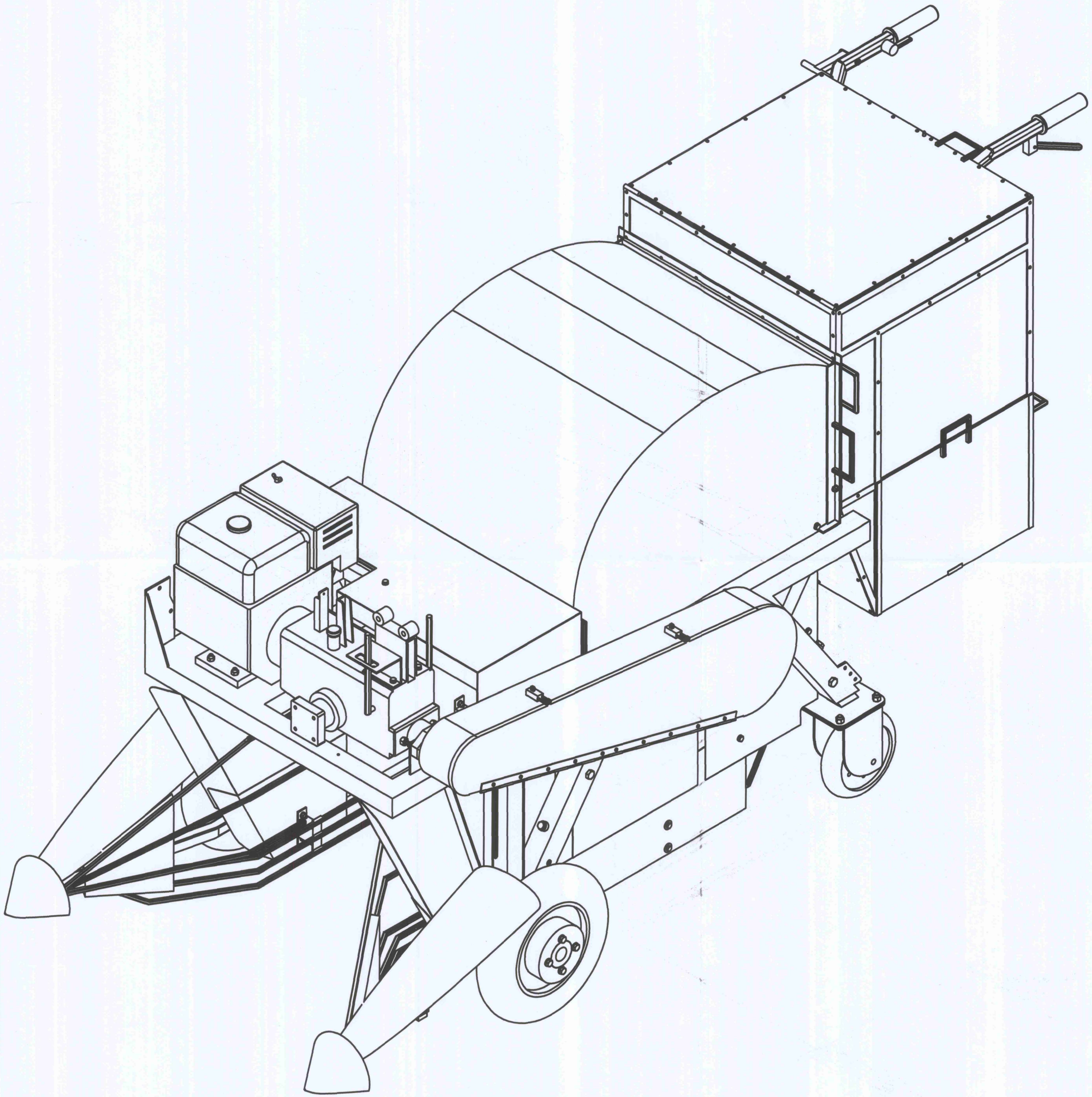
DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE SPECIFIED

THIRD ANGLE PROJECTION

TOLERANCES ON DIMENSIONS UNLESS OTHERWISE SPECIFIED

NOMINAL SIZE OF DIMENSION	0-120	120-315	315-1000	1000+
0 or 1 DECIMAL PLACE	+-0.5	+-1	+-1.5	+-3.0
2 DECIMAL PLACES	+/- 0.25			
ANGULAR TOLERANCE	+/- 0' 30'			

DRAWN BY: *CHRISTOS I.DIMITRIADIS* TEL.Ex. DATE:	TITLE *LAVENDER HARVESTER MASTER ASSEMBLY*
CHECKED BY: DATE: DO NOT SCALE	PART No. SHT. *1* OF. *2* *720000A01*



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1	PRODUCTION REL.	CD01

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NOMINAL SIZE OF DIMENSION	0-120	120-315	315-1000	1000+
0 or 1 DECIMAL PLACE	+-0.5	+-1	+-1.5	+-3.0
2 DECIMAL PLACES	+/- 0.25			
ANGULAR TOLERANCE	+/- 0' 30'			

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TITLE: LAVENDER HARVESTER MASTER ASSEMBLY

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DATE:

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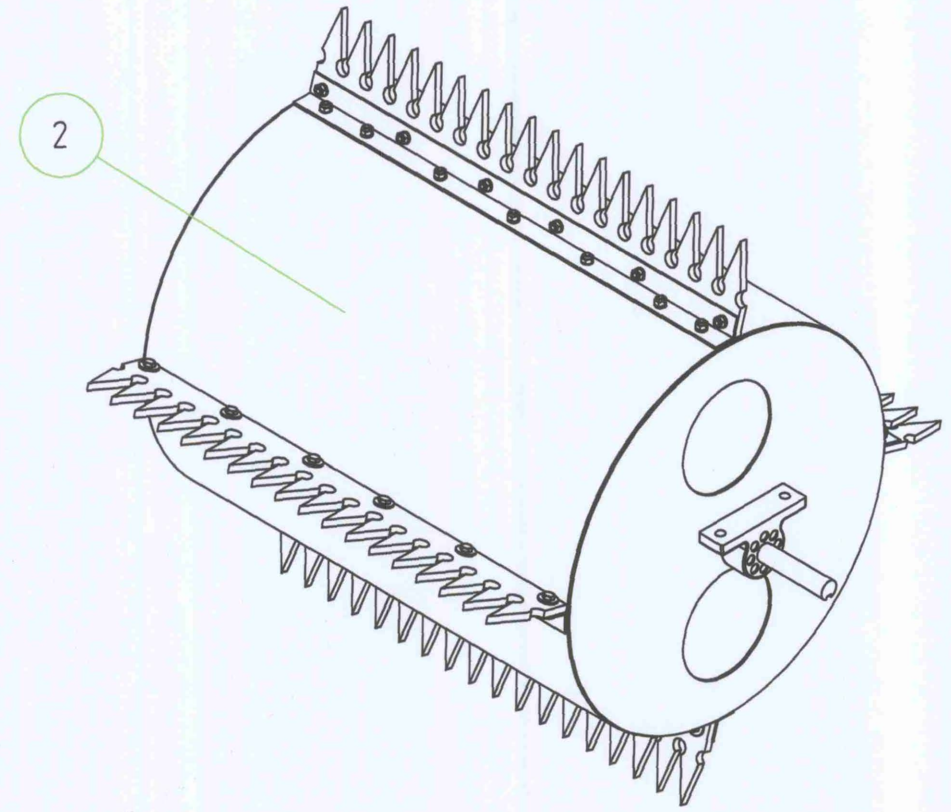
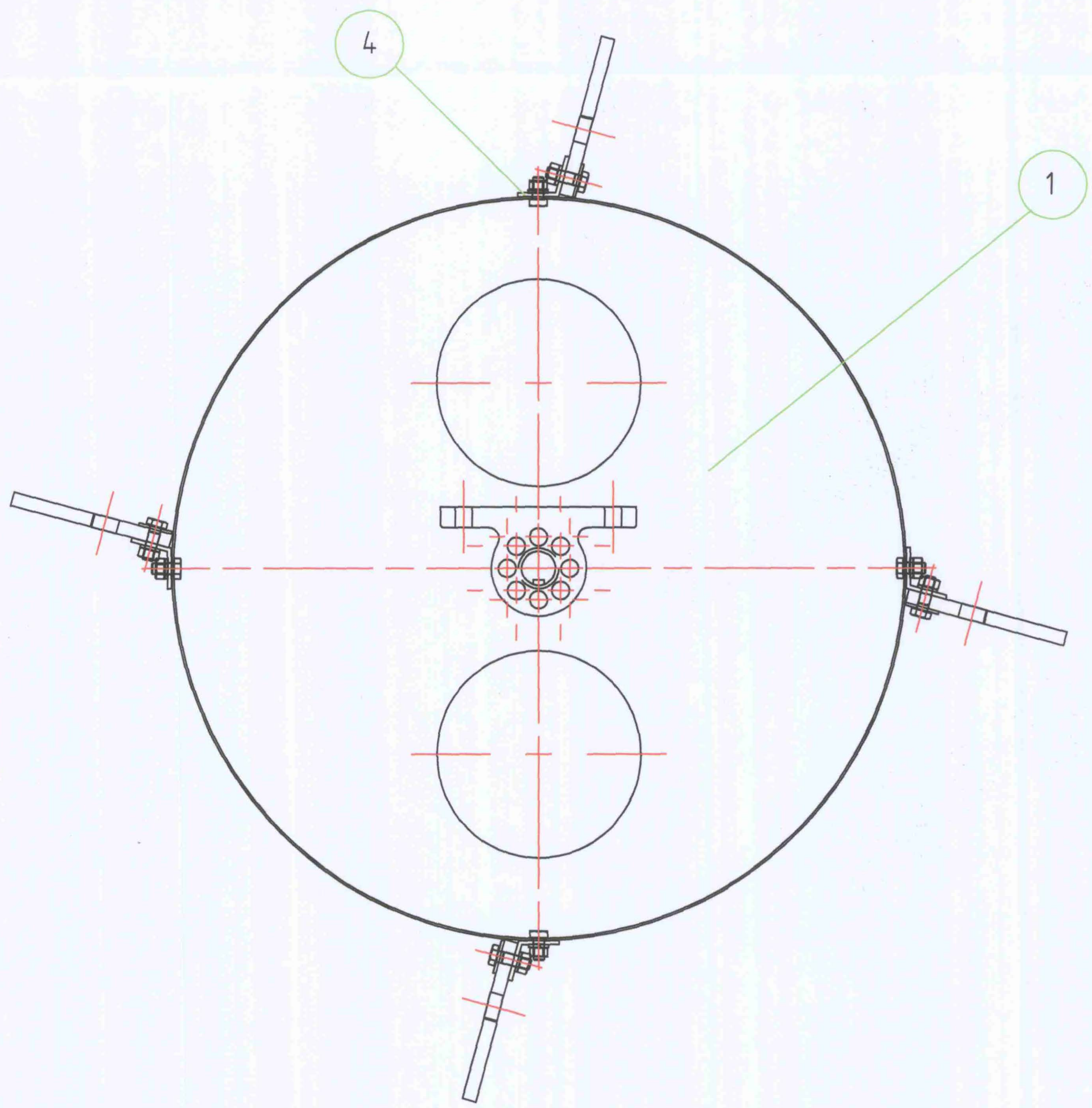
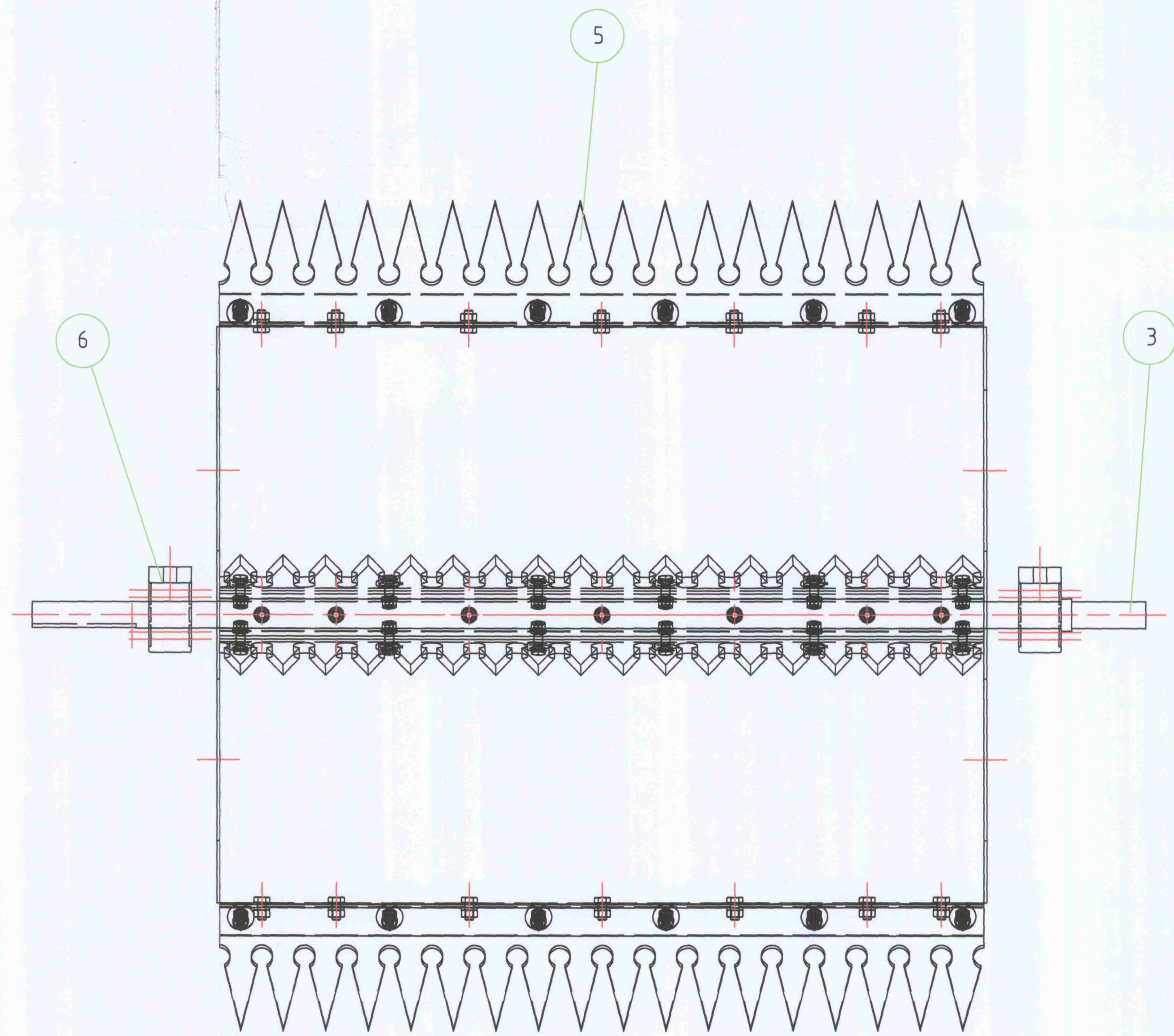
PART No.	720001A01	
ISSUE	CHANGE RECORD DATE+AUTHY	
1	PRODUCTION REL.	CD01

NOTES:

6	BEARING	720104P01	2
5	STRIPPING ELEMENT	720103P01	4
4	ANGLE BRACKET	720102P01	4
3	ROTOR SHAFT	720101P01	1
2	DRUM	720100P01	1
1	ROTOR ASSEMBLY	720001A01	
ITEM	DESCRIPTION	PART#	QTY







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TOLERANCES ON DIMENSIONS UNLESS OTHERWISE SPECIFIED

NOMINAL SIZE OF DIMENSION	0-120	120-315	315-1000	1000+
0 or 1 DECIMAL PLACE	+-0.5	+-1	+-1.5	+-3.0
2 DECIMAL PLACES	+/- 0.25			
ANGULAR TOLERANCE	+/- 0' 30'			

DRAWN BY:
CHRISTOS I.DIMITRIADIS
TEL.Ex.
DATE:

TITLE
LAVENDER HARVESTER
ROTOR ASSEMBLY

CHECKED BY:
DATE:

PART No. 720001A01
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PART No. 720002A01

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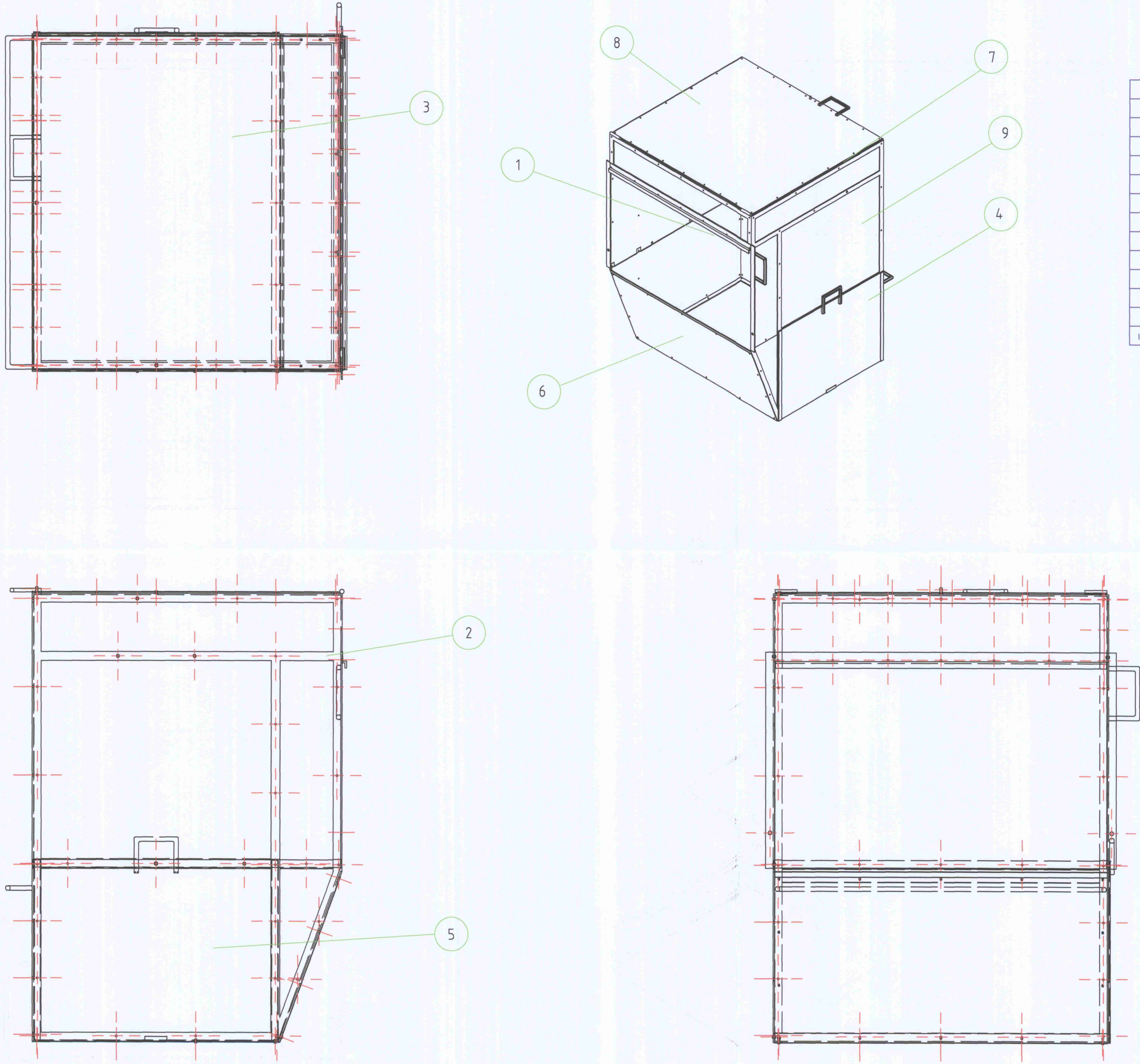
1	PRODUCTION REL.		CD01

NOTES:



ITEM	DESCRIPTION	PART#	QTY
9	CONTAINER MESH	720207P01	1
8	BEE RELEASER MESH	720206P01	1
7	BEE RELEASER FRAME	720205P01	1
6	ANGLE COVER	720204P01	1
5	SIDE COVER	720203P01	1
4	SIDE DRAWER	720202P01	1
3	BOTTOM COVER	720201P01	1
2	CONTAINER FRAME	720200P01	1
1	CONTAINER ASSEMBLY	720002A01	

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TOLERANCES ON DIMENSIONS UNLESS OTHERWISE SPECIFIED

NOMINAL SIZE OF DIMENSION	0-120	120-315	315-1000	1000+
0 or 1 DECIMAL PLACE	+-0.5	+-1	+-1.5	+-3.0
2 DECIMAL PLACES	+/- 0.25			
ANGULAR TOLERANCE	+/- 0' 30'			

DRAWN BY: CHRISTOS I.DIMITRIADIS
TEL.Ex.
DATE:

TITLE: LAVENDER HARVESTER CONTAINER ASSEMBLY

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DATE:

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PART No. 720002A01 SHT. OF.

PART No.	720003A01	
ISSUE	CHANGE RECORD DATE+AUTHY	
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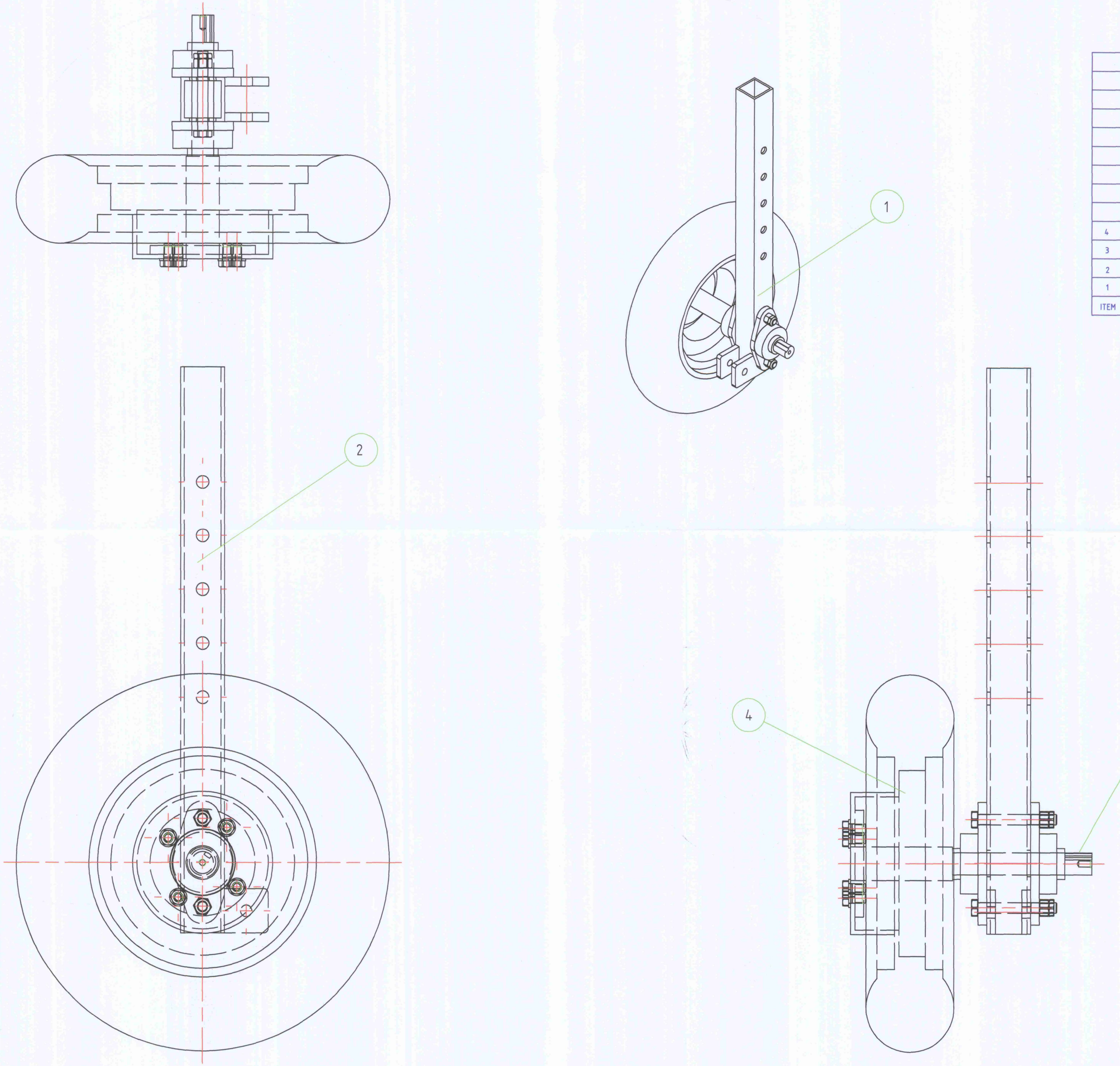
NOTES:



4	HOUSING OF THE DRIVE SHAFT	720302P01	1
3	WHEEL DRIVE SHAFT	720301P01	1
2	LEG INSERT	720300P01	1
1	FRONT RIGHT LEG ASSEMBLY	720003A01	
ITEM	DESCRIPTION	PART#	QTY

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THIRD ANGLE PROJECTION

TOLERANCES ON DIMENSIONS UNLESS OTHERWISE SPECIFIED

NOMINAL SIZE OF DIMENSION	0-120	120-315	315-1000	1000+
0 or 1 DECIMAL PLACE	+-0.5	+-1	+-1.5	+-3.0
2 DECIMAL PLACES	+/- 0.25			
ANGULAR TOLERANCE	+/- 0' 30'			

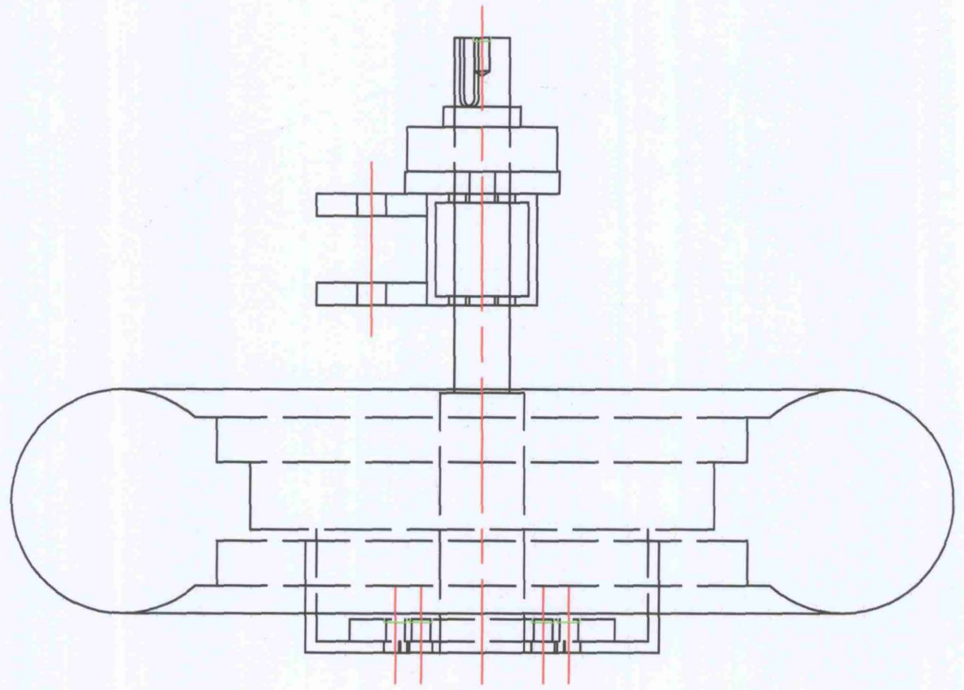
DRAWN BY: CHRISTOS I.DIMITRIADIS
TEL.Ex.
DATE:

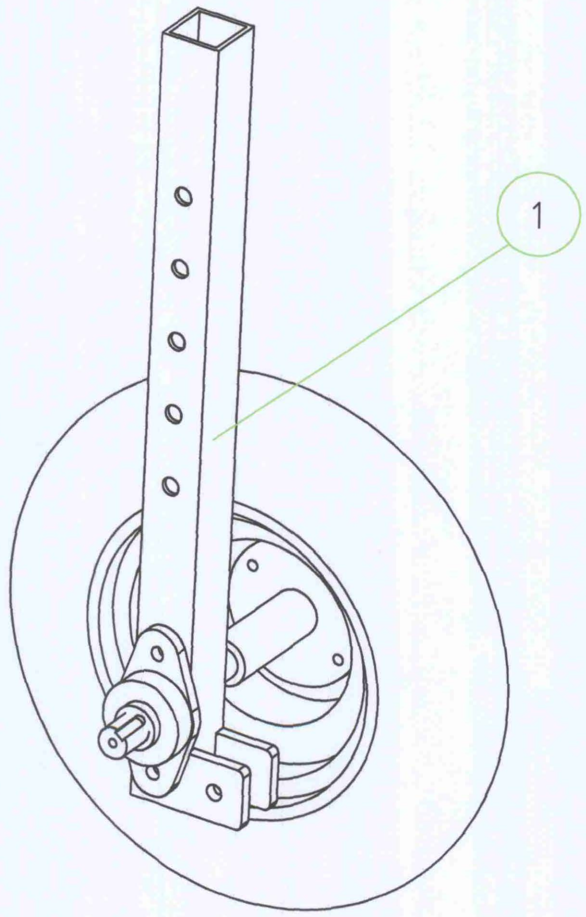
TITLE
LAVENDER HARVESTER
FRONT RIGHT LEG ASSEMBLY

