A Commercial Herb Industry for NSW - an Infant Enterprise

Report for the
Rural Industries Research and Development Corporation
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May 1997

RIRDC Research Paper Series No 97/18

ISBN 1 86389 267 2
ISSN 1321 2656

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Published in May 1997

Printed by DPIE Copyshop

Foreword

The demand for herbs and herb products in Australia has been growing at an estimated 20 to 30 per cent a year. It is a market worth many millions of dollars and, surprisingly, most of the material is imported.

Herbs are used for culinary purposes, in manufacturing and food industries and medicinal and aromatic plants are used in cosmetic and craft industries.

A feasibility study in 1989 indicated that northern NSW had climate and soil conditions well suited to growing a wide range of herb types.

This report describes how to overcome some of the constraints in establishing a herb industry for northern NSW. It looks at agronomic and cultural aspects of commercial production, seedling production, harvesting, handling, processing, packaging and marketing of the final product.

It brings together valuable technical and commercial advice and culminates in detailed production guides for sage, thyme, parsley and basil.

The project is part of the Rural Industries Research and Development Corporation's culinary herbs, spices, teas and coffee program which fosters the development of viable industries based on these products.

Peter Core
Managing Director
Rural Industries Research and Development Corporation

TABLE OF CONTENTS

SECTION ONE

SUMMARY

The project described in the following report set about to overcome perceived constraints to the establishment of a commercial herb production industry in Northern New South Wales. Little information was available to local growers on agronomic and cultural aspects of commercial production in the field, seedling production, and harvesting, handling, processing, packaging and marketing of the final product.

The research covered field trials as experimental plots, and more extensive grower trials, as well as searches of the literature for current commercial practices. Growers plots were used for initial harvesting trials, and the industry partner, New England Natural Products Pty. Ltd., purchased a Branco hydronically heated dehydrator which was then employed for the duration of the project. This allowed trial runs to determine best cleaning and processing techniques, and grower material to be processed commercially.

The agronomic and cultural information covered nitrogen and phosphorus fertiliser application to basil, sage, thyme and oregano crops, and mulch treatments on plots of basil, thyme and chamomile. Effects from the use of the mulches included weed control, soil moisture, soil nitrogen mineralisation, soil temperatures, plant growth, oil yield and oil composition. Grower plots supplied us with information on best field densities and arrangement, dry matter and subsequent oil yields, and costs of production. They also supplied us with initial information on some germplasm suitability as field crops, and allowed minimal selection within a population.

The product specification, network identification and market analysis were contracted to a consultant, who provided us with limited information. More has been collected by the industry partner since this was completed in June 1993.

Essential oils were isolated via steam distillation, and gas chromatography was used to determine the oil character as our assessment of quality. Changes in oil composition were monitored where possible, and related to applied treatments.

Production guides have been compiled for sage, thyme, parsley and basil from results gained from this project, and from the literature. They cover planting stock propagation, sowing, fertilisers, water and light requirements during the growing stage, weed control, harvesting for different sections of the market, and processing and storage for minimal product deterioration.

BACKGROUND TO THE RESEARCH PROJECT

When the project was devised in 1991 there was a surging interest in the commercial production of medicinal and aromatic plants. In 1986 Australia imported herbs and herb products with an estimated value of $16m, and the demand for these products has been growing by some 20 to 30% *per annum*. Up-to-date figures of the retail value of the products consumed in Australia are not available, but the Australian Bureau of Statistics put household consumption of herbs and spices (for culinary purposes) at $57m *per annum* for 1988/89, while it is expected that a similar amount of product is directed into the manufacturing and food industries. The cosmetic, perfumery and craft industries are also users of medicinal and aromatic plants, but no estimates are easily obtainable for the value of the product consumed by these industries. The medicinal manufacturers use a further $10m of product.

While Australians are consuming ever increasing amounts of herbs and herbal products, evidence suggests that well over 90% of this material is still being imported. A feasibility study carried out in Armidale in 1989 identified herbs as a potential growth industry for Australia and, specifically, for northern NSW. Our climate and soils are considered suitable for a wide range of herb plants with a large variety of end-uses. Screening trials carried out over the period 1989 -1990 identified a large number of herb types which grow extremely well under simulated field conditions. Further selection was based on market analyses, and ease of establishment, growth and harvesting.

Initially, publicity on the proposed project in the local press and on radio prompted strong support from people keen to participate in this industry including: individuals and groups of growers, a processor, and potential capital investors. This interest in herbs, coupled with a broader interest among the Armidale community in the development of industries based on 'natural products', resulted in the formation of the Natural Products Group (NPG) which also included researchers and technical staff from the University of New England. This group's R&D programme initially focussed on herbs, with plans to extend to pharmaceutical and/or industrial crops over the next five to ten years. NPG commissioned a market survey which identified the potential market for selected herbs in the Armidale area. The market information revealed that although the local demand was primarily for fresh culinary herbs, it encompassed dried herbs, seeds and oils for culinary and medicinal purposes. This information can be extrapolated using demographic data to assess the size of the Australian demand.

The constraints to commercial herb production in northern NSW were identified as in Chart 1. The project was designed to be a broad research programme to overcome these constraints.

Chart 1: Production chain limitations.

Propagation	Production method	Harvesting	Processing	Storage	Marketing/ Distribution
Selection of higher yielding varieties	Controlled environment vs field grown - cost - yield - chemical use - fertiliser requirements	Machine vs hand Pre-process cleaning and handling	Rate of drying and final moisture content effects on product quality	Optimal conditions for minimal product deterioration	Product specification Network identification Market analysis

OBJECTIVE

The objective was to establish an integrated system of herb production in northern New South Wales, from growing through to marketing of high quality, value-added herb products.

The production chain was, and continues to be, guided by the product specification demands and product is being sold through existing distribution networks. All constraints were to be tackled more or less at once, resulting in an integrated production system.

INTRODUCTORY TECHNICAL INFORMATION

The local group originally lacked technical information in many areas. These included the production of seedlings on a large scale and their successful transplantation into the field, methods of, and problems associated with, direct seeding of herbs into field areas, field density and arrangement, non-chemical weed and pest control in the growing crop, fertiliser types required, their application rates and methods, harvesting cycle and techniques, cleaning and handling methods, processing such as drying and distillation techniques, storage requirements and packaging alternatives. Some information was available from other researchers in the industry on some of these topics, but was generally unavailable, and it was necessary to assess if the knowledge was directly applicable to an herb industry in Northern NSW.

RESEARCH METHODOLOGY

1) ***Selection*** to identify superior varieties based on agronomic performance and laboratory analysis of quality characteristics was not conducted as part of the project. These features were monitored, but the limited germplasm available for seedling raising made selection within such a small population nonsensical. It is only now becoming necessary as the products are being

assessed by the buyers, and prior to larger areas being sown. Product had to be grown, processed and packaged for presentation to potential buyers for comment before this step could be undertaken.

2) ***Production*** concentrated on methods of non-chemical control of weeds (see mulch section), field density and arrangement (see section two - field production), fertilisers (see section three - N and P fertilisation), harvesting times and techniques. The comparison of two basic growing systems: open field production *versus* an intensive polyhouse/pot system was made for parsley on a small scale with costings. The difference in yields obtained pointed out that in the New England climate, polyhouse production over the summer months is greatly inferior to open field production. Consequently, polyhouse production was abandoned.

The development of economic harvesting techniques is ongoing, with different growers either adapting existing agricultural machinery, or designing small harvesters based around hedge trimmer type cutters.

3) ***Processing*** The problem noted here was that it was not economic to conduct the tests originally planned i.e. identification of optimum drying rates, moisture content and other postharvest treatments to produce and maintain quality on an open ended basis. The industry partner purchased a Branco dryer, and protocols specific to it have been developed. These vary with plant type, plant part being dried, and load size, but are based on fast drying to reduce microbial contamination, and controlled humidity which dries the material more evenly.

Packaging is being developed in the light of feedback from buyers, and in consultation with a packaging company based in Sydney. Product needs to be packed specifically for the purchaser as both the size of the packs and the type of material used will depend on their requirements. Specific product packaging advice is available from companies such as 'Total Packaging' Brookvale.

Packaging impacts on all aspects of marketing. For consumer goods (at least) saleability will be heavily influenced by product's appearance and its security. The cost of packaging can be relatively high, and will influence product price whether wholesale or retail. It becomes increasingly important per unit of product as the quantity per package is reduced.

Packaging can also be an important part of the product's promotion, and hence the packaging must be chosen in line with a planned promotion. For example, an inexpensive looking package will be used for the discount lines and an impressive one for the up-market ones.

The way the product is to be distributed will also influence packaging. Product security will be affected by handling, storage and sale conditions, and the packaging used must be adequate to retain the quality of the product through to the final stage, the end user.

Storage tests intended to be undertaken in the project were limited by financial considerations. Consequently, the simplest measures were undertaken i.e. low light/low temperature storage areas.

4) ***Marketing*** The professional market analyst conducted the survey proposed. Batches of finished product were produced for market trials, and this is ongoing to new, potential buyers.

SECTION TWO

Production Guides for Four Herbs Suitable for Production in Northern NSW

by

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THE PRODUCTION OF SAGE

INTRODUCTION

The term Sage can refer to plants in the genus *Salvia*, Family Lamiaceae (formerly Labiatae), which contains around 750 species of herb, sub-shrub and shrub growing in dry, stony areas around the world (Hortus Third, 1976).

The main horticultural species are:

Salvia officinalis L.

Common names: Garden Sage and Common Sage (Hortus Third, 1976). Seed sourced from the Dalmatian Islands is commonly named Dalmatian Sage, and is highly esteemed (Prakash, 1990). It also produces the highest oil yields (Douglas, 1969).

Cultivars: Albiflora, Purpurascens, Purpurea, Tricolor (Hortus Third, 1976). A sterile non flowering form has also been described (Nicholson, 1969).

Description: Erect shrub to 60 cm high, stems more or less white-woolly; leaves oblong, 2.5 to 6 cm long, pubescent; corolla to 3.5 cm long, violet-blue, pink or white (Hortus Third, 1976).

Salvia sclarea L.

Common Name : Clary sage

Description: Erect to 1m, stems are glandular; leaves simple broad-ovate, 15-20cm long, cordate, pubescent, petaloid; verticillasters 4-6 flowered, bracts longer than calix, white or lilac; calyx about 9mm long, pubescent, teeth spinose, corolla about 2.5 cm long. Source of aromatic oil used in flavouring and fragrances, main use is perfumery (Hortus Third, 1976).

HISTORY

Sage has been cultivated as a spice plant for many centuries (Prakash, 1990), with reports of its medicinal properties dating back to the Middle Ages (Low *et al.*, 1994). Common or Garden Sage is a native to the Mediterranean, and can be found spread profusely over the hillsides and shores of southern Europe (Prakash, 1990). It is cultivated in various parts of continental Europe and the Americas, including Spain, Italy, Yugoslavia, Greece, Albania, Argentina, Germany, France, Malta, Turkey, England, Canada and the USA. Its use as a culinary herb has facilitated its spread into many countries, and its now naturalised throughout the world.

Sage is produced commercially in a number of countries for both its essential oil and dried leaves. Yugoslavia (15 tons, 1984) and Albania (25 tons, 1984) are the main producers of Sage products (Lawrence, 1985). Much of the Yugoslavian Sage oil is produced on the Island of Dalmatia, and is often referred to as Dalmatian Sage oil (Prakash, 1990).

USES FOR SAGE

Dried herb

Sage is recognised as an important herb in western cooking, and is used in the making of poultry stuffings and the flavouring of meat and fish dishes. The food industry uses dried Sage to flavour meats, sausages and poultry stuffings (Prakash, 1990).

Essential oil

Sage oil is used in perfumes, as a deodorant, insecticidal treatments for thrush and gingivitis, and as a calmative (Prakash, 1990).

Herbal use

A tea is used for excessive sweating, nervous disorders, as a calmative, and to reduce nursing mothers milk when weaning. Its also recommended as a gargle, and a lotions for wounds. Scientific research has confirmed the use of Sage as a calmative, and possibly, for lowering fever (Low *et al.*, 1994), however, these uses have been questioned, due to the toxic affects of thujone (Tyler, 1993).

SOURCES OF GERMPLASM

Sage seed is available around the world, but the source and quality of this seed is questionable. Some characterisation of clonal Sage plants has occurred (Bezzi *et al.*, 1992), but to date most Sage is classified by origin. The appearance of varying oil characteristics produced from plants of different origin suggests that a number of chemotypes may also exist. Three seed origins have been mentioned in the literature - Dutch, English (Basker and Putievsky, 1978) and Dalmatian (Lawrence, 1985).

The USA germplasm repositories have records of four acquisitions for *Salvia officinalis*.

GERMINATION OF SAGE SEED

Sage seed is large and can have a slow, variable germination. Because field establishment of seed can be difficult, and many producers prefer the non flowering form; cuttings and seedlings are the preferred establishment methods.

Seedling production

The large seed of Sage makes seeding in individual cells with a vacuum seeder relatively simple. For small scale operations a home made vacuum seeder is suitable. A plastic box the size of the seeding tray can have a plastic fitting attached to fit a household vacuum cleaner, the opposite side should be drilled with 0.5mm holes positioned to correspond with the centres of each cell. When the vacuum cleaner is on seeds will be held against the holes until placed over the seedling tray and the vacuum cut. This method can allow a large number of trays to be seeded in a relatively short time.

For the planting of large areas of Sage, the cost of buying prepared seedlings from an established nursery would be more economical than trying to produce seedlings in an under-equipped home nursery.

Storage of seeds

The viability of Sage seed stored at temperatures of between 10 and 30°C is greatly reduced after one year. The optimum storage temperature is 5°C, maintaining seed viability for 5 to 6 years (Kretschmer, 1989).

CUTTING PRODUCTION

Sage is relatively easy to strike from cuttings, and clonal plots of selected plants are a useful form of establishment (Gaskell, 1988). Sage plants will strike throughout the year from semi-soft tip cuttings. A hormone mixture of 500ppm IBA 500ppm NAA in association with bottom heat and mist can produce a good strike rate. A fine potting mix is the most suitable, a mix of 1 vermiculite: 1 peat :1 perlite adjusted to between pH 6 and 6.5 by additions of agricultural lime. As a rule of thumb when using New Zealand peat add 60g of lime per L of mix. Slow release nutrients can be added to the mix at a rate of 3g per L of 4 month Osmocote®.

AGRONOMY

Sowing

Sage seedlings should be planted into well formed beds. Following a good fallow, ripping, discing, and tilling with a rotary hoe fitted with bed formers. Beds can be spaced 50-70 cm apart and two staggered rows (20-25 cm between rows) sown on each bed. Beds wider than 50cm with more than 2 rows of plants can tend to show reduced middle row growth, as a result of light competition. Sage seedlings establish slowly, and during this time weed control is critical. If weeds are not well controlled during the fallow and cultivation periods, high labour and / or chemical controls will be necessary.

Plant spacing

The plant spacing for Sage varies from country to country, spacings within rows of 30cm and 60cm between rows have been tried in the U.S.A.; however, these were later concluded to be too sparse (Gaskell, 1988). A plant spacing within rows of 25cm on a 50cm wide ridged bed, two staggered rows per bed, has been successfully used in Australia.

Fertilisers

The addition of fertilisers is dependent on the soil type and existing soil fertility. U.S.A. growers broadcast triple superphosphate fertiliser prior to planting sowing at a rate of 1360 kg/ha, and following harvest, side dress with a nitrogen fertiliser. Increased nitrogen levels will improve the leaf biomass and crop colour, however some environmental responsibility must be shown as excess additions of nitrogen not only waste money, but can pollute waterways. In Australia most herb crops are treated as leafy vegetables and fertiliser rates suggested vary between 1200 and 1500 kg/ha of an NPK fertiliser analysis 5: 7: 4. Following each harvest a light side dressing up to 75kg/ha ammonium nitrate can be applied. Agricultural lime should be applied to the soil before sowing if the pH is less than 5.5.

Water requirements

Sage should be treated as a leafy vegetable when considering water requirements. During seedling establishment beds should be always moist but not wet, and during growth the plants like to be in a well drained soil with adequate sub soil moisture. Sage plants will survive periods of drought due to their Mediterranean origin, and it's not often recommended to irrigate, however, the plants will produce at their maximum if water is not limiting. Good water management will maximise production, and repay the investment cost. Sage in hot areas will lose water quickly, hence in Australia it would be advisable to have some form of irrigation as a back up.

Light

Sage needs full sun to achieve high leaf production levels. If excess shading occurs the plants will etiolate and produce little leaf. High light conditions also maximise the oil yield.

Disease control

There are no reports of diseases affecting Sage plants, however, in the U.S.A. and Europe a preventative fungicide spray with a mancozeb based fungicide is used during wet establishment periods (Gaskell, 1988).

The average climatic conditions of the New England Tablelands are not conducive to diseases. However, during abnormally wet summers or wet weeks following irrigation, monitoring for disease outbreaks would be necessary. Root rot is the main fungal disease in Australia, and the use of raised beds on free draining soil is the best control. To date no fungicides have been registered for use on Sage in Australia, so preventative methods of using ridged beds and not irrigating if there is a chance of rain would be the best production methods.

Weed control

Weed control in Sage crops, as with all herbs, is especially difficult. Some pre and post emergent herbicides have been tested (Maas, 1978), but none of these have been registered for use in Australia. The best method to reduce weeds is to grow a dense stand of pasture prior to planting the crop, then follow up by fallowing the land prior to planting. The use of a chemical fallow and smothering pasture crop will help reduce the weed seed reserves prior to planting.