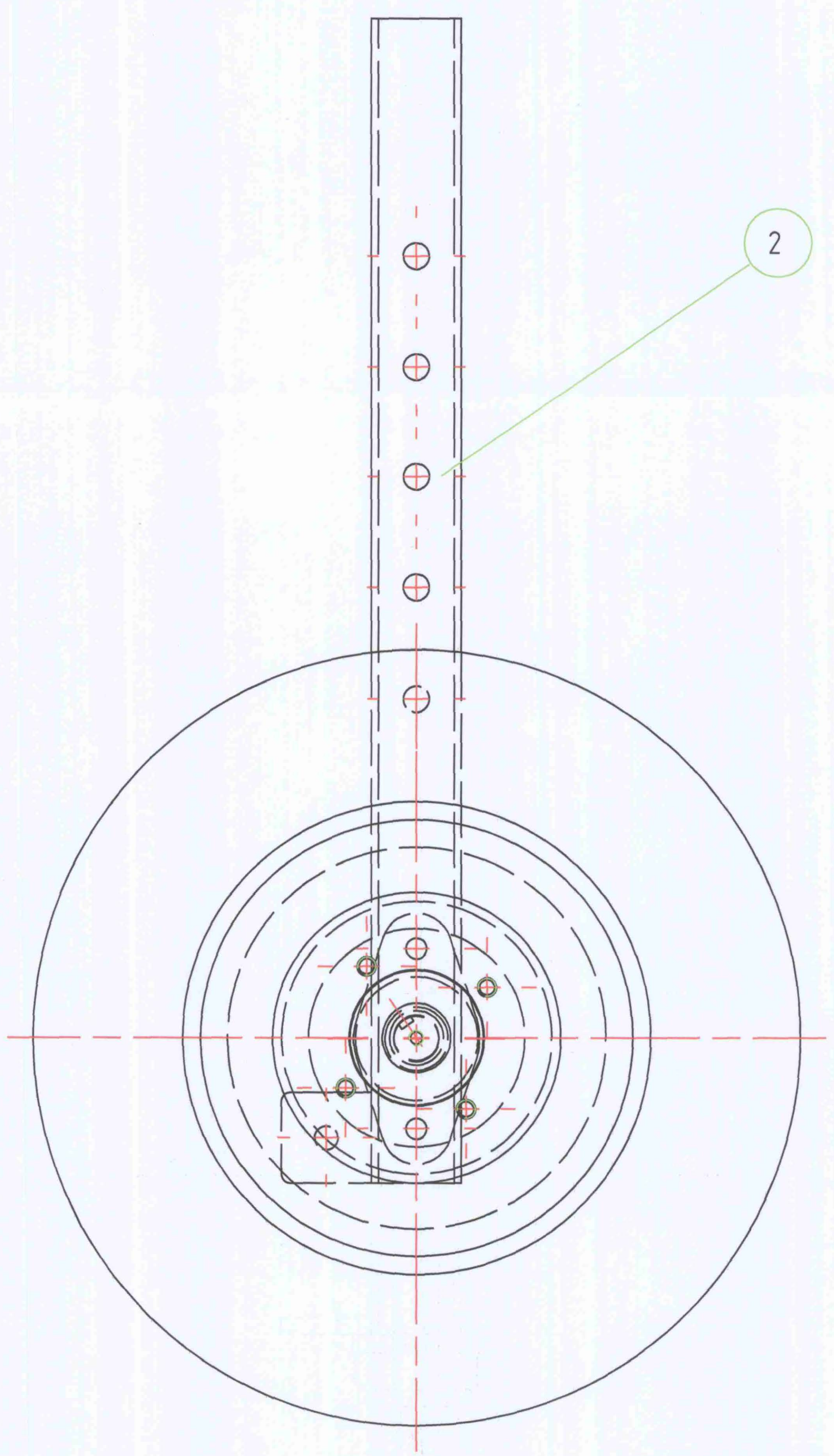
CHECKED BY:
DATE:

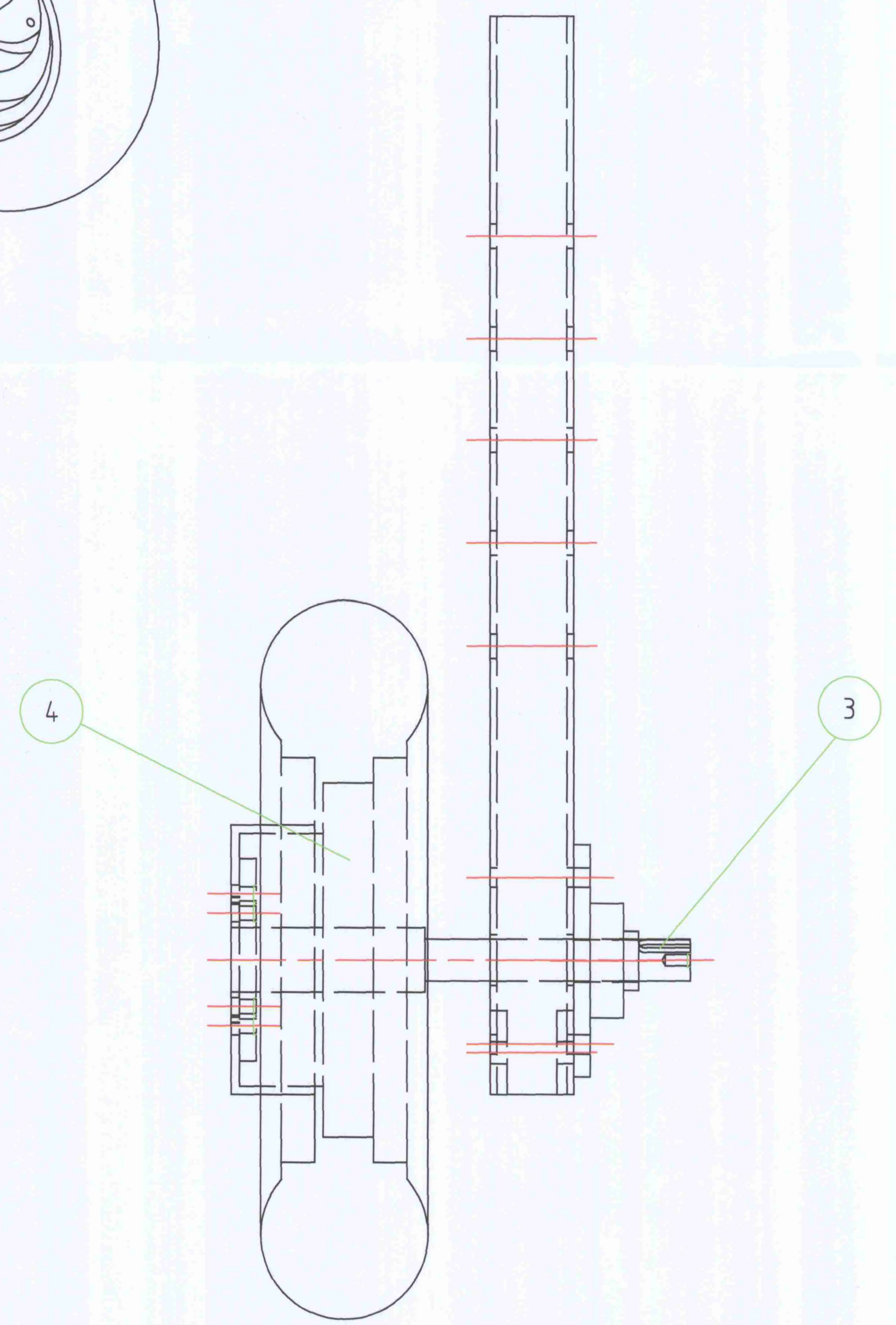
PART No. 720003A01 SHT. OF.

DO NOT SCALE









ITEM	DESCRIPTION	PART#	QTY
4	HOUSING OF THE DRIVE SHAFT	720402P01	1
3	WHEEL DRIVE SHAFT	720401P01	1
2	LEG INSERT	720400P01	1
1	FRONT LEF LEG ASSEMBLY	720004A01	

PART No. 720004A01

ISSUE	CHANGE RECORD	DATE+AUTHY	
1	PRODUCTION REL.		CD01

NOTES:

Cranfield UNIVERSITY Silsoe

SILSOE CAMPUS DESIGN OFFICE
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BEDFORDSHIRE, MK45 4DT,
UNITED KINGDOM.

TEL +44 (0) 1525 863000
FAX +44 (0) 1525 863001

MATERIAL AS SUPPLIED

No.off 1

FINISH AS SUPPLIED

DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE SPECIFIED

THIRD ANGLE PROJECTION

TOLERANCES ON DIMENSIONS UNLESS OTHERWISE SPECIFIED

NOMINAL SIZE OF DIMENSION	0-120	120-315	315-1000	1000+
0 or 1 DECIMAL PLACE	+-0.5	+-1	+-1.5	+-3.0
2 DECIMAL PLACES	+/- 0.25			
ANGULAR TOLERANCE	+/- 0' 30'			

DRAWN BY: CHRISTOS I.DIMITRIADIS
TEL.Ex.
DATE:

TITLE LAVENDER HARVESTER
FRONT LEFT LEG ASSEMBLY

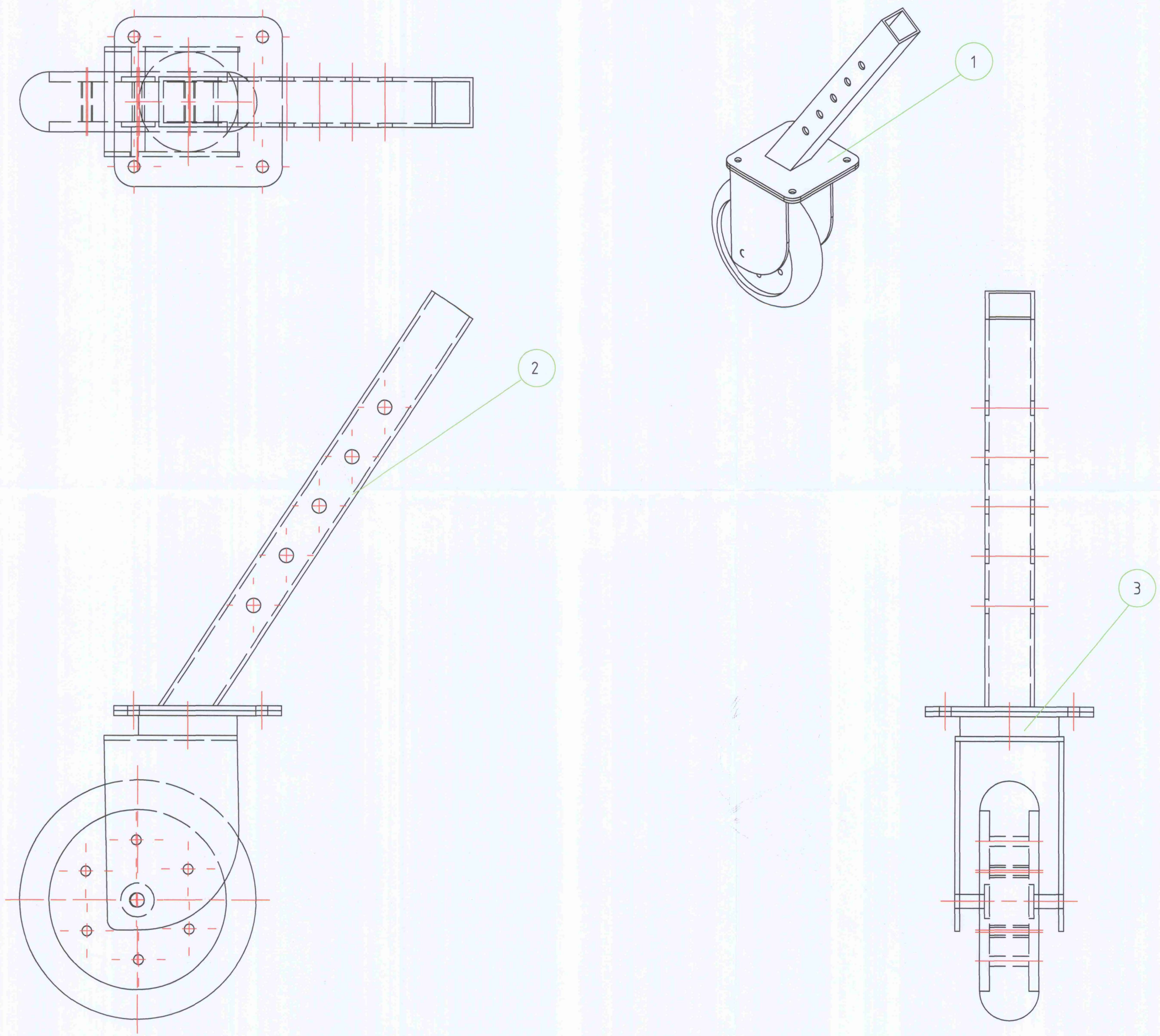
CHECKED BY:
DATE:

PART No. 720004A01 SHT. OF.

DO NOT SCALE

PART No. 720005A01

ISSUE	CHANGE RECORD	DATE+AUTHY
1	PRODUCTION REL.	CD01



ITEM	DESCRIPTION	PART#	QTY
3	CUSTER WHEEL	720501P01	1
2	LEG INSERT	720500P01	1
1	REAR LEG ASSEMBLY	720005A01	

NOTES:

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FAX +44 (0) 1525 863001

MATERIAL: *AS SUPPLIED*

FINISH: *AS SUPPLIED*

No.off: 1

DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE SPECIFIED

THIRD ANGLE PROJECTION

TOLERANCES ON DIMENSIONS UNLESS OTHERWISE SPECIFIED

NOMINAL SIZE OF DIMENSION	0-120	120-315	315-1000	1000+
0 or 1 DECIMAL PLACE	+-0.5	+-1	+-1.5	+-3.0
2 DECIMAL PLACES	+/- 0.25			
ANGULAR TOLERANCE	+/- 0' 30'			

DRAWN BY: *CHRISTOS I.DIMITRIADIS*
TEL.Ex.
DATE:

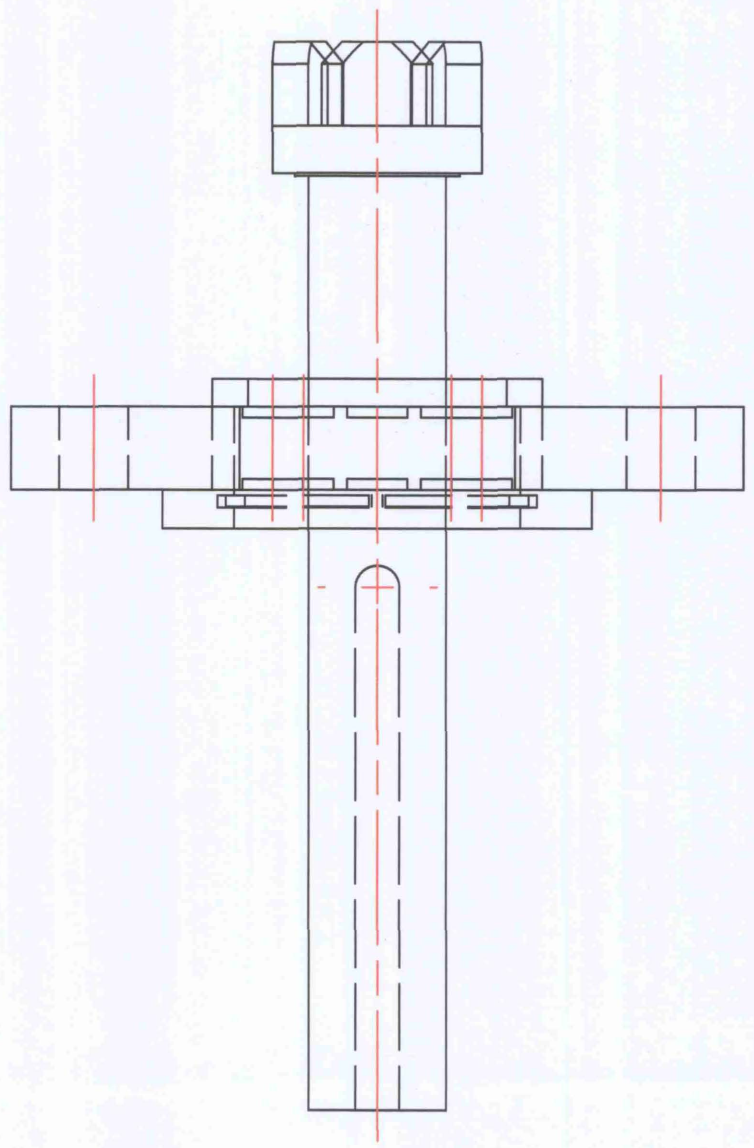
TITLE: *LAVENDER HARVESTER*
REAR LEG ASSEMBLY

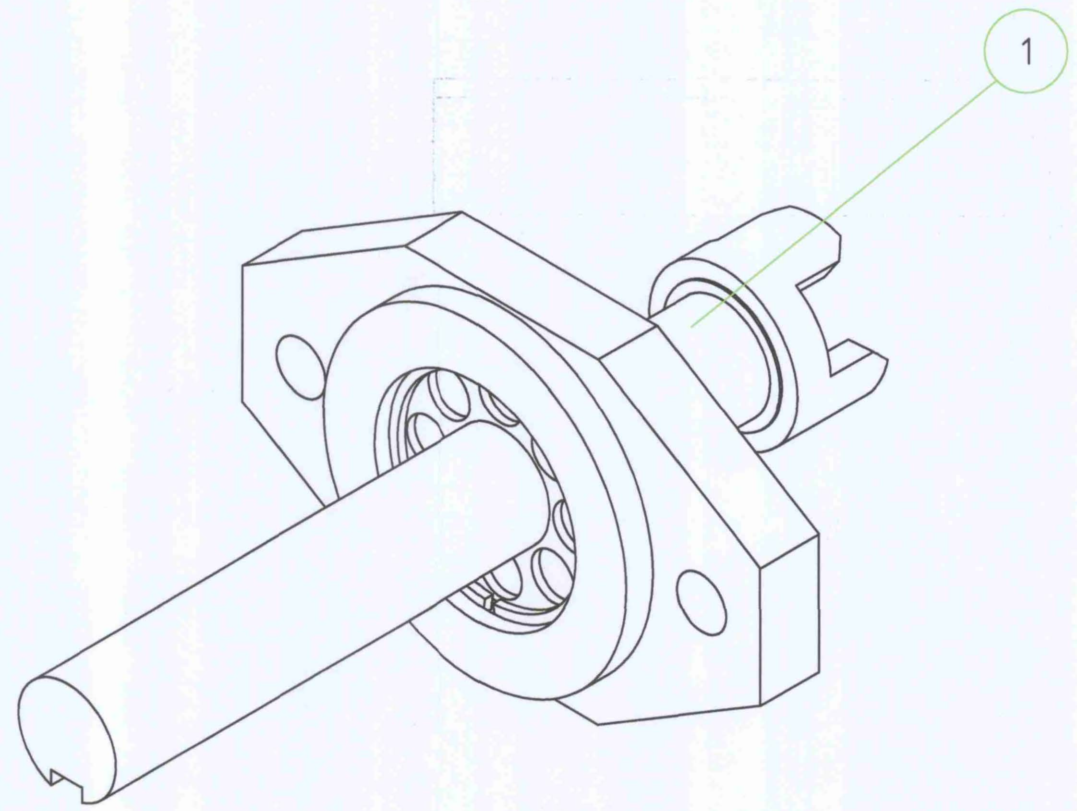
CHECKED BY:
DATE:

PART No. 720005A01 SHT. OF.

PART No. 720006A01

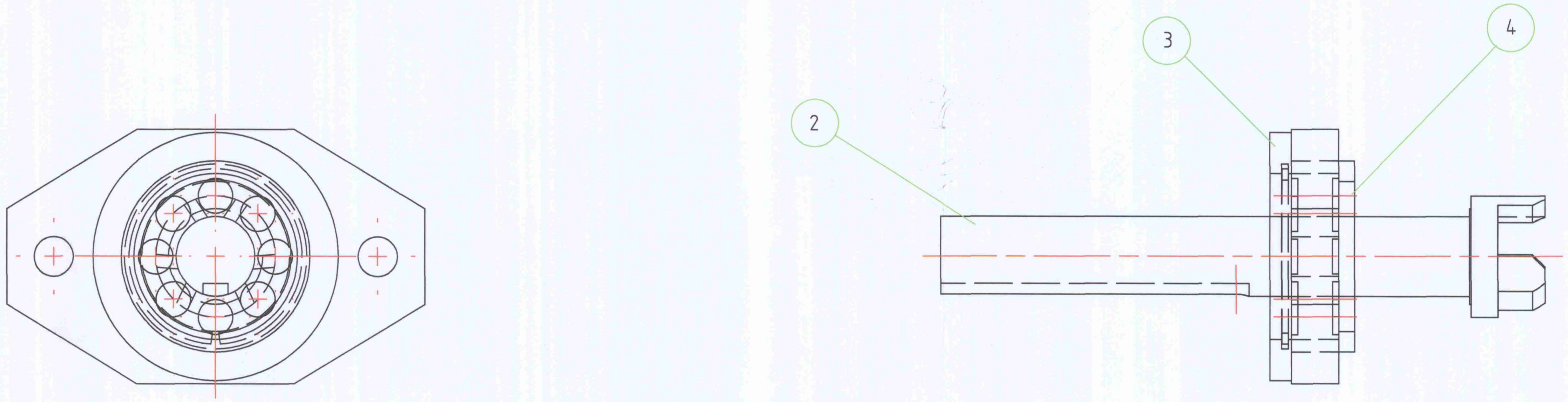
ISSUE	CHANGE RECORD	DATE+AUTHY
1	PRODUCTION REL.	CD01





ITEM	DESCRIPTION	PART#	QTY
4	P.T.O RING	720602P01	1
3	P.T.O HOUSING	720601P01	1
2	P.T.O SHAFT	720600P01	1
1	P.T.O ASSEMBLY	720006A01	

NOTES:



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FAX +44 (0) 1525 863001

MATERIAL
AS SUPPLIED

FINISH
AS SUPPLIED

No.off 1

DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE SPECIFIED

THIRD ANGLE PROJECTION

TOLERANCES ON DIMENSIONS UNLESS OTHERWISE SPECIFIED

NOMINAL SIZE OF DIMENSION	0-120	120-315	315-1000	1000+
0 or 1 DECIMAL PLACE	+-0.5	+-1	+-1.5	+-3.0
2 DECIMAL PLACES	+/- 0.25			
ANGULAR TOLERANCE	+/- 0' 30'			

DRAWN BY: CHRISTOS I.DIMITRIADIS
TEL.Ex.
DATE:

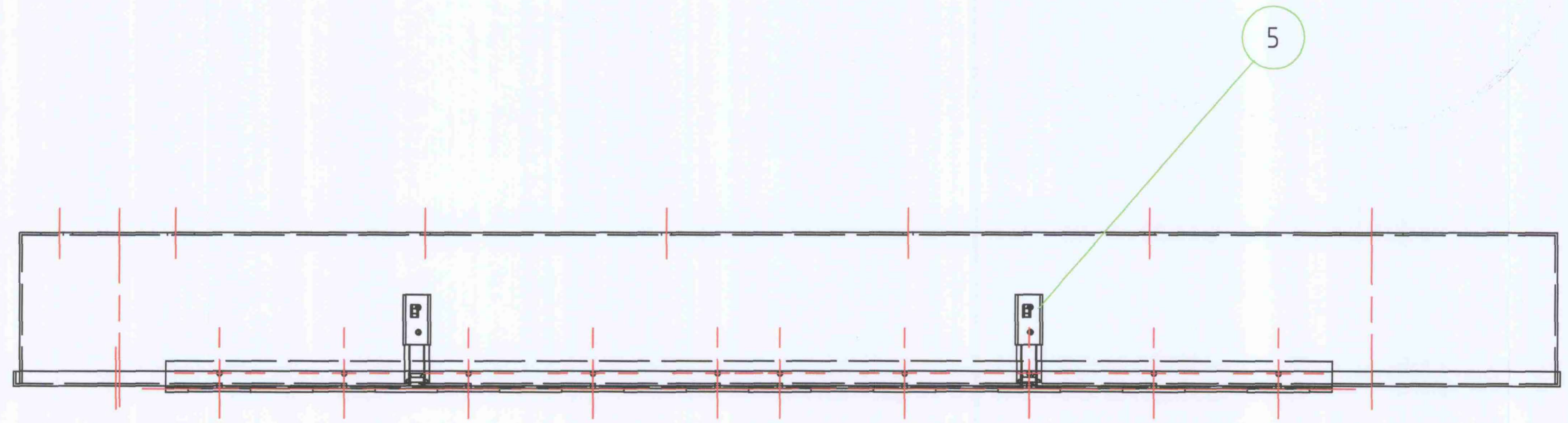
TITLE
LAVENDER HARVESTER
P.T.O SHAFT ASSEMBLY

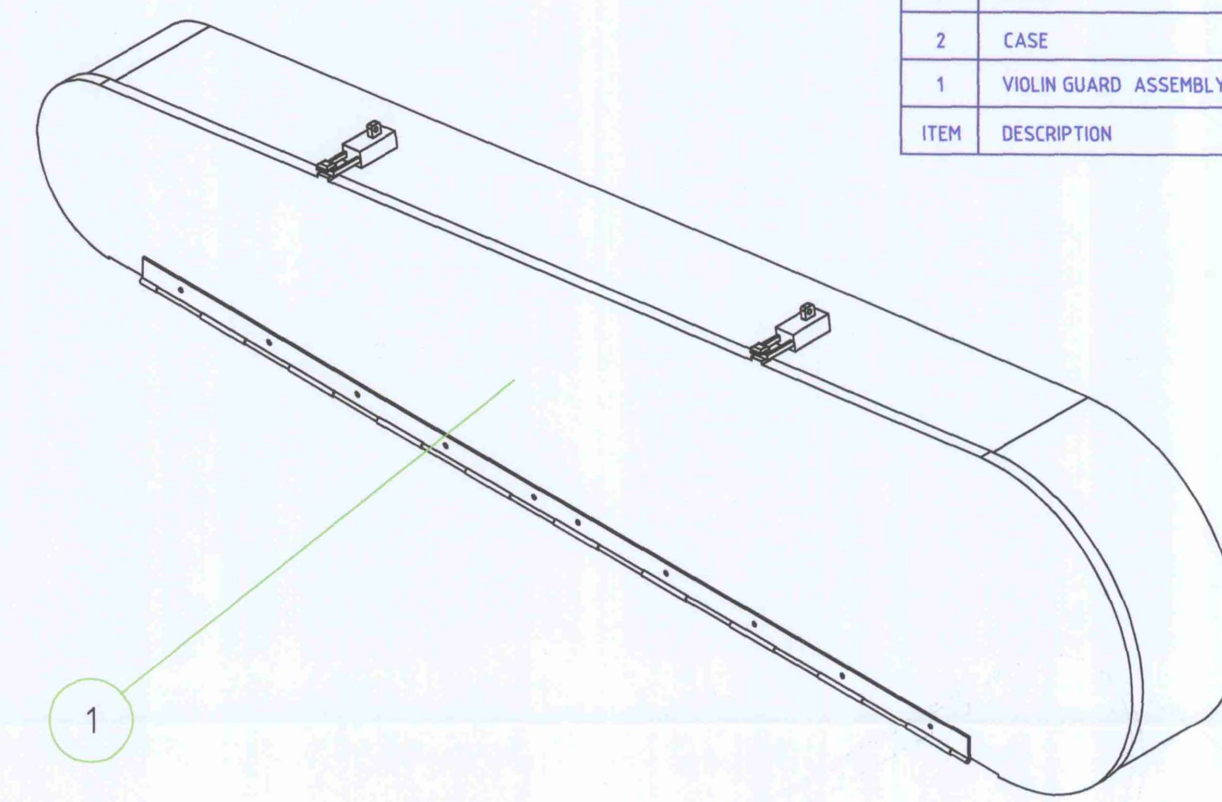
CHECKED BY:
DATE:

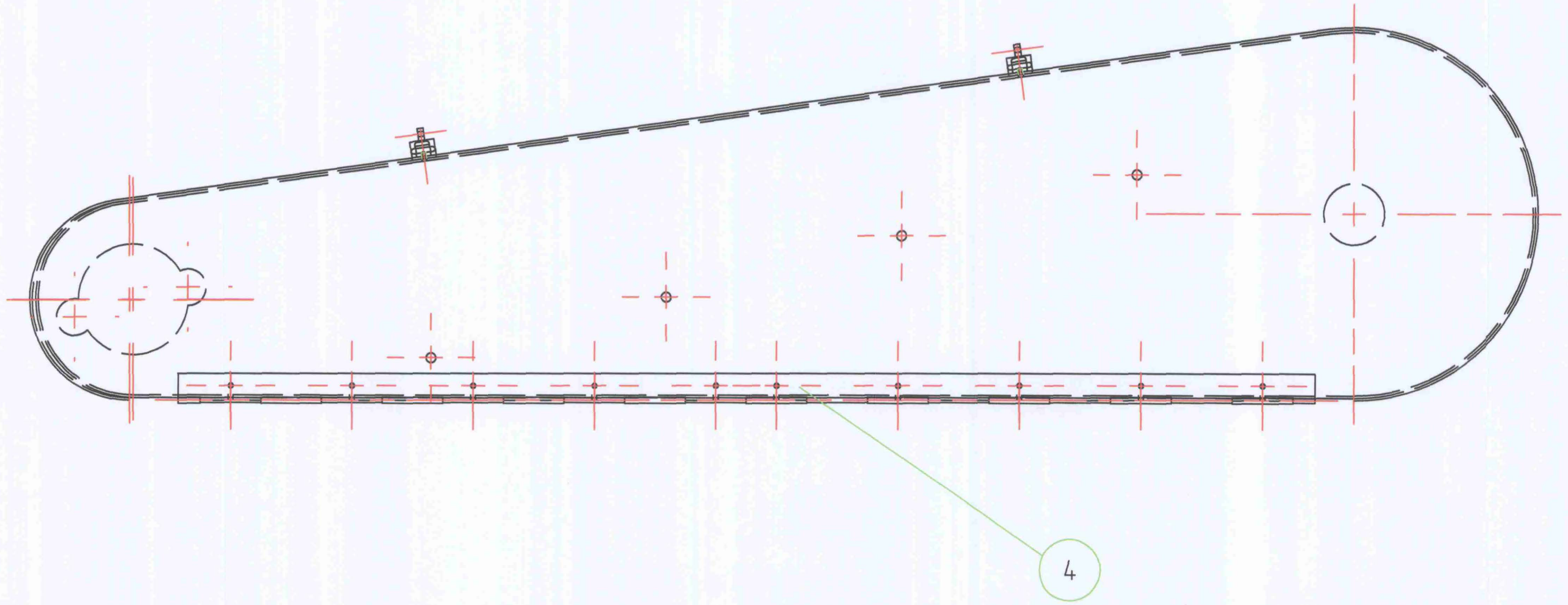
PART No. 720006A01 SHT. OF.