Chemical weed control

Some work on suitable herbicides for Sage has been done in New Zealand (James *et al.*, 1991), and the tentative recommendations listed are: use Linuron (1kg/ha) as a pre emergence spray in spring, and Chloridazon as a post emergence follow up. These chemicals are not registered for use on Sage in Australia. If grass weeds are a problem Fusilade (2.5L/ha) (active ingredient fluazifop) will not damage the Sage plants, but again this chemical is not registered for use in Australia.

Mechanical weed control

Mechanical weed control in the form of cultivation is an age old method of controlling weeds that works by the uprooting and burying of young weed seedling. This is most efficient when the weeds are small and hence dry out quickly. More established weeds will not dry as fast, and may re-shoot following cultivation. Sage sown on ridges can be cultivated between the ridges, leaving the ridge top and inter-row area to be hand chipped. Once the canopy closes the problems of inter-row weeds will be greatly reduced.

Galambosi and Szebeni-Galambosi (1992) found the use of ridges and inter-row cultivation to be as successful as black plastic. Both methods were found to significantly increase the dry matter production of Sage in Finland.

The best time to use mechanical weed control is during a fallow period when cultivation can be alternated with herbicide application. This will allow control of the weed population without applying excessive stress to the soil through cultivation, which would damage the soil structure and result in increasing the development of plough pans (Swarbrick, 1982).

Use of mulch

Two forms of mulch exist, inorganic and organic. Inorganic mulches are plastic mulches and can have a number ancillary benefits in addition to weed control (See section on mulching). Organic mulches are used when sufficient organic waste material can be obtained and applied cheaply. (See section on mulching). Organic mulch is applied after the seedlings are established, and will generally be of benefit to the plant while controlling the weed population. The cost of applying any mulch must be examined in relation to the benefits the plants will receive.

Mulching is a good method of controlling weeds, and Sage plants do well under mulch responding to both organic and inorganic forms. The use of a woven weed matting is a good cost effective form; plastic film is cheaper, but the high humidity and temperatures around the root zone may encourage disease. Plastic film has been successfully used for Sage production in Finland (Galambosi and Szebeni-Galambosi, 1992).

GROWING FOR OIL

The production of Sage oil is a broad acre enterprise. The oil yield varies between cultivars and countries, and is highest in those plants which have never flowered (Prakash, 1990). Hence, the best time to harvest Sage is just prior to flower initiation. On average the oil yield is around 1.8% (Prakash, 1990). A Sage plot in Northern NSW with irrigation could be harvested once in the first year and two to three times each subsequent year.

VOLATILE OIL CONSTITUENTS

As with many herb oils, the characteristics of Sage oil varies between countries, and plant parts. This is most likely a result of different environmental conditions and different cultivars. The oil is a pale yellow, mobile liquid with a fresh, warm spicy, herbaceous, somewhat camphoraceous odour (Lawless, 1992). The main constituents are thujone (about 42%), cineol, borneol, caryophyllene and other terpenes, however, these constituents are variable depending on the country of origin and the plants history.

Table 1. Physiochemical properties of volatile oils of Sage of different Origin (Prakash, 1990).

Property	Yugoslavian	American	Turkey	Poland	India	Appenine Zone
Yield of oil	0.7-1.4%	-	1.0%	-	1.1% (yellow)	0.5-0.6% (yellow)
Specific gravity (20°C)	0.915-0.927	0.922-0.926	0.890	0.6-0.9218 at 15°	0.9268	0.818
Optical rotation (20°C)	+28°56'-11°38'	+4°28'-+4°56'	+24.4°	+2.74°	0.2°	+1.6°
Refractive indices	1.4571-1.4758	1.4637-1.4699	-	-	-	-
Ester content (borneol acetate)	1.6-4.9%	3.3-6.0%	-	-	-	-
Total alcohol content (borneol)	6.9-16%	13%	-	-	-	-
Ketone (thujone)	22.0-61.2%	35.41-46.7%	-	-	-	-
Saponification number	-	-	-	-	-	11.06
Ester value	-	-	-	-	30.1	-
Ester value after acetylation	-	-	-	-	30	-
Ester number	-	-	17.2	6.48	-	-
Acid value	-	-	-	-	1.1	-
Solubility in alcohol	9.5 vol of 80%	1 vol of 80% 5.5 vol of 70%	-	-	-	3 vol of ethyl alcohol
Acetylation number	-	-	-	33.2	-	-
Acid Number	-	-	1.4	0.37	-	-

The different parts of the Sage plant (non flowering and flowering) will produce oils with different characteristics (Table 2).

Table 2. Content of the volatile oil in flowering and non flowering parts of *Salvia officinalis* (Prakash, 1990).

Contents	Flowering Part (%)	Nonflowering Part (%)
Cineole	32-35	13.0-20
Sesquiterpenes	About 30	About 20
Camphor and thujone	5.0-10.0	20.0-32

Borneol	9.0-14.0	7.5-12.0
Terpenes	-	About 15.0
Esters	2.0	2.2-3.7

HARVESTING FOR VOLATILE OIL

The timing of harvest is determined by the composition and quantity of oil in the plant. The oil yield and oil components will change during the year, but when the oil yield and desired oil components are at their maximum, harvesting should commence. However, it is not always advantageous to harvest when the oil concentration is at its maximum. A Sage plant can be divided into 3 sections: the top section contains the young new growth, the middle section the more mature growth, and the bottom the older leaves. The dry matter yields decrease as you ove down the plant, with the lower section having the lowest dry matter, as a result of leaf senescence. These lower mature leaves have the highest content of oil (Basker and Putiesky, 1978). During the season the content of oil within the plant changes, as does the dry matter yield. Unfortunately, Sage plants do not reach their maximum oil content at the same time as maximum dry matter, thus harvesting the plants when the dry matter content is at it highest will not return the maximum oil yield per hectare. Basker and Putiesky (1978) found the maximum yield of dry leaves occurred in late summer, yet harvesting in mid summer produced the maximum oil yield per hectare.

The actual process of harvesting can utilise a standard forage harvester which will cut the stems and deposit the cut material into a trailing distillation bin. This reduces the need for double handling of the material prior to distilling. It is not necessary to de-stem or chop the material as this may cause oil loss and increase the cost of processing.

HARVESTING FOR DRIED LEAF

When harvesting for dried product more care is required than when harvesting for oil, and mechanical methods employing a cutter bar set in front of a conveyer belt are often used. The cut material falls on the belt and is lifted up to collection bins thus reducing bruising of the foliage. Another method is to mow the Sage, allow it to partially dry then windrow and pick up with conventional hay making machinery (Galambosi, 1991).

Following harvesting the plant material may be washed to reduce soil and dust impurities, as these will reduce the quality of the final product. If plants are grown on mulched beds the need to wash the product is reduced. Soil contamination is a major problem with sage, the fine hairs on the leaf surface catch dust and soil particles. Thus, Sage should be washed before drying to reduce this contamination and improve the herb quality.

HARVESTING FOR THE FRESH MARKET

Hand harvesting is the best method to collect plant material for the fresh market, as only top quality leaves should be collected. The plants should be cut with a sharp knife or clippers, and bunched. The bunches can be fastened with a rubber band and placed in cool boxes to start removing field heat. A hand held hedge trimmer powered by a small petrol engine can be used and will reduce harvesting time. Some form of sorting and classing is required after this form of cutting.

DISTILLATION FOR OIL

Distillation is the main form of essential oil extraction used for Sage, and the two methods commonly used are steam and hydro. For more information on the distillation of plant material see the section on distilling.

DRYING AND PACKAGING FOR DRY PRODUCT

Dried Sage should have a bright green colour, hence it should be dried quickly in order to inactivate the enzyme chlorophyllase which breaks down chlorophyll turning the leaf yellow-brown. Heat can destroy this enzyme quickly. However temperatures in excess of 40°C will remove the volatile oils (Deans *et al.*, 1992) reducing flavour. The moisture content should be reduced to less than 13%. Following drying the product should be packaged and sent to market without delay as the loss of volatile oil is continuous.

The commercial specifications for "Dried Sage" being imported into the U.S.A. are:

1. The product must consist of the dried leaves and flowering tops of *Salvia officinalis*..

2. It should consist of the dried green to grey-green, oblong, lanceolate leaves, covered with fine short hairs that possess a strong, fragrant, and aromatic odour free from any camphoraceous note.

3. It shall contain a maximum of 10% by weight, of stems, excluding petioles.

4. There should be no less than 1.0 mL of volatile oil (vol wt) per 100g.

5. Not less than 95% should pass through a U.S. standard No. 20 sieve (850 µm mesh) (Prakash, 1990).

6. For rubbed Sage, 95% shall be retained on a U.S. standard No. 40 Sieve (425 µm mesh) and at

least 95% shall pass through a U.S. standard No. 20 sieve (850 µm mesh)

7. Dried Sage should be stored below 25°C .

The standard U.S. processing specifications for dried culinary Sage is to pass the whole plant through a shear mill using either a fine round perforated screen or a herringbone screen. The material may then be passed through a hammer mill with a 1/16" (1.58 mm) screen. Some people use only the hammer mill, but a number of passes through different sized screens are required before it can be passed through the final 1/16" (1.58 mm) screen (Miller, 1985). The powdering of herbs through screen sizes of 1/16" (1.58 mm) and less can cause the loss of volatile oils. To avoid this the material is super cooled in liquid N or CO_2 prior to grinding and packaging.

COOLING AND PACKAGING FOR THE FRESH MARKET

The aim of packaging herbs for the fresh market is to present the material at point of sale in the same condition as when it was harvested. To maintain this quality the best post harvest handling procedures must be determined for each individual herb. These include temperature, humidity, atmospheric composition, package size and handling techniques. Herbs are often associated with vegetables and hence the methods used to handle vegetables are used for herbs, with mixed success. The factors which reduce herb quality commence from the moment the herb is cut. Once cut the herb plant continues to respire, and attempts to maintain metabolic activity. This uses the supplies of water and carbohydrates held in the stem of the plant, after which the plant begins to break down its own cells in an attempt to maintain respiration. Once this happens off tastes and odours develop, while the destruction of the plant cells enables bacteria and microorganisms to penetrate the plant and hasten decay (Corey, 1989).

Different preservation methods have been developed over the years to slow plant decay but each commodity must be examined individually and a specific method designed (Corey, 1989). The main features of any post harvest protocol is to maintain turgor, texture, colour, and oil content. To do this metabolic activity must be slowed, and physical injury to the plant such as bruising and tissue damage avoided.

Temperature

The reduction of temperature is an efficient method with which to reduce the metabolic activity of a plant, as the rate of biochemical reactions such as respiration in excised plant parts is reduced by approximately 50% for every 10°C decrease in temperature (Corey, 1989). The temperature must not be reduced too far as freezing of the plant material will cause ice to form within the cells of the plant, and irreversible damage. Some plants such as basil and watercress cannot withstand low temperatures, their leaves will darken, discolour, and eventually collapse. Sage is not overly sensitive to chilling and can tolerate temperatures between 0°C and 5°C for a period of two weeks when sealed in perforated polyethylene bags (Joyce and Reid, 1986).

The post-harvest handling of fresh food requires two stages of temperature monitoring. The first stage is often called the precooling and is done to remove field heat from the crop as rapidly as possible so that metabolic activity (respiration) can be reduced. Forced air cooling is the simplest method, and most suitable for the small producer as it utilises a small cool room with a high speed fan (Joyce and Reid, 1986). Vacuum cooling is the most efficient means of precooling, however, it does require expensive equipment and would only be suited to large producers (Joyce and Reid, 1986). Hydro cooling and liquid icing are methods used on fruit, but these are not suited to the succulent foliage of most herbs (Joyce and Reid, 1986).

It is commonly believed that precooling should be performed as soon after harvest as possible however, Aharoni *et al.* (1989) showed successful precooling of herbs could occur once the bunches had been packed in cartons lined with polyethylene bags. Vacuum cooling was used and it was found that most herbs were well suited to this method because of a high surface to volume ratio. Cooling in cartons had no effect on the cooling rate, and helped reduce the formation of condensation on the plastic liners. Harvesting herbs during the early morning reduces the degree of precooling required.

Storage temperatures

During storage it is important that the temperature remains constant and does not fluctuate. Excess cooling during storage will cause ice to form and damage the plant cell integrity. If field heat is not removed quickly and Sage is packaged, a metallic odour can develop. This is usually lost after the package has been allowed to air.

Humidity during Storage

When plants are harvested their internal humidity is 100%, but water loss can immediately occur causing the plants to wilt. The maintenance of a high storage humidity will reduce this water loss by slowing the water movement from the high humidity in the plant to the lower humidity air. Humidity of between 90 and 95% is the most suitable as this will reduce the loss of plant water without the formation of condensation on the plant or containers, which would encourage the growth and spread of spoilage organisms. To maintain high humidity during storage, film wraps or plastic lined cartons can be used to provide a barrier to water loss (Corey, 1990). Ensuring high humidity in the cool storage room will also help.

Atmospheric control

When plants are cut or damaged they produce a gaseous hormone, ethylene. Elevated levels of ethylene trigger a series of biochemical reactions in the plant that lead to the breakdown of cell walls, loss of pigments such as chlorophyll, softening of tissue, and leaf abscission. This sequence is generally referred to as plant senescence (Corey, 1990). Modifying the atmosphere around the plant can inhibit ethylene activity. This can be accomplished by reducing the oxygen content of fresh air from about 21% to between 2 and 4% and increasing the CO_2 concentration from 0.035% to between 5 and 10%. If the oxygen level is reduced too far, the plants will become anaerobic and spoilage due to fermentation will occur. Modified atmospheres can be created within the cold storage room, or within the carton by using different polymeric films around the plant material, and specific plastics can be made for each crop type (Aharoni *et al.*, 1989). During storage the CO_2 level should be above 7% and the O_2 level should not drop below 5% (Aharoni *et al.*, 1989).

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Another development in herb production is fresh pot herbs. These are herbs produced in pots and sold cheaply at supermarkets for use in kitchens. The herbs will provide a small volume of fresh material to households while being an attractive ornamental plant. An economic plan of this form of production based in Southern Queensland showed Sage plants could be ready for sale every 6 weeks in summer and 8 weeks in winter. The return on capital invested was estimated at 58.65% when a range of herbs were produced in this way (Avard *et al.*, 1982)

CONCLUSION

The production of Sage is well suited to the New England region of NSW. The fresh, dried and essential oil market could all be supplied from this area. Seedlings and cuttings would be the most efficient method to establish the plants, as these could be produced over winter months and sown as the soil begins to warm in spring. To avoid water stress and maximise production irrigation would be required. Spray, drip or flood irrigation could be used depending on the availability of resources. Sage is a perennial crop and a number of harvests should be possible during the year. Inorganic mulch would be the most economic weed control provided irrigation systems are compatible, and the cost of laying and planting not prohibitive.

THE PRODUCTION OF THYME

INTRODUCTION

The term Thyme commonly refers to a number of species of the genus *Thymus*, Family Lamiaceae (formerly Labiatae). There is a range of common names and cultivars, and much confusion exists as to which common name is associated with which species. The genus *Thymus* consists of between 300 and 400 species (Hortus Third, 1976), but the main horticultural species are:

Thymus vulgaris L**.**

Common names: Garden Thyme and Common Thyme (Hortus Third, 1976; Bodkin, 1986) Cultivars: Argenteus, Aureus, Fragrantissimus, Roseus (Hortus Third, 1976)

Chemotypes are distinguished by the dominant terpene: geraniol, linalool, a-terpineol, carvacrol, thymol, trans-thuyanol-4 / terpineol-4 or cineole-1,8. The predominant chemotypes are thymol and carvacrol (Granger and Passet, 1973 cited by Morgan, 1989).

Description: Shrub with 15-30 cm long stems. Woody erect plant with linear to elliptic leaves 5-16 mm long, revolute tomentose, not ciliate. Produces many flowers on a petaloid inflorescence which is dense and headlike or interrupted. The flowers have a whitish to lilac corolla about 5mm long (Hortus Third, 1976).

Thymus serpyllum L**.** [*T. angustifolius* Pers.]

Common Name: Lemon Thyme, Wild Thyme, Creeping Thyme

Description: Mat forming plant which produces roots at nodes. The stems are woody at the base, flowering stems are erect to 10 cm and hairy on 4 sides. Leaves are linear to elliptic about 8 mm long and sessile. The inflorescence is headlike with purple flower corolla about 5mm long (Hortis Third, 1976). Much of the material offered as *Thymus serpyllum* represents other species such as *T. nummularius*, *T. pannonicus*, *T. praecox*, *T. pseudolanuginosus*, or *T. pulegioides* (Phillips, 1988).

HISTORY

Common Thyme is a native of the Mediterranean region (Prakash, 1990; Hornok, 1992). Its geographic range stretches from northern Spain through southern France to northern Italy (Prakash, 1990). Being a culinary herb it has also been introduced into many countries, and is now naturalised throughout the world

Thyme is produced commercially in a number of countries for both essential oil and dried leaf. The main producing countries are: Spain, Portugal, France, Germany, Italy and other continental European countries, North Africa, England, Canada and the U.S.A. (Prakash, 1990). Spain, Jamaica and Morocco are the main suppliers of dried leaf to the U.S. Market, while Spain and France supply the oil market (Simon, 1990).

USES FOR THYME

For culinary purposes, the leaves of thyme are included in many food products, and are often ground and blended with other herbs to make special stuffings. Many oils, vinegars and preserved meats are also enhanced by the use of dried Thyme. The essential oil of Thyme has antiseptic properties, and is utilised in pharmaceutical preparations such as gargles, cough drops, dentifices and mouthwashes (Prakash, 1990; Lawless, 1992; Low *et al.*, 1994). It is also used to preserve meat, as a vermifuge to cure hookworm in horses and dogs (Prakash, 1990), and in the cosmetic industry (Hornok, 1992).