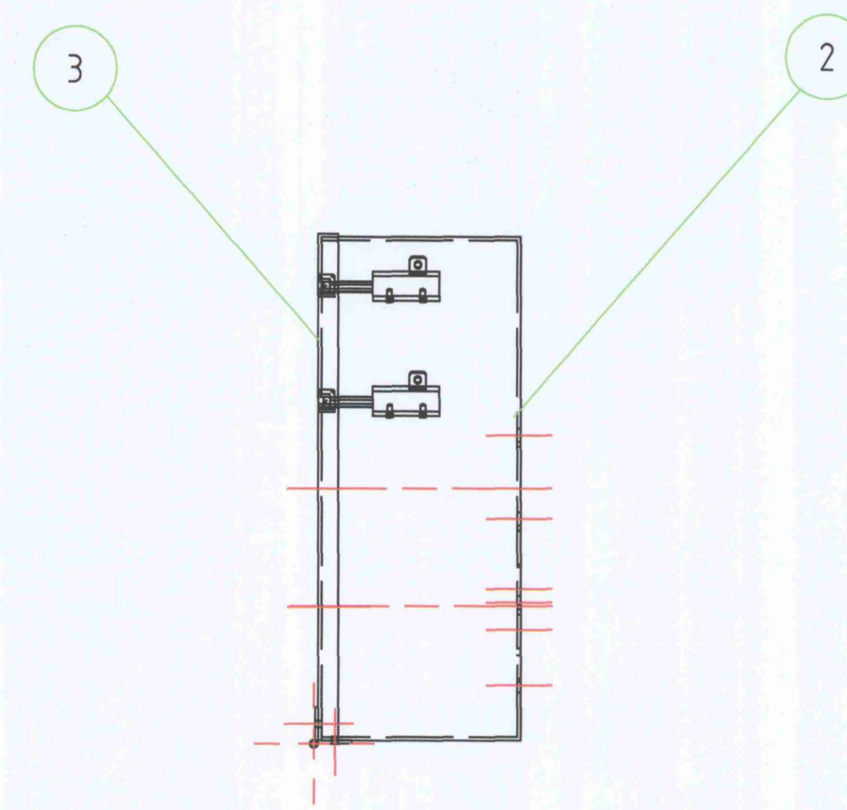
DO NOT SCALE

ITEM	DESCRIPTION	PART#	QTY
5	CATCHER	720703P01	1
4	HINTCH	720702P01	1
3	COVER	720701P01	1
2	CASE	720700P01	1
1	VIOLIN GUARD ASSEMBLY	720007A01	









PART No. 720007A01

ISSUE	CHANGE RECORD DATE+AUTHY	
1	PRODUCTION REL.	CD01

NOTES:

Cranfield UNIVERSITY Silsoe

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UNITED KINGDOM.

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FAX +44 (0) 1525 863001

MATERIAL AS SUPPLIED

No.off 1

FINISH AS SUPPLIED

DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE SPECIFIED

THIRD ANGLE PROJECTION

TOLERANCES ON DIMENSIONS UNLESS OTHERWISE SPECIFIED

NOMINAL SIZE OF DIMENSION	0-120	120-315	315-1000	1000+
0 or 1 DECIMAL PLACE	+-0.5	+-1	+-1.5	+-3.0
2 DECIMAL PLACES	+/- 0.25			
ANGULAR TOLERANCE	+/- 0' 30'			

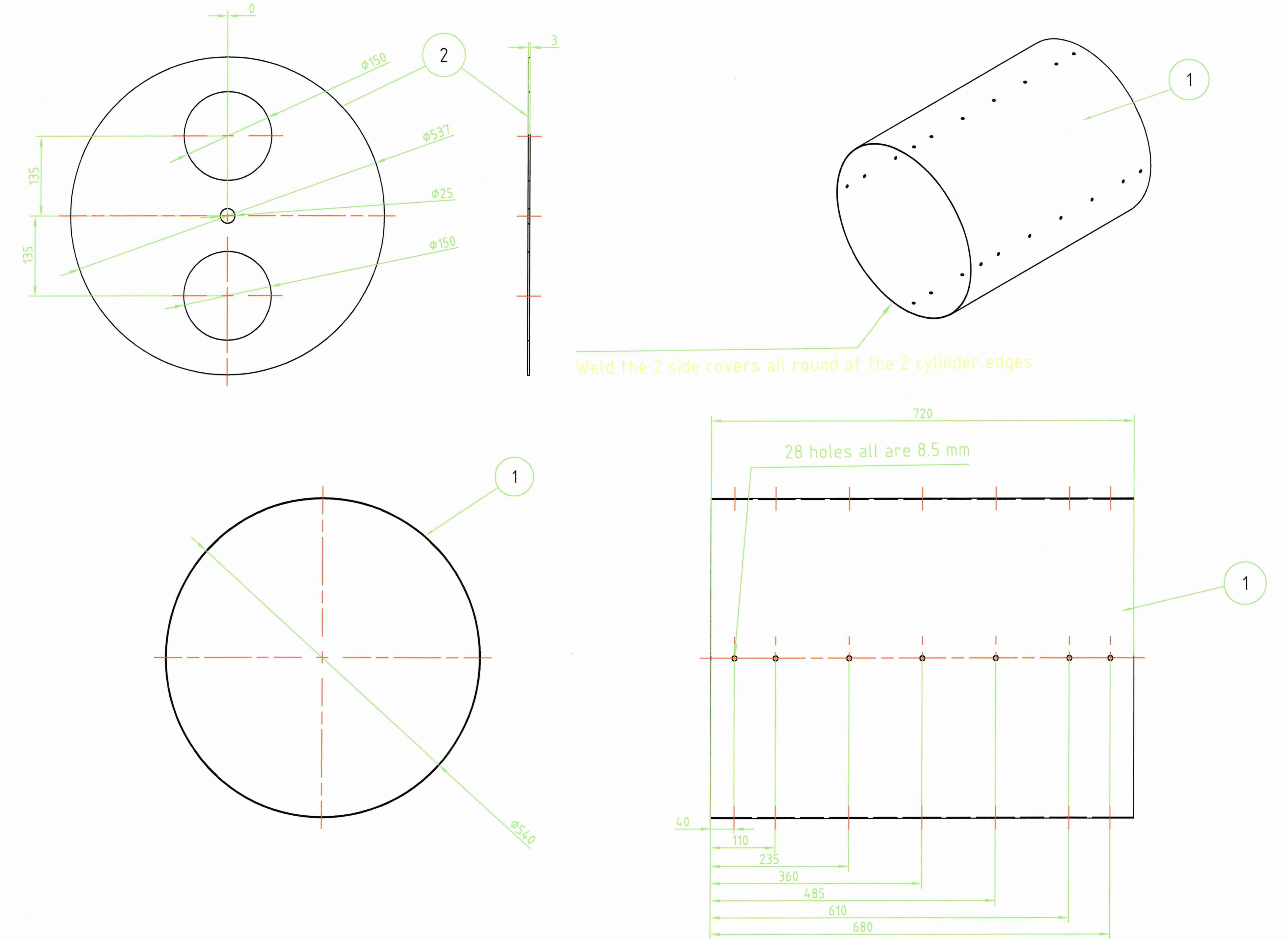
DRAWN BY: CHRISTOS I.DIMITRIADIS
TEL.Ex.
DATE:

TITLE LAVENDER HARVESTE
VIOLIN GUARD ASSEMBLY

CHECKED BY:
DATE:

PART No. 720007A01 SHT. OF.

DO NOT SCALE



PART No. 720100 P01

ISSUE	CHANGE RECORD	DATE+AUTHY
1	PRODUCTION REL.	CD02

2	CYLINDER SIDE COVER	2 items
1	CYLINDER SURFACE	1 item

NOTES:

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FAX +44 (0) 1525 863001

MATERIAL: MILD STEEL
FINISH:
No.off: 1

DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE SPECIFIED

THIRD ANGLE PROJECTION

TOLERANCES ON DIMENSIONS UNLESS OTHERWISE SPECIFIED

NOMINAL SIZE OF DIMENSION	0-120	120-315	315-1000	1000+
0 or 1 DECIMAL PLACE	+-0.5	+-1	+-1.5	+-3.0
2 DECIMAL PLACES	+/- 0.25			
ANGULAR TOLERANCE	+/- 0° 30'			

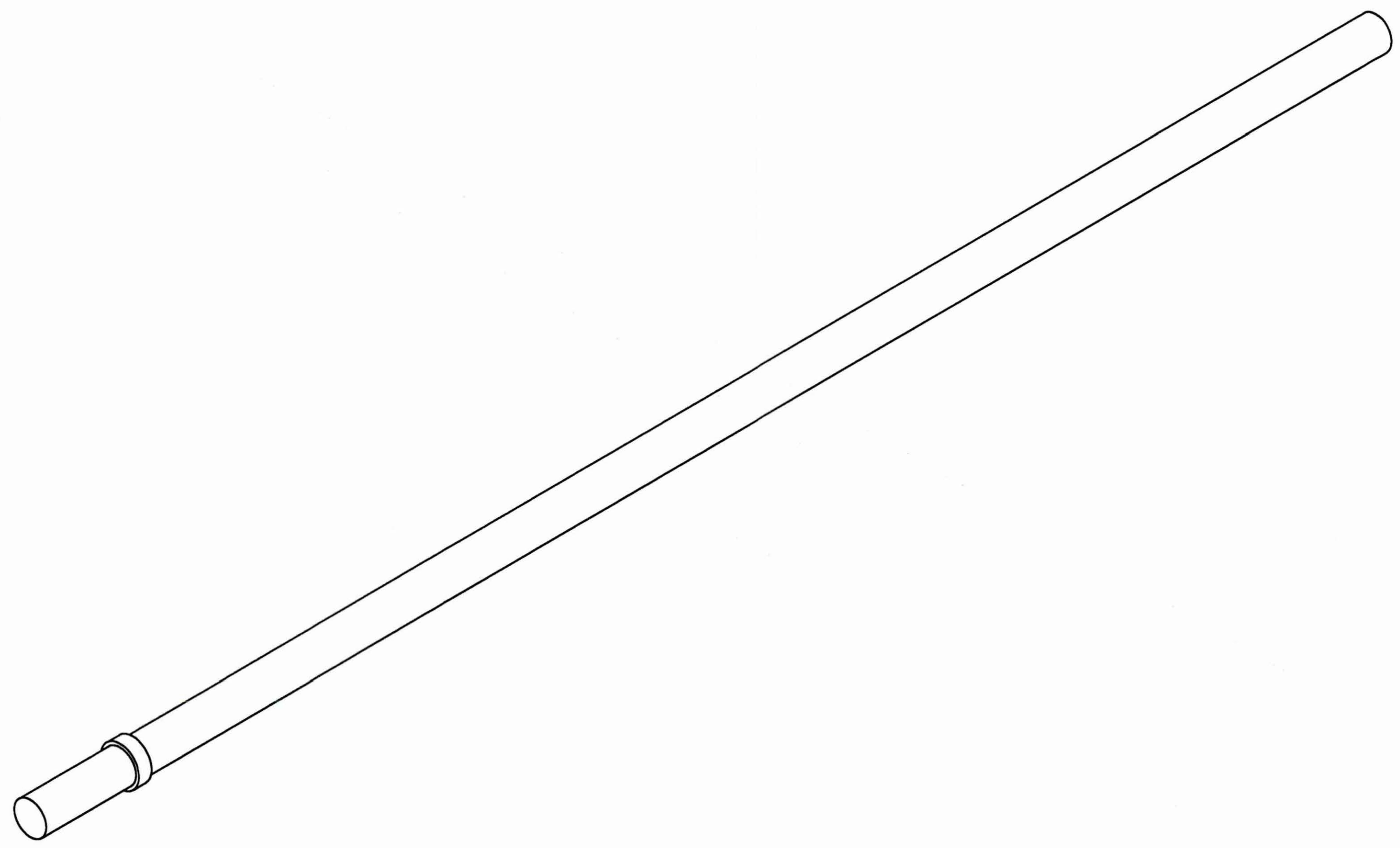
DRAWN BY: CHRISTOS I.DIMITRIADIS
TEL.Ex.
DATE:

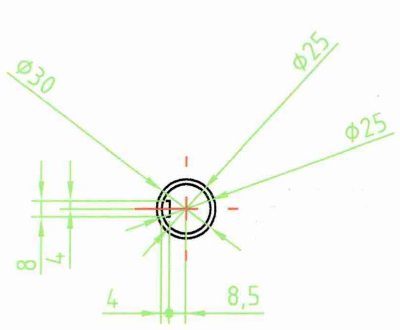
TITLE: LAVENDER HARVESTER DRUM

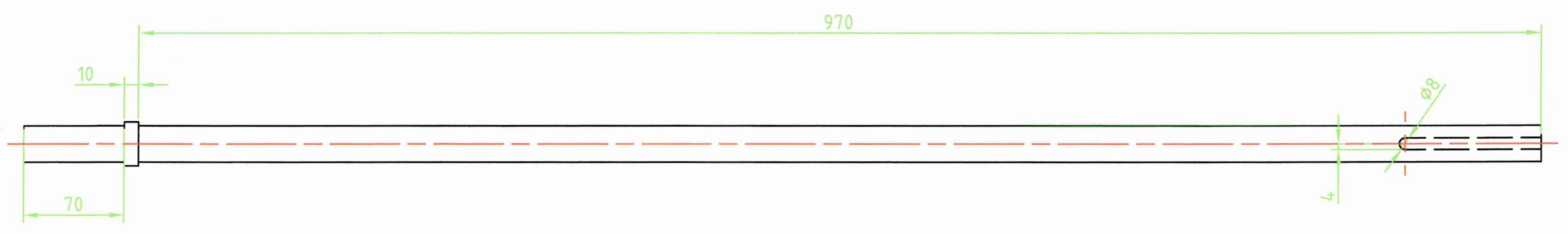
CHECKED BY:
DATE:

PART No. 720100 P01
SHT. OF.

DO NOT SCALE







PART No.	720101P01	
ISSUE	CHANGE RECORD DATE=AUTHY	
1	PRODUCTION REL.	CD02

NOTES:

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MATERIAL: MILD STEEL

No.off: 1

FINISH

DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE SPECIFIED

THIRD ANGLE PROJECTION

TOLERANCES ON DIMENSIONS UNLESS OTHERWISE SPECIFIED

NOMINAL SIZE OF DIMENSION	0-120	120-315	315-1000	1000+
0 or 1 DECIMAL PLACE	+-0.5	+-1	+-1.5	+-3.0
2 DECIMAL PLACES	+/- 0.25			
ANGULAR TOLERANCE	+/- 0° 30'			

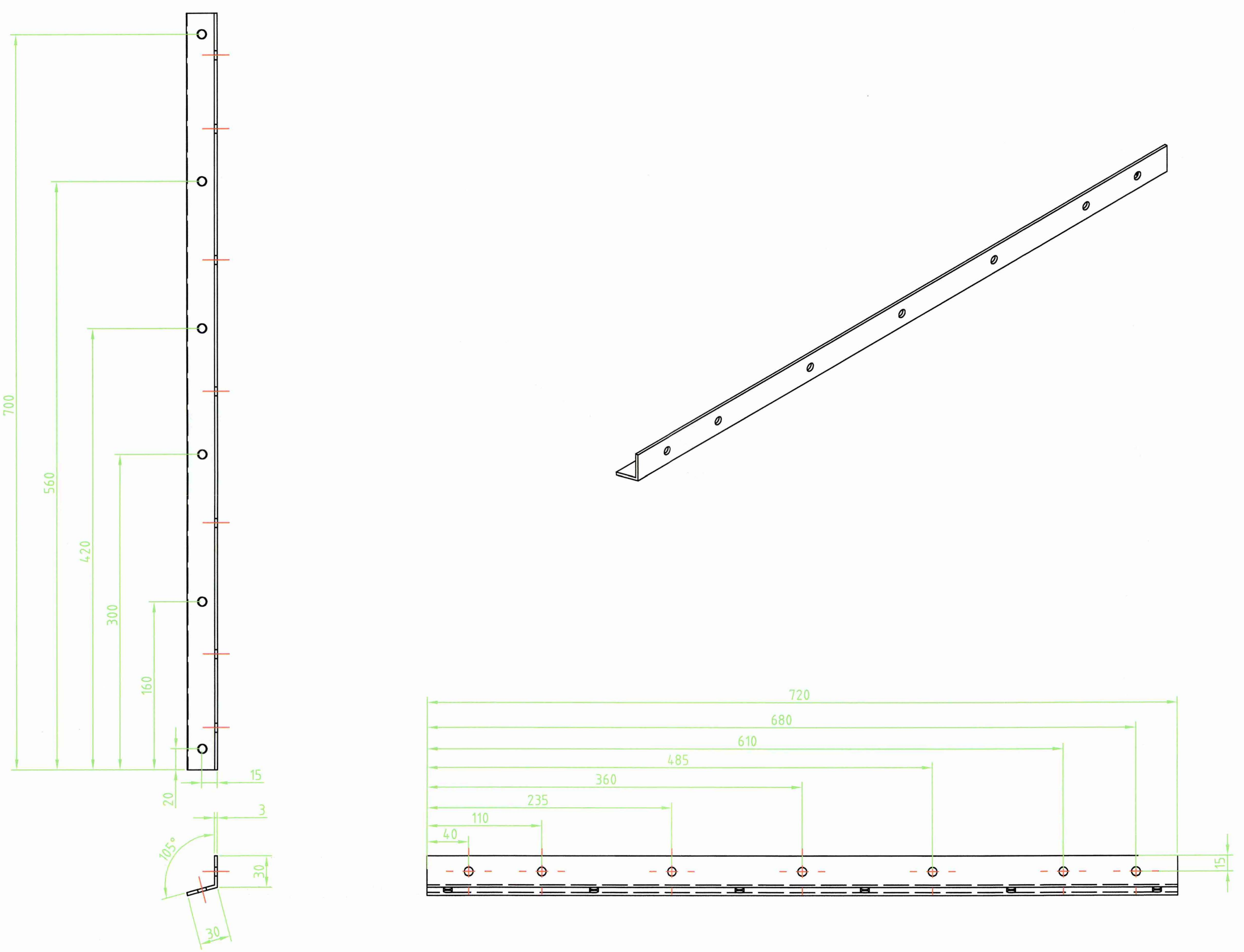
DRAWN BY: CHRISTOS I.DIMITRIADIS
TEL.Ex.
DATE:

TITLE: LAVENDER HARVESTER ROTOR SHAFT

CHECKED BY:
DATE:

DO NOT SCALE

PART No. 720101P01 SHT. OF.



PART No. 720102P01

ISSUE	CHANGE RECORD	DATE+AUTHY
1	PRODUCTION REL.	CD02

NOTES: 4 items

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FAX +44 (0) 1525 863001

MATERIAL: MILD STEEL
No.off: 1
FINISH

DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE SPECIFIED

THIRD ANGLE PROJECTION

TOLERANCES ON DIMENSIONS UNLESS OTHERWISE SPECIFIED

NOMINAL SIZE OF DIMENSION	0-120	120-315	315-1000	1000+
0 or 1 DECIMAL PLACE	+-0.5	+-1	+-1.5	+-3.0
2 DECIMAL PLACES	+/- 0.25			
ANGULAR TOLERANCE	+/- 0° 30'			

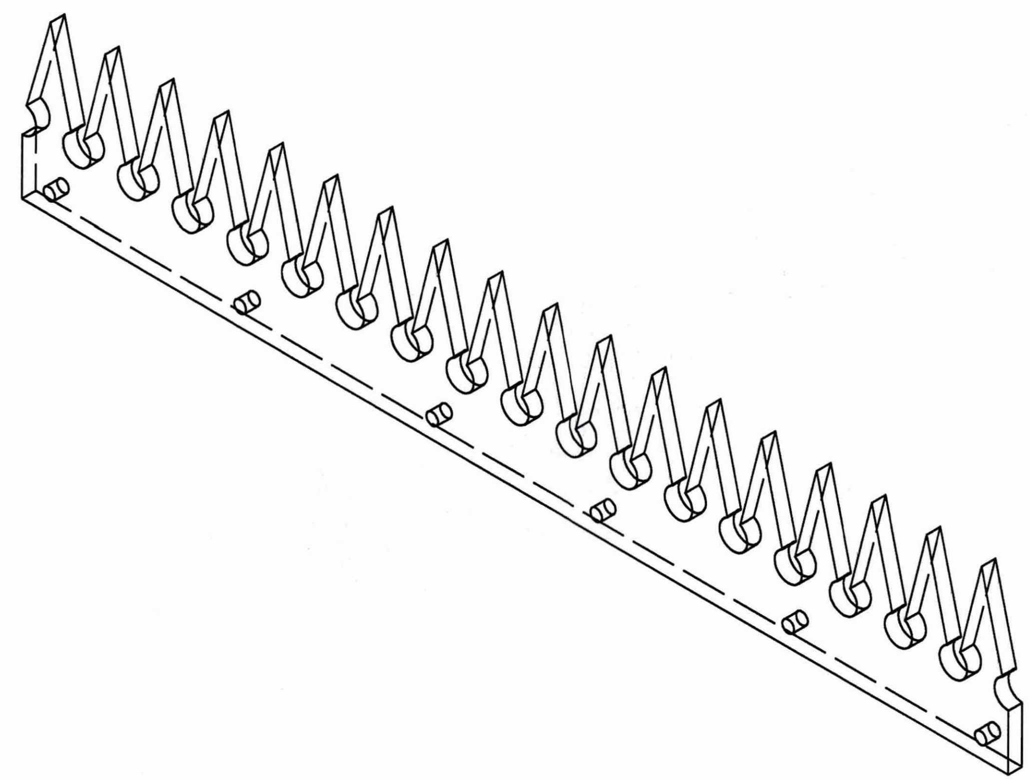
DRAWN BY: CHRISTOS I.DIMITRIADIS
TEL.Ex.
DATE:

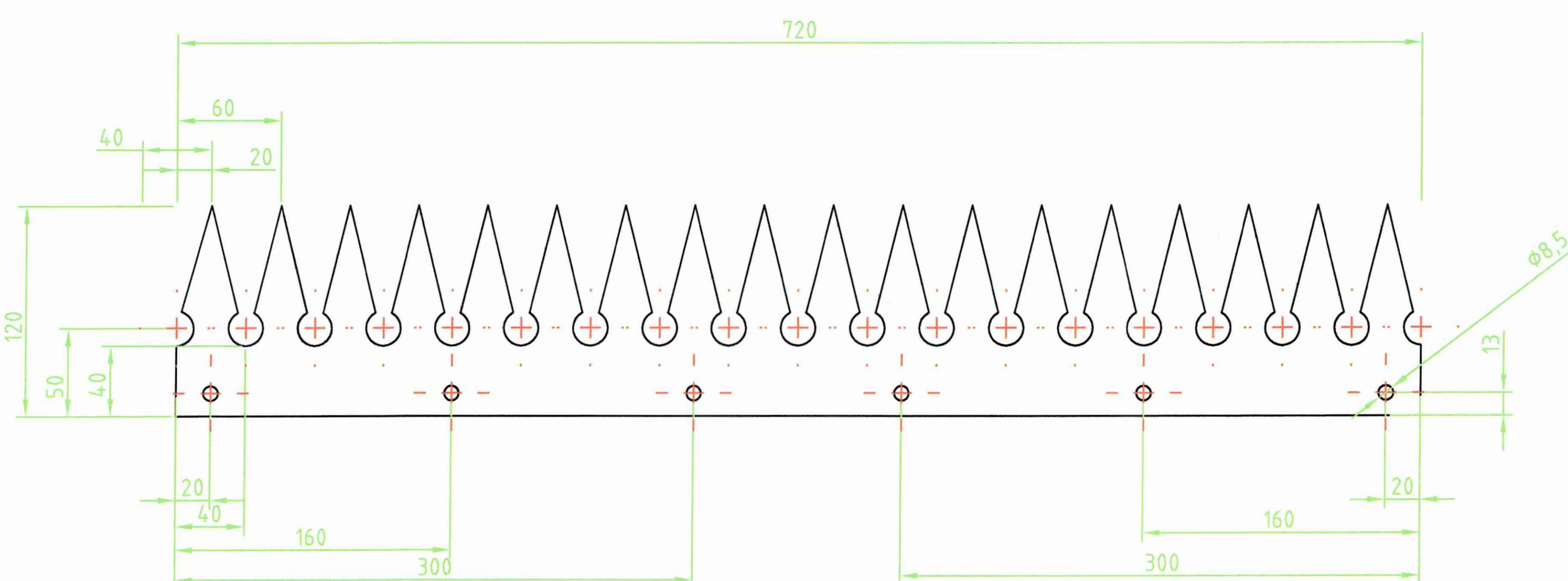
TITLE: LAVENDER HARVESTER ROTOR ANGLE BRAGET

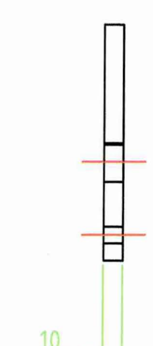
CHECKED BY:
DATE:

DO NOT SCALE

PART No. 720102P01 SHT. OF.