The herbal and folk uses of Thyme extend back many centuries. The Egyptians used the oil in the embalming process, while the early Greeks used it to fumigate against infectious diseases. In western medicine Thyme was used for respiratory and digestive complaints, and the treatment of infection (Low *et al.*, 1994).

SOURCES OF GERMPLASM

Due to the confusion about correct identification of Thyme, it is difficult to find germplasm and be sure that it is true to label. The central Ohio unit of the Herb Society of America at the Inniswood Metro Gardens in Westerville, Ohio, have a collection of plants that have been both taxonomically and chemotypically identified (Phillips, 1989). However, it is not known if they can provide germplasm. Rey (1992) studied a number of Thymes, assessing their suitability for areas of Switzerland. This study examined a large range of Thyme plants including hybrids and sterile individuals. It is not known if they can provide germplasm, but they would be a worthwhile contact (Federal Agronomical Research Station, Changin (R.A.C.) Centre des Fougeres, Conthey, Switzerland). Some cultivar evaluation has been done at Purdue University, U.S.A. (Simon *et al.*, 1989). Material for this evaluation was obtained from Abbott and Cobb Inc and Harris Moran, it is assumed that these are U.S. seed suppliers.

GERMINATION OF THYME SEED

Thyme seed is a small seed which makes direct sowing in fields difficult. Seed can be directly sown by use of fluid seeding gels or by broadcasting, however the cost of seed and the high rates required to establish an even stand make these methods uneconomic. The seeding areas need to be well prepared with a fine seed bed and protected from wind and dessication for several months, as inital growth is slow and weed competition strong. Consequently, the majority of Thyme plots are established by seedlings prepared in a glasshouse, or by selected clones struck as cuttings in individual cells.

Seedling production

The fine seeds of Thyme and the low gemination rate (72%) (Kretschmer, 1989) makes seeding in individual cells difficult, however, a double seeding using either a vacuum seeder suitable for small seeds or a fluid seeder will be suitable for large scale plantings. For small scale operations the seed can be directly placed in the cells by the use of a wet paper clip point or by mixing with fine sand and spreading a measured quantity over each tray. Some small nurseries have also had success using a salt shaker with an adjustable orifice which allows only one or two seeds to pass.

For the planting of large areas of Thyme the cost of buying prepared seedlings from an established nursery would be more economical than trying to produce seedlings in an under equipped home nursery. It should be possible to generate the desired 160,000 to 240,000 seedlings per ha from 50 to 80g of seed.

Storage of seeds

The viability of Thyme seed stored at temperature of between 10 and 30°C is greatly reduced after one year. The optimum storage temperatures are 5 and -20°C maintaining seed viability for 5 and 6 years respectively (Kretschmer, 1989).

CUTTING PRODUCTION

Thyme is relatively easy to strike from cuttings and plots of high quality clonal plants are a common way of establishment (Gaskell, 1988). Thyme plants will strike throughout the year from semi-soft tip cuttings. A hormone mixture of 500ppm IBA 500ppm NAA in association with bottom heat and mist can produce a 90% strike rate. Cuttings can have a tendancy to etiolate if not hardened quickly, however, regular pruning following root formation will reduce this. A fine potting mix is the most suitable, a mix of 1 vermiculite: 1peat :1 perlite adjusted to between pH 6 and 6.5 by additions of agricultural lime. As a rule of thumb when using New Zealand peat add 60g of lime per L of mix. Slow release nutrients can be added to the mix at a rate of 3g per L of 4 month Osmocote®.

AGRONOMY

Sowing

Thyme should be sown into a well formed seed bed. A good fallow, ripping, discing, and tilling with a rotary hoe fitted with bed formers will produce a fine seed bed. Beds can be spaced 50-70 cm apart and three rows of Thyme (15-20 cm between rows) sown on each bed. Beds wider than 50 cm with more than 3 rows of plants can tend to show reduced middle row growth, as a result of light competition. Thyme seedlings establish slowly, during this time weed control is critical. If weeds are not well controled during the fallow and cultivation periods, high labour and / or chemical controls will be necessary.

Plant spacing

The spacing for Thyme plants varies from country to country - spacings within rows of 30cm with 60cm between rows have been tried in the U.S.A., however, these were later concluded to be too sparse (Gaskell, 1988). Densities of 36 plants per m^2 have been successfully used in Australia with the plots quickly reducing weed competition. This work (Mulch section) used six rows 15cm apart (15 cm between plants) across a 1m bed, and resulted in a slight edge effect with the centre rows producing less material. The use of 50 cm ridges with 3 rows on the ridge would avoid this problem.

Fertilisers

The addition of fertilisers is dependent on the soil type and existing soil fertility. U.S.A. growers broadcast triple superphosphate fertiliser prior to sowing at a rate of 1360 kg/ha, and following each harvest, side dress with a nitrogen fertiliser. Increased nitrogen levels will improve the top growth and crop colour; however, some environmental responsibility must be shown as excess additions of nitrogen not only waste money, but can pollute waterways. In Australia most herb crops are treated as leafy vegetables and fertiliser rates suggested vary between 1200 and 1500 kg/ha of an NPK fertiliser analysis 5: 7: 4. Following each harvest a light side dressing of up to 75kg/ha ammonium nitrate can be applied. Agricultural lime should be applied to the soil before sowing if the pH is less than 5.5.

Water requirements

Thyme should be treated as a leafy vegetable when considering water requirements. During seedling establishment beds should be always moist but not wet, and during growth the plants like to be in a well drained soil with adequate subsoil moisture. Thyme plants will survive periods of drought due to their Mediterranean origin, and it is not often recommended to irrigate, however, the plants will produce at their maximum if water is not limiting.

Light

Thyme can survive in semi shaded areas, but to achieve high production levels full sun is required.

Disease control

There are no reports of diseases affecting Thyme plants. However, in the U.S.A. a preventative fungicide spray with a mancozeb based fungicide is used during wet establishment periods (Gaskell, 1988).

The average climatic conditions of the New England Tablelands are not conducive to diseases, however during abnormally wet summers or wet weeks following irrigation, monitoring for disease outbreaks would be necessary, but it is unlikely that any disease would occur. To date no fungicides have been registered for use on Thyme in Australia so preventative methods of using ridged beds and not irrigating if there is a chance of rain would be the best production methods.

Weed control

Weed control in Thyme crops, as with all herbs is especially difficult. Some pre and post emergent herbicides have been tested (Mass, 1978), but none of these have been registered for use on Thyme in Australia. The best method to reduce weeds is to grow a dense stand of pasture prior to planting the crop, then follow up by fallowing the land prior to planting. The use of a chemical fallow and smothering pasture crops would help reduce the weed seed reserves prior to planting. If the Thyme plants are sown on a close spacing they will close their canopy quickly and out compete most weeds (see section on mulching)

One consideration when planting Thyme is its ability to become a weed. There are no accounts of Thyme escaping and becoming a problem in Australia, but several thousand hectares of the Otago Valley in New Zealand have been covered with Thyme. The plant can cause a photosensitisation in some grazing animals.

Mechanical weed control

Mechanical weed control in the form of cultivation is an age old method of controlling weeds that works by the uprooting and burying of young weed seedlings. This is most efficient when the weed is small and hence dry out quickly. More established weeds will not dry as fast and may re-shoot following cultivation. Thyme sown on ridges can be cultivated between the ridges, leaving the ridge top and inter-row area to be hand chipped. Once the canopy closes the problems of inter-row weeds will be greatly reduced.

The best time to use mechanical weed control is during a fallow period when cultivation can be alternated with herbicide application. This will allow control of the weed population without applying excessive stress to the soil through cultivation, which could damage the soil structure and result in the development of plough pans (Swarbrick,1982).

Use of Mulch

Mulching is a useful weed control method, however, as Thyme plants can produce a dense cover, the crop will out compete many weeds. Mulches are also useful for stopping soil splash, and if the crop is being grown for fresh markets, could be worthwhile. Unfortunately, the spreading nature of Thyme is impeded by the use of inorganic mulch, and for this reason if mulch is to be applied, a long lasting organic form would be more suitable.

GROWING FOR OIL

The production of Thyme oil is a broad acre enterprise, with large areas of plants required to produce limited quantities of oil. The oil yield varies between cultivars and countries usually lying some where between 0.5 and 2.5%. The best time to harvest Thyme oil is around flowering as the oil concentration in the plant is then at its highest. A plot in Northern NSW with irrigation should enable at least two harvests per year.

VOLATILE OIL CONSTITUENTS

As with many herb oils, the characteristics of Thyme oil vary between countries. This is most likely a result of both different environmental conditions, and different cultivars. Usually an oil yield of 2 to 2.5% is obtained, however, some sterile individuals and hybrids have been reported to produce 6% volatile oil (Rey, 1992). The oil is a colourless to yellowish red liquid with a pleasant odour characteristic of the herb. The ordinary Thyme oil (*Thymus vulgaris*) contains 42% to 60% phenols mainly thymol or carvacrol (crystallisable). Adulteration of Thyme oil can be assessed by crystallisation of the phenols as synthetic carvacrol will not crystallise (Prakash, 1990).

Table 3. The physiochemical properties of the different types of Thyme oil (From Prakash, 1990).

Characteristic	Spanish	Moroccan	Sardinian
Specific gravity 25/25°	0.916-0.934	0.891-0.910	0.902-0.904
Optical rotation 25°	-0°16'-1°52"	-2°20'- -3°12"	-
Refractive index 20°	1.4971-1.5040	1.4909-1.4967	1.489-1.497
Phenol content	42.5-59.0%	28-37%	44-54%
Solubility at 25°	2.5-3.5 vols and more of 70% alcohol and 3 vols and more 80% alcohol	1-1.5 vols and more of 80% alcohol	1-1.5 vol% at 20°

The principal constituents of Thyme oils are: thymol and carvacrol (up to 60%), cymene, terpinene, camphene, borneol and linalool, depending on the source. It can also contain geraniol, citral and thuyanol.

There are many chemotypes occurring throughout the world and in different regions. The most notable are the thymol and carvacrol types, the thuyanol types and the linalool or citral types. (Lawless, 1992).

HARVESTING FOR VOLATILE OIL

The timing of harvest is determined by the composition and quantity of the oil in the plant. The oil yield and oil components vary during the year, but when the oil yield and the desired oil components are at their maximum, harvesting should commence.

The actual process of harvesting can utilise a standard forage harvester which will cut the material, and deposit it into a trailing distillation bin. This reduces the need for double handling of the material prior to distilling. It is not necessary to de-stem or chop the material as this may cause oil loss and increase the cost of processing.

HARVESTING FOR DRIED LEAF

When harvesting for dried product more care is required than when harvesting for oil, and mechanical methods employing a cutter bar set in front of a conveyer belt are often used. The cut material falls on the belt and is lifted up to collection bins thus reducing bruising of the foliage. Another method is to mow the Thyme, allow it to partially dry then windrow and pick up with conventional hay making machinery (Galambosi, 1991).

Following harvesting the plant material may be washed to reduce soil and dust impurities as again these will reduce the quality of the final product. If plants are grown on mulched beds the need to wash the product is reduced.

HARVESTING FOR THE FRESH MARKET

Hand harvesting is the best method to collect plant material for the fresh market, as only top quality leaves should be collected. The plants should be cut with a sharp knife or clippers, and bunched. The bunches can be fastened with a rubber band and placed in cool boxes to start removing field heat. A hand held hedge trimmer powered by a small petrol engine can be used and will reduce harvesting time. Some form of sorting and classing is required after this form of cutting.

DISTILLATION FOR OIL

Distillation is the main form of essential oil extraction used for Thyme, and the two methods commonly used are steam and hydro. For more information on the distillation of plant material see the section on distilling.

DRYING AND PACKAGING FOR DRY PRODUCT

Dried Thyme should have a bright green colour, hence it should be dried quickly in order to inactivate the enzyme chlorophyllase which breaks down chlorophyll turning the leaf yellow. Heat can destroy this enzyme quickly, However temperatures in excess of 60°C will remove the volatile oils (Deans *et al.*, 1992) reducing flavour. Cut Thyme material includes a lot of woody stem material. The energy used to dry the stem is wasted, however, the stem material stops the leaves from "packing" in the dryer, and enables air to move easily through the product thus reducing overall drying times.

The commercial specifications for "Dried Thyme" being imported into the U.S.A. are:

1. The product must consist of the dried leaves and flowering tops of *Thymus vulgaris* L.

2. The dried brownish-green curled leaves, when crushed should yield a fragrant, aromatic odour and have a warm, pungent taste.

3. It shall contain not more than 11% total ash, 5.0% acid insoluble ash, and 9.0% moisture.

4. There should be no less than 0.9ml of volatile oil (vol wt) per 100g.

5. Not less than 95% should pass through a U.S. standard No. 30 sieve (600 µm mesh) (Prakash, 1990).

6. Dried Thyme should be stored below 25°C .

The standard U.S. processing specifications for dried culinary Thyme is to pass the whole plant through a Shear mill using either a fine round perforated screen or a herringbone screen. The material may then be passed through a hammer mill with a 1/16" screen. Some people use only the hammer mill but a number of passes through different sized screens are required before it can be passed through the final 1/16" screen (Miller, 1985). The powdering of herbs through screen sizes of 1/16" and less can cause the loss of volotile oils. To avoid this the material is super cooled in liquid N or CO_2 prior to grinding and packaging.

COOLING AND PACKAGING FOR THE FRESH MARKET

The aim of packaging herbs for the fresh market is to present the material at point of sale in the same condition as when it was harvested. To maintain this quality the best post harvest handling procedures must be determined for each individual herb. These include temperature, humidity, atmospheric composition, package size and handling techniques. Herbs are often associated with vegetable and hence the methods used to handle vegetables are used for herbs, with mixed success. The factors which reduce herb quality commence from the moment the herb is cut. Once cut the herb plant continues to respire, and attempts to maintain metabolic activity. This uses the supplies of water and carbohydrates held in the stem of the plant, after which the plant begins to break down its own cells in an attempt to maintain respiration. Once this happens off tastes and odours develop, while the destruction of the plant cells enables bacteria and microorganisms to penetrate the plant and hasten decay (Corey, 1989).

Different preservation methods have been developed over the years to slow plant decay but each commodity must be examined individually and a specific method designed (Corey, 1989). The main features of any herb post harvest protocol is to maintain turgor, texture, colour, and oil content. To do this metabolic activity must be slowed, and physical injury to the plant such as bruising and tissue damage avoided.

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THE PRODUCTION OF PARSLEY

INTRODUCTION

Parsley is a member of the carrot family, (Umbelliferae) genus *Petroselinum*. Three species are commonly called parsley; however, recent literature describes these three species as varieties of *Petroselinum crispum* (Hortus Third, 1976; Tanakas, 1976). They are:

Varieties

Petroselinum crispum var. *crispum* (Mill.) Nyman ex A. W. Hill

A biennial plant from southern Europe and Asia minor. Grows to a height of 0.5m with a spread of 0.5m. The plant produces a profusion of bright green leaves, segmented and curly. The flowers produced in the second year, are small, white and borne in compound terminal umbels. The plant has many branched stems bearing divided leaves which are greatly curled and crisped (Hortus Third, 1976; Bodkin, 1986; Prakash, 1990)

A number of curly leaf cultivars exist and these include Banquet, Moss Curled, Decorator, Forest green, Perfection, Improved Market Gardener, Dark Moss Colour (Simon and Overley, 1986), Sherwood (Simon *et al.,* no date) **Green Market, Austral, Triple Curled, Flamenco** and **Verdant** (Eccles, 1989).[**BOLD =** Available in Australia]

Petroselinum crispum var. *neapolitanum* Danert [*P.crispum* var. *latifolium* of auth., not (Mill.) Airy-Shaw] (Hortus Third, 1976).

Similar to var. crispum but without the curled crisp leaves. The leaves are large, flat and divided. Is often described as having a stronger taste compared to var. crispum. Common flat leafed cultivars include **Plain leafed** and **Plain Italian Dark Green** (Simon *et al.*, no date; Simon and Overley, 1986; Eccles, 1989)

Petroselinum crispum var. *tuberosum* (Bernh.) Crov. [*P.hortense* var *radicosum* (Alef.) L.H. Bailey].

Turnip rooted. Roots thick and edible if leaf segments flattened, not crisped (Hortus Third, 1976). Common cultivar is Hamburg (Simon *et al.*, no date; Simon and Overley, 1986).

A number of other names are often given to Parsley, but these are now all grouped under *Petroselinum crispum* :

Petroselinum hortense = *Petroselinum crispum* (Tanaka, 1976)

Petroselinum sativum = *Petroselinum crispum* (Tanaka, 1976)

var. *latifolium* = *Petroselinum crispum* var. *radicosum* (Tanaka, 1976)

HISTORY

Parsley is believed to have originated in Sardinia and has been grown in England since the middle of the 16th century (Prakash, 1990). Over the centuries parsley has been moved from the old world to the new and is now naturalised in India, the Americas (Prakash, 1990), Australia and New Zealand (Low *et al.*, 1994).

USES FOR PARSLEY

Parsley has had many uses both as a culinary and a medicinal herb. Ancient Egyptians used it as a remedy for stomachache and urinary disorders (Low *et al.*, 1994). Parsley was held sacred by the ancient Greeks, and later the Christians who dedicated it to St. Peter (Bodkin, 1986). The Romans believed parsley prevented intoxication and used it to deodorise the alcohol filled air during banquets (Low *et al.*, 1994).

Parsley still has a multitude of uses. The leaf is used fresh as a garnish, seasoning and eaten raw. The dried leaves of parsley (known as parsley flakes) are used to flavour soups, sausages, meat, fish, vegetable dishes and salads (Prakash, 1990). Parsley oil is produced from the seed or the leaf (Lawless (1992). Seed oil is used in perfumes, soaps and creams, while the leaf oil which is considered to be of superior quality, is used in condiments and seasonings (Simon *et al.,* no date). Parsley juice is also used by the health food industries as it is a rich source of Vitamin C, carotene, iodine and most of the valuable organic salts (Prakash, 1990). Parsley is still used as a tonic for the kidneys and a tea is often used as a carminative and diuretic or to aid digestion (Low *et al.*, 1994). Apiole, a component of parsley oil, has been used in minute doses in the treatment of epileptic fits (Prakash, 1990).

The root of the hamburg type parsley is eaten as a vegetable in many Middle European countries.

SOURCES OF GERMPLASM

The United States of America Department of Agriculture (USDA) maintains a National plant germplasm system and stores a number of Parsley cultivars at their repository in Ames, IA. Seed or tissue culture material may also be obtained from : "Setropa" Bussum Netherlands, and "Cebeco" Handelsraad Rotterdam Netherlands. To import seed the Australian Quarantine and inspection service must be contacted at Quarantine and Export Centre, 160 Curtin Avenue, Eagle Farm QLD 4007.

GERMINATION OF PARSLEY SEED

Parsley seed, like many of the Umbelliferae is notoriously difficult to germinate and produce a good stand establishment. The international seed testing association rules acknowledge this by allowing 10 and 28 days respectively before the first and final germination count, at a temperature regime of 20-30°C for 16 to 18 hours per day (Avard *et al.*, 1982).

As a result of this slow germination the seeds become susceptible to pre and post emergence damping off caused by soil fungi predominantly *Pythium spp.* Emergence could be improved if 2.33kgha^{-1} Ridomil 2E ® is applied (Rabin *et al.*, 1986). This product has 250g/L of Metlaxylon but is not registered for use on parsley in Australia and for this reason can't be used.

In New Jersey U.S.A. The largest production cost in producing direct drilled parsley is the cost of seed. To improve field establishment parsley is sown at highly elevated rates. Knott's handbook for vegetable growers recommends a seeding rate of 3 to 4 kgha^{-1}. In New Jersey a seeding rate of 44 to 67 kgha^{-1} is used, while Ohio farmers use 13 to 22 kgha^{-1} (Rabin *et al.*, 1986).

There are a number of germination inhibitors in the seed coat of Parsley. Coumarin heraclenol has been identified as one of these (Kato *et al.*, 1978), but as it is water soluble, washing parsley seeds prior to planting can improve the germination (Simon *et al.*, no date; Kato *et al.*, 1978; Avard *et al.*, 1982).

The use of seed priming has also been investigated as a method of reducing both the time to first emergence and parsley's erratic germination (Akers *et al.*, 1987; Ely and Heydecker, 1981; Pill, 1986; Rabin and Berkowitz, 1988). The use of primed seed has been questioned for some vegetable crops (Hartz, 1994), however Rabin *et al.* (1988) showed that field sown primed parsley seed produced a good even stand at one third the usual seeding rate. Primed parsley seed was sown at a rate of 12.5kgha^{-1}, significantly reducing establishment costs.

Primed seed has also been shown to improve stand establishment during unfavourable conditions. This is important in areas such as the New England Tablelands where a short growing season limits the number of harvests. Parsley seed should be sown when the soil temperature is above 15°C. In the New England region soil temperatures average above 15°C in

November (UNE meteorological records). To establish seeds before this time a number of approaches can be tried. Primed seed will assist in aiding early germination, and the use of east west oriented rows with 30 to 35° sloping soil beds will increase seed bed temperatures by 1-2°C(Hartz, 1994). Soil temperatures can also be increased by the use of plastic film which covers the seed bed. In most cases seedling transplants are used in conjugation with plastic film, but specialised seeding equipment has been developed to allow direct seeding of dry or pre-germinated seed through holes in the plastic (Hartz, 1992). The use of plastic does impose an additional cost which must be offset by the increased production during the extended season. Plastic mulch would be an economic addition if fresh market parsley was to be produced. The use of plastic or other mulches reduces soil splash and improves the quality of the final product (See section on mulching).

The use of sloping beds or plastic would enable parsley to be planted in the New England Tablelands by the beginning of October, or late September. Watering the plants during the day would also help to maintain the soil at a warm temperature, as night watering and the cool night temperatures would negate any advantage achieved by the sloping beds or black plastic.

Areas to the west and east of the Tablelands could plant parsley earlier, but the stress of frosting can cause the plants to "bolt" to seed as the weather warms. In frost free areas, parsley can be grown year round and continuously harvested. Parsley fields should be sown on a staggered pattern to allow for continual harvests throughout the year. Although parsley is a biennial plant it should be treated as an annual because regrowth and quality decline after a number of cuts.

In many areas early seed plantings are risky because of the unfavourable environmental conditions, and with increasing seed prices the most efficient means of producing an even crop stand is by the use of seedling transplants.

Seedling production

Parsley seedlings can be produced in small cell trays in a heated plastic or glass house. If large numbers of seedlings are required, the cost of purchasing seedlings from recognised vegetable producing nurseries should be investigated.

Small cells are suitable for the raising of parsley seedlings in general 100 cell trays Ritegrow® or 300 cell Speedling® type trays. A fine potting mix is the most suitable. If weight is not a problem a mix of 2 peat: 2 sand: 1 vermiculite: 1 perlite is suitable, or 1peat: 1 perlite if a light mix is required for transport. The pH should be adjusted to between 6 and 6.5 by additions of agricultural lime. As a rule of thumb when using New Zealand peat add 60g of lime per L of mix. Slow release nutrients can be added to the mix at a rate of 3g per L of 4 month Osmocote®. Cells can be vacuum or gel seeded with either primed or unprimed seed. Primed seed would be best if available but unprimed seed that has been washed for 2 days in clean water (replace water every 6 hours) would be adequate. Washed seeds should be dried at room temperature in the dark.

Seeds can be placed in shallow dibble holes and covered with moist fine grade vermiculite; double seeding ensures an even tray coverage. Following seeding the trays can be placed in a high humidity incubator set at 25°C or under mist in a 25°C hot house. Parsley is prone to damping off so routine applications of Fungerid® (100g/100L at a rate of 2-4L/m^2)may be necessary in humid environments. Once true leaves have commenced development the seedlings can be moved from the mister and begin being hardened. During hardening it is vital that the seedlings don't dry out. The use of small cells means plants can dry out easily and a short period of water stress can kill many seedlings.

Following emergence and before transplanting weekly additions of a suitable liquid fertiliser (20N:20P:20K + Calcium Nitrate) will encourage leaf growth and development of a good root ball.

AGRONOMY

Sowing

Parsley like other fine seeded vegetables, should be sown into a well formed seed bed. Following ripping and discing, tilling with rotary hoe fitted with bed formers can be used to produce a fine seed bed. Beds can be spaced 50-70 cm apart and two rows of parsley (15-25 cm between rows) sown on the bed. Parsley seed should be sown 5 to 8mm deep and the soil kept moist until germination. On crusting soils peat or a fine mulch should be spread to avoid crust formation

Plant spacing

Seedlings can be planted on the same spacing with the plants being staggered down each row along each bed. Beds wider than 50cm with more than 2 rows of plants can tend to show reduced middle row growth as a result of light competition.

Fertilisers

The addition of fertilisers is dependent on the soil type and the existing soil fertility. Growers in the U.S.A. broadcast an NPK fertilizer before sowing at a rate of 135-135-135$kgha^{-1}$, and then side dress with high nitrogen fertiliser following each harvest. Increased nitrogen levels will improve the production and crop colour, however some environmental responsibility must be shown and excess additions of nitrogen will waste money and pollute waterways. The NSW

Agriculture Department do not recommend such high rates of fertiliser. They suggest between 1200 and 1500 kgha^{-1} of an NPK fertiliser analysis 5: 7: 4. Following each harvest a side dressing of 75kgha^{-1} ammonium nitrate would suffice. Agricultural lime should be applied to the soil before sowing if the pH is less than 5.5.

Water requirements

Parsley should be treated as a leafy vegetable when considering watering. During seed germination the seed bed should be moist but not wet, and during growth the plants like to be in moist, well drained soil. Production on formed beds is considered to be the most suitable. Allowing parsley to experience water stress reduces yields and regrowth while encouraging flowering. Once parsley has "bolted" to seed its functional life as a foliage plant is over. Removal of the seed heads will not encourage vegetative growth.

Light

Parsley is often described as a plant that can survive in semi shaded areas. But to achieve high production levels full sun is required.

Disease control

In Australia only one disease has been identified as effecting parsley. Murtagh *et al.* (1990) identified late blight (*Septoria petroselini*) in a parsley stand on the North Coast of NSW following a period of wet weather. Overseas, *Septoria* blight is also a main disease (Cerkauskas, 1990) along with damping-off of seed and young seedlings by many of the soil borne fungi *Alternaria*, *Fusarium* , *Pythium*, *Rhizoctonia solaniand* and *Sclerotinia sclerotiorum* (Hershman *et al.*, 1986). *Pythium paroecandrum* has also been associated with root rot in parsley grown in Northern Ireland (McCracken, 1984).

The average climatic conditions of the New England Tablelands is not conducive to these diseases. During abnormally wet summers, or wet weeks following irrigation, monitoring for these disease outbreaks would be necessary. No fungicides are registered for use on parsley in Australia, so preventative methods such as using ridged beds, and not irrigating if there is a chance of rain, would be the best production methods.

Weed control

Weed control on parsley, as with all herbs, is especially difficult. Some pre and post emergent herbicides have been tested, but none of these have been registered for use on parsley in

Australia. The best method to reduce weeds is to grow a dense stand of pasture prior to planting the crop and then follow up by fallowing the land prior to planting. The use of a chemical fallow and smothering pasture crops would help reduce the weed seed reserves prior to planting.

If parsley is planted on a spacing of 25x20 cm the plants will soon grow and cover the soil surface reducing weed germination. The slow germination and initial growth rates of seed parsley make weed control difficult, but continual inter row cultivation and hand hoeing will limit the size of the weed population.

Chemical Weed Control

In Australia there are no herbicides registered for use on parsley although some trial work has been done to investigate the effects of different herbicides on parsley growth. The herbicide SMY 1500 (Bayer) was used as a pre-emergent herbicide, but while good weed control was achieved, a large number of the plants were injured (Walker, 1986). R-40244 (Stauffer) gave good weed control without plant loss, however some bleaching of the crop seedlings did occur. This was overcome without affecting growth (Roberts, 1984).

In the U.S.A. Stoddard Solvent is the only herbicide registered for use on parsley. This is a post emergent herbicide and is applied after the development of 3 true leaves at a rate of 60 gal /acre. This solvent is a mixture of petroleum based solvents and is similar to kerosene. ,Although still recommended for use in America it is generally not used due to the cost and flavour tainting that can occur.

Mechanical Weed Control

Mechanical weed control in the form of cultivation is an age old method of controlling weeds which works by uprooting and burying the young weed seedlings. Cultivation is most effective when the weed is small and hence dry out quickly. Older, more established weeds will not dry as quickly, and may re-shoot following cultivation. Parsley sown on ridges can be easily cultivated between the ridge leaving the ridge top and inter-row area to be hand chipped. Once the parsley canopy closes the problems of inter-row weeds will be greatly reduced.

The best time to use mechanical weed control is during a fallow period prior to the crop, as cultivation can be alternated with herbicide application to reduce the weed population without over cultivation. Over cultivation will damage soil structure, and can increase the development of plough pans below the root zone (Swarbrick,1982).

Use of Mulch

Mulch is a good method of reducing weeds provided an adequate supply of mulching material can be obtained. Parsley responds well to both organic and inorganic forms of mulch . The use of a woven weed matting is a good cost effective form; plastic film is cheaper, and the increased temperatures produced can improve the length of the production season. (See section on Mulching)

GROWING FOR OIL

The production of parsley oil is necessarily a broad acre enterprise due to the low oil yield of the plant. For this reason parsley is sown by direct drilled seed with the aim of establishing a good stand. The sowing time is dependent on the climate of the site. Areas with cold winters (New England Tablelands) can plant in autumn, but this may result only in one leaf harvest, and a seed harvest in spring. Warmer areas will get a number of leaf harvest during a warm winter (North Coast NSW) and a seed harvest in spring (Murtagh *et al.*, 1990). Spring sowing in cold winter areas (New England Tablelands) allows a number of harvests during the summer, a possible winter harvest, and a spring seed harvest. The difficulty with summer planting is weed control, and avoiding water stress which will stimulate flowering and seed production.

Parsley leaf oil is distilled solely from the plant leaf, and it demands the highest price. The leaves yield only between 0.04 and 0.15% on a fresh weight basis (Simon and Quinn, 1988). Parsley herb oil is derived from the leaves and immature seeds, and in some areas it is classed as leaf oil. It does not have the same quality as a pure leaf oil. Parsley seed oil is collected from the seeds. Parsley seeds have the highest essential oil content (about 7%) (Prakash, 1990), but produce the lowest quality oil. Finally, a fixed oil or oleoresin can be produced from the seeds. This has a flavour characteristic of the entire plant. It is a deep green semi viscous liquid containing 12 to 15 ml of volatile oil per 100g. One hundred and fifty grams of oleoresin is equivalent to 45.45kg of fresh parsley (Prakash, 1990).

VOLATILE OIL CONSTITUENTS

A number of examinations of the volatile constituents in parsley leaves have been performed (Kastings *et al.*, 1972; Macleod *et al.*, 1985; Nitz, *et al.*, 1989; Murtagh *et al.*, 1990). These examinations agree in part, but differ over some compounds and the relative proportions of the major elements. Simon and Quinn (1988) examined a 104 different parsley accessions from the USDA germplasm collection at Ames. Their results demonstrated a rich diversity in essential oil constituents of parsley suggesting a genetic basis. For this reason it is only possible to suggest which major oil constituents can be found in parsley, and not what their relative proportions will be. As a result of this genetic diversity different cultivars can be grown to suit specific markets. When deciding to grow parsley for oil, a cultivar should be selected after consultation with the processing oil company, thus matching the plant cultivar with specific oil requirements. An example of the variation in different parsley cultivars can be seen in Table 4.

Table 4. The Physiochemical properties of the different types of parsley herb oil (From Prakash, 1990).

Characteristics	**French**	**American**	**Hungarian**
Specific gravity 15°	0.911-1.002	0.909-1.046	0.948-.987
Optical rotation	-6°10'-+6°0'	-7°40'-+2°13"	-6°18'-+2°3'
Refractive index 20°	1.5029-1.5159	1.5080-1.5179	1.5053-1.5250
Acid number	1.4	-	0.1-0.2
Ester number	0.9-8.9	-	2.0-6.1
Ester number after acetylation	26.1-50.4	-	11.5-22.2
Saponification number	-	0.0-6.1	7.4-7.7
Solubility	95% alcohol soluble with opalescence	0.5 vol of 90% alcohol	3.5 vol of 90% alcohol

The principal constituents of parsley leaf oils are: myristicin (up to 85%) with phellandrene, myrcene, apiole, terpinolene, menthatriene, pinene and carotel among others (Lawless, 1992). Seed oils contain apiole, with myristicin, tetramethoxyally-benzene, pinene and volatile fatty acids (Lawless, 1992)

HARVESTING FOR VOLATILE OIL

The timing of harvest is determined by the composition and quantity of the oil in the plant. The oil yield and oil components will change during the year (Murtagh *et al.*, 1990), but when the oil yield and desired oil components are at their maximum, harvesting should commence. Monitoring of the crop will enable the optimum harvest time to be deturmined.

The actual process of harvesting can utilise a standard forage harvester which will cut the stems and deposit the cut material into a trailing distillation bin. It is not necessary to remove the stems or macerate the plant material as this may cause seed and oil loss.

If pure seed oil is desired a standard combine harvester modified to receive small light seed is suitable.

HARVESTING FOR DRIED LEAF

When harvesting for dried product more care is required than when harvesting for oil, and mechanical methods employing a cutter bar set in front of a conveyer belt are often used. The cut material falls on the belt and is lifted up to collection bins thus reducing any bruising of the foliage. Hand harvesting is often used because only good quality green leaves are collected. The harvesting of yellow leaves will reduce the quality of the final dried product. Following harvesting the plant material may be washed to reduce soil and dust impurities as again these will reduce the quality of the final product. If plants are grown on mulched beds the need to wash the product is reduced.

HARVESTING FOR THE FRESH MARKET

Hand harvesting is the best method to collect plant material for the fresh market as only top quality leaves should be collected. The plants should be cut with a sharp knife or clippers and bunched. The bunches can be fastened with a rubber band and placed in cool boxes to start removing field heat.

DISTILLATION FOR OIL

Distillation is the main form of essential oil extraction used for parsley, and the two methods commonly used are steam and hydro. For more information on the distillation of plant material see the section on distilling. Solvent extraction is used to produce seed oleoresin, and hence this product will also contain fats and waxes.

DRYING AND PACKAGING FOR DRY PRODUCT

Dried parsley should have a bright green colour, hence it should be dried quickly in order to inactivate the enzyme chlorophyllase which breaks down chlorophyll turning the leaf yellow. Heat can destroy this enzyme quickly, and in many parsley drying enterprises temperatures in excess of 80°C are used to produce a vivid green product (Axtell and Bush, 1991). However, temperatures in excess of 60°C will cause a significant loss of the herb volatile oil (Deans *et al.*, 1991). Drying parsley at 40°C with a large volume of air moving through the material will reduce the loss of oil while drying the herb before colour is lost. This method maintains the flavour in the dried flakes. Some markets of dried parsley are interested only in colour, not flavour, e.g. the manufacturers of dried soups (Axtell and Bush, 1991), hence high temperature drying is best for these end-users.