PART No. 720103P01

ISSUE	CHANGE RECORD	DATE+AUTHY
1	PRODUCTION REL.	CD02

NOTES:

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SILSOE CAMPUS DESIGN OFFICE
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BEDFORDSHIRE, MK45 4DT,
UNITED KINGDOM.
TEL +44 (0) 1525 863000
FAX +44 (0) 1525 863001

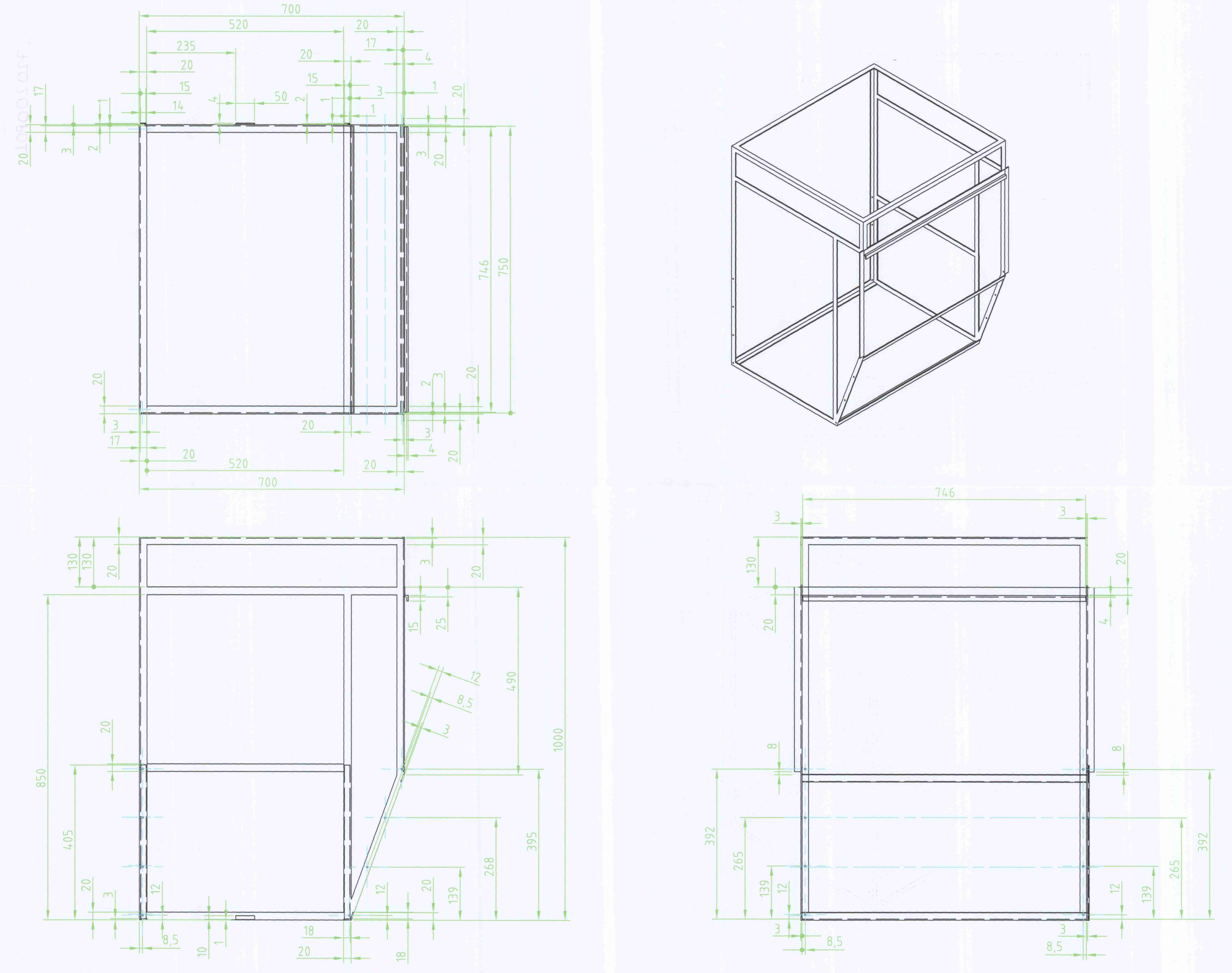
MATERIAL: POLYURETHANE & MILD STEEL
No.off: 1
FINISH

DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE SPECIFIED
THIRD ANGLE PROJECTION

TOLERANCES ON DIMENSIONS UNLESS OTHERWISE SPECIFIED

NOMINAL SIZE OF DIMENSION	0-120	120-315	315-1000	1000+
0 or 1 DECIMAL PLACE	+-0.5	+-1	+-1.5	+-3.0
2 DECIMAL PLACES	+/- 0.25			
ANGULAR TOLERANCE	+/- 0° 30'			

DRAWN BY: CHRISTOS I.DIMITRIADIS
TEL.Ex.
DATE:
TITLE: LAVENDER HARVESTER STRIPPING ELEMENTS
CHECKED BY:
DATE:
PART No. 720103P01
SHT. OF.
DO NOT SCALE



PART No. 720200P01

ISSUE	CHANGE RECORD	DATE+AUTHY	
1	PRODUCTION REL.		CD03

NOTES:

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BEDFORDSHIRE, MK45 4DT,
UNITED KINGDOM.
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FAX +44 (0) 1525 863001

MATERIAL: MILD STEEL
FINISH
No.off

DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE SPECIFIED
THIRD ANGLE PROJECTION

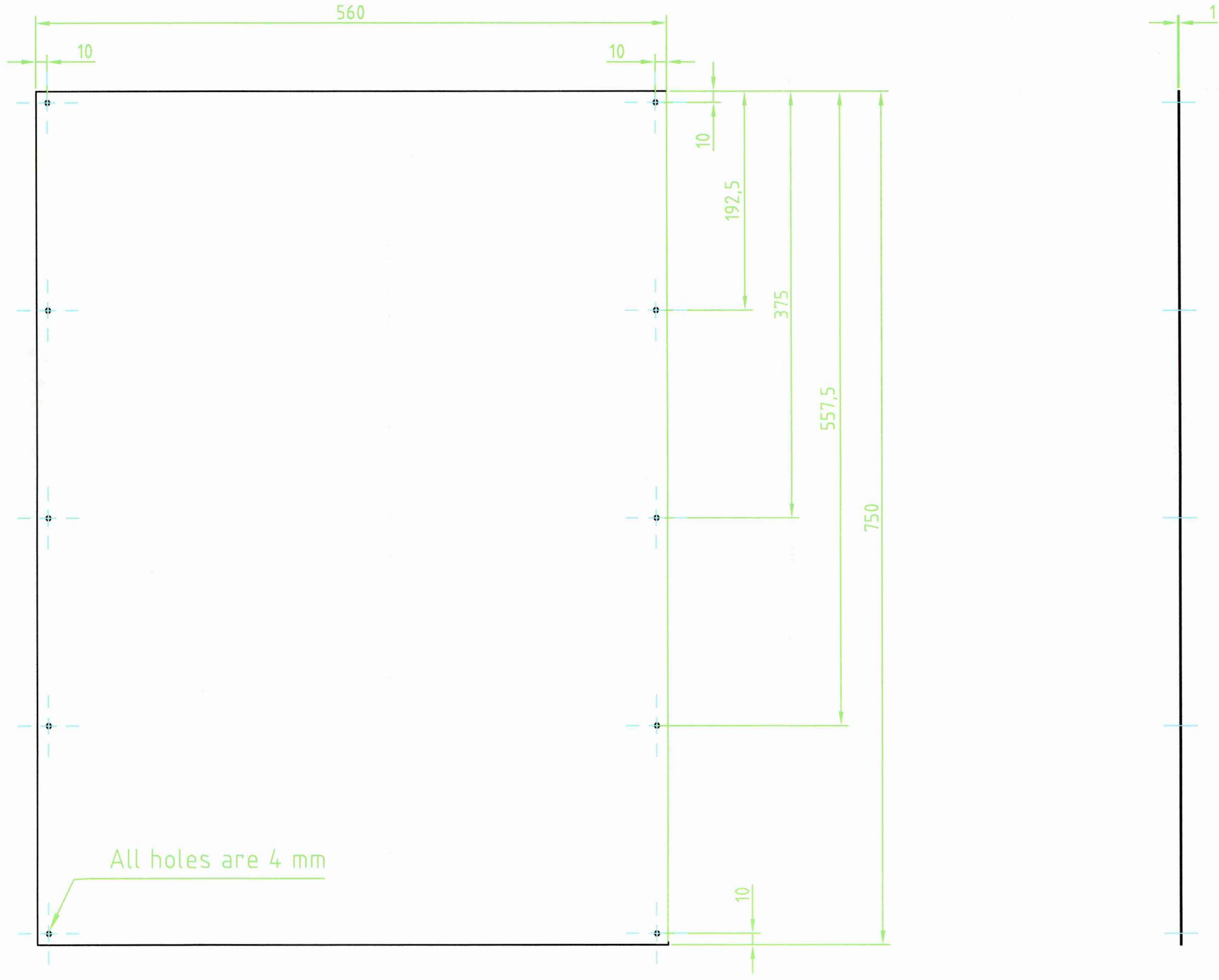
TOLERANCES ON DIMENSIONS UNLESS OTHERWISE SPECIFIED

NOMINAL SIZE OF DIMENSION	0-120	120-315	315-1000	1000+
0 or 1 DECIMAL PLACE	+-0.5	+-1	+-1.5	+-3.0
2 DECIMAL PLACES	+/- 0.25			
ANGULAR TOLERANCE	+/- 0' 30'			

DRAWN BY: CHRISTOS I.DIMITRIADIS
TEL.Ex.
DATE:
CHECKED BY:
DATE:
DO NOT SCALE

TITLE: Lavender Harvester Container Frame

PART No. 720200P01 SHT. OF.



PART No.	720201P01	
ISSUE	CHANGE RECORD DATE+AUTHY	
1	PRODUCTION REL.	CD02

NOTES:

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FAX +44 (0) 1525 863001

MATERIAL MILD STEEL

FINISH

No.off

DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE SPECIFIED

THIRD ANGLE PROJECTION

TOLERANCES ON DIMENSIONS UNLESS OTHERWISE SPECIFIED

NOMINAL SIZE OF DIMENSION	0-120	120-315	315-1000	1000+
0 or 1 DECIMAL PLACE	+-0.5	+-1	+-1.5	+-3.0
2 DECIMAL PLACES	+/- 0.25			
ANGULAR TOLERANCE	+/- 0' 30'			

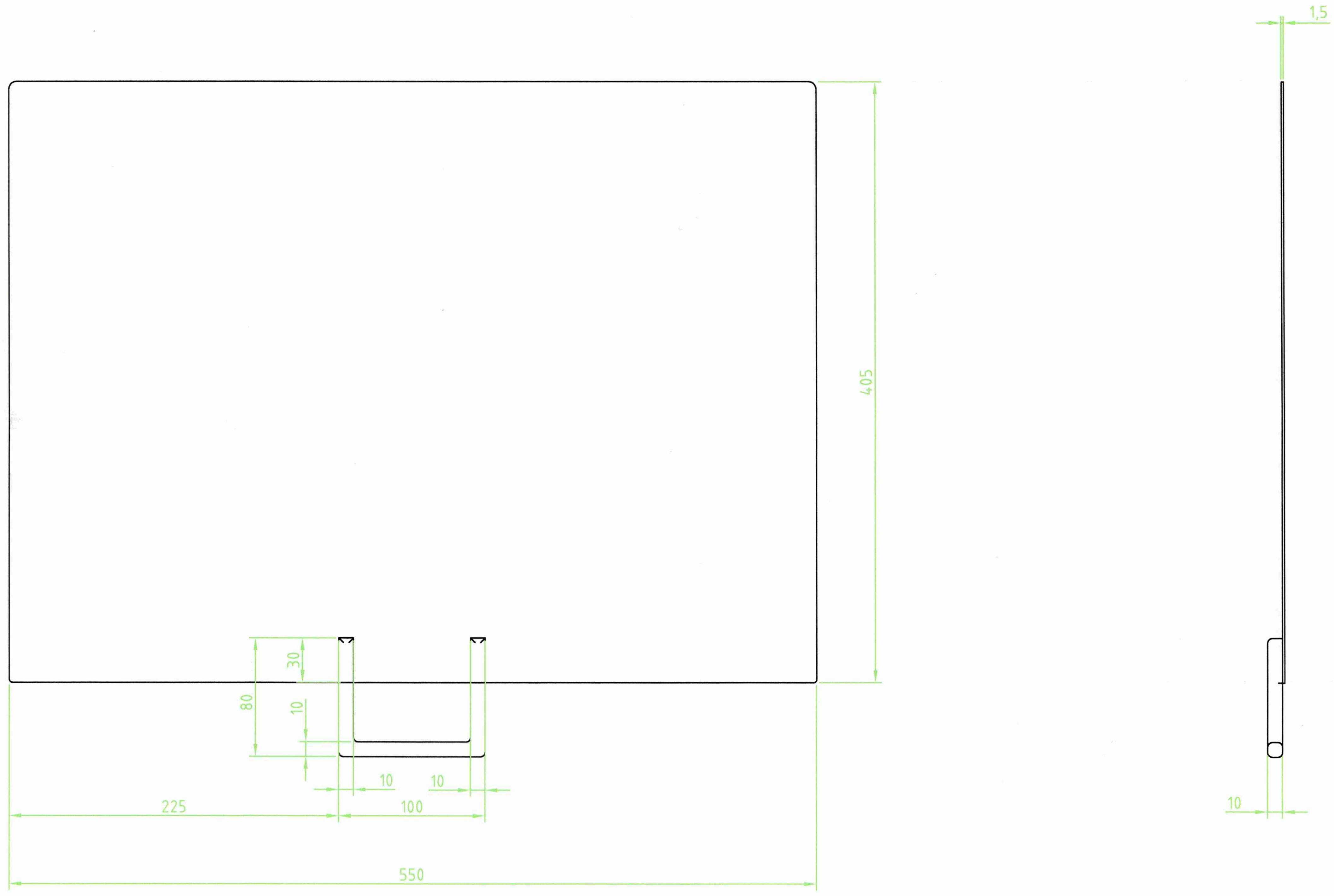
DRAWN BY: CHR.I.DIMITRIADIS
TEL.Ex.
DATE:

TITLE
Lavender Harvester
Bottom container cover

CHECKED BY:
DATE:

DO NOT SCALE

PART No. 720201P01 SHT. OF.



PART No. 720202P01

ISSUE	CHANGE RECORD	DATE+AUTHY
1	PRODUCTION REL.	CD02

NOTES:

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UNITED KINGDOM.
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FAX +44 (0) 1525 863001

MATERIAL: MILD STEEL
FINISH:
No.off:

DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE SPECIFIED

THIRD ANGLE PROJECTION

TOLERANCES ON DIMENSIONS UNLESS OTHERWISE SPECIFIED

NOMINAL SIZE OF DIMENSION	0-120	120-315	315-1000	1000+
0 or 1 DECIMAL PLACE	+-0.5	+-1	+-1.5	+-3.0
2 DECIMAL PLACES	+/- 0.25			
ANGULAR TOLERANCE	+/- 0' 30'			

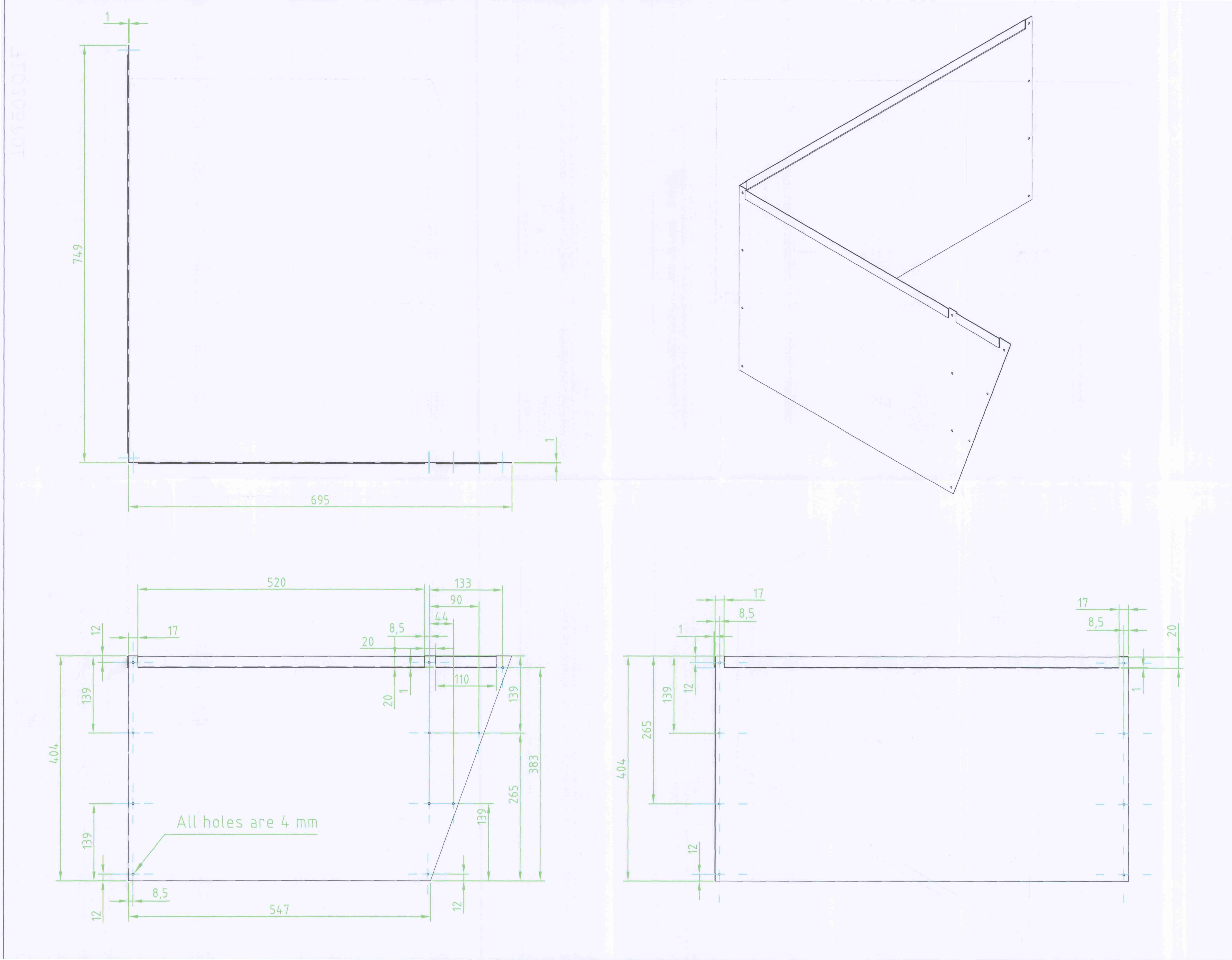
DRAWN BY: CHR.I.DIMITRIADIS
TEL.Ex.
DATE:

TITLE: Lavender Harvester
Side container drawer

CHECKED BY:
DATE:

PART No. 720202P01
SHT. OF.

DO NOT SCALE



PART No. 720203P01

ISSUE	CHANGE RECORD	DATE+AUTHY	
1	PRODUCTION REL.		CD02

NOTES:

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BEDFORDSHIRE, MK45 4DT,
UNITED KINGDOM.
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FAX +44 (0) 1525 863001

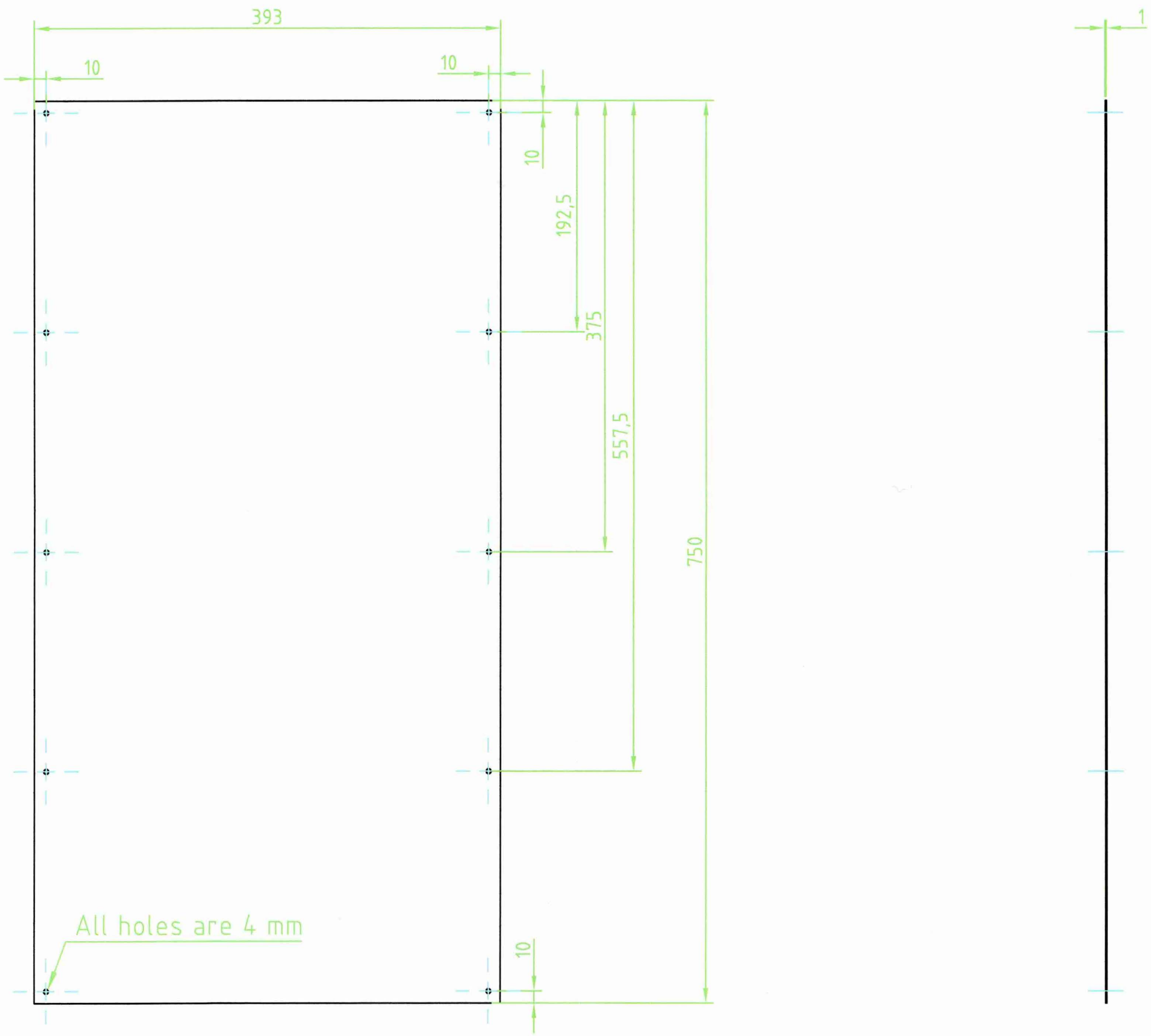
MATERIAL: MILD STEEL
No.off
FINISH

DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE SPECIFIED
THIRD ANGLE PROJECTION

TOLERANCES ON DIMENSIONS UNLESS OTHERWISE SPECIFIED

NOMINAL SIZE OF DIMENSION	0-120	120-315	315-1000	1000+
0 or 1 DECIMAL PLACE	+-0.5	+-1	+-1.5	+-3.0
2 DECIMAL PLACES	+/- 0.25			
ANGULAR TOLERANCE	+/- 0° 30'			

DRAWN BY: CHR.I.DIMITRIADIS
TEL.Ex.
DATE:
TITLE: Lavender Harvester Side container cover
CHECKED BY:
DATE:
PART No. 720203P01
SHT. OF.
DO NOT SCALE



PART No.	720204P01	
ISSUE	CHANGE RECORD	DATE+AUTHY
1	PRODUCTION REL.	CD02

NOTES:

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BEDFORDSHIRE, MK45 4DT,
UNITED KINGDOM.
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FAX +44 (0) 1525 863001

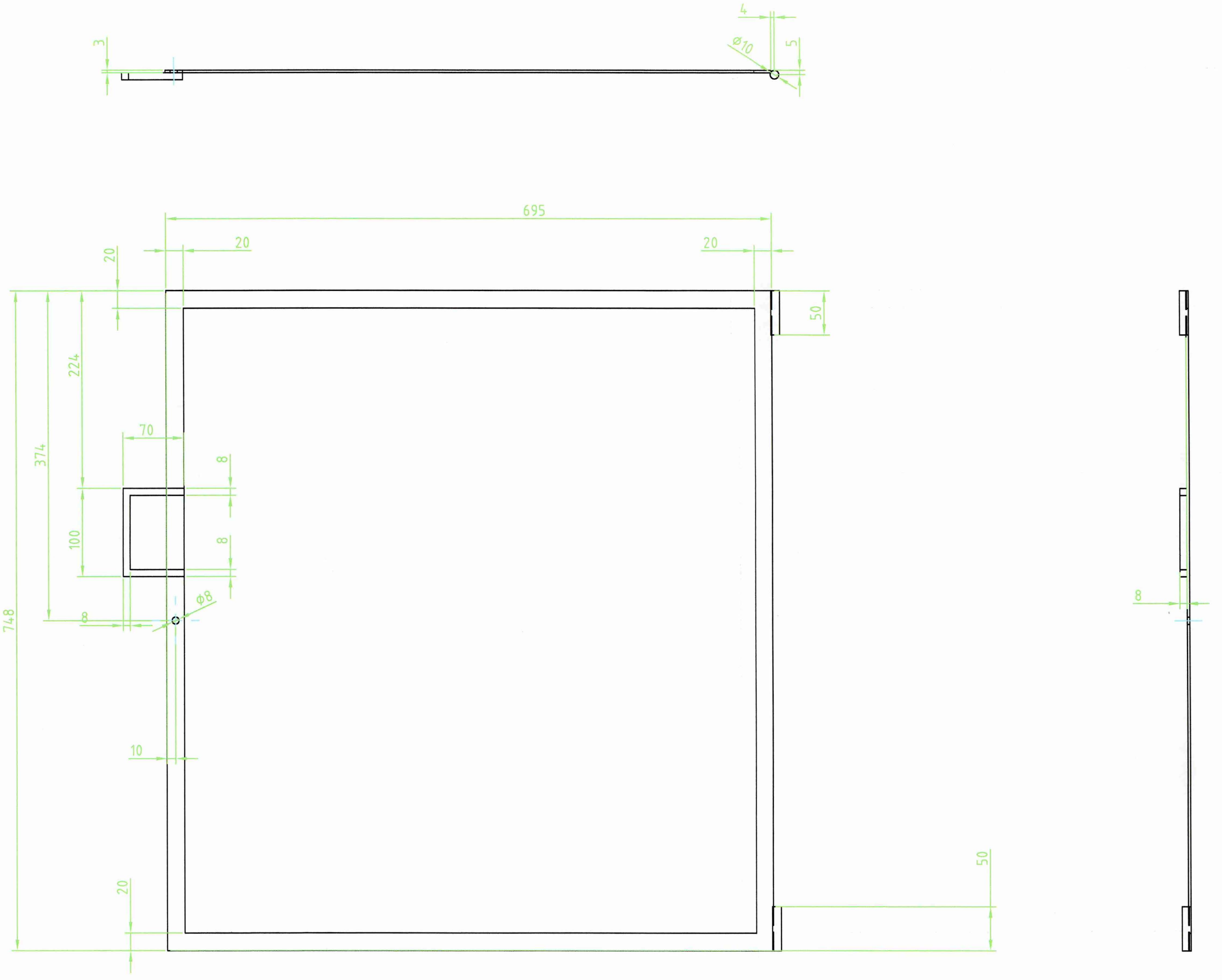
MATERIAL: MILD STEEL
FINISH:
No.off:

DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE SPECIFIED
THIRD ANGLE PROJECTION

TOLERANCES ON DIMENSIONS UNLESS OTHERWISE SPECIFIED

NOMINAL SIZE OF DIMENSION	0-120	120-315	315-1000	1000+
0 or 1 DECIMAL PLACE	+-0.5	+-1	+-1.5	+-3.0
2 DECIMAL PLACES	+/- 0.25			
ANGULAR TOLERANCE	+/- 0' 30'			

DRAWN BY: CHR.I.DIMITRIADIS
TEL.Ex.
DATE:
TITLE: Lavender Harvester Angle container cover
CHECKED BY:
DATE:
PART No. 720204P01
SHT. OF.
DO NOT SCALE



PART No. 720205P01

ISSUE	CHANGE RECORD	DATE+AUTHY
1	PRODUCTION REL.	CD02

NOTES:

Cranfield UNIVERSITY Silsoe

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BEDFORDSHIRE, MK45 4DT,
UNITED KINGDOM.

TEL +44 (0) 1525 863000
FAX +44 (0) 1525 863001

MATERIAL: MILD STEEL

FINISH:

No.off:

DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE SPECIFIED

THIRD ANGLE PROJECTION

TOLERANCES ON DIMENSIONS UNLESS OTHERWISE SPECIFIED

NOMINAL SIZE OF DIMENSION	0-120	120-315	315-1000	1000+
0 or 1 DECIMAL PLACE	+-0.5	+-1	+-1.5	+-3.0
2 DECIMAL PLACES	+/- 0.25			
ANGULAR TOLERANCE	+/- 0° 30'			

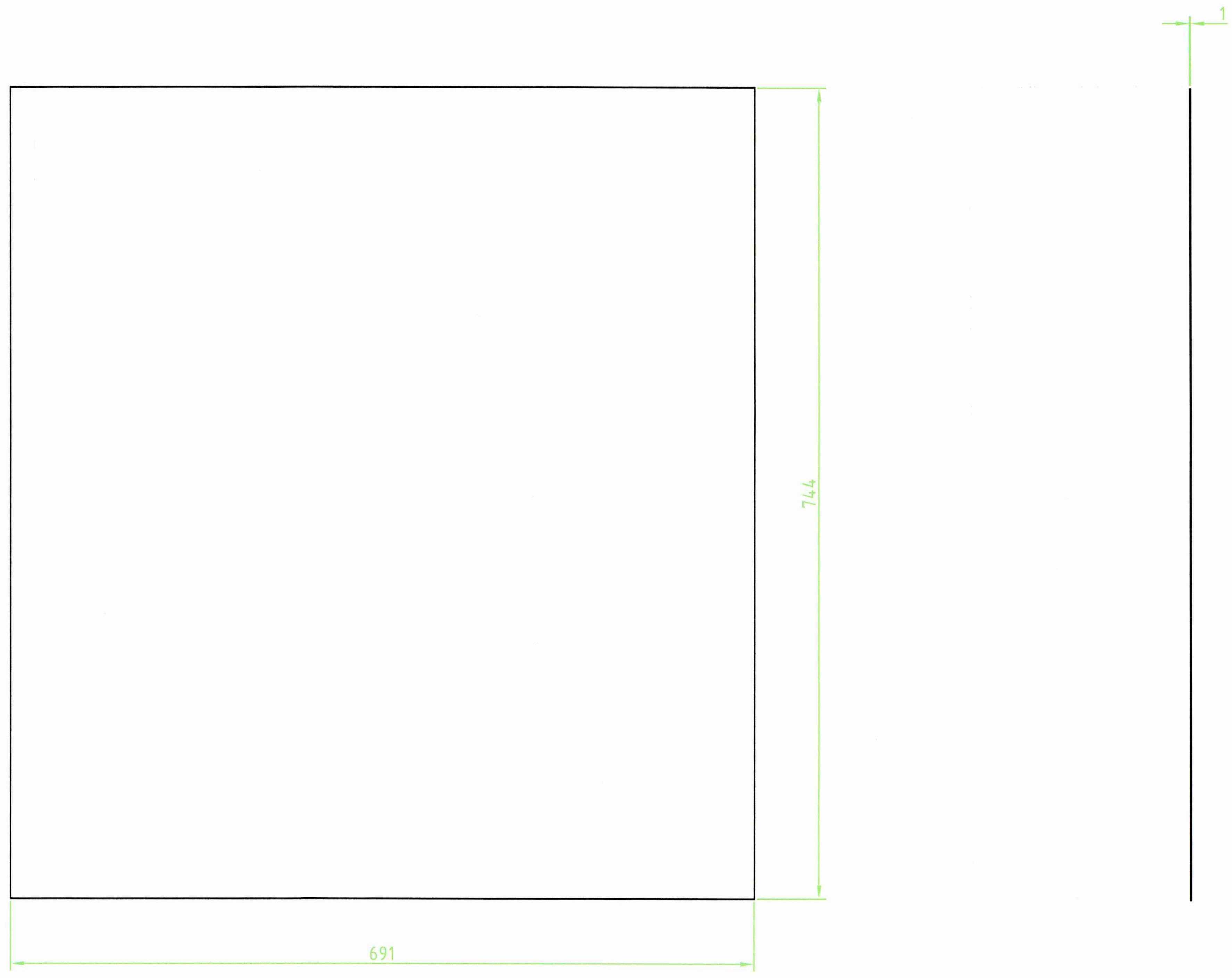
DRAWN BY: CHR. I. DIMITRIADIS
TEL.Ex.
DATE:

TITLE: Lavender Harvester Bee releaser frame

CHECKED BY:
DATE:

PART No. 720205P01 SHT. OF.