Parsley is a very moist product and about 12kg of fresh parsley are required to produce 1kg of dried parsley (Prakash, 1990). The commercial specifications for dried parsley being imported into the U.S.A. are:

1. The product must consist of the leaf proportion of freshly harvested parsley that has been washed, trimmed and size classified.

2. Flavour should be of fresh parsley on reconstitution, and the colour will be of a bright uniform green.

3. A maximum of 20% of the flakes may pass through a U.S. standard No. 20 sieve.

4. The dehydrated flakes should be practically free of yellow discoloured leaves and its moisture content should not exceed 4.5%.

5. The product should be packaged in heat sealed polyethylene lined corrugated fibre cases, hermetically sealed metal containers, or in 25 L metal containers with friction top lids.

6. Dried parsley should be stored below 25°C (Prakash, 1990).

COOLING AND PACKAGING FOR FRESH MARKET

The aim of packaging herbs for the fresh market is to present the material at point of sale in the same condition as when it was harvested. To maintain this quality the best post harvest handling procedures must be determined for each individual herb. These include temperature, humidity, atmospheric composition, package size and handling techniques. Herbs are often associated with vegetable and hence the methods used to handle vegetables are used for herbs, with mixed success. The factors which reduce the quality of the herbs commence from the moment the herb is cut. Once cut the herb plant does not stop functioning; it continues to respire and attempts to maintain metabolic activity. This uses the supplies of water and carbohydrates held in the stem of the plant, after which the plant begins to break down its own cells in an attempt to maintain respiration. Once this happens off tastes and odours develop while the destruction of the plant cells enables bacteria and microorganisms to penetrate the plant and hasten decay (Corey, 1989).

Different preservation methods have been developed over the years to slow plant decay but each commodity must be examined individually and a specific method designed (Corey, 1989). The main features of any herb post harvest protocol is to maintain turgor, texture, colour, and oil content. To do this metabolic activity must be slowed, and physical injury to the plant such as bruising and tissue damage avoided.

Temperature

The reduction of temperature is an efficient method with which to reduce the metabolic activity of a plant, as the rate of biochemical reactions such as respiration in excised plant parts is reduced by approximately 50% for every 10°C decrease in temperature (Corey, 1989). The temperature must not be reduced too far as freezing of the plant material will cause ice to form within the cells of the plant, and irreversable damage. Some plants such as basil and watercress cannot withstand low temperatures, their leaves will darken, discolour, and eventually collapse. Parsley is not overly sensitive to chilling and can tolerate temperatures between 0°C and 5°C for a period of two weeks when sealed in perforated polyethylene bags (Joyce and Reid, 1986).

The post-harvest handling of fresh food requires two stages of temperature monitoring. The first stage is often called the precooling and is done to remove field heat from the crop as rapidly as possible so that metabolic activity (respiration) can be reduced. Forced air cooling is the simplest method and most suitable for the small producer as it utilises a small cool room with a high speed fan (Joyce and Reid, 1986). Vacuum cooling is the most efficient means of precooling, however it does require expensive equipment and would only be suited to large producers (Joyce and Reid, 1986). Hydro cooling and liquid icing are methods used on fruit and are not suited to the succulent foliage of most herbs (Joyce and Reid, 1986).

It is believed that precooling should be performed as soon after harvest as possible however, Aharoni *et al.* (1989) showed successful precooling of parsley could occur once the bunches had been packed in cartons lined with polyethylene bags. Vacuum cooling was used and it was found that parsley was well suited to to this method due to its high surface to volume ratio. Cooling in cartons had no effect on the cooling rate and helped reduce the formation of condensation on the plastic liners. Harvesting Parsley during the early morning reduces the degree of precooling required

Storage temperatures

During storage it is important that the temperature remains constant and does not fluctuate. Excess cooling during storage will cause ice to form and damage the plant cell integrity.

Humidity during Storage

When plants are harvested their internal humidity is 100%, but once cut water loss lowers this causing the plants to wilt. The maintenance of a high storage humidity will reduce this water loss by slowing the water movement from the high humidity in the plant to the low humidity air. Humidity of between 90 and 95% is the most suitable as this will reduce the loss of plant water, without the formation of condensation on the plant or containers, which encourages the growth and spread of spoilage organisms. To maintain high humidity during storage, film wraps or plastic lined cartons can be used to provide a barrier to water loss (Corey, 1990). Ensuring high humidity in the cool storage room will also help.

Atmospheric control

When plants are cut or damaged they produce a gaseous hormone called ethylene. Elevated levels of ethylene trigger a series of biochemical reactions within the plant that lead to the breakdown of cell walls, loss of pigments such as chlorophyll, softening of tissue, and leaf abscission, this sequence is generally referred to as plant senescence (Corey, 1990).

Modifying the atmosphere around the plant can inhibit ethylene activity. This can be accomplished by reducing the oxygen content of fresh air from about 21% to between 2 and 4% and increasing the CO_2 concentration from 0.035% to between 5 and 10%. If the oxygen level is reduced too far, the plants will become anaerobic and spoilage due to fermentation will occur. Modified atmospheres can be created within the cold storage room, or within the carton by using, different polymeric films around the plant material, and specific plastics can be made for each crop type (Aharoni *et al.*, 1989). Aharoni *et al.* (1989) investigated the use of modified atmospheres on the storage of parsley. They found that if parsley was packed in 3kg corrugated cardboard cartons lined with a sealed polyethylene liner, vacuum cooled from a field temperature of 15°C to 2°C within 25 minutes and then stored at between 6-8°C for 5 days, a high quality product was maintained. With some other herbs an alcoholic smell developed in the sealed containers. This odour could be avoided by reducing the carton size from 3kg to 1kg; the smaller size cooled more quickly and developed a better carbon dioxide to oxygen ratio. The CO_2 level should be above 7% and the O_2 level should not drop below 5% (Aharoni *et al.*, 1989). Using this method fresh parsley could be successfully air freighted from Israel to Europe without loss of quality.

FRESH POT HERB PRODUCTION

Another development in herb production is fresh pot herbs. These are herbs produced in pots and sold cheaply at supermarkets for use in kitchens. The herbs will provide a small volume of fresh material to households while being an attractive ornamental plant. An economic plan of this form of production based in Southern Queensland showed parsley plants could be ready for sale every 6 weeks in summer and 8 weeks in winter. The return on capital invested was estimated at 58.65% when a range of herbs were produced in this way (Avard *et al.*, 1982)

CONCLUSION

The production of parsley has two major drawbacks: the slow, difficult germination of the seed, and the cost of controlling weeds. In the New England region the production of parsley is best suited for the fresh and dried markets. Seedlings would be the most efficient method to establish the plants as these could be produced over winter months and sown as the soil begins to warm in spring. Seedlings would also allow the use of plastic mulch for weed control. Black plastic film is well suited to parsley production as it reduces weeds, and by maintaining higher soil temperatures, will allow an early winter harvest. To avoid water stress sub-surface under-mulch irrigation would be advised, or channel flood irrigation along furrows on either side of the mulch. Parsley should be produced as an annual crop with the one layer of mulch persisting for two or more seasons. Weed matting could be used instead of plastic film as this will last longer, but it will not warm the soil during the winter months.

THE PRODUCTION OF BASIL

INTRODUCTION

The term Basil is collectivly used to describe plants of the genus *Ocimum*, Family Lamiaceae (formerly Labiatae). There are between 50 and 150 species of herbs and shrubs in the genus *Ocimum*, differing in growth, habit, colour, and aromatic composition (Simon, 1989; Simon *et al.*, 1990), making the botanical identification of Basil difficult (Hortus Third, 1976).

The main horticultural species is:

Ocimum basilicum *L..*

Common names: Sweet basil, Common Basil, French Basil, Basil and Bush Basil (Hortus Third, 1976; Simon *et al.*, 1990; Hornok, 1992).

Cultivars: Citriodorum, is a lemon sented variety; minimum, leaves are much smaller, sometimes described as a separate species; Purpurascens, produces a purple leaf (Hortus Third, 1976).

Description: Glabrous or glabrescent annual, to 60 cm high. Leaves are ovate to ovate elliptic, 7-13 cm long, generally cuneate. The flower infloresence is a racemose, and the corolla is about 8 mm long, white or purplish. It is a summer annual from a tropical origin in the old world (Hortus Third, 1976).

HISTORY

During the course of medicinal plant history Basil has been both praised and excoriated. Early herbalists asserted that Basil damaged the internal organs, the eyes and caused insanity. Subsequent writers argued that Basil did none of these things, but was good both as a condiment and for a variety of medicinal purposes (Low *et al.*, 1994).

In recent times Basil has become a popular condiment, and is naturalised in many parts of the world expanding from its original Asian origin. In Australia Basil is widely grown as a condiment, and has naturalised in Queensland (Low *et al.*, 1994)

USES FOR BASIL

Dried herb

Basil is recognised as an important herb in cooking, and is used as a condiment in a number of countries, especially in southern European countries, and recently the U.S.A. and Australia (Simon *et al.*, 1990).

Essential oil

Basil oil is extracted by steam distillation and is used to flavour foods, in dental and oral products, in fragrances and for traditional medicines (Guenther, 1950; Simon *et al.*, 1990). The oil has also been shown to display insecticidal and antimicrobial properties, two minor components of the oil - juvocimene I and II are reported to act as juvenile hormone analogs (Nishida *et al.*, 1984 cited by Simon *et al.*, 1990).

Herbal use

A tea is made from the leaves and used for nausea, gas pains and dysentery. Basil's effectiveness as a carminative has been established, and research shows that extracts of the plant inhibit organisms that can cause dysentery (Low *et al.*, 1994).

SOURCES OF GERMPLASM

Basil seed is available around the world, but the identification and purity of this seed is questionable. The U.S.D.A., germplasm repository has an extensive collection of Basil (*Ocimum basilicum*) cultivars, many of which have been both taxonomically and chemotypically classified. A number of different chemotypes have been identified and field tested under U.S. growing conditions (Simon and Reiss-Bubenheim, 1987).

GERMINATION OF BASIL SEED

Basil seed is large and is germinates easily, hence field establishment by direct drilling is a good production option. However, Basil is a frost tender annual, and in areas where the frost free period is short, establishment by seedlings is more viable.

Seedling production

The large seed of Basil makes seeding in individual cells with a vacuum seeder relatively simple. For small scale operations a home made vacuum seeder is suitable. A plastic box the size of the seeding tray can have a plastic fitting attached to fit a household vacuum cleaner, the opposite side should be drilled with 0.5mm holes positioned to correspond with the centres of each cell. When the vacuum cleaner is on seeds will be held against the holes until placed over the seedling tray, and the vacuum cut. This method can allow a large number of trays to be seeded in a relatively short time.

For the planting of large areas of Basil, the cost of buying prepared seedlings from an established nursery would be more economical than trying to produce seedlings in an under-equipped home nursery.

Storage of seeds

The optimum storage temperature of Basil seed is 5°C, however, the seed does lose viability quickly. The germination rate of basil seed should be 80 - 95%, and seed should not be used if the germination rate is below 70% (Simon, 1989).

CUTTING PRODUCTION

Basil is relatively easy to strike from cuttings, however, cuttings would only be used for selection and breeding trials to increase the population of a selected line. The ease of seed germination, and the annual nature of basil plants, does not make clonal establishment a viable option.

AGRONOMY

Sowing

Basil seed and seedlings should be planted into well formed beds. Following a good fallow, ripping, discing, and tilling with a rotary hoe fitted with bed formers. Beds can be spaced 60-90 cm apart and two staggered rows (20-30 cm between rows) sown on each bed. Beds wider than 50cm with more than 2 rows of plants can tend to show reduced middle row growth, as a result of light competition. Weed control is critical during the establishment of basil plants. If weeds are not well controlled during the fallow and cultivation periods, high labour and / or chemical controls will be necessary. For direct field sowing, Hornok and Lenches (1992) recommend sowing basil seed at a depth of 0.5 cm using about 2-3 kg of seed per hectare.

Plant spacing

The plant spacing for Basil varies from country to country, usually depending on the type of machinery used. A good spacing is to grow basil in rows spaced 60 to 90 cm apart, with plants spaced every 15cm in the row. Beds can also be used with two to three rows per bed. Rows should be 30cm apart and the plants spaced between 15 -30 cm in the row (Simon, 1989). It is not advisable to plant more than three rows per bed as shading will reduce growth in the centre rows.

Fertilisers

The addition of fertilisers is dependent on the soil type and existing soil fertility. U.S. recomendations are to apply an N:P:K fertilizer ratio 1:1:1 at a rate of 120 kg per ha, then sidedress with 20-30kg N per ha after the first harvest. Increased nitrogen levels will improve the leaf biomass and crop colour, however, Hornok (1988) showed that moderate levels of nitrogen and high levels of P increased the essential oil content. The oil composition of basil can be changed by the use of unbalanced nutrient additions. Basil plants displayed a significant decrease in their main components (menthol and linalool) as nitrogen levels were increased (Hornok, 1983; Adler *et al.*, 1989). However, an increase in potassium caused an increase of menthol and linalool, while varying phosphorous levels had no effect (Hornok, 1983). This ability to change the chemical composition of the oil by various nutrient combinations is important when supplying companies who require a specific oil chemistry.

Water requirements

Basil should be treated as a leafy vegetable when considering water requirements. During seedling establishment beds should be always moist but not wet, and during growth the plants like to be in moist, well drained soil. Basil plants originate from more tropical environments than many other herbs, and hence will not tolerate drought. In Northern NSW some form of irrigation will be necessary to maximise production.

Light

Basil needs full sun to achieve high leaf production levels. If excess shading occurs the plants will etiolate and produce little leaf. High light conditions maximise the oil yield.

Disease control

Basil plants are susceptible to a number of fungal diseases which usually occur in wet humid conditions (Simon, 1989). Davis (1994) describes how different mulches that maintained good soil moisture cause significant plant losses, as a result of soft rot (*Erwinia* spp.).

The average climatic conditions of the New England Tablelands are not conducive to diseases. However, during abnormally wet summers or wet weeks following irrigation, monitoring for disease outbreaks would be necessary. Root and leaf soft rot are the main fungal disease, and the use of raised beds on free draining soil is the best control. To date no fungicides have been registered for use on Basil in Australia, so preventative methods of using ridged beds and not irrigating if there is a chance of rain are be the best production methods.

Weed control

Weed control in Basil crops, as with all herbs, is especially difficult. The best method to reduce weeds is to grow a dense stand of pasture prior to planting the crop, then follow up by fallowing the land prior to planting. The use of a chemical fallow and smothering pasture crop will help reduce the weed seed reserves prior to planting.

Chemical weed control

There is no registered chemical for use on basil in Australia, however good land preparation and the establishment of a thick stand will help reduce weeds. It is important to remember that the presence of weeds in either fresh or dried basil will greatly decrease the quality of the final product.

Mechanical weed control

Mechanical weed control in the form of cultivation is an age old method of controlling weeds that works by the uprooting and burying of young weed seedling. This is most efficient when the weeds are small and hence dry out quickly. More established weeds will not dry as fast, and may re-shoot following cultivation. Basil sown on ridges can be cultivated between the ridges, leaving the ridge top and inter-row area to be hand chipped. Once the canopy closes the problems of inter-row weeds will be greatly reduced.

The best time to use mechanical weed control is during a fallow period when cultivation can be alternated with herbicide application. This will allow control of the weed population without applying excessive stress to the soil through cultivation, which would damage the soil structure and result in increasing the development of plough pans (Swarbrick,1982).

Use of Mulch

Mulching is a good method of controlling weeds, and Basil plants do well under mulch, responding to both organic and inorganic forms. Plastic mulch has been shown to increase the production of basil (Ricotta and Masiunas, 1983; Davis, 1994). However, the high humidity also increased disease (Davis, 1994). Davis (1994) also tested a number of other mulchs with mixed success; however, if mulch is used the basil plants are normally established as seedlings, and this plus the mulch greatly increase the cost of production. For more information on the use of mulch in Australia (see the section on mulching).

GROWING FOR OIL

The production of Basil oil is a broad acre enterprise. The oil yield varies between cultivars and countries, and is highest in flowering plants (Prakash, 1990). Hence, the best time to harvest Basil is during flowering. On average the oil yield is around 0.4% (Prakash, 1990). A Basil plot in Northern NSW with irrigation could be harvested two to four times a year.

VOLATILE OIL CONSTITUENTS

As with many herb oils, the characteristics of Basil oil changes between countries and plant parts. This is most likely a result of different environmental conditions and different cultivars. "True" sweet basil oil is a colourless or pale yellow liquid with a light, fresh sweet-spicy sent and balsamic undertone (Lawless, 1992). Exotic basil oil which comes from the plant commonly known as "bush basil", taxonomically classified as *Ocimum basilicum,* is described as having a yellow or pale green colour, with a slightly course sweet herbaceous odour, and a camphoraceous tinge (Lawless, 1992).

The main oil constituents of "true" sweet basil are linalool (40-45%), methyl chavicol (23.8%), and small amounts of eugenol, limonene and citronellol among others (Lawless, 1992). Bush basil is mainly methyl chavicol (70-88%) with small amounts of linalool, cineole, camphor, eugenol, limonene and citronellol (Lawless, 1992). However, many of these constituents are variable depending on the country of origin and the plant history (Table 5).

Table 5. Chemotaxonomic classification of *Ocimum basilicum* based on the U.S.D.A. germplasam collection (adapted from Simon *et al.*, 1990).

Plant number or Cultivar name	**Predominant Constituents**	**Country of Origin**
175793	linalool	Turkey
368699	linalool, 1,8-cineole	Yugoslavia
358465	linalool, geraniol	Yugoslavia
174285	linalool, methyl chavicol	Turkey
190100	methyl chavicol, linalool	Iran
253157	methyl chavicol, citral	Iran
170579	methyl cinnamate, and Z isomer	Turkey
170579	methyl chavicol, methyl chavicol, linalool	Turkey
Purdue selection	methyl eugenol	Thailand

HARVESTING FOR VOLATILE OIL

The timing of harvest is determined by the composition and quantity of oil in the plant. The oil yield and oil components will change during the year, but when the oil yield and desired oil components are at their maximum, harvesting should commence. However, it is not always advantageous to harvest when the oil concentration is at its maximum. It has often considered that basil should be harvested at the onset of flowering (Rosengarten, 1969 cited by Basker and Putievsky, 1978; Hornok and Lenches, 1992), as this is when the essential oil content in the plant approaches its highest. However, if the plants are harvested prior to flowering, a greater number of harvests are possible during the season, and the overall yield of leaf and oil is higher (Basker and Putievsky, 1978).

The actual process of harvesting can utilise a standard forage harvester which will cut the stems and deposit the cut material into a trailing distillation bin. This reduces the need for double handling of the material prior to distilling. It is not necessary to de-stem or chop the material as this may cause oil loss and increase the cost of processing.

HARVESTING FOR DRIED LEAF

When harvesting for dried product more care is required than when harvesting for oil, and mechanical methods employing a cutter bar set in front of a conveyer belt are often used. The cut material falls on the belt and is lifted up to collection bins, thus reducing bruising; a 10 to 12 cm stubble is left providing a number of growing points for regrowth. Another method is to mow the Basil, allow it to partially dry, then windrow and pick up with conventional hay making machinery (Hornok, 1992).

Following harvesting, the plant material may be washed to reduce soil and dust impurities, as these will reduce the quality of the final product. If plants are grown on mulched beds the need to wash the product is reduced. A blanching in boiling water is often combined with the washing prior to drying to help maintain the dry colour (Rocha *et al.*, 1993).

HARVESTING FOR THE FRESH MARKET

Hand harvesting is the best method to collect plant material for the fresh market, as only top quality leaves should be collected. The plants should be cut with a sharp knife or clippers, and bunched. The bunches can be fastened with a rubber band and placed in cool boxes to start removing field heat. A hand held hedge trimmer powered by a small petrol engine can be used, reducing harvest time. Some form of sorting and classing is required after this form of cutting.

DISTILLATION FOR OIL

Distillation is the main form of essential oil extraction used for Basil, and the two methods commonly used are steam and hydro. For more information on the distillation of plant material see the section on distilling.

DRYING AND PACKAGING FOR DRY PRODUCT

Dried Basil should have a bright green colour, hence it should be dried quickly in order to inactivate the enzyme chlorophyllase which breaks down chlorophyll turning the leaf yellow-brown. Heat can destroy this enzyme quickly. However temperatures in excess of 40°C will remove the volatile oils (Deans *et al.*, 1992) reducing flavour. The moisture content should be reduced to less than 13%. Following drying the product should be packaged and sent to market without delay as the loss of volatile oil is continuous.

Current specifications for the importing of spices into the U.S.A. do not include Basil, either whole or ground.

A good commercial sample of "Sweet Basil" should contain a minimum of 0.4% volatile oil, a maximum total ash content of 15%, maximum acid insoluble ash of 1.0%, maximum moisture of 8% and total ether extractives, a minimum of 4% on moisture free basis.

COOLING AND PACKAGING FOR THE FRESH MARKET

The aim of packaging herbs for the fresh market is to present the material at point of sale in the same condition as when it was harvested. To maintain this quality the best post harvest handling procedures must be determined for each individual herb. These include temperature, humidity, atmospheric composition, package size and handling techniques. Herbs are often associated with vegetables and hence the methods used to handle vegetables are used for herbs, with mixed success. The factors which reduce herb quality commence from the moment the herb is cut. Once cut the herb plant continues to respire, and attempts to maintain metabolic activity. This uses the supplies of water and carbohydrates held in the stem of the plant, after which the plant begins to break down its own cells in an attempt to maintain respiration. Once this happens off tastes and odours develop, while the destruction of the plant cells enables bacteria and microorganisms to penetrate the plant and hasten decay (Corey, 1989).

Different preservation methods have been developed over the years to slow plant decay but each commodity must be examined individually and a specific method designed (Corey, 1989). The main features of any post harvest protocol is to maintain turgor, texture, colour, and oil content. To do this metabolic activity must be slowed, and physical injury to the plant such as bruising and tissue damage avoided.

Temperature

The reduction of temperature is an efficient method with which to reduce the metabolic activity of a plant, as the rate of biochemical reactions such as respiration in excised plant parts is reduced by approximately 50% for every 10°C decrease in temperature (Corey, 1989). The temperature must not be reduced too far as freezing of the plant material will cause ice to form within the cells of the plant, and irreversible damage. Some plants such as basil and watercress cannot withstand low temperatures, their leaves will darken, discolour, and eventually collapse. For this reason Basil should not be chilled below 15-10°C Basil that is stored at 15°C will last for 15 days without signs of chilling injury. If Basil is harvested and cooled to 5-0°C the expected shelf life is 1-3 days (Lange and Cameron, 1994). It has also been shown that harvesting Basil at the end of the day helps maintain shelf life (Lange and Cameron, 1994).

The post-harvest handling of fresh food requires two stages of temperature monitoring. The first stage is often called the precooling and is done to remove field heat from the crop as rapidly as possible so that metabolic activity (respiration) can be reduced. Forced air cooling is the simplest method, and most suitable for the small producer as it utilises a small cool room with a high speed fan (Joyce and Reid, 1986). Vacuum cooling is the most efficient means of precooling, however it does require expensive equipment and would only be suited to large producers (Joyce and Reid, 1986). Hydro cooling and liquid icing are methods used on fruit, but these are not suited to the succulent foliage of most herbs (Joyce and Reid, 1986).

It is commonly believed that precooling should be performed as soon after harvest as possible however, Aharoni *et al.* (1989) showed successful precooling of herbs could occur once the bunches had been packed in cartons lined with polyethylene bags. Vacuum cooling was used and it was found that most herbs were well suited to this method because of a high surface to volume ratio. Cooling in cartons had no effect on the cooling rate, and helped reduce the formation of condensation on the plastic liners. Harvesting herbs during the early morning or evenings reduces the degree of precooling required.

Storage temperatures

During storage it is important that the temperature remains constant and does not fluctuate. Excess cooling during storage will cause ice to form and damage the plant cell integrity.

Humidity during storage

When plants are harvested their internal humidity is 100%, but water loss can immediately occur causing the plants to wilt. The maintenance of a high storage humidity will reduce this water loss by slowing the water movement from the high humidity in the plant to the lower humidity air. Humidity of between 90 and 95% is the most suitable as this will reduce the loss of plant water without the formation of condensation on the plant or containers, which would encourage the growth and spread of spoilage organisms. To maintain high humidity during storage, film wraps or plastic lined cartons can be used to provide a barrier to water loss (Corey, 1990). Ensuring high humidity in the cool storage room will also help. Basil is often packed in perforated plastic bags to reduce condensation and maintain a high humidity. Preliminary results show the new breathing plastics such as "Everfresh" are well suited to basil.

Atmospheric control

When plants are cut or damaged they produce a gaseous hormone, ethylene. Elevated levels of ethylene trigger a series of biochemical reactions in the plant that lead to the breakdown of cell walls, loss of pigments such as chlorophyll, softening of tissue, and leaf abscission. This sequence is generally referred to as plant senescence (Corey, 1990). Modifying the atmosphere around the plant can inhibit ethylene activity. This can be accomplished by reducing the oxygen content of fresh air from about 21% to between 2 and 4% and increasing the CO_2 concentration from 0.035% to between 5 and 10%. If the oxygen level is reduced too far, the plants will become anaerobic and spoilage due to fermentation will occur. Modified atmospheres can be created within the cold storage room, or within the carton by using different polymeric films around the plant material, and specific plastics can be made for each crop type (Aharoni *et al.*, 1989). During storage the CO_2 level should be above 7% and the O_2 level should not drop below 5% (Aharoni *et al.*, 1989).

FRESH POT HERB PRODUCTION

Another development in herb production is fresh pot herbs. These are herbs produced in pots and sold cheaply at supermarkets for use in kitchens. The herbs will provide a small volume of fresh material to households while being an attractive ornamental plant. An economic plan of this form of production based in Southern Queensland showed Basil plants could be ready for sale every 6 weeks in summer and 8 weeks in winter. The return on capital invested was estimated at 58.65% when a range of herbs were produced in this way (Avard *et al.*, 1982). However, basil will not withstand temperature below 5°C so sales during the winter months would be limited.

CONCLUSION

The production of Basil is possible in the New England region of NSW, however the short growing season and the occasional early and late frosts will reduce the growing season and the number of harvests possible. The production of Basil for oil and dried product would be better suited to the Slopes to the west of the New England Tablelands where the frost free peroid is longer. On the Tablelands seedlings would be the only economical method to establish the plants, as these could be produced over the cooler months and sown as the soil begins to warm in spring. To avoid water stress and maximise production irrigation would be required. Spray, drip or flood irrigation could be used depending on the availability of resources. Basil is an annual crop and a number of harvests should be possible during the year. Inorganic mulch would be the most economic weed control provided irrigation systems are compatible, and the cost of laying and planting not prohibitive.

SECTION THREE

Experimental Research

THE EFFECTS OF NITROGEN AND PHOSPHORUS ON YIELD PRODUCTION OF FOUR CULINARY HERBS

INTRODUCTION

The mineral nutrition of culinary herbs can affect oil production and quality. Recommendations as to the type, and quantity of mineral nutrients required by particular herbs is available for European and American conditions, however little information is available for Australia. If soil nutrition is low then the addition of fertilisers may have a number of effects on production - increased biomass, increased oil yield or a change in oil composition. To determine the nutritional requirements of herbs in Australia each of these factors must be considered.

Nutrients are added to agricultural crops with the specific purpose of optimising plant growth, and increasing dry matter or grain return. In essential oil bearing plants the biomass production is not as critical as the net production of oil, and in some cases the specific components within the oil which produce the distinctive flavours. The type and proportion of these components determines the unique characteristics of the oil, and its market value. Thus, when examining the agronomic effects on herb production, particular attention must be applied to the oil composition.

The difficulty with measuring nutrient effects on secondary products ie. the components of essential oils, is the interaction with environmental factors and ontogenetic changes (Fluck, 1963; Bernath and Hornok, 1992). During ontogenetical development essential oil concentrations can alter, in chamomile young buds had a higher concentration of bisabolol, but as the flowers developed the concentration of chamazulene increased (Franz, 1980). The oil components can also vary between plant parts of different ages, as the level of pre-cursers is often higher in young plant parts (Fluck, 1963; Southwell and Stiff, 1989; Economakis and Fournaraki, 1993).

Oil quantity and quality can also be affected by environmental factors: changing temperatures, day lengths and light intensities over the season or diurnally may affect the oil (Basker and Putievsky, 1978; Clarke and Menary, 1979; Franz, 1986; Murtagh and Etherington, 1990; Doran and Bell, 1991; Bernath and Hornok, 1992; Bettray and Vomel, 1992). These factors interact with the plant to modify the relative concentrations of oil components; however, they do not change the spectrum of components, assuming these are genetically linked (Franz, 1986).

The response of essential oil plants to mineral nutrients depends on the type of nutrient applied, and the time of application. These responses may directly or indirectly affect the oil quality and quantity. Increased nitrogen levels can maintain the plants in a physiologically younger state, resulting in precursory components dominating the oil spectrum (Baerheim-Svendsen and Scheffer, 1986). Such an indirect response can increase the content of bisabolol in chamomile plants (Franz, 1983), or possibly increase the concentration of cis-sabinene hydrate - the precursor to terpinene-4-ol in Tea tree (Southwell and Stiff, 1989).

The direct response of plants to increased nutrients, particularly nitrogen, is to increase dry matter production. To this point most authors agree, but the effect of nitrogen on the production of secondary products, specifically essential oils, displays a number of contradictory results (Franz, 1983). Wormseed (*Chenopodium ambrosioides*) (Vomel, 1984), Caraway (*Carum carvi*) (Dachler, 1992) and Geranium (*Pelargonium graveolens*) (Rao *et al.*, 1991) show no increase in essential oil concentration with nutrient application, while Peppermint (*Mentha piperita*) (Clark and Menary, 1980; Franz, 1983; Hornok, 1983), Japanese mint (*Mentha arvensis*) (Munsi, 1992), Basil (*Ociumum basilicum*) (Hornok, 1983; Adler *et al.*, 1989), Fennel (*Foeniculum vulgare*) (Omidbaigi and Hornok, 1992), Eucalypts (*Eucalyptus torquata* and *E. angulosa*) (Mahdi *et al.*, 1987) and Rosemary (*Rosmarinus officinalis*) (Boyal *et al.*, 1991) all show an increase in essential oil concentration as the available nutrient supply is increased. These responses can be influenced by environmental conditions (Franz, 1980; Letchamo, 1992). These differences are not common, but illustrate the fact that each plant species, and environment, must be examined individually (Bryant, 1950).

The chemical components of an essential oil may be classified into four groups:

(1) The hydrocarbons, which can be subdivided into the monoterpenes, sequiterpenes and diterpenes. Terpenes are a major constituent of many oils, yet they have very little influence on flavour (Baerheim-Svendsen and Scheffer, 1986). They do, however, provide a crisp freshness to the odour.

(2) Oxygenated derivatives are the compounds which often give an oil its distinctive aroma. They include the alcohols, carbonyls and esters (Baerheim-Svendsen and Scheffer, 1986).

(3) Aromatic compounds with a benzenoid structure. These aromas cover a wide spectrum of aromatic compounds. They are common in spice oils, and are responsible for the characteristic fragrance of thyme oil (Baerheim-Svendsen and Scheffer, 1986).

(4) Compounds containing nitrogen and sulphur. These compounds are not found widely in the spice and herb oils, but are present in many aromatic vegetables (Baerheim-Svendsen and Scheffer, 1986). They also play a major part in opium and morphine extracts of poppy (Laughlin, 1983).

The effects of nitrogen, phosphorous or potassium on the characteristics of essential oils has also been widely studied, and is likewise variable, being strongly influenced by environmental conditions. No all encompassing answer can describe what will happen to particular compounds if x units of nutrient are supplied, but some guide can be taken from the literature for specific species. The oil composition of the Mint species *M. spicata* (Singh and Singh, 1985), *M. arvensis* (Singh and Singh, 1985; Munsi, 1992), *M. piperita* (Singh and Singh, 1985), *M. citrata* (Singh and Singh, 1985), and Fennel (Omidbaigi and Hornok, 1992) remained unchanged when varying levels of nutrient were applied, while either a positive or a negative response occurred when nutrient additions were made to other plants. Peppermint and Basil plants displayed a significant decrease in their main components (menthol and linalool) as nitrogen levels were increased (Hornok, 1983; Adler *et al.*, 1989). However, an increase in potassium caused an increase of menthol and linalool, while varying phosphorous levels had no effect (Hornok, 1983).

The seasonal variation in response to minerals is illustrated by the cineol content of Eucalypt trees. The level of cineol varies throughout the year, yet nutrient additions can cause an increase during specific times (Mahdi *et al.*, 1987). Other plants do not display such an environmental influence. High levels of nitrogen showed no seasonal affect on the Apigenin-7-glycoside concentration of Chamomile (Letchamo, 1992).

The form of fertiliser used can also affect the concentrations of oil components. The application of different nitrogen forms to basil changed the major constituent concentration (Adler *et al.*, 1989). Nitrate nitrogen significantly increased the concentration of linalool and eugenol compared to ammonium nitrogen. Similar work has been done with poppies in Australia, but the different forms of nitrogen had no effect on plant growth or morphine production (Laughlin, 1983).

Because of the variability discussed above, response predictions to nutrient additions are not possible. Therefore, it is important to examine the effects of nutrients on individual species and in significantly different environments.

Herb production in Australia is in its infancy, and the effect of nutrient additions in Australian conditions is virtually unknown. The following experiments attempt to investigate the initial effects of various nutrient combinations on the growth and development of some common herbs. Later work will extend these findings to determine the effect of nutrients on the essential oil composition, and field experiments will confirm the results of these preliminary pot trials.

METHODS

Seedlings of Thyme (*Thymus vulgaris*) Sage (*Salvia officinalis*) Oregano (*Origanum vulgare*) and Basil (*Ocimum basilicum*) were raised in 100 cell Kwik Pots® (Ritegro Australia) in a 1:1:1 Washed sand : Peat : Perlite v/v medium, and fertilised with 3g/L slow release fertiliser (Osmocote N:P:K 16:4.4:8.3).

A grey-brown podzolic soil ("Kirby" 0-10 cm topsoil), was sieved and mixed with 10% washed sand, and equilibrated to 10% moisture. 1700g of soil mix was added to each 15cm pot (Ritegro Australia), and the seedling plugs transplanted, one per pot. Four nitrogen and four phosphorus treatments were factorially arranged (ie. each N treatment was coupled with the four P treatments) (Table 6). The nutrient combinations were added to the pots in solution after transplanting. To avoid precipitation the nutrient solutions kept separate as basal, nitrogen and phosphorus. Following the nutrient solution addition, 50 mL of distilled water was applied to ensure an even distribution of the nutrients through the soil.

The pots were randomly arranged on individual saucers in a 10% shade, "Solarweave" (VP Industries, Australia) covered plastic house. Each plant was watered with an individual dripper placed in the saucer. The initial watering filled the saucers ensuring all plants received an equal water application.

Table 6. Nutrient additions applied to experimental pots calculated in kg/ha. The factorially designed experiment produced 16 different nutrient combinations.