DO NOT SCALE



PART No. 720206 P01

ISSUE	CHANGE RECORD	DATE+AUTHY
1	PRODUCTION REL.	CD02

NOTES:

Cranfield UNIVERSITY Silsoe
INSTITUTE OF AGRITECHNOLOGY
SILSOE CAMPUS, SILSOE,
BEDFORDSHIRE, MK45 4DT,
UNITED KINGDOM.
TEL +44 (0) 1525 863000
FAX +44 (0) 1525 863001

MATERIAL COPER MESH
FINISH
No.off

DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE SPECIFIED
THIRD ANGLE PROJECTION

TOLERANCES ON DIMENSIONS UNLESS OTHERWISE SPECIFIED

NOMINAL SIZE OF DIMENSION	0-120	120-315	315-1000	1000+
0 or 1 DECIMAL PLACE	+-0.5	+-1	+-1.5	+-3.0
2 DECIMAL PLACES	+/- 0.25			
ANGULAR TOLERANCE	+/- 0' 30'			

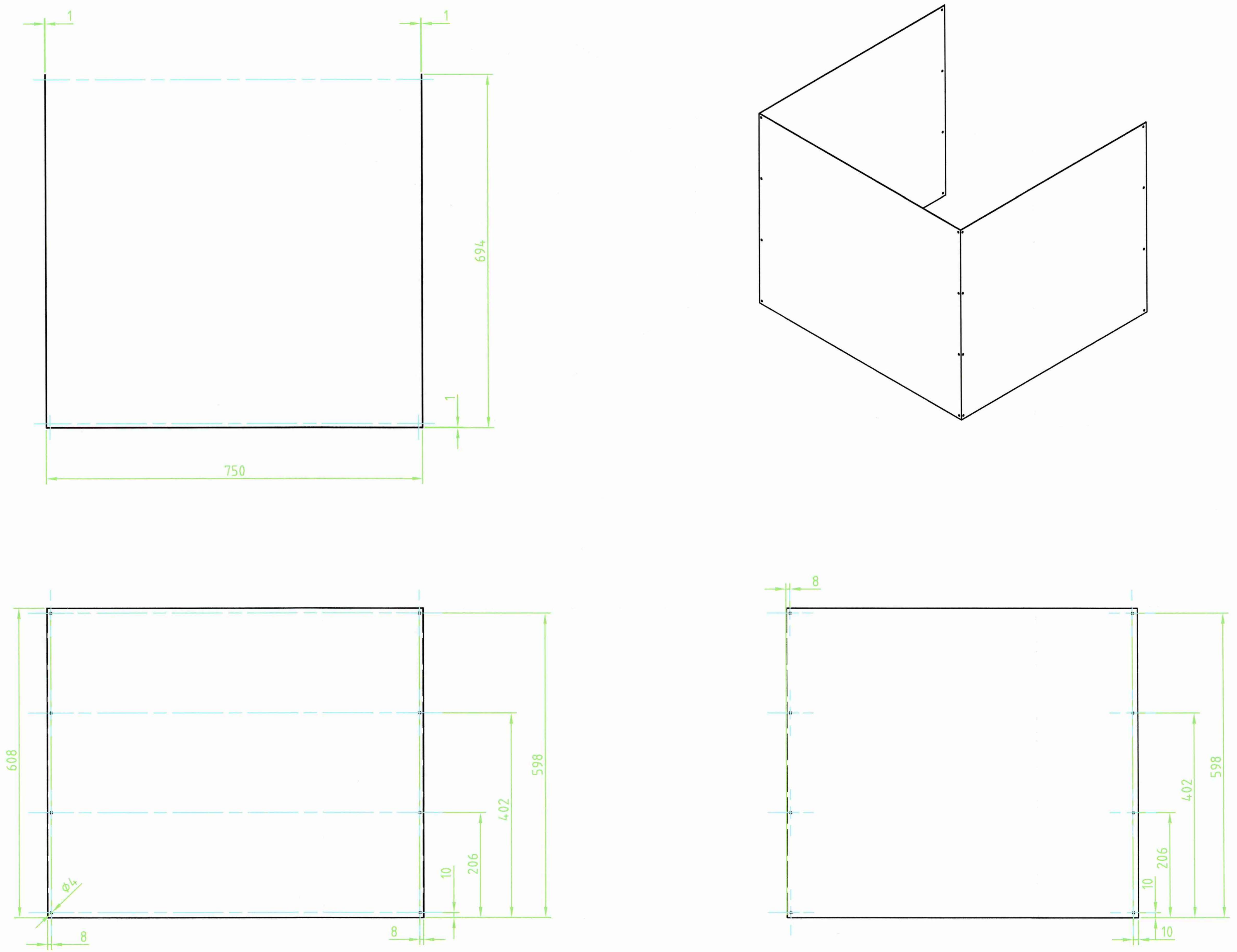
DRAWN BY: CHR.I.DIMITRIADIS
TEL.Ex.
DATE:

TITLE Lavender Harvester Bee releaser mesh

CHECKED BY:
DATE:

PART No. 720206 P01 SHT. OF.

DO NOT SCALE



PART No. 720207P01

ISSUE	CHANGE RECORD	DATE+AUTHY
1	PRODUCTION REL.	CD02

NOTES:

Cranfield UNIVERSITY Silsoe
INSTITUTE OF AGRITECHNOLOGY
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BEDFORDSHIRE, MK45 4DT,
UNITED KINGDOM.
TEL +44 (0) 1525 863000
FAX +44 (0) 1525 863001

MATERIAL: COPER MESH
FINISH:
No.off:

DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE SPECIFIED

THIRD ANGLE PROJECTION

TOLERANCES ON DIMENSIONS UNLESS OTHERWISE SPECIFIED

NOMINAL SIZE OF DIMENSION	0-120	120-315	315-1000	1000+
0 or 1 DECIMAL PLACE	+-0.5	+-1	+-1.5	+-3.0
2 DECIMAL PLACES	+/- 0.25			
ANGULAR TOLERANCE	+/- 0' 30'			

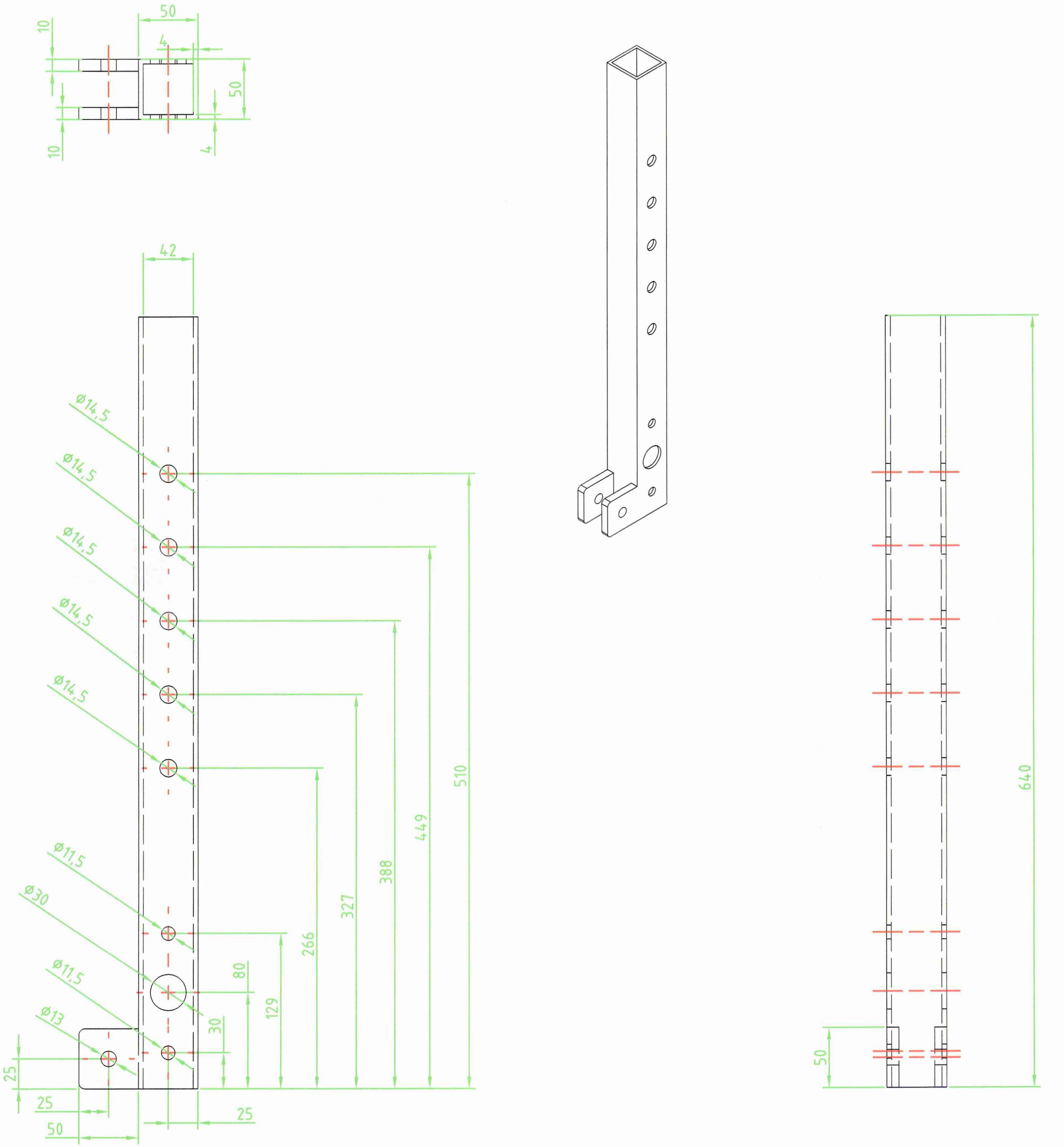
DRAWN BY: CHR.I.DIMITRIADIS
TEL.Ex.
DATE:

TITLE: Lavender Harvester Container mesh

CHECKED BY:
DATE:

PART No. 720207P01 SHT. OF.

DO NOT SCALE



PART No.	720300P01

ISSUE	CHANGE RECORD	DATE+AUTHY
1	PRODUCTION REL.	CD02

NOTES:

Cranfield UNIVERSITY Silsoe

SILSOE CAMPUS DESIGN OFFICE
NSRI ENGINEERING GROUP
SILSOE CAMPUS, SILSOE,
BEDFORDSHIRE, MK45 4DT,
UNITED KINGDOM.
TEL +44 (0) 1525 863000
FAX +44 (0) 1525 863001

MATERIAL: MILD STEEL
FINISH:
No.off: 1

DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE SPECIFIED

THIRD ANGLE PROJECTION

TOLERANCES ON DIMENSIONS UNLESS OTHERWISE SPECIFIED

NOMINAL SIZE OF DIMENSION	0-120	120-315	315-1000	1000+
0 or 1 DECIMAL PLACE	+-0.5	+-1	+-1.5	+-3.0
2 DECIMAL PLACES	+/- 0.25			
ANGULAR TOLERANCE	+/- 0° 30'			

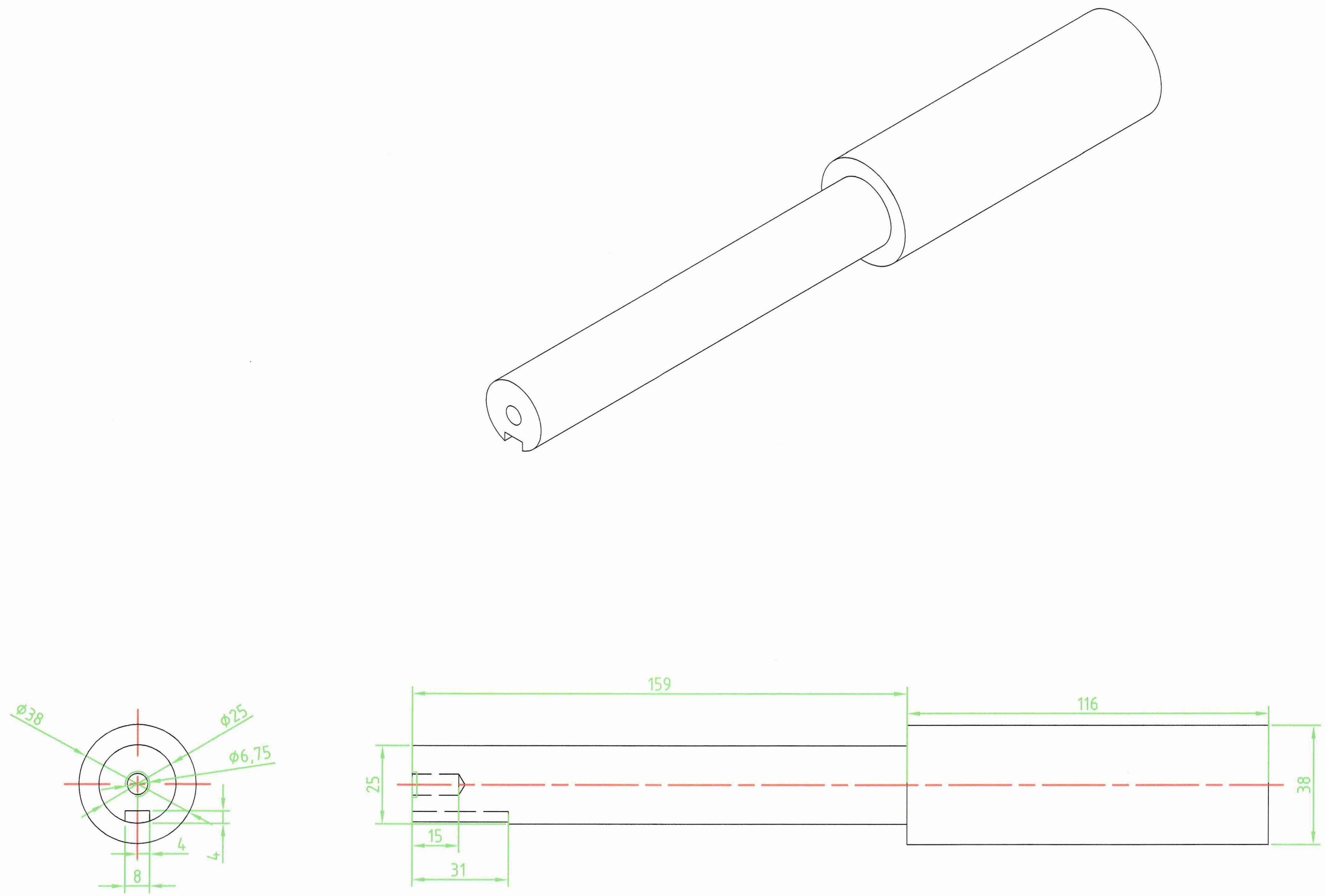
DRAWN BY: CHRISTOS I.DIMITRIADIS
TEL.Ex.
DATE:

TITLE: LAVENDER HARVESTER
FRONT RIGHT LEG INSERT

CHECKED BY:
DATE:

PART No. 720300P01 SHT. OF.

DO NOT SCALE



PART No. 720301P01

ISSUE	CHANGE RECORD	DATE+AUTHY
1	PRODUCTION REL.	CD02

NOTES:

Cranfield UNIVERSITY
Silsoe

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BEDFORDSHIRE, MK45 4DT,
UNITED KINGDOM.

TEL +44 (0) 1525 863000
FAX +44 (0) 1525 863001

MATERIAL
MILD STEEL
FINISH

No.off 1

DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE SPECIFIED

THIRD ANGLE PROJECTION

TOLERANCES ON DIMENSIONS UNLESS OTHERWISE SPECIFIED

NOMINAL SIZE OF DIMENSION	0-120	120-315	315-1000	1000+
0 or 1 DECIMAL PLACE	+-0.5	+-1	+-1.5	+-3.0
2 DECIMAL PLACES	+/- 0.25			
ANGULAR TOLERANCE	+/- 0° 30'			

DRAWN BY: CHRISTOS I.DIMITRIADIS
TEL.Ex.
DATE:

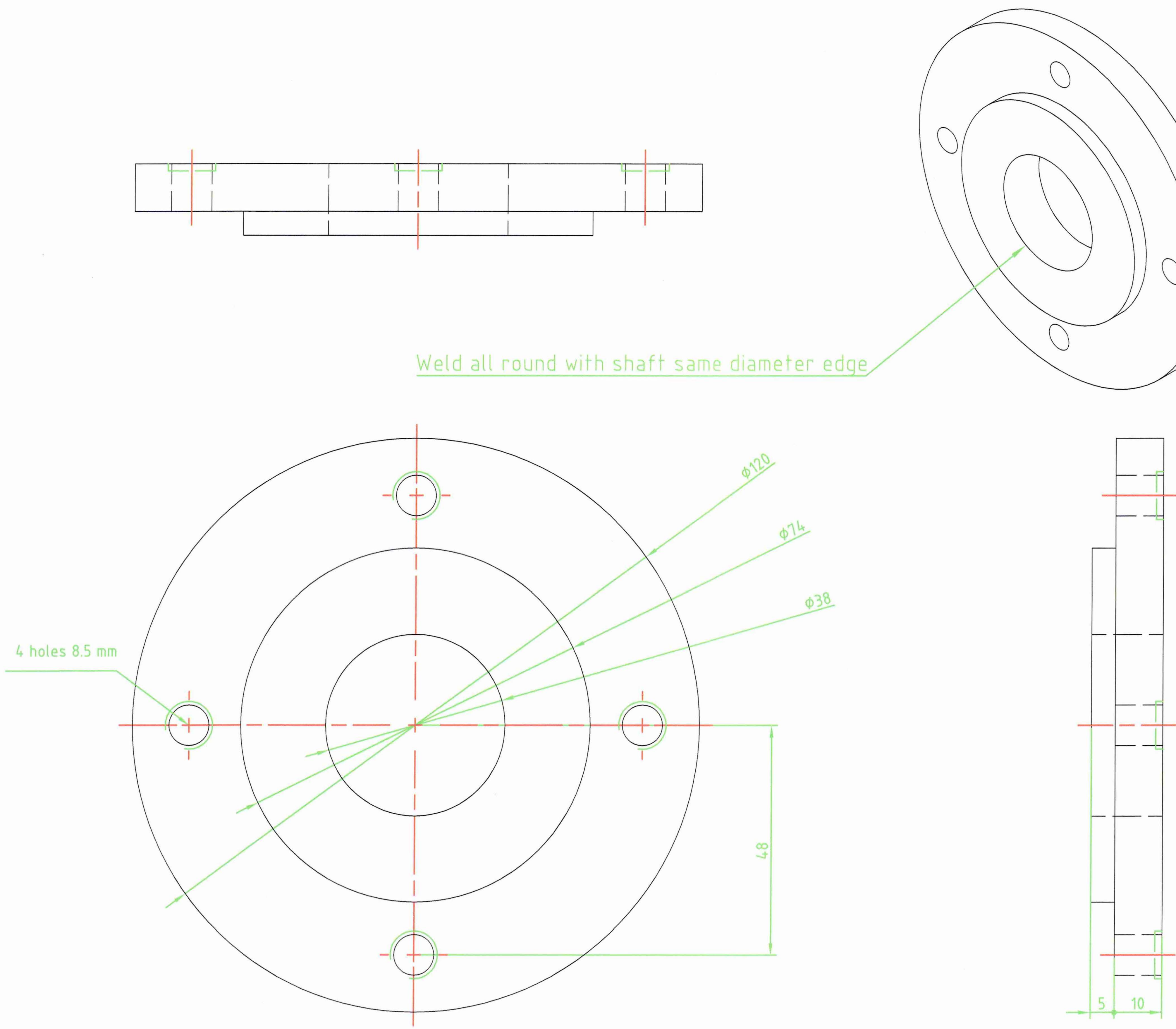
TITLE
LAVENDER HARVESTER
FRONT RIGHT WHEEL DRIVE SHAFT

CHECKED BY:
DATE:

PART No. 720301P01
SHT. OF.

DO NOT SCALE

4



PART No. 720302P01

ISSUE	CHANGE RECORD DATE+AUTHY	
1	PRODUCTION REL.	CD02

NOTES: FIT AND WELD THE WHEEL SHAFT AT THE HOUSING

Cranfield UNIVERSITY Silsoe

SILSOE CAMPUS DESIGN OFFICE
NSRI ENGINEERING GROUP
SILSOE CAMPUS, SILSOE,
BEDFORDSHIRE, MK45 4DT,
UNITED KINGDOM.

TEL +44 (0) 1525 863000
FAX +44 (0) 1525 863001

MATERIAL
MILD STEEL
FINISH

No.off 1

DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE SPECIFIED

THIRD ANGLE PROJECTION

TOLERANCES ON DIMENSIONS UNLESS OTHERWISE SPECIFIED

NOMINAL SIZE OF DIMENSION	0-120	120-315	315-1000	1000+
0 or 1 DECIMAL PLACE	+-0.5	+-1	+-1.5	+-3.0
2 DECIMAL PLACES	+/- 0.25			
ANGULAR TOLERANCE	+/- 0' 30'			

DRAWN BY: CHRISTOS I.DIMITRIADIS
TEL.Ex.
DATE:

TITLE: LAVENDER HARVESTER
FRONT RIGHT DRIVE WHEEL HOUSING

CHECKED BY:
DATE:

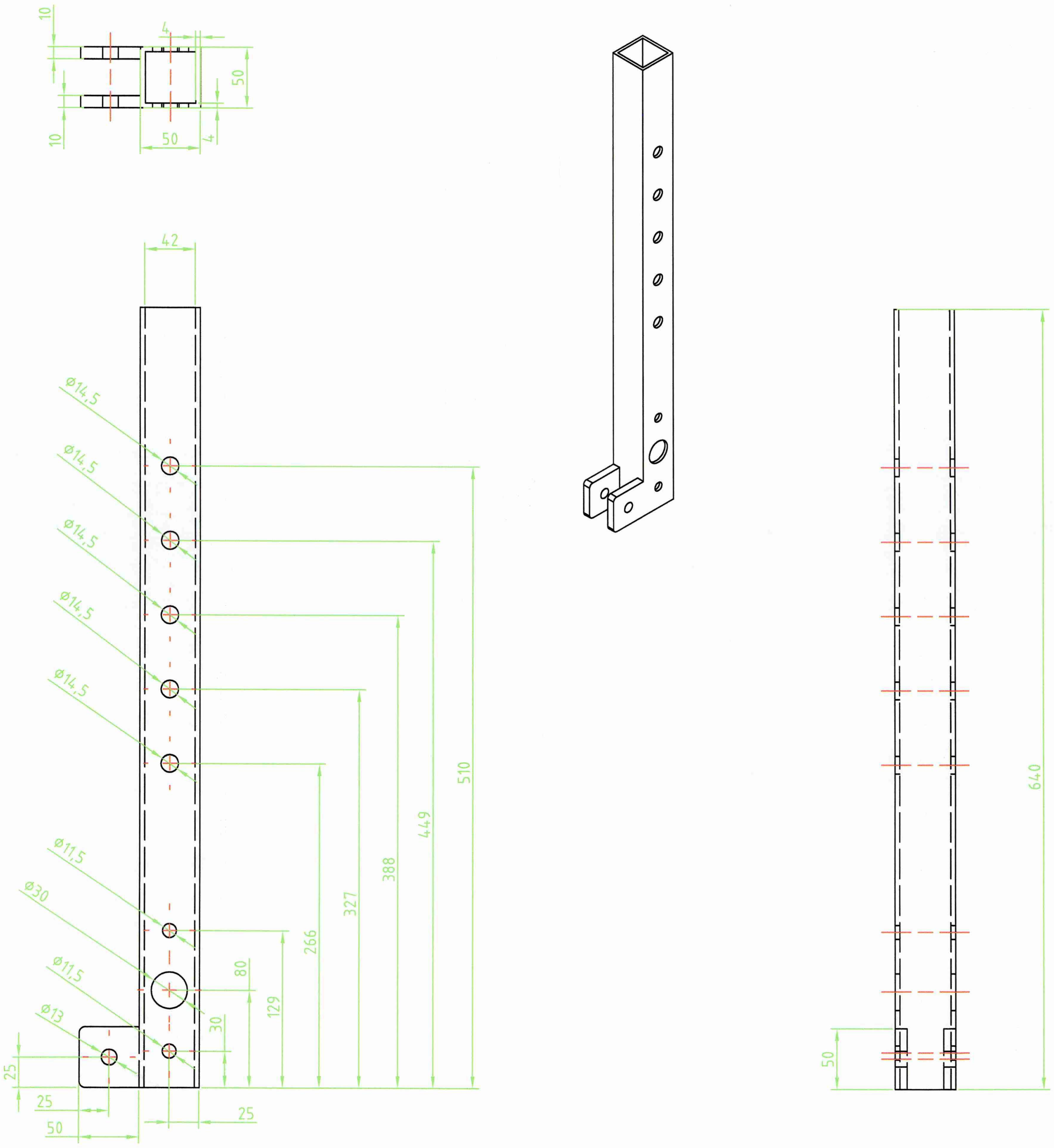
PART No. 720302P01 SHT. OF.

DO NOT SCALE

PART No. 720400P01

ISSUE	CHANGE RECORD	DATE+AUTHY
1	PRODUCTION REL.	CD02

NOTES:



Cranfield UNIVERSITY Silsoe
SILSOE CAMPUS DESIGN OFFICE
NSRI ENGINEERING GROUP
SILSOE CAMPUS, SILSOE,
BEDFORDSHIRE, MK45 4DT,
UNITED KINGDOM.
TEL +44 (0) 1525 863000
FAX +44 (0) 1525 863001

MATERIAL: MILD STEEL
FINISH:
No.off: 1

DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE SPECIFIED
THIRD ANGLE PROJECTION

TOLERANCES ON DIMENSIONS UNLESS OTHERWISE SPECIFIED

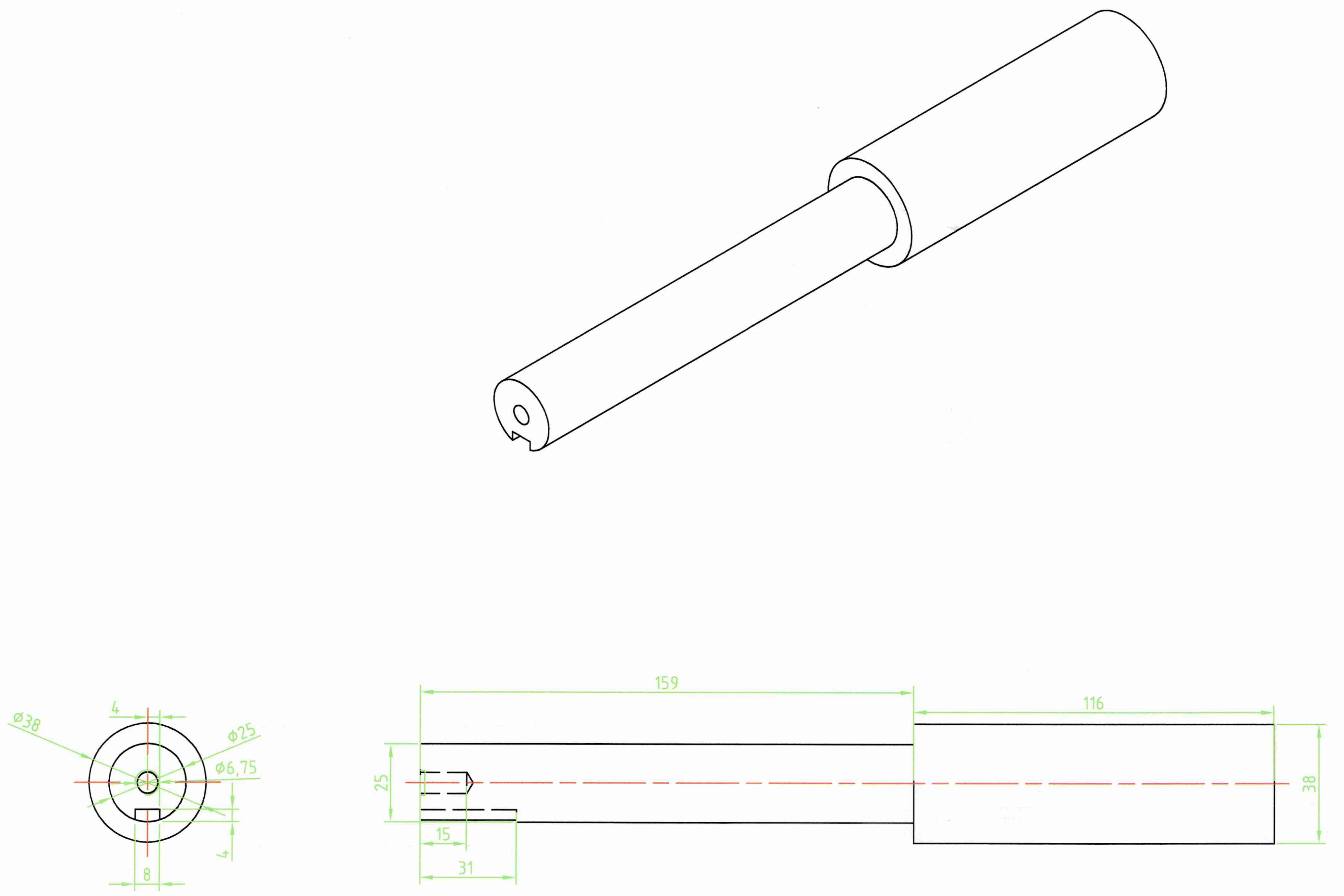
NOMINAL SIZE OF DIMENSION	0-120	120-315	315-1000	1000+
0 or 1 DECIMAL PLACE	+-0.5	+-1	+-1.5	+-3.0
2 DECIMAL PLACES	+/- 0.25			
ANGULAR TOLERANCE	+/- 0° 30'			

DRAWN BY: CHRISTOS I.DIMITRIADIS
TEL.Ex.
DATE:
TITLE: LAVENDER HARVESTER
FRONT LEFT LEG INSERT
CHECKED BY:
DATE:
DO NOT SCALE
PART No. 720400P01 SHT. OF.