Nitrogen		Phosphorus
0		0
40	X	15
80		30
160		60

Table 7. The Basal Mix concentrations calculated as kg/ha of element.

Nutrient	Kg/ha element
K	100
S	41
Mg	31
Cl	91
Fe	2
Cu	1
Mn	1
Zn	0.35
Mo	0.014
B	0.52

At 182 days the Sage, Thyme and Oregano plants were harvested at the soil surface, bagged and dried in a fan forced oven at 40°C for 48 hours. The leaf was then removed from the stem to give leaf and stem dry wights. The Basil plants were harvested twice during the growing season, the first harvest at 44 days, the second at 66 days post transplanting. Following harvesting the basil plants were processed as above.

The results were analysed as complete factorials using an analysis of variance program "Neva" (Burr, 1980). The results of the Basil harvest were analysed as a split plot in time.

RESULTS AND DISCUSSION

Thyme

Dry matter production increases as the nitrogen level increases to 160 kg/ha (Fig 1). Dry matter production plateaus after 80 kg/ha and the production for 160 kg/ha is not significantly different. A search of the literature has revealed little information on the effects of nitrogen on oil quality, however thyme plants are members of the Labiaceae as are mint and basil, therefore, varying nutrition levels may change the oil composition. For this reason, some caution should be taken when applying nutrients. From our results it appears that between 80 and 160 kg/ha of N will provide good plant growth on light granitic soils. The extra growth resulting from doubling the N rate is small suggesting the lower rate (80kg/ha N) to be more economical. This is in the range recommended for leafy vegetables by the NSW Department of Agriculture.

The 30 kg/ha phosphorus application produced the greatest total dry weight (Fig. 2), but this was due largely to an increase in stem dry matter. Leaf dry matter did not vary significantly at any level of P. As the desired harvest material is the leaf (the stems contain virtually no essential oil), it would be uneconomic to apply P alone on this soil. Low levels of P in association with applied N may improve the leaf to stem ratio of the Thyme, however, during this trial no N x P. interactions were observed. The NSW Department of Agriculture recommends 80 kg/ha P for leafy vegetables.

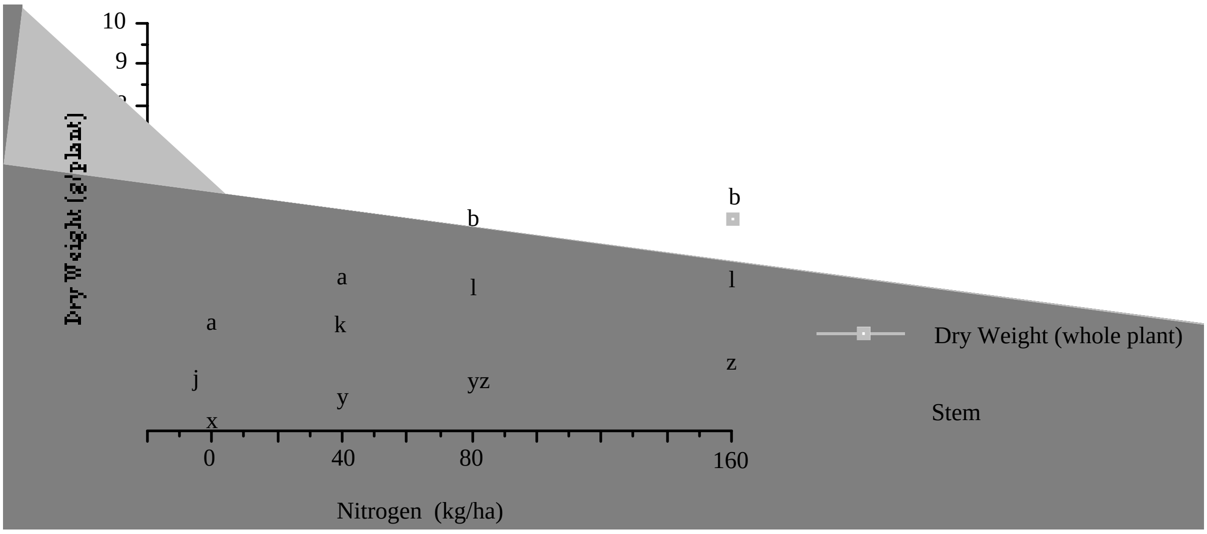

Fig. 1. The effect of nitrogen on the dry matter production of Thyme (g/plant). Letters are specific to individual curves, points with the same letter do not differ significantly. LSD = P • 0.05

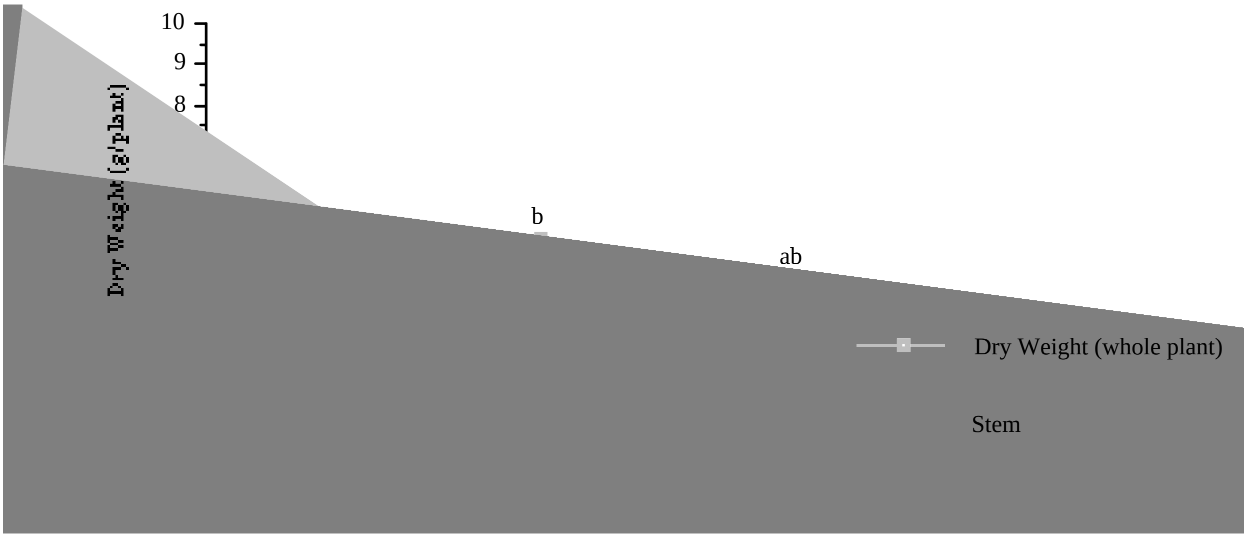

Fig. 2. The effect of phosphorus on the dry matter production of Thyme (g/plant). Letters are specific to individual curves, points with the same letter do not differ significantly. LSD = P • 0.05

Sage

The total and leaf dry matter production of sage showed linear responses to nitrogen from 0 to

160 kg/ha N (Fig. 3), but no significant difference between 80 and 160 kg/ha. Leaf and Stem production followed a similar trend but with significant differences. A search of the literature uncovered no published information on the effect of nutrition on sage oil composition. Without considering oil changes, and accepting the limitations of pot trials, this work shows that a high level of nitrogen nutrition (60-160 kg/ha)will improve dry matter production.

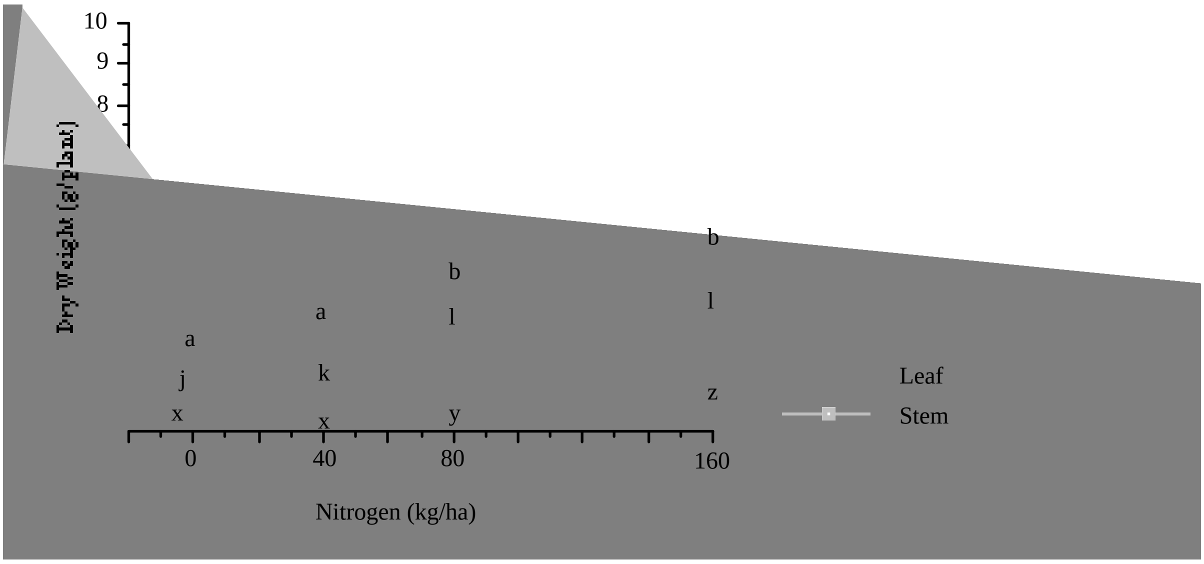

Fig. 3. The effect of nitrogen on the dry matter production of Sage (g/plant). Letters are specific to individual curves, points with the same letter do not differ significantly. LSD = P • 0.05

Additions of phosphorus caused little affect, 30 kg/ha of P showed a significant difference in total dry matter, but had no significant effect on leaf production (Fig. 4). From this result, and with consideration that these results have been generated from pot trials, 30 kg/ha P would encourage optimum growth. There was no NxP interactions observed during this trial.

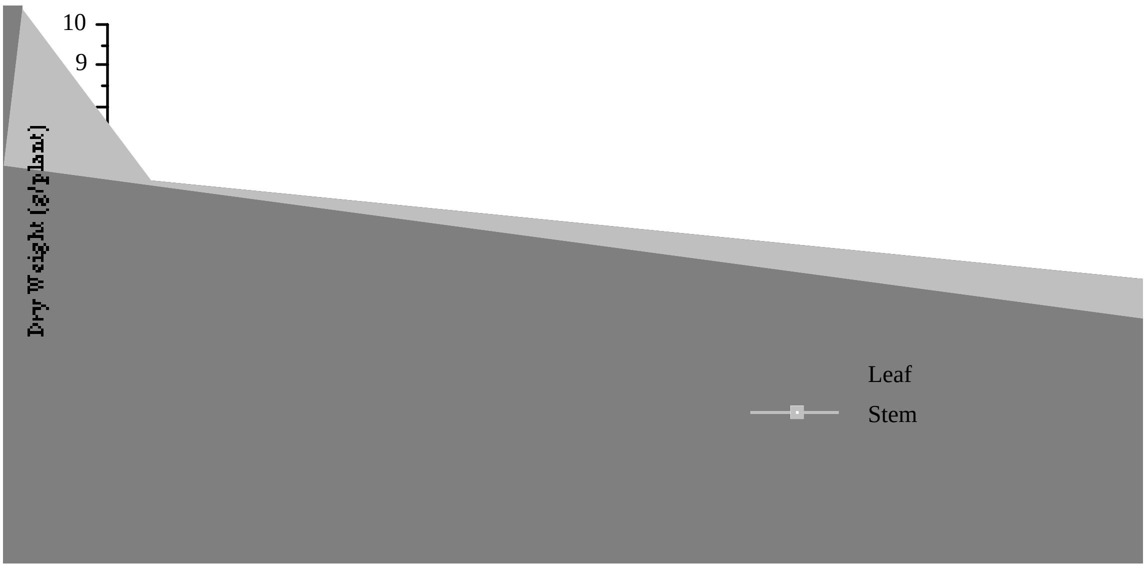

Fig. 4. The effect of phosphorus on the dry matter production of Sage (g/plant). Letters are

specific to individual curves, points with the same letter do not differ significantly. LSD = P • 0.05

Oregano

The addition of 160 kg/ha N caused no response in oregano. The 40 and 80 kg/ha N treatments resulted in a significant increase over the control (Fig. 5). With the application of P only the 15 kg/ha treatment produced a significant response (Fig. 6). The results recorded during this experiment must be examined judiciouly, as disease and insect attack resulted in a large coefficient of variation, thus only trends should be concluded from these results. There does appear to be some N toxicity occurring at the higher nutrient concentrations, and 15 kg/ha P appears to be the most beneficial. However, further trials are needed to confirm these observations. No NxP interactions were observed during this trial.

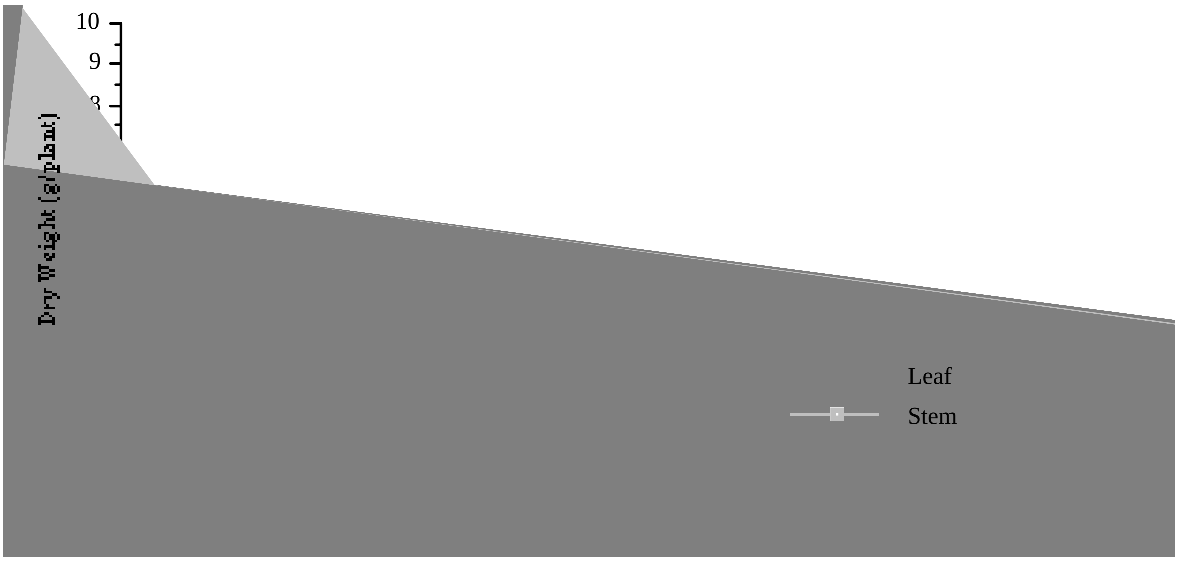

Fig. 5. The effect of nitrogen on the dry matter production of oregano (g/plant). Letters are specific to individual curves, points with the same letter do not differ significantly. LSD = P • 0.05

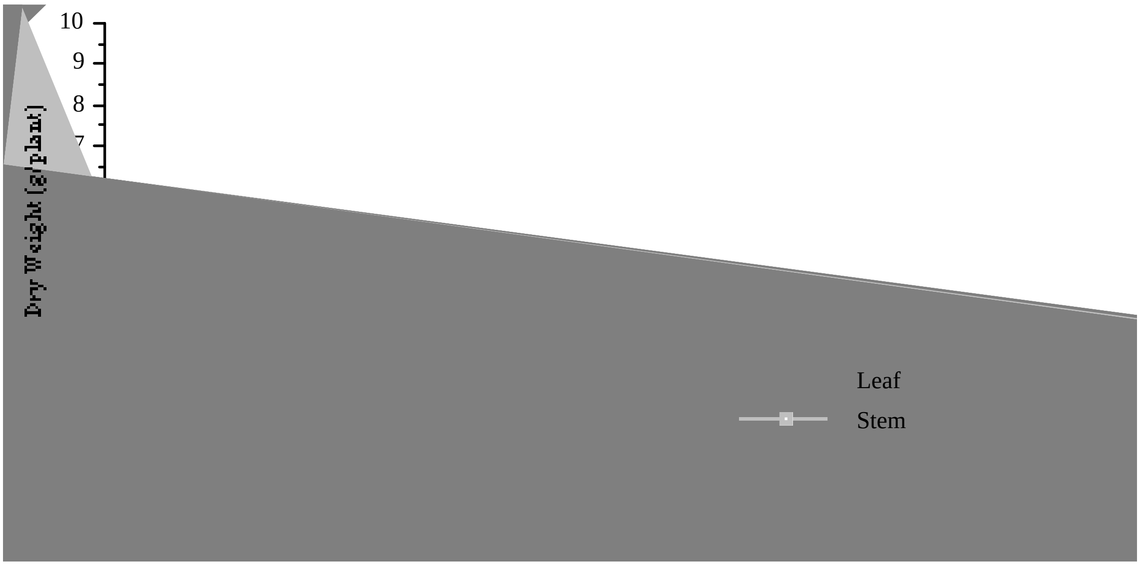

Fig. 6. The effect of phosphorus on the dry matter production of Oregano (g/plant). Letters are specific to individual curves, points with the same letter do not differ significantly. LSD = P • 0.05

Basil

Nitrogen and phosphorus had significant affects on the dry matter production of basil plants over the two consecutive harvests (Table 8). An interaction occurred between nitrogen and phosphorus at the highest level of N (160 kg/ha) and 30 kg/ha P (Fig. 7). At all other levels of applied P the 160 kg/ha N level did not produce the highest plant growth, indicating signs of toxicity.