PART No. 720401P01

ISSUE	CHANGE RECORD DATE+AUTHY	
1	PRODUCTION REL.	CD02

NOTES:



Cranfield UNIVERSITY Silsoe
SILSOE CAMPUS DESIGN OFFICE
NSRI ENGINEERING GROUP
SILSOE CAMPUS, SILSOE,
BEDFORDSHIRE, MK45 4DT,
UNITED KINGDOM.
TEL +44 (0) 1525 863000
FAX +44 (0) 1525 863001

MATERIAL: MILD STEEL

FINISH

No.off: 1

DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE SPECIFIED

THIRD ANGLE PROJECTION

TOLERANCES ON DIMENSIONS UNLESS OTHERWISE SPECIFIED

NOMINAL SIZE OF DIMENSION	0-120	120-315	315-1000	1000+
0 or 1 DECIMAL PLACE	+-0.5	+-1	+-1.5	+-3.0
2 DECIMAL PLACES	+/- 0.25			
ANGULAR TOLERANCE	+/- 0° 30'			

DRAWN BY: CHRISTOS I.DIMITRIADIS

TEL.Ex.

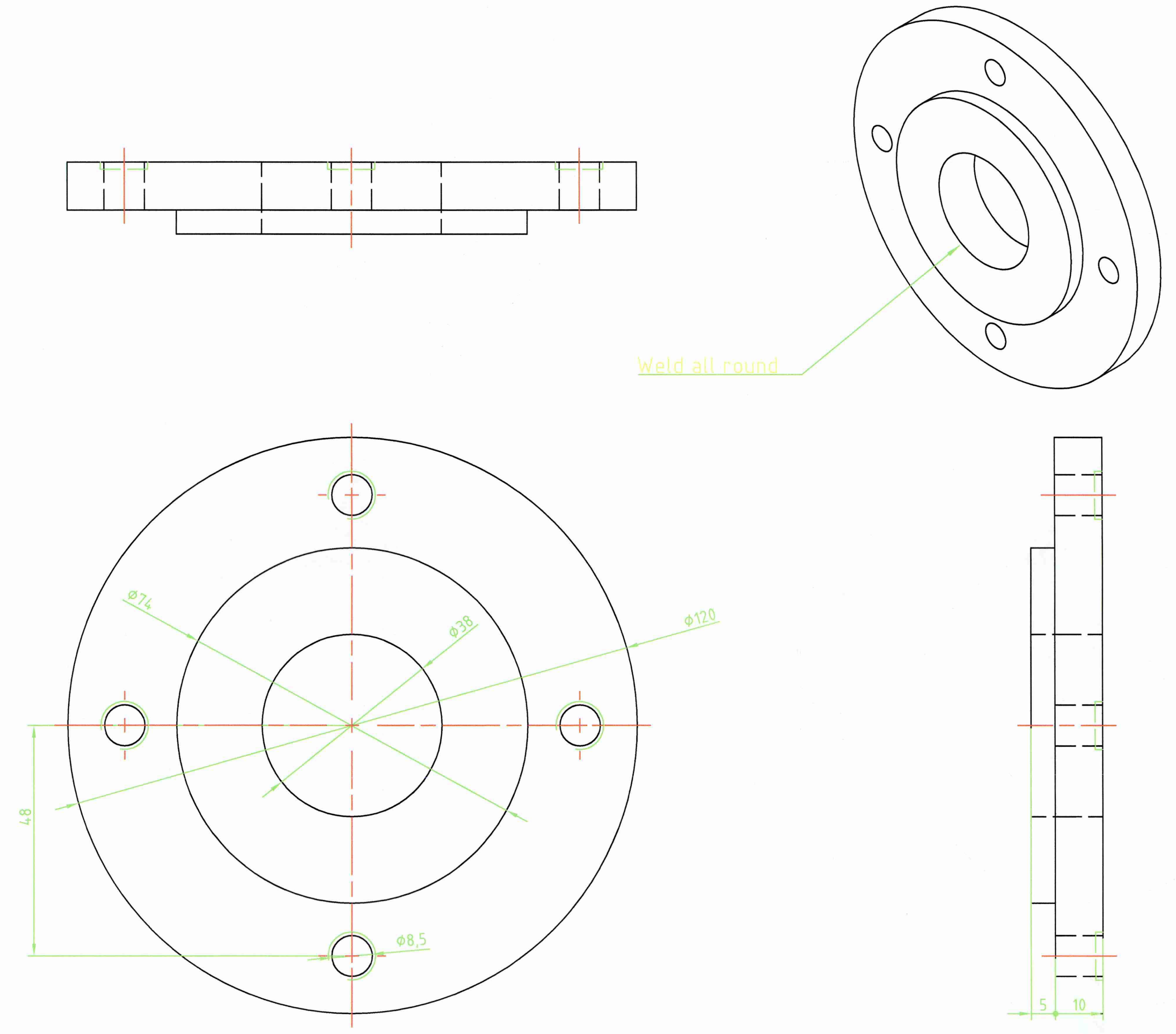
DATE:

TITLE: LAVENDER HARVESTER
FRONT LEFT WHEEL DRIVE SHAFT

CHECKED BY:
DATE:

PART No. 720401P01 SHT. OF.

DO NOT SCALE



PART No. 720402P01

ISSUE	CHANGE RECORD DATE+AUTHY	
1	PRODUCTION REL.	CD02

NOTES: FIT AND WELD THE WHEEL SHAFT AT THE HOUSING

Cranfield UNIVERSITY Silsoe

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NSRI ENGINEERING GROUP
SILSOE CAMPUS, SILSOE,
BEDFORDSHIRE, MK45 4DT,
UNITED KINGDOM.

TEL +44 (0) 1525 863000
FAX +44 (0) 1525 863001

MATERIAL
MILD STEEL
FINISH

No.off
1

DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE SPECIFIED

THIRD ANGLE PROJECTION

TOLERANCES ON DIMENSIONS UNLESS OTHERWISE SPECIFIED

NOMINAL SIZE OF DIMENSION	0-120	120-315	315-1000	1000+
0 or 1 DECIMAL PLACE	+-0.5	+-1	+-1.5	+-3.0
2 DECIMAL PLACES	+/- 0.25			
ANGULAR TOLERANCE	+/- 0° 30'			

DRAWN BY: CHRISTOS I.DIMITRIADIS
TEL.Ex.
DATE:

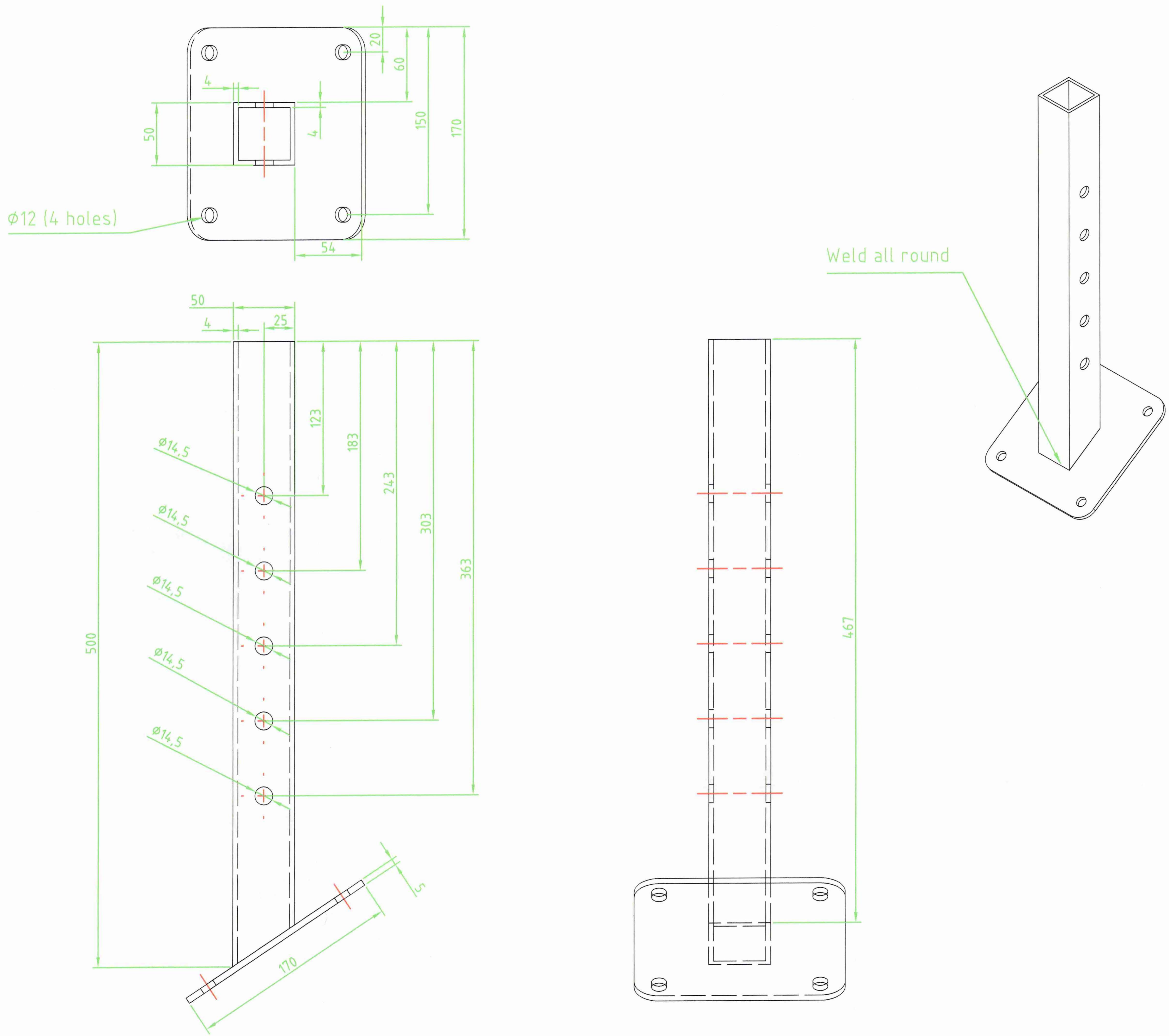
TITLE
LAVENDER HARVESTER
FRONT LEFT DRIVE WHEEL HOUSING

CHECKED BY:
DATE:

DO NOT SCALE

PART No. 720402P01
SHT. OF.

3



PART No. 720500P01

ISSUE	CHANGE RECORD	DATE+AUTHY
1	PRODUCTION REL.	CD02

NOTES:

Cranfield UNIVERSITY Silsoe
SILSOE CAMPUS DESIGN OFFICE
NSRI ENGINEERING GROUP
SILSOE CAMPUS, SILSOE,
BEDFORDSHIRE, MK45 4DT,
UNITED KINGDOM.
TEL +44 (0) 1525 863000
FAX +44 (0) 1525 863001

MATERIAL: MILD STEEL
No.off: 1
FINISH

DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE SPECIFIED
THIRD ANGLE PROJECTION

TOLERANCES ON DIMENSIONS UNLESS OTHERWISE SPECIFIED

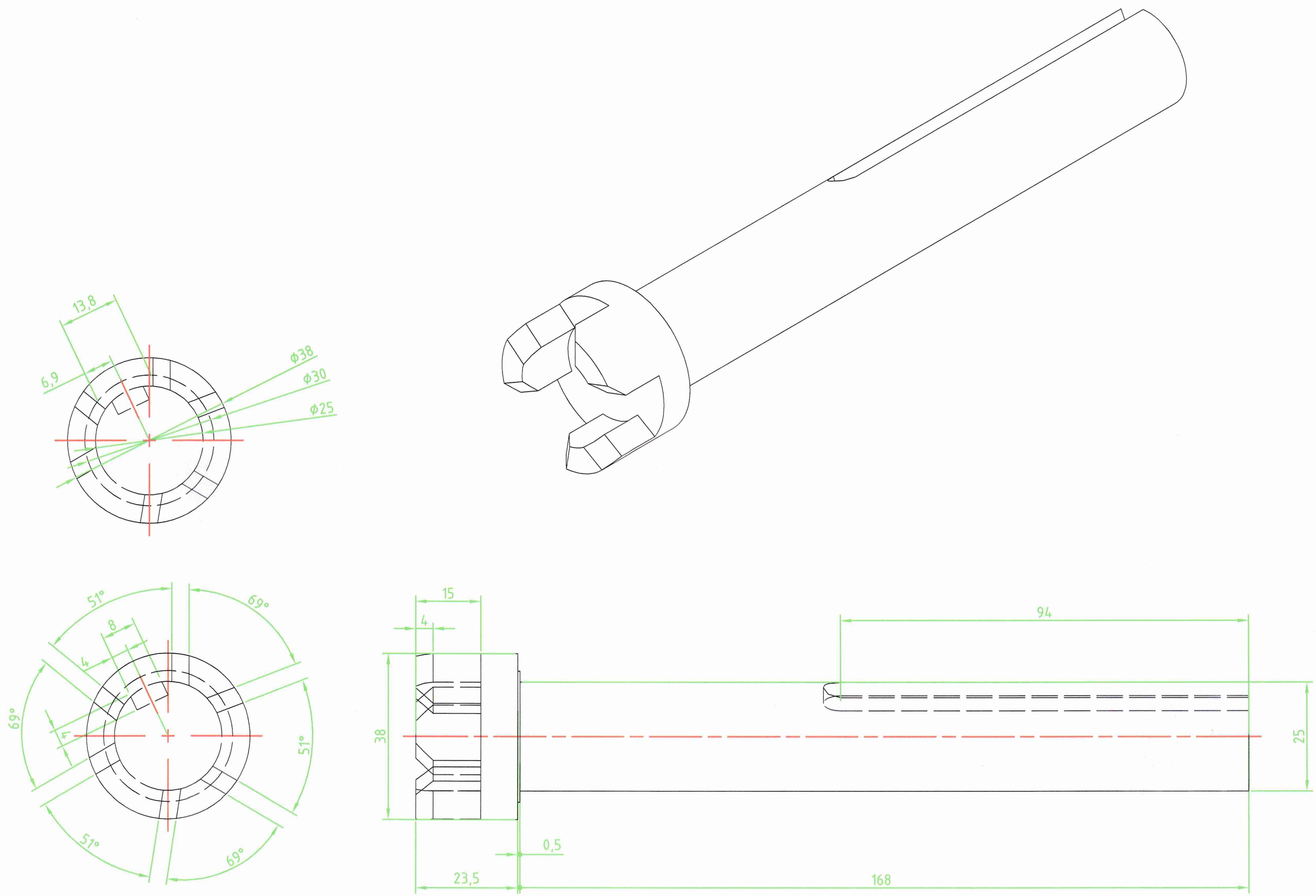
NOMINAL SIZE OF DIMENSION	0–120	120–315	315–1000	1000+
0 or 1 DECIMAL PLACE	+-0.5	+-1	+-1.5	+-3.0
2 DECIMAL PLACES	+/- 0.25			
ANGULAR TOLERANCE	+/- 0° 30'			

DRAWN BY: CHRISTOS I.DIMITRIADIS
TEL.Ex.
DATE:
TITLE: LAVENDER HARVESTER
REAR LEG INSERT
CHECKED BY:
DATE:
PART No. 720500P01
SHT. OF.
DO NOT SCALE

PART No. 720600P01

ISSUE	CHANGE RECORD	DATE+AUTHY
1	PRODUCTION REL.	CD02

NOTES:



Cranfield UNIVERSITY Silsoe
SILSOE CAMPUS DESIGN OFFICE
NSRI ENGINEERING GROUP
SILSOE CAMPUS, SILSOE,
BEDFORDSHIRE, MK45 4DT,
UNITED KINGDOM.
TEL +44 (0) 1525 863000
FAX +44 (0) 1525 863001

MATERIAL: MILD STEEL
FINISH:
No.off: 1

DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE SPECIFIED

THIRD ANGLE PROJECTION

TOLERANCES ON DIMENSIONS UNLESS OTHERWISE SPECIFIED

NOMINAL SIZE OF DIMENSION	0-120	120-315	315-1000	1000+
0 or 1 DECIMAL PLACE	+-0.5	+-1	+-1.5	+-3.0
2 DECIMAL PLACES	+/- 0.25			
ANGULAR TOLERANCE	+/- 0° 30'			

DRAWN BY: CHRISTOS I.DIMITRIADIS
TEL.Ex.
DATE:

TITLE: LAVENDER HARVESTER
P.T.O SHAFT

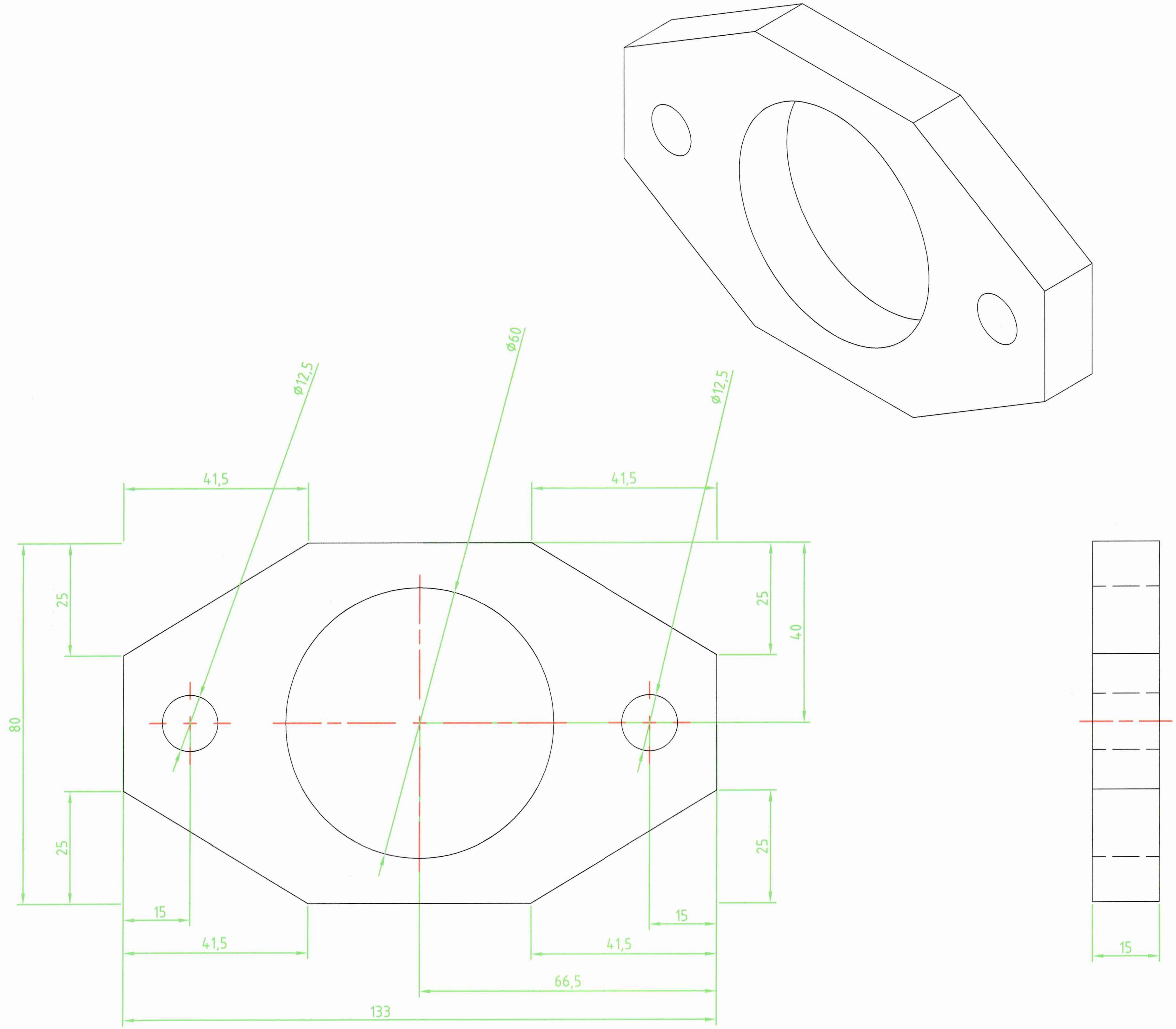
CHECKED BY:
DATE:

PART No. 720600P01
SHT. OF.

DO NOT SCALE

PART No.	720601P01	
ISSUE	CHANGE RECORD	DATE+AUTHY
1	PRODUCTION REL.	CD02

NOTES:



Cranfield UNIVERSITY Silsoe
SILSOE CAMPUS DESIGN OFFICE
NSRI ENGINEERING GROUP
SILSOE CAMPUS, SILSOE,
BEDFORDSHIRE, MK45 4DT,
UNITED KINGDOM.
TEL +44 (0) 1525 863000
FAX +44 (0) 1525 863001

MATERIAL: MILD STEEL

FINISH

No.off: 1

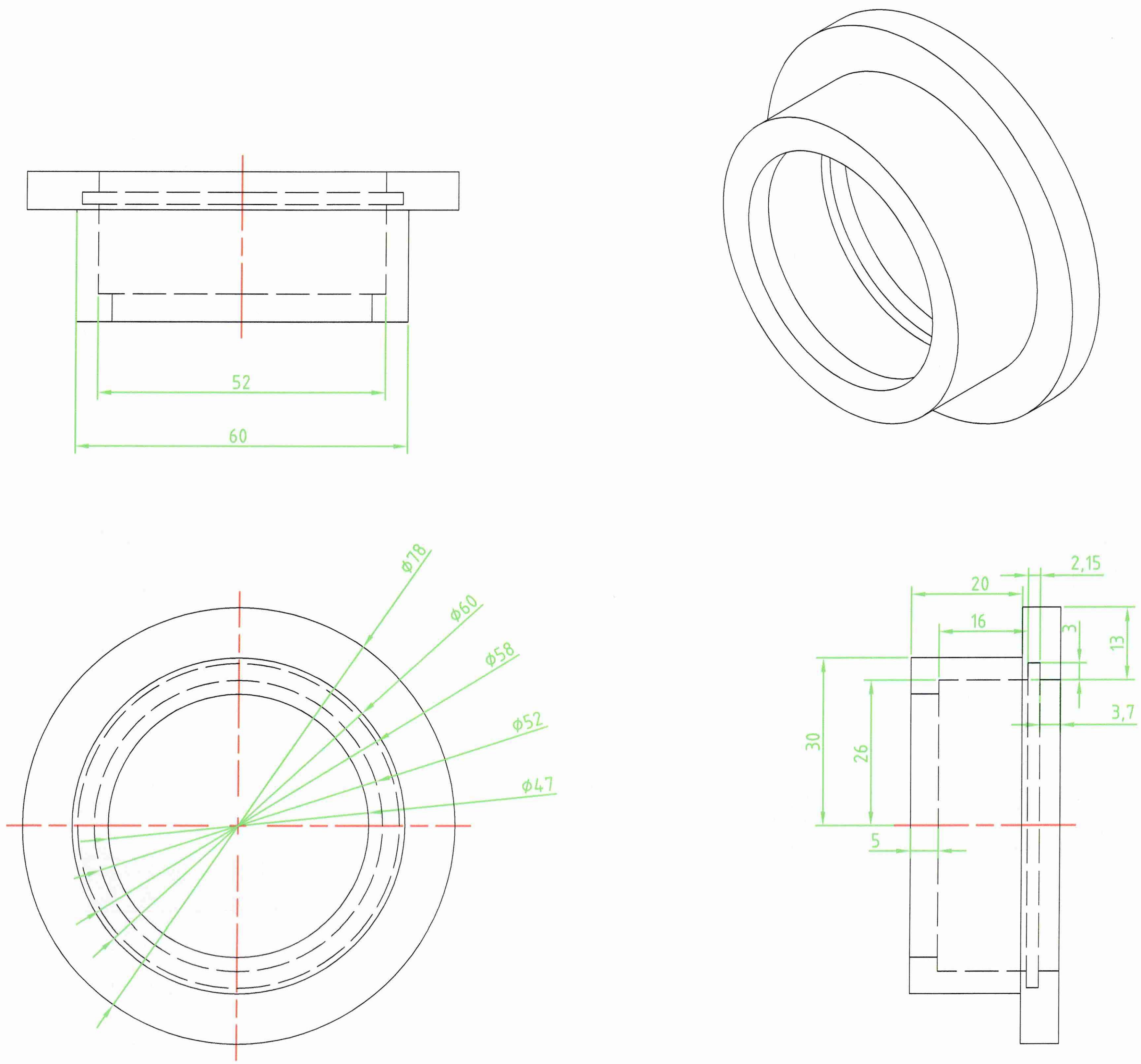
DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE SPECIFIED

THIRD ANGLE PROJECTION

TOLERANCES ON DIMENSIONS UNLESS OTHERWISE SPECIFIED

NOMINAL SIZE OF DIMENSION	0-120	120-315	315-1000	1000+
0 or 1 DECIMAL PLACE	+-0.5	+-1	+-1.5	+-3.0
2 DECIMAL PLACES	+/- 0.25			
ANGULAR TOLERANCE	+/- 0° 30'			

DRAWN BY: CHRISTOS I.DIMITRIADIS TEL.Ex. DATE:	TITLE LAVENDER HARVESTER P.T.O HOUSING
CHECKED BY: DATE: DO NOT SCALE	PART No. 720601P01 SHT. OF.



PART No.	720602P01	
ISSUE	CHANGE RECORD DATE+AUTHY	
1	PRODUCTION REL.	CD02

NOTES:

Cranfield UNIVERSITY Silsoe

SILSOE CAMPUS DESIGN OFFICE
NSRI ENGINEERING GROUP
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BEDFORDSHIRE, MK45 4DT,
UNITED KINGDOM.

TEL +44 (0) 1525 863000
FAX +44 (0) 1525 863001

MATERIAL: MILD STEEL

FINISH:

No.off: 1

DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE SPECIFIED

THIRD ANGLE PROJECTION

TOLERANCES ON DIMENSIONS UNLESS OTHERWISE SPECIFIED

NOMINAL SIZE OF DIMENSION	0-120	120-315	315-1000	1000+
0 or 1 DECIMAL PLACE	+-0.5	+-1	+-1.5	+-3.0
2 DECIMAL PLACES	+/- 0.25			
ANGULAR TOLERANCE	+/- 0° 30'			

DRAWN BY: CHRISTOS I.DIMITRIADIS
TEL.Ex.
DATE:

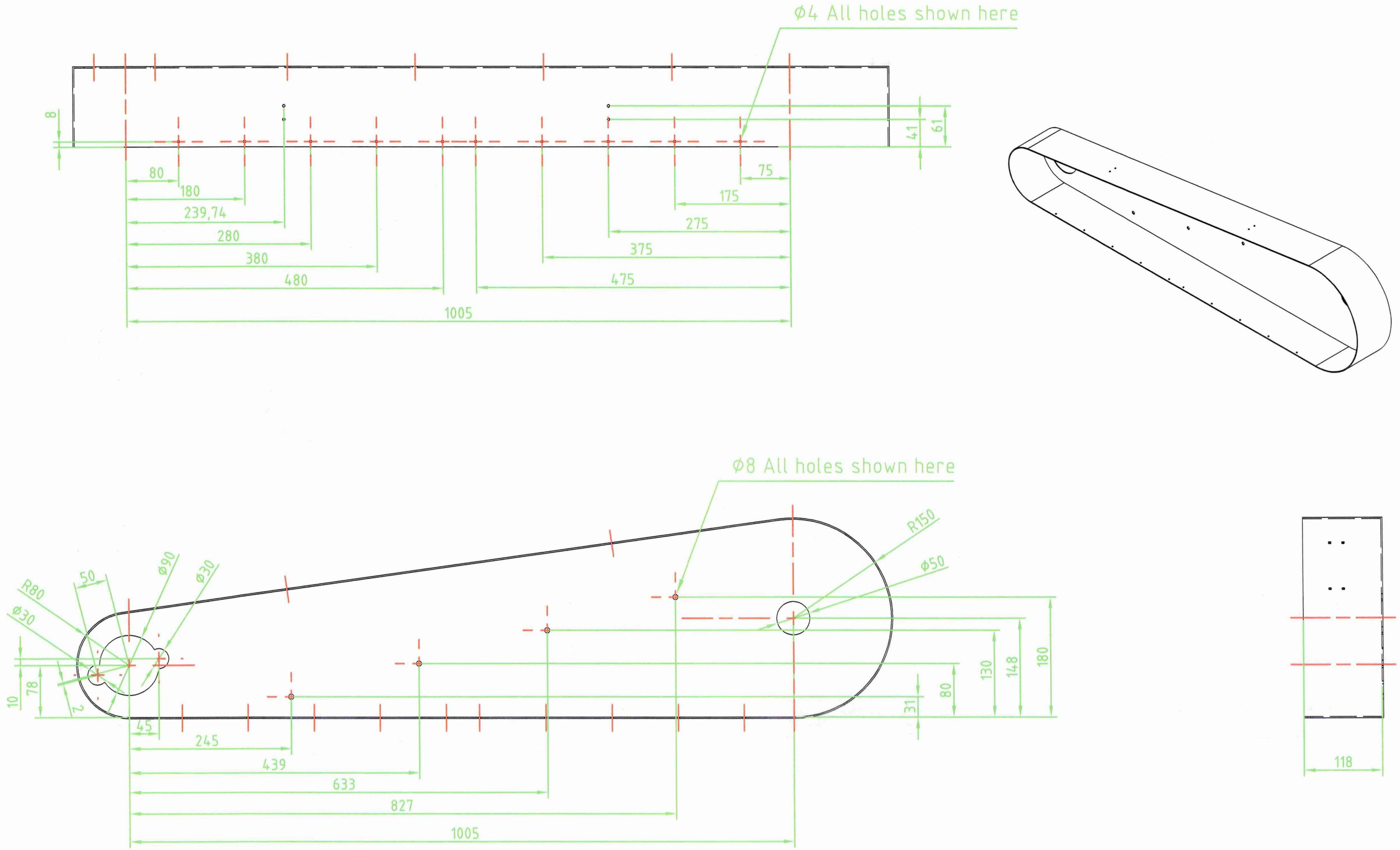
TITLE: LAVENDER HARVESTER
P.T.O RING

CHECKED BY:
DATE:

PART No. 720602P01 SHT. OF.

DO NOT SCALE

32



PART No.	720700 P01		
ISSUE	CHANGE RECORD	DATE+AUTHY	
1	PRODUCTION REL.		CD02

NOTES:

Cranfield UNIVERSITY Silsoe
SILSOE CAMPUS DESIGN OFFICE
SILSOE CAMPUS, SILSOE,
BEDFORDSHIRE, MK45 4DT,
UNITED KINGDOM.
TEL +44 (0) 1525 863000
FAX +44 (0) 1525 863001

MATERIAL: MILD STEEL
FINISH
No.off: 1

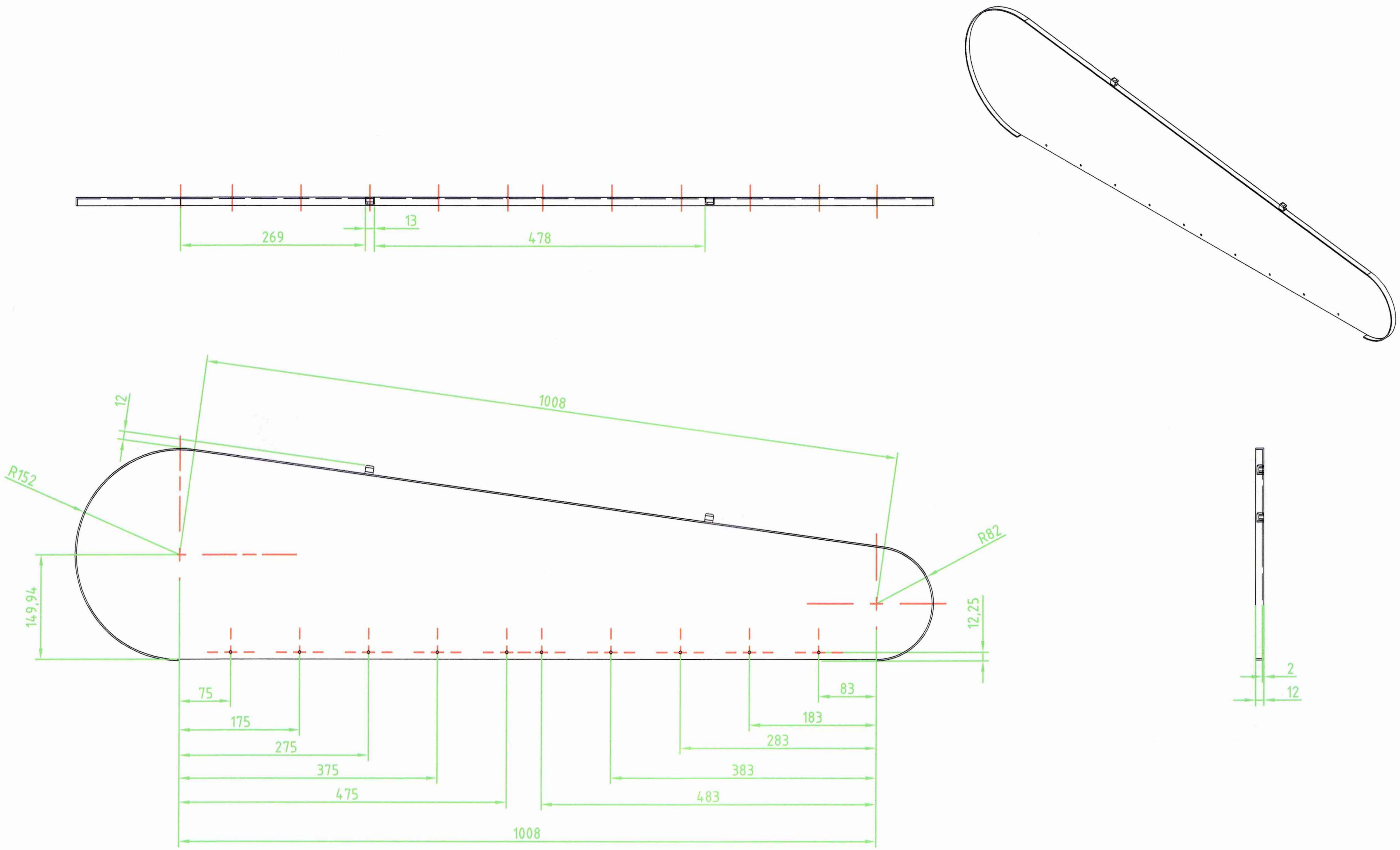
DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE SPECIFIED
THIRD ANGLE PROJECTION

TOLERANCES ON DIMENSIONS UNLESS OTHERWISE SPECIFIED

NOMINAL SIZE OF DIMENSION	0-120	120-315	315-1000	1000+
0 or 1 DECIMAL PLACE	+-0.5	+-1	+-1.5	+-3.0
2 DECIMAL PLACES	+/- 0.25			
ANGULAR TOLERANCE	+/- 0° 30'			

DRAWN BY: CHRISTOS I.DEMETRIADIS
TEL.Ex.
DATE:
TITLE: LAVENDER HARVESTER
VIOLIN CASE
CHECKED BY:
DATE:
PART No. 720700 P01
SHT. OF.
DO NOT SCALE

33



PART No. 720701P01

ISSUE	CHANGE RECORD	DATE+AUTHY
1	PRODUCTION REL.	CD02

NOTES:

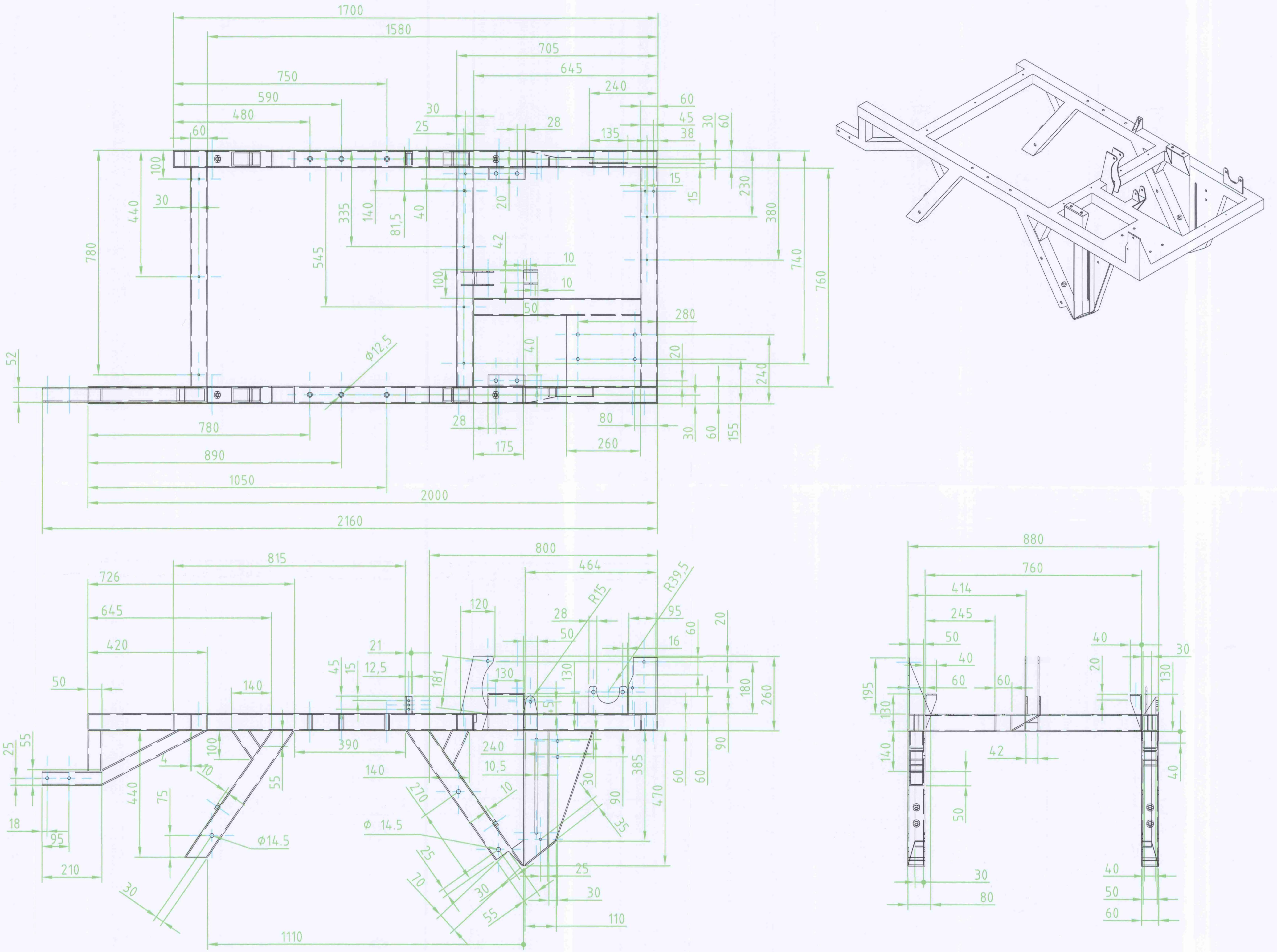
Cranfield UNIVERSITY Silsoe
SILSOE CAMPUS DESIGN OFFICE
SILSOE CAMPUS, SILSOE,
BEDFORDSHIRE, MK45 4DT,
UNITED KINGDOM.
TEL +44 (0) 1525 863000
FAX +44 (0) 1525 863001

MATERIAL: MILD STEEL
FINISH:
No.off: 1

DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE SPECIFIED
THIRD ANGLE PROJECTION

TOLERANCES ON DIMENSIONS UNLESS OTHERWISE SPECIFIED
NOMINAL SIZE OF DIMENSION: 0-120 120-315 315-1000 1000+
0 or 1 DECIMAL PLACE +-0.5 +-1 +-1.5 +-3.0
2 DECIMAL PLACES +/- 0.25
ANGULAR TOLERANCE +/- 0° 30'

DRAWN BY: CHRISTOS I.DIMITRIADIS
TEL.Ex.
DATE:
TITLE: LAVENDER HARVESTER
VIOLIN COVER
CHECKED BY:
DATE:
PART No. 720701P01 SHT. OF.
DO NOT SCALE



PART No. 720800P01

ISSUE	CHANGE RECORD	DATE+AUTHY
1	PRODUCTION REL.	CD02

NOTES:

Cranfield UNIVERSITY Silsoe

INSTITUTE OF AGRITECHNOLOGY
SILSOE CAMPUS, SILSOE,
BEDFORDSHIRE, MK45 4DT,
UNITED KINGDOM.

TEL +44 (0) 1525 863000
FAX +44 (0) 1525 863001

MATERIAL
MILD STEEL
FINISH

No.off

DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE SPECIFIED

THIRD ANGLE PROJECTION

TOLERANCES ON DIMENSIONS UNLESS OTHERWISE SPECIFIED

NOMINAL SIZE OF DIMENSION	0-120	120-315	315-1000	1000+
0 or 1 DECIMAL PLACE	+-0.5	+-1	+-1.5	+-3.0
2 DECIMAL PLACES	+/- 0.25			
ANGULAR TOLERANCE	+/- 0' 30'			

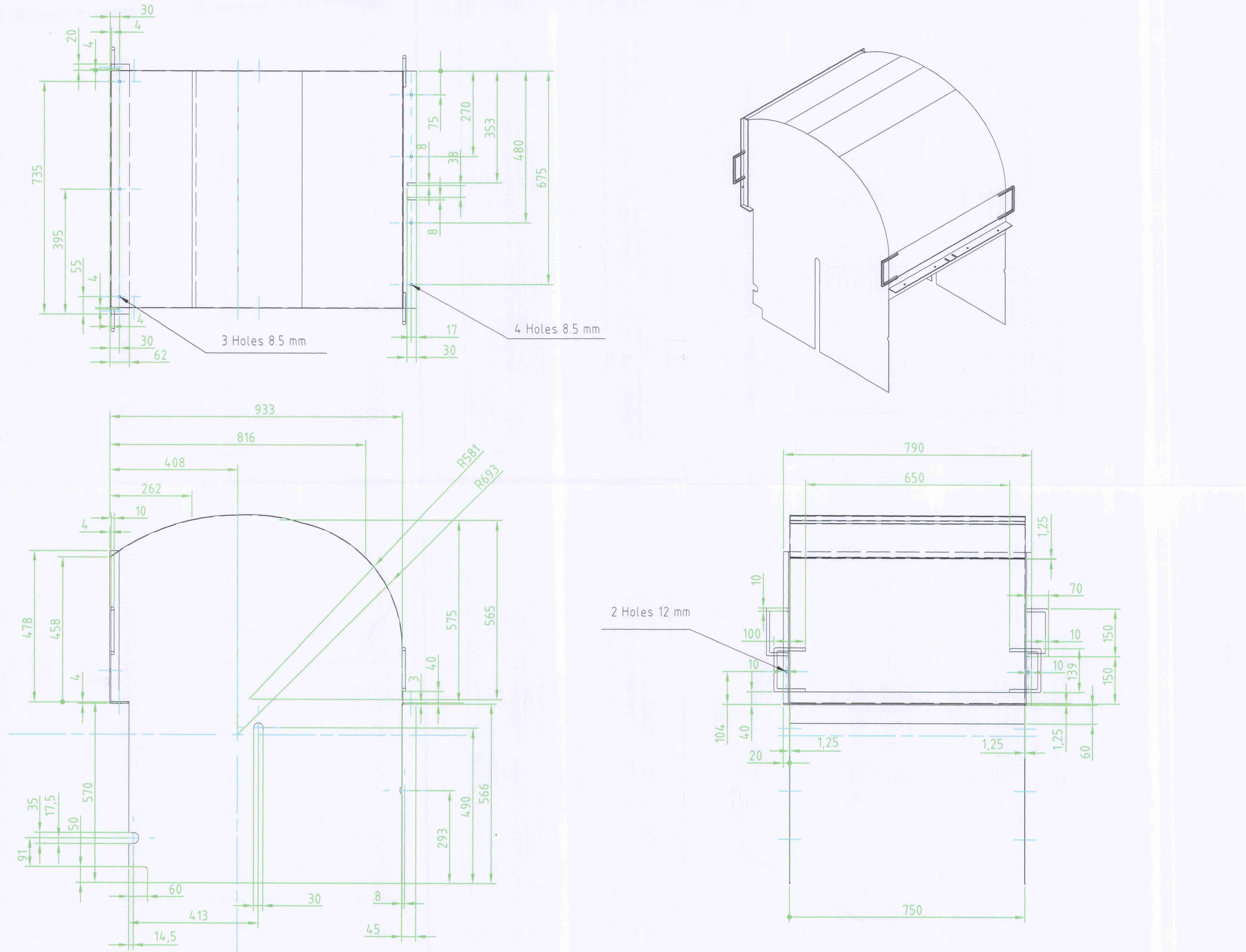
DRAWN BY: CHRISTOS I.DIMITRIADIS
TEL.Ex.
DATE:

TITLE: LAVENDER HARVESTER FRAME

CHECKED BY:
DATE:

PART No. 720800P01 SHT. OF.

DO NOT SCALE



PART No. 720801P01

ISSUE	CHANGE RECORD	DATE+AUTHY
1	PRODUCTION REL.	CD02

NOTES:

Cranfield UNIVERSITY Silsoe
INSTITUTE OF AGRITECHNOLOGY
SILSOE CAMPUS, SILSOE,
BEDFORDSHIRE, MK45 4DT,
UNITED KINGDOM.
TEL +44 (0) 1525 863000
FAX +44 (0) 1525 863001

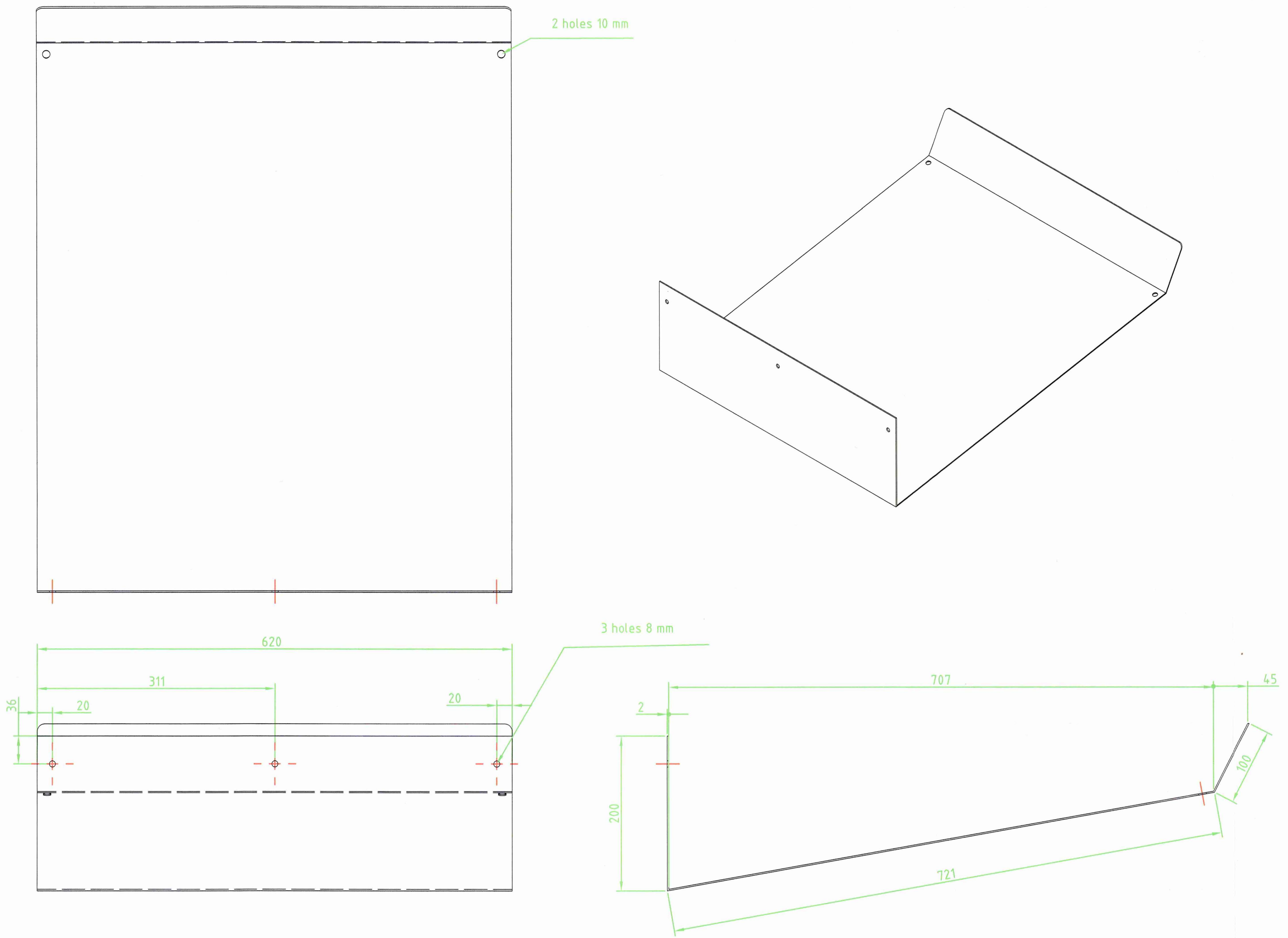
MATERIAL MILD STEEL
FINISH
No.off

DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE SPECIFIED
THIRD ANGLE PROJECTION

TOLERANCES ON DIMENSIONS UNLESS OTHERWISE SPECIFIED

NOMINAL SIZE OF DIMENSION	0-120	120-315	315-1000	1000+
0 or 1 DECIMAL PLACE	+-0.5	+-1	+-1.5	+-3.0
2 DECIMAL PLACES	+/- 0.25			
ANGULAR TOLERANCE	+/- 0° 30'			

DRAWN BY: CHR.I.DIMITRIADIS
TEL.Ex.
DATE:
TITLE LAVENDER HARVESTER HOOD COVER
CHECKED BY:
DATE:
PART No. 720801P01
SHT. OF.
DO NOT SCALE



PART No. 720802P01

ISSUE	CHANGE RECORD	DATE+AUTHY
1	PRODUCTION REL.	CD02

NOTES:

Cranfield UNIVERSITY Silsoe
SILSOE CAMPUS DESIGN OFFICE
NSRI ENGINEERING GROUP
SILSOE CAMPUS, SILSOE,
BEDFORDSHIRE, MK45 4DT,
UNITED KINGDOM.
TEL +44 (0) 1525 863000
FAX +44 (0) 1525 863001

MATERIAL: MILD STEEL
FINISH:
No.off: 1

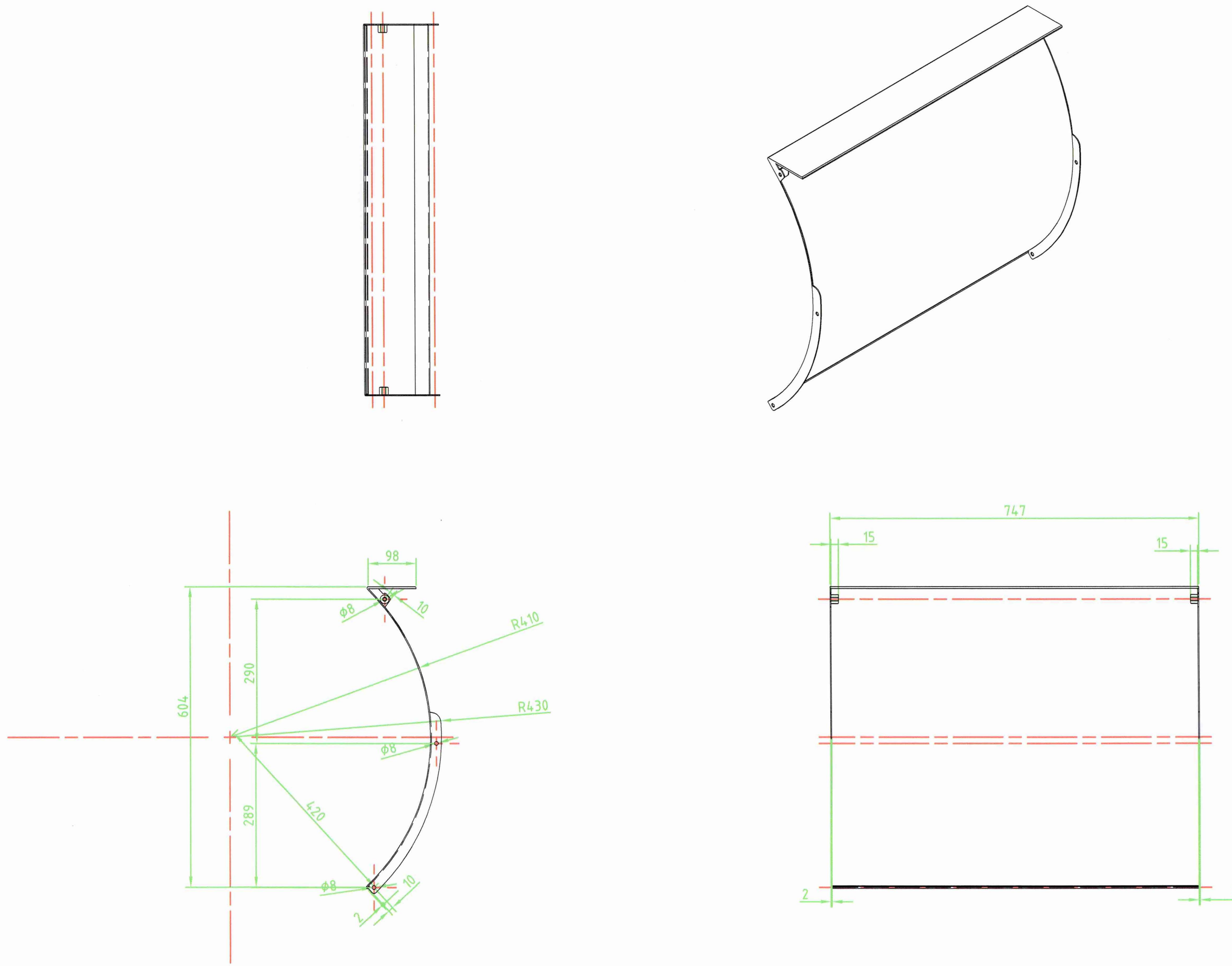
DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE SPECIFIED
THIRD ANGLE PROJECTION

TOLERANCES ON DIMENSIONS UNLESS OTHERWISE SPECIFIED

NOMINAL SIZE OF DIMENSION	0-120	120-315	315-1000	1000+
0 or 1 DECIMAL PLACE	+-0.5	+-1	+-1.5	+-3.0
2 DECIMAL PLACES	+/- 0.25			
ANGULAR TOLERANCE	+/- 0° 30'			

DRAWN BY: CHRISTOS I.DIMITRIADIS
TEL.Ex.
DATE:
TITLE: LAVENDER HARVESTER HOOD NOSE
CHECKED BY:
DATE:
PART No. 720802P01
SHT. OF.
DO NOT SCALE

37



PART No.	720803P01	
ISSUE	CHANGE RECORD	DATE+AUTHY
1	PRODUCTION REL.	CD02

NOTES:

Cranfield UNIVERSITY Silsoe
SILSOE CAMPUS DESIGN OFFICE
NSRI ENGINEERING GROUP
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BEDFORDSHIRE, MK45 4DT,
UNITED KINGDOM.
TEL +44 (0) 1525 863000
FAX +44 (0) 1525 863001

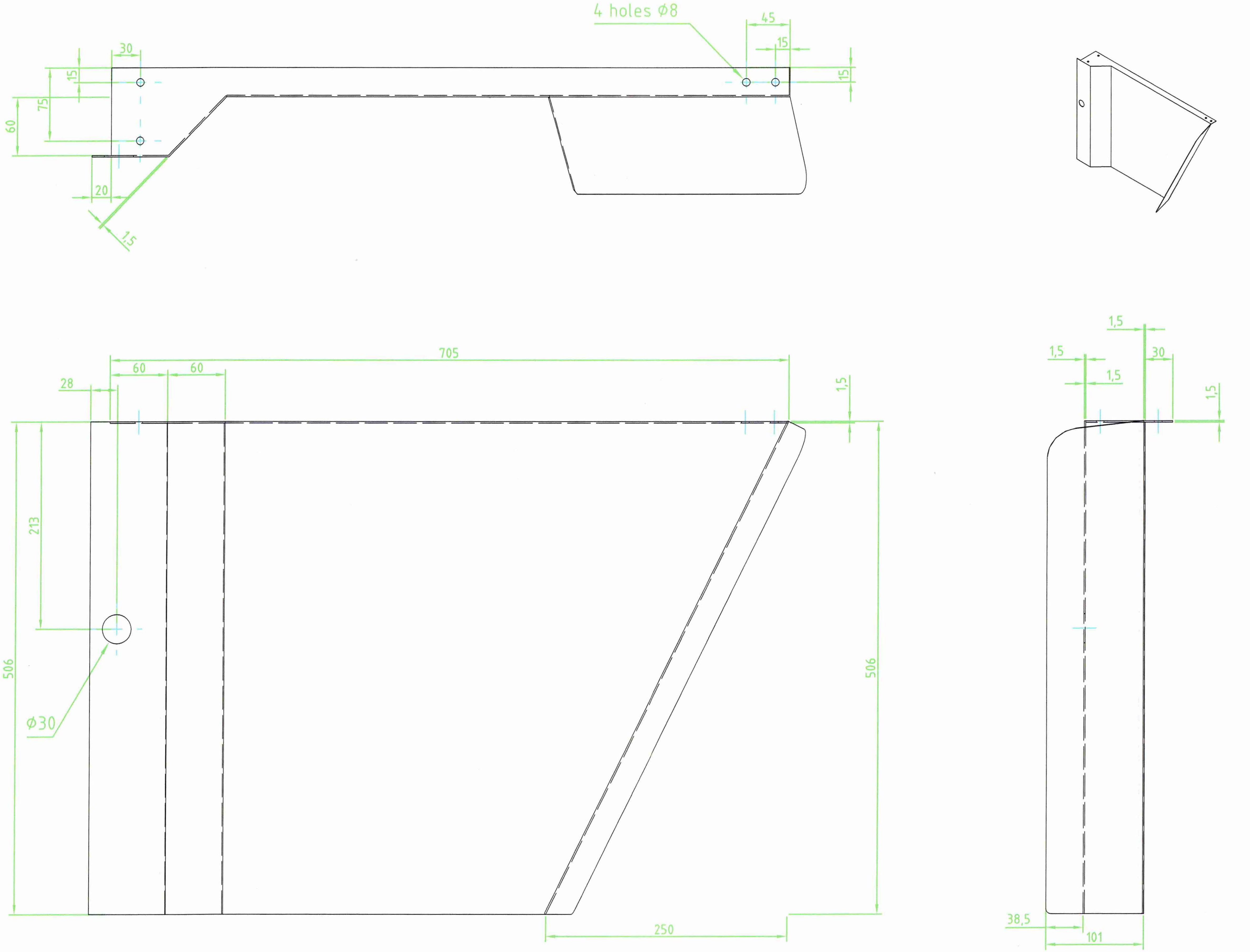
MATERIAL: MILD STEEL
FINISH:
No.off: 1

DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE SPECIFIED
THIRD ANGLE PROJECTION

TOLERANCES ON DIMENSIONS UNLESS OTHERWISE SPECIFIED

NOMINAL SIZE OF DIMENSION	0-120	120-315	315-1000	1000+
0 or 1 DECIMAL PLACE	+-0.5	+-1	+-1.5	+-3.0
2 DECIMAL PLACES	+/- 0.25			
ANGULAR TOLERANCE	+/- 0° 30'			

DRAWN BY: CHRISTOS I.DIMITRIADIS
TEL.Ex.
DATE:
TITLE: LAVENDER HARVESTER UNDER COVER
CHECKED BY:
DATE:
PART No. 720803P01
SHT. OF.
DO NOT SCALE



PART No.	720804P01	
ISSUE	CHANGE RECORD DATE+AUTHY	
1	PRODUCTION REL.	CD03

NOTES:

Cranfield UNIVERSITY Silsoe
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UNITED KINGDOM.
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FAX +44 (0) 1525 863001

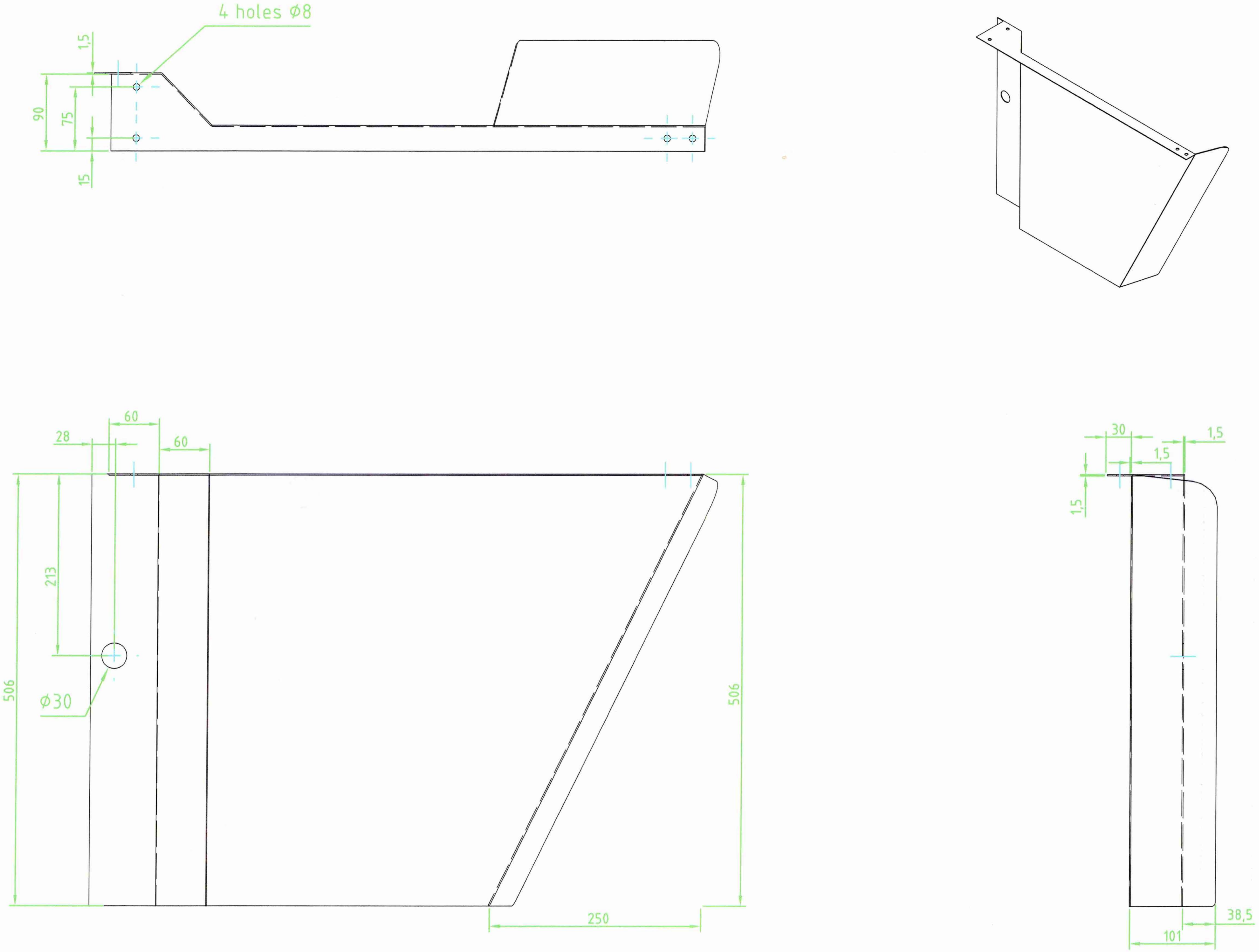
MATERIAL MILD STEEL
FINISH
No.off

DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE SPECIFIED
THIRD ANGLE PROJECTION

TOLERANCES ON DIMENSIONS UNLESS OTHERWISE SPECIFIED

NOMINAL SIZE OF DIMENSION	0-120	120-315	315-1000	1000+
0 or 1 DECIMAL PLACE	+-0.5	+-1	+-1.5	+-3.0
2 DECIMAL PLACES	+/- 0.25			
ANGULAR TOLERANCE	+/- 0' 30'			

DRAWN BY: CHR. I. DIMITRIADIS
TEL.Ex.
DATE:
TITLE LAVENDER HARVESTER RIGHT INTERNAL SIDE
CHECKED BY:
DATE:
PART No. 720804P01 SHT. OF.
DO NOT SCALE



PART No. 720805P01

ISSUE	CHANGE RECORD DATE+AUTHY	
1	PRODUCTION REL.	CD02

NOTES:

Cranfield UNIVERSITY Silsoe
INSTITUTE OF AGRITECHNOLOGY
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BEDFORDSHIRE, MK45 4DT,
UNITED KINGDOM.
TEL +44 (0) 1525 863000
FAX +44 (0) 1525 863001

MATERIAL: MILD STEEL
No.off
FINISH

DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE SPECIFIED
THIRD ANGLE PROJECTION

TOLERANCES ON DIMENSIONS UNLESS OTHERWISE SPECIFIED

NOMINAL SIZE OF DIMENSION	0-120	120-315	315-1000	1000+
0 or 1 DECIMAL PLACE	+-0.5	+-1	+-1.5	+-3.0
2 DECIMAL PLACES	+/- 0.25			
ANGULAR TOLERANCE	+/- 0° 30'			

DRAWN BY: CHR.I.DIMITRIADIS
TEL.Ex.
DATE:

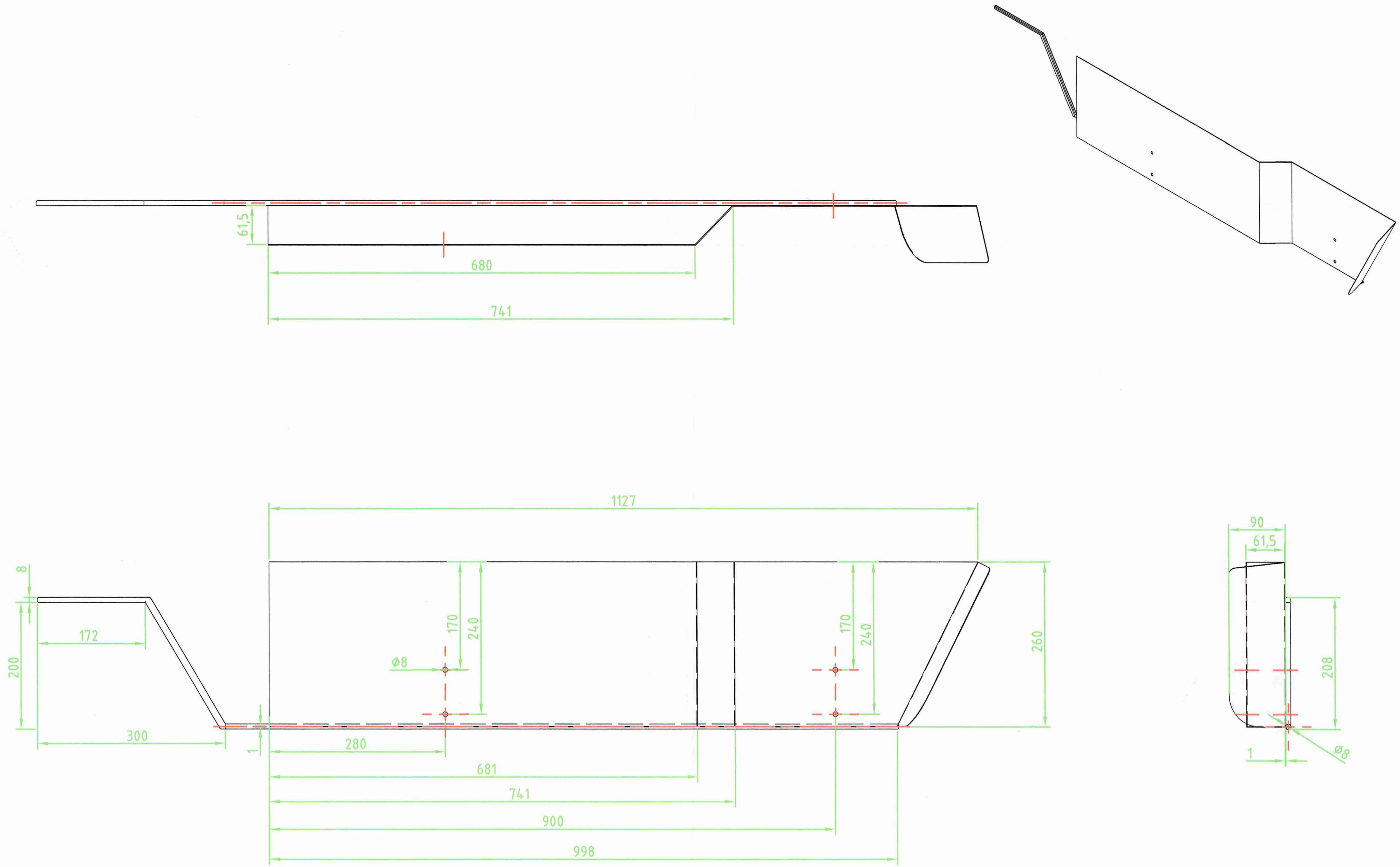
TITLE: LAVENDER HARVESTER
LEFT INTERNAL SIDE

CHECKED BY:
DATE:

PART No. 720805P01 SHT. OF.

DO NOT SCALE

40



PART No. 720806P01

ISSUE	CHANGE RECORD	DATE+AUTHY
1	PRODUCTION REL.	CD01

NOTES:

Cranfield UNIVERSITY Silsoe
SILSOE CAMPUS DESIGN OFFICE
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FAX +44 (0) 1525 863001

MATERIAL: MILD STEEL
FINISH:
No.off: 1

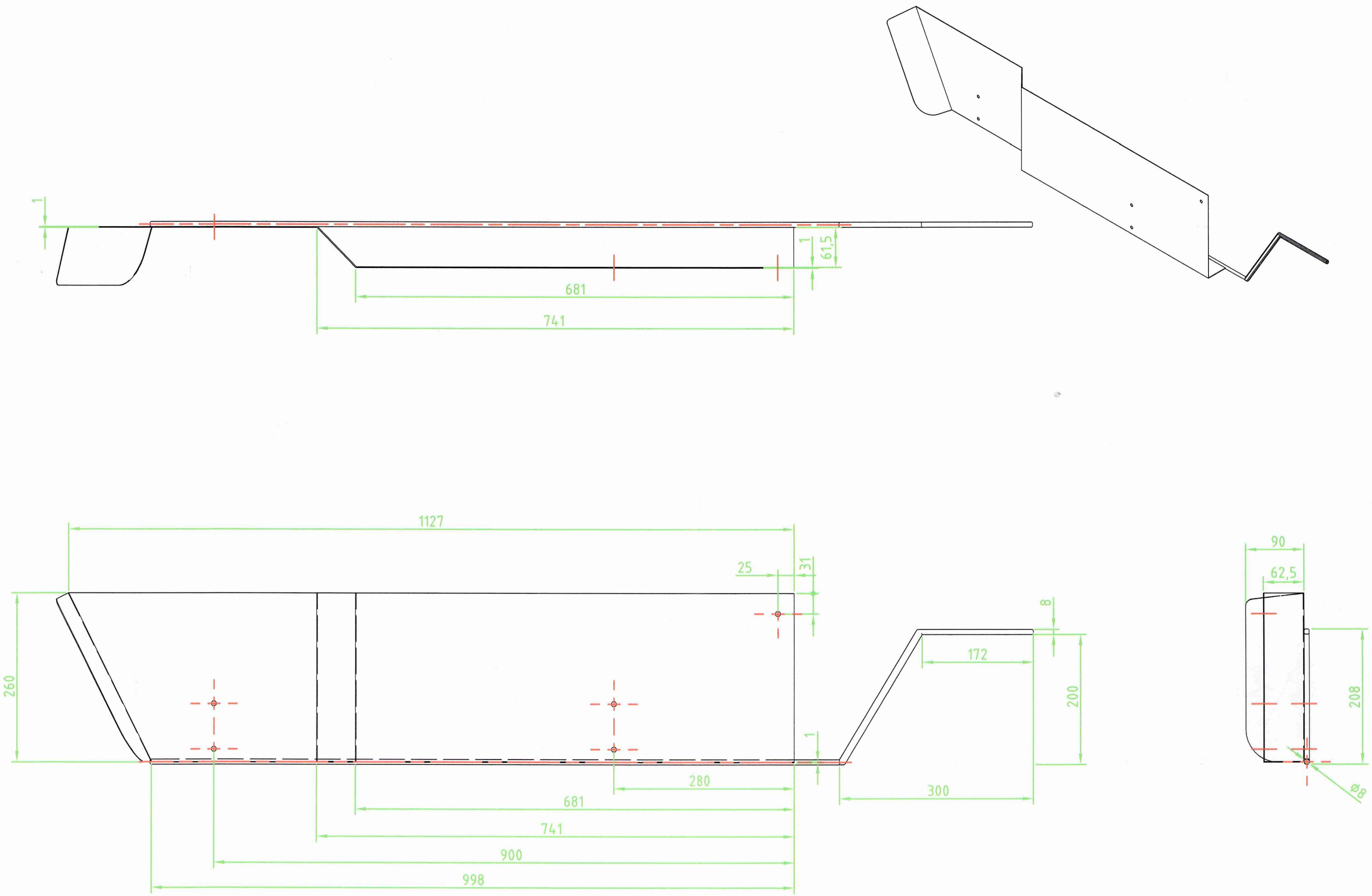
DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE SPECIFIED
THIRD ANGLE PROJECTION

TOLERANCES ON DIMENSIONS UNLESS OTHERWISE SPECIFIED

NOMINAL SIZE OF DIMENSION	0-120	120-315	315-1000	1000+
0 or 1 DECIMAL PLACE	+-0.5	+-1	+-1.5	+-3.0
2 DECIMAL PLACES	+/- 0.25			
ANGULAR TOLERANCE	+/- 0° 30'			

DRAWN BY: CHRISTOS I.DIMITRIADIS
TEL.Ex.
DATE:
TITLE: LAVENDER HARVESTER
SIDE RIGHT INTERNAL EXTENSI
CHECKED BY:
DATE:
PART No. 720806P01
SHT. OF.
DO NOT SCALE

41



PART No. 720807P01

ISSUE	CHANGE RECORD	DATE+AUTHY
1	PRODUCTION REL.	CD01

NOTES:

Cranfield UNIVERSITY Silsoe

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UNITED KINGDOM.

TEL +44 (0) 1525 863000
FAX +44 (0) 1525 863001

MATERIAL: MILD STEEL

FINISH

No.off: 1

DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE SPECIFIED

THIRD ANGLE PROJECTION

TOLERANCES ON DIMENSIONS UNLESS OTHERWISE SPECIFIED

NOMINAL SIZE OF DIMENSION	0-120	120-315	315-1000	1000+
0 or 1 DECIMAL PLACE	+-0.5	+-1	+-1.5	+-3.0
2 DECIMAL PLACES	+/- 0.25			
ANGULAR TOLERANCE	+/- 0° 30'			

DRAWN BY: CHRISTOS I.DIMITRIADIS
TEL.Ex.
DATE:

CHECKED BY:
DATE:

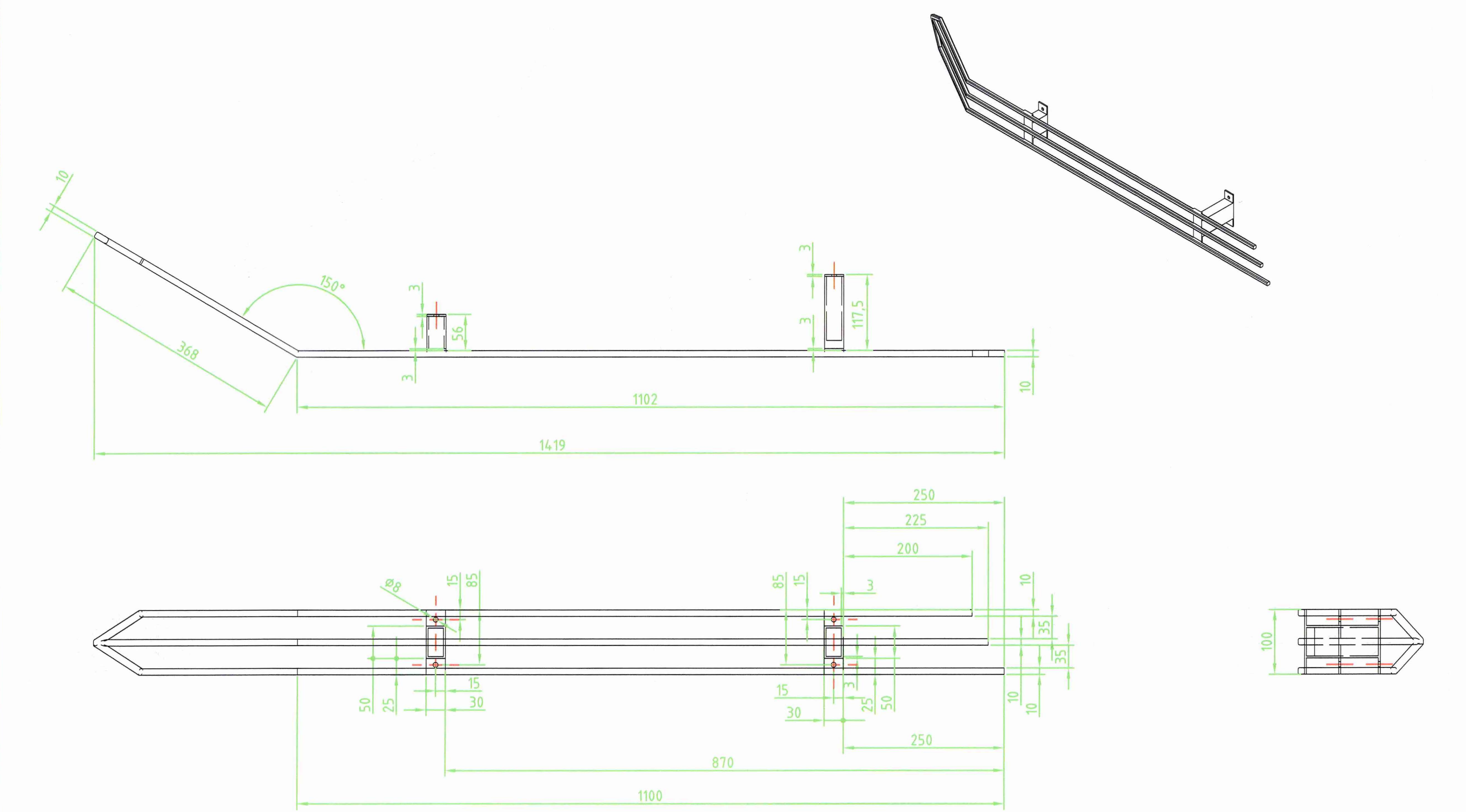
DO NOT SCALE

TITLE: LAVENDER HARVESTER
SIDE LEFT INTERNAL EXTENSION

PART No. 720807P01

SHT. OF.

42



PART No. 720808P01

ISSUE	CHANGE RECORD	DATE+AUTHY
1	PRODUCTION REL.	CD02

NOTES:

Cranfield UNIVERSITY Silsoe
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FAX +44 (0) 1525 863001

MATERIAL: MILD STEEL

FINISH:

No.off: 1

DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE SPECIFIED

THIRD ANGLE PROJECTION

TOLERANCES ON DIMENSIONS UNLESS OTHERWISE SPECIFIED

NOMINAL SIZE OF DIMENSION	0-120	120-315	315-1000	1000+
0 or 1 DECIMAL PLACE	+-0.5	+-1	+-1.5	+-3.0
2 DECIMAL PLACES	+/- 0.25			
ANGULAR TOLERANCE	+/- 0° 30'			

DRAWN BY: CHRISTOS I.DIMITRIADIS
TEL.Ex.
DATE:

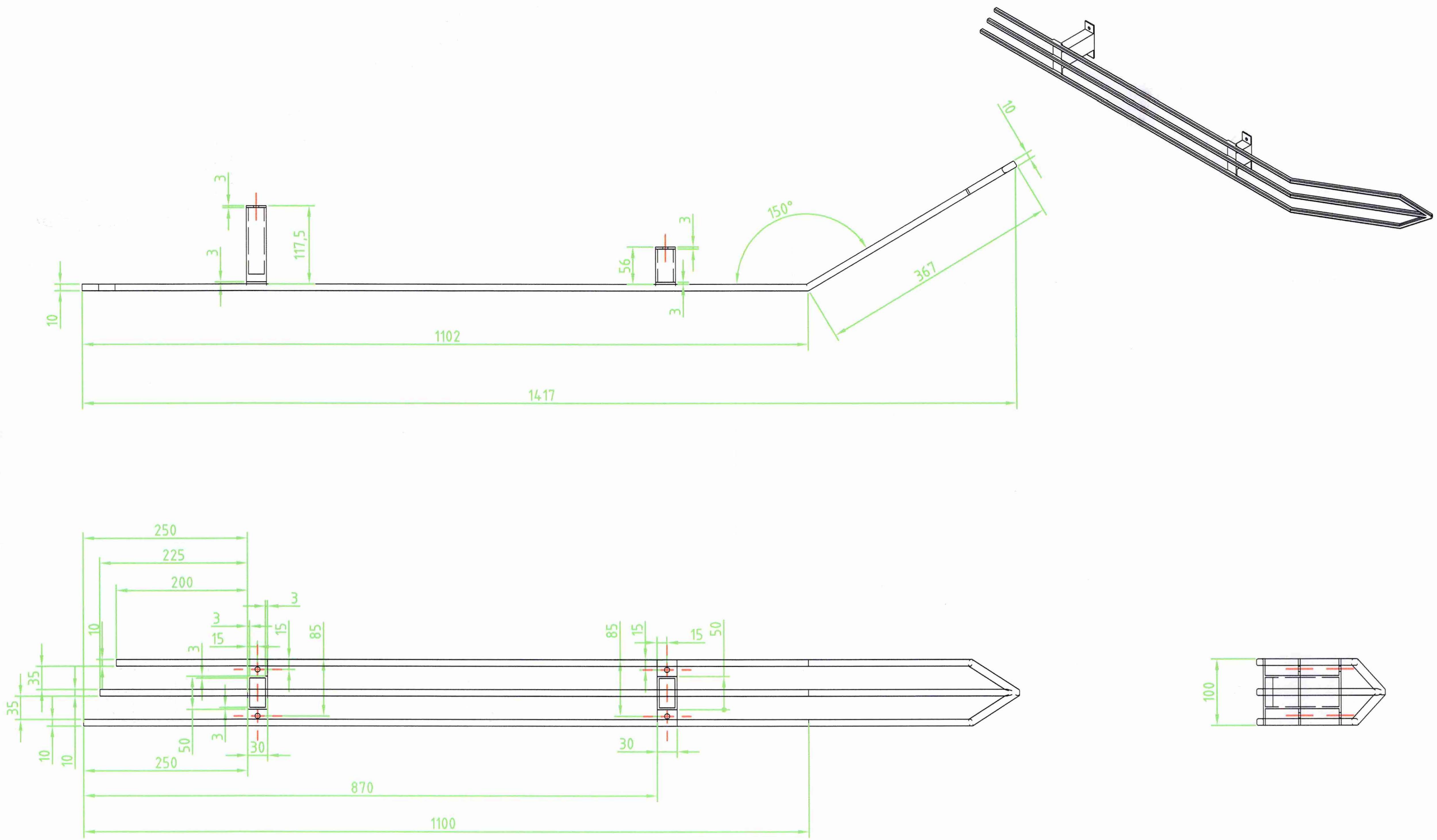
TITLE: LAVENDER HARVESTER LATERAL RIGHT GUIDE

CHECKED BY:
DATE:

PART No. 720808P01 SHT. OF.

DO NOT SCALE

43



PART No.	720809 P01	
ISSUE	CHANGE RECORD	DATE+AUTHY
1	PRODUCTION REL.	CD02

NOTES:

Cranfield UNIVERSITY Silsoe
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TEL +44 (0) 1525 863000
FAX +44 (0) 1525 863001

MATERIAL: MILD STEEL
FINISH:
No.off: 1

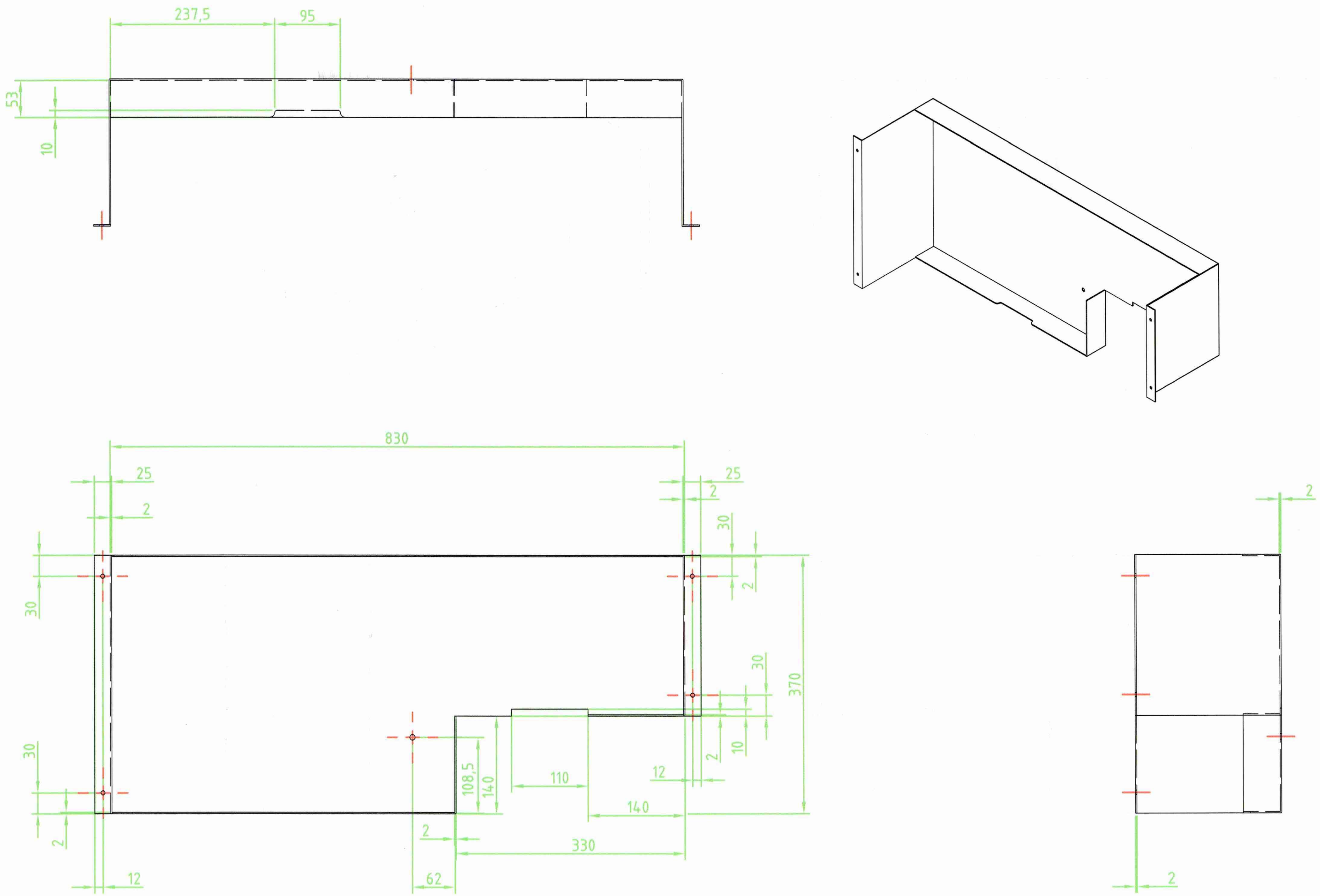
DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE SPECIFIED
THIRD ANGLE PROJECTION

TOLERANCES ON DIMENSIONS UNLESS OTHERWISE SPECIFIED

NOMINAL SIZE OF DIMENSION	0-120	120-315	315-1000	1000+
0 or 1 DECIMAL PLACE	+-0.5	+-1	+-1.5	+-3.0
2 DECIMAL PLACES	+/- 0.25			
ANGULAR TOLERANCE	+/- 0° 30'			

DRAWN BY: CHRISTOS I.DIMITRIADIS
TEL.Ex.
DATE:
TITLE: LAVENDER HARVESTER LATERAL LEFT GUIDE
CHECKED BY:
DATE:
PART No. 720809 P01
SHT. OF.
DO NOT SCALE

44



PART No. 720823P01

ISSUE	CHANGE RECORD	DATE+AUTHY
1	PRODUCTION REL.	CD02

NOTES:

Cranfield UNIVERSITY Silsoe
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UNITED KINGDOM.
TEL +44 (0) 1525 863000
FAX +44 (0) 1525 863001

MATERIAL: MILD STEEL
FINISH
No.off 1

DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE SPECIFIED
THIRD ANGLE PROJECTION

TOLERANCES ON DIMENSIONS UNLESS OTHERWISE SPECIFIED

NOMINAL SIZE OF DIMENSION	0-120	120-315	315-1000	1000+
0 or 1 DECIMAL PLACE	+-0.5	+-1	+-1.5	+-3.0
2 DECIMAL PLACES	+/- 0.25			
ANGULAR TOLERANCE	+/- 0° 30'			

DRAWN BY: CHRISTOS I.DIMITRIADIS
TEL.Ex.
DATE:
TITLE: LAVENDER HARVESTER DIFFERENTIAL GUARD
CHECKED BY:
DATE:
PART No. 720823P01
SHT. OF.
DO NOT SCALE