Table 8. Plant dry weight in (g/pot) at each harvest.The levels of significance were determined by analysis of variance for each nutrient element, and interactions between the elements for the two harvest times.

	Dry Weight /pot				levels of significance (Whole plant)
Nitrogen (N) kg/ha	**0**	**40**	**80**	**160**	
Harvest One	4.24	6.48	7.96	4.81	***
Harvest Two	3.67	5.11	7.59	7.64	***
Mean of Harvest 1 + 2	3.96	5.80	7.77	6.23	***
Phosphorus (P) kg/ha	**0**	**15**	**30**	**60**	
Harvest One	1.48	6.32	7.77	7.92	
Harvest Two	3.44	5.80	8.25	6.53	
Mean of Harvest 1 + 2	2.45	6.06	8.01	7.23	***
	Harvest 1	**Harvest 2**			
Harvest (H) means	5.87	6.00			NS
NxP					*
NxH					***
PxH					**
NxPxH					NS

*** → Indicates a probability level of 0.1%
** → Indicates a probability level of 1.0%
* → Indicates a probability level of 5.0%
- → Indicates a probability level of 10%
NS → Indicates no significant difference

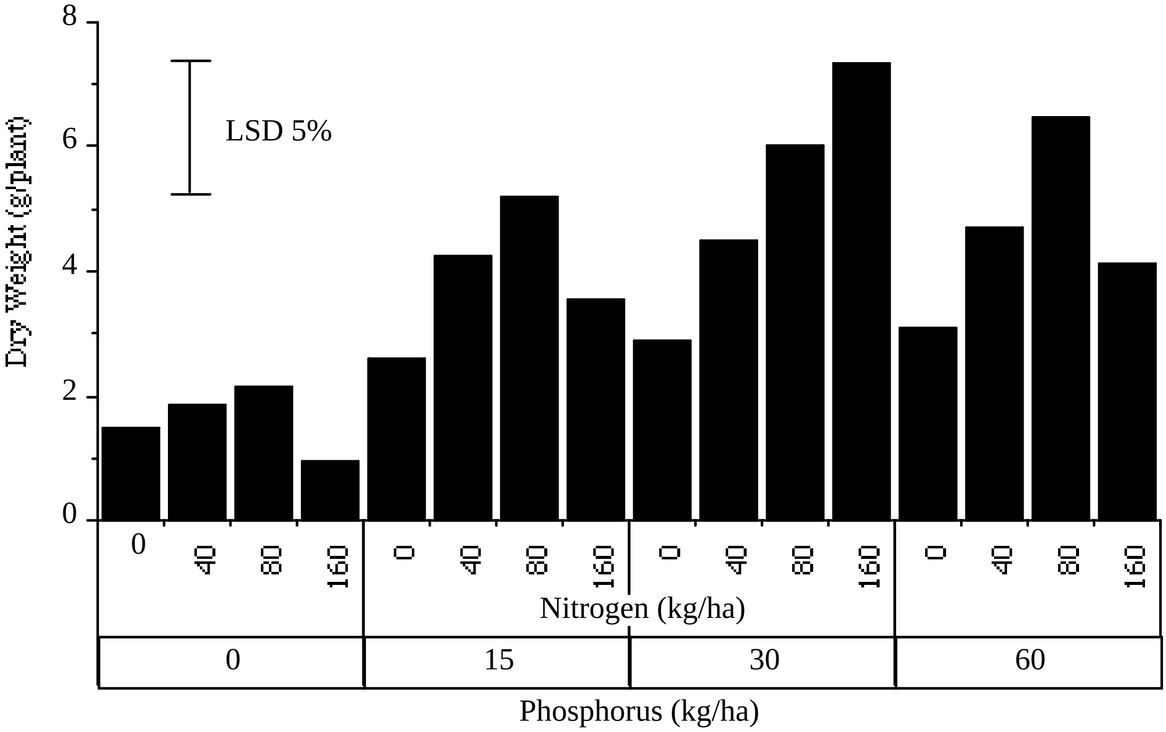

Fig. 7. Interaction between nitrogen (applied at 0, 40, 80 and 160 kg/ha N) and phosphorus (0, 15, 30 and 60 kg/ha P) on the dry matter production of basil (in g/plant).

Hornok (1983) conducted a similar nutritional examination of basil examining oil yield and composition only. He showed levels of N up to 240 kg/ha increased essential oil content, as did P additions up to 150 kg/ha. Unfortunately, while the high nutrient levels increased the essential oil content in the plant, the composition of the oils were also changed. The essential oil content and composition were not measured during this preliminary experiment, so conclusions of the effects of the different nutrient combinations can only be extrapolated from the literature

The results from this pot study show that high N nutrition (80 or 160kg/ha N) combined with a P level of 30 kg/ha maximises dry matter production of basil plants grown in fine granitic Australian soils.

CONCLUSION

When examining the results from the above trials, it must be remembered that these experiments were conducted in pots. It is dangerous to extrapolate nutrient data from pot trials to the field, so these experiments should only be used as a rough guide, or to help determine limits for future, more detailed investigations. The results showed thyme and sage to respond well to increased N levels, and high levels of N to be toxic to basil if accompanied by an inadequate level of P.

Future work is required to assess if these same responses would occur in a field situation. Field trials would also provide sufficient material for the affect on oil production and quality to be investigated.

THE ISOLATION OF ESSENTIAL OIL FROM PLANT MATERIAL

INTRODUCTION

The isolation of essential oils from plant material is an age old process. In Pakistan at the museum of Taxila a terracotta distillation apparatus dating from 3000BC shows that man has long been extracting flavours and fragrances from plants (Lawless,1992). In recent times a number of new methods have been developed to enable the isolation of minute quantities of oil from limited material, for the purpose of monitoring and scientific investigation. The methods used to extract material can be divided into two schools, the traditional methods utilising different forms of steam distillation, and the more recent methods which utilise solvents, supercritical fluids and microwaves. All these processes remove oils from plant material, but before selection of a method, the purpose of the study must be defined.

Essential oils are a combination of many components produced within the plant, but they may be changed to different components during the isolation process (Baerheim-Svendsen and Scheffer, 1986; Foster and Singh, 1989). To study the commercial form of an essential oil it is necessary to use an isolation process that mirrors the commercial process, but to study the chemical composition of the living plant, an isolation process which is going to impose minimal changes on the chemical components is necessary.

Distillation can be described as the volatilisation and subsequent condensation of a liquid. The traditional process of essential oil isolation uses steam to pass through the plant material, which extracts the plant oils. Debate exists as to the exact methods by which steam removes the oil from the plant. Hydrodiffusion (diffusion by chemical solubility) is the most accepted method, which would explain why the lower boiling point components are not necessarily the first components to elude during a distillation (Baerheim-Svendsen and Scheffer, 1986). Evaporation and liberation due to a hydrophilic effect has also been suggested (Denny, 1989 a,b). This involves the evolution of oil components by their solubility. A combination of these methods has been shown to occur in Australian Tea Tree (Johns *et al.*, 1992), where different components have been shown to respond differently during distillation. For example, oxygenated compound isolation is faster, and controlled by mass-transfer film, while the later eluding compounds are controlled by diffusion (Johns *et al.*, 1992).

Three main forms of distillation exist: immersed water distillation, steam distillation and steam-water distillation. Each of these methods extracts oil from plant material using steam which is condensed so that the oil and water separate out. The basic apparatus for essential oil distillation is the same for the three methods, the supply of heat and steam differs.

Immersed water distillation

The plant material to be distilled is in contact with the boiling water used to create the steam for the distillation (Foster and Singh, 1989). This method of distillation is a standard method for research. The stills recommended for oil isolationby the British Pharmacopoeia (1980), and The American Spice Trade Association (1968), are immersed water stills. The immersed water still is claimed to be less efficient than the steam still (Foster and Singh, 1989; Charles and Simon, 1989) and said to increase the production of artefacts due to heat and hydrolysis (Foster and Singh, 1989). The chemical changes which occur in a water distillation may not necessarily be due to the immersion of plant material in boiling water, as when plant material is boiled not only essential oils are liberated, but also tannins and organic acids. These organic plant acids change the pH of the distllation water, and this has been shown to cause an increase in artefact formation (Baerheim-Svendsen and Scheffer, 1986).

Steam distillation

Steam distillation is the preferred method of commercial essential oil isolationin Australia (Foster and Singh, 1989). It is also the cheapest form of commercial essential oil extraction, however, as the process heats the leaf, it can cause chemical changes to the oil (Southwell and Stiff, 1989; Kasting Andersson and von Sydow, 1972).

Steam distillation uses a steam generator which passes steam through the suspended plant material. Different degrees of dryness can be applied to the plant material depending on the rate of steam superheating in the external boiler.

Steam distillation is considered to be more efficient than water distillation (Charles and Simon, 1990) and to reduce the formation of artefacts due to hydrolysis (Foster and Singh, 1989).

Steam-water distillation

As the name implies, the steam-water distillation combines the water and steam stills. Leaf material is suspended on a mesh above boiling water. The still operates at atmospheric pressure so no steam superheating occurs (Foster and Singh, 1989).

Micro and semi micro distillation

These methods are refinements of the steam and water distillations enabling them to measure very small quantities of oil from 1 or 2 grams of leaf material. These methods either distil the leaf material under vacuum (Franklin and Keyzer, 1962), or capture the oil within a solvent which is later evaporated (Godefroot *et al.,* 1981). These methods require a prolonged distillation time and expensive equipment, hence do not lend themselves to rapid routine quantity analysis.

Routine oil analysis

The standard methods used for routine analysis of essential oils, as recommended by the American Spice Trade Association or the British Pharmacopoeia, rely on the Clevenger trap or modifications thereof. The Clevenger trap was developed in 1928 and featured a circular distillation apparatus. The Clevenger system and its modifications are suited to rapid yield analysis. These methods require a sample size that will produce sufficient oil to be read in the calibrated section of the still, ie. between 1 and 0.1 mL of oil. If the bore of the calibrated section is too fine, the diameter of the capillary combined with the adhesive forces of the water and oil prevent oil water separation.

Many of the aromatic plants from which essential oils are extracted have a low oil concentration necessitating a charge size in excess of 100g for an accurate assessment. When large charge sizes are required, repeated sampling of individual plants for plant improvement studies is impractical.

One alternative to using large samples is the introduction of solvents. Xylene and toluene have been used as a means of increasing oil volume within the calibrated section of a still (Charles and Simon, 1990). This method is suitable for a quantitative measure of oil, but if a pure oil sample is also required then some form of enrichment is needed. Oil enrichment involves the evaporation of the solvent to leave the pure oil, but lower boiling point components may be lost during this process (Burbott and Loomis, 1967; Charles and Simon, 1990)

Solvent extraction

Solvent extraction is used to remove the oil components from within the plant without the formation of artefacts or chemical change associated with heat and distillation. It also extracts the high boiling point components di and tri terpenes otherwise lost during distillation. Solvent extraction has been used to identify the original chemical components in a plant, as in the case of cis sabinene hydrate in tea tree (Southwell and Stiff, 1989), or to monitor the metabolic turnover of monoterpenes in peppermint (Burbott and Loomis, 1967).

Solvent extraction is not often used as a routine method of oil analysis because quantitative measures of the oil can only be calculated by the use of an internal standard. In addition to this, some solvents are expensive, and they remove all the plants' soluble products including waxes and chlorophyll.

Supercritical fluid extraction

This new concept uses solvents which are heated above their critical temperature and compressed beyond their critical pressure (Calame and Steiner, 1982, cited in Moyler, 1988). In this condition they behave both as a liquid and a gas (Foster and Singh, 1989). Carbon dioxide is the most commonly used supercritical fluid, and has the advantage of being completely removed from the oil at atmospheric conditions, removing the risk of solvent contamination in the final product (Moyler, 1988).

Solvent extraction and liquid CO_2 extraction produce oils that have not been heated. This often means a greater proportion of the lower boiling point components are present. A higher proportion of the high boiling point components are also present, as distillation cannot extract these. Conesquently the oil is different from the accepted plant extract, and more closely aligned to the actual chemicals in the plant, because artefact formation has not occurred during extraction (Moyler, 1988; Charles and Simon, 1990). In association with this,however, the time and equipment required to perform these extractions do not make them conducive to a rapid routine form of analysis.

Microwave distillation

Microwave distillation was developed to reduce the time required for oil extraction. This method can extract oil from small volumes of material within 5 minutes; however, the oil characteristics differ from steam distilled samples and are not suitable for quantitative analysis (Craveiro, *et.al.*, 1989; Deans, *et. al.*, 1991).

The methods described all perform different types of isolation and require varying amounts of equipment, time and cost. The different methods themselves produce an oil with a different character by extracting different components or producing artifacts, as previously mentioned. This production of artefacts in some oils can give the oil its distinguishing characteristics, as in the case of chamomile oil (Bernath and Hornok, 1992). In these cases it is important that laboratory sampling methods imitate the commercial isolationprocess.

The form of distillation may also have an effect on the oil quantity (Gunther, 1948). Steam distillation in general extracts a greater percentage of oil than hydro-distillation, however, Charles and Simon (1990) showed that while steam distillation of Basil (*Ocimum basilicum*) was more efficient than water distillation extracting a greater quantity of oil, it removed fewer constituents than water distillation. Charles and Simon (1990) used water distillation and a modified Clevenger Trap. This apparatus is widely used in the U.S.A. and is able to distil small volumes of oil without the loss of oil by adherence to the glass. One fault with the Clevenger trap is the way the condensate passes the steam flow prior to collection in the graduated trap.

When the condensate is reheated by the steam flow the opportunity exists for low boiling point components to be lost.

Steam and water distillation have their place, but the need still exists for a fast, repeatable, small scale system of oil yield analysis. To date no system will analyse small volumes of plant material in either a steam or water form without the use of solvents and time consuming procedures.

Commercial distillation

A number of commercial distillation systems exist and the majority are based on steam injection distillation. Large capacity stills (2-10 tonnes) are normally steam injection stills. The plant material is collected in a trailing bin with a false floor, and at the still a steam pipe is attached to the bin below the false floor, and a lid fitted to the top. A condenser is attached to the lid and the distillation begins. Steam enters the bin, rises up through the plant material, is condensed, and the oil and water flows to the separator where the oil is collected.

Water and steam-water distillations are also used on a commercial scale, but only with small quantities of material up to about 500kg. Steam injection stills are powered by an external steam generating boiler, while water and steam-water stills are powered by wood or gas fires directly under the distillation bin (Plates 1, 2). When designing a commercial still attention must be paid to the ease of operation and isolation efficiency. Using collection bins for the distillation stops double handling - plant material is harvested and placed into the distillation bin, distilled and removed.

Condensers are also an important feature of any still. To shorten the length and size, multi-cored tube condensers are used. These consist of a number of small tubes running through a condenser jacket. Within each of the tubes, a fluted spiral insert should be placed to cause turbulence in the flow of air, thus, creating greater contact with the cooling sides of the tubes. Baffles should also be placed at the beginning and end of the condenser to disrupt the air flow. Likewise, baffles in the cooling jacket maximise the cooling power of the coolant.

It is important with commercial stills to have an adequate supply of steam, as insufficient steam will increase distillation time, while reducing the isolation efficiency. Too much steam can also cause problems as efficiency drops when large quantities of steam are produced for very little oil. The perfect balance is just enough steam to extract the oil and flow through the system.

The coolant used for the condenser is an important feature of the still that is often overlooked. Many stills recycle dam water or use large tanks of water to provide the coolant to the condenser. These systems are successful, but it must be remembered that water displays its lowest density at 4°C, and if the condensate is cooled to this temperature, oil and water separation may be improved, while oil volatility will be reduced. Distillation systems in Australia are custom made for each specific purpose, and consideration of each stage of a distillation should be examined before commissioning a system.

Plate 1

Plate 2

A FLEXIBLE DISTILLATION SYSTEM FOR THE ISOLATION OF ESSENTIAL OILS

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International Journal of Essential Oil Research (In Press)

ABSTRACT: Isolation of essential oils by distillation was facilitated by the development of an inexpensive apparatus capable of operation in steam injection and water distillation modes. The apparatus compared well with accepted methods. In small laboratory distillations it gave results that were reliably comparable with one another. It required less plant material and displayed good reproducibility for macro (1 to 10 mL) and semi-micro (5 to 700μL) quantities of oil.

The combination of low expense and flexibility offers multiple still operation for large-scale screening and yield based selection of individual species or genotypes. At the same time it provides for easy and rapid installation of modular components for samples of varying oil yields and/or physical properties.

KEYWORDS: distillation, oil isolation, laboratory still, steam distillation, water distillation.

INTRODUCTION: The progeny of wild plant species that are propagated by fertilised seed give rise to many different genotypes. The content of essential oil from these genotypes is variable, and to isolate the most productive individuals yield asscessment of each genotype is required. For this asscessment the distillation system must utilise small quantities of plant material and enable fast, and repeatable oil isolation.

The apparatus described in this paper was developed to provide such a flexible form of oil isolation. The system has been designed to work as a steam or water still, with the capacity to measure macro and semi-micro volumes of oil.

A number of methods have been used to quantitatively measure essential oil yield; macro and micro, water and steam distillation (1), microwave distillation (2), solvent extraction (3-4) and CO_2 extraction (5). The microwave method is quick, requiring little material, but it is only useful for qualitative analysis (2). Solvent and CO_2 extractions require expensive equipment and are not suited to rapid yield analysis.

Two distillation processes can be used for the quantitative isolation of essential oils; steam-distillation (steam is pumped through the leaf charge to extract the oil) and water distillation (the leaf charge is immersed in water and boiled by an external heat source). Two distillation types, macro and micro exist for each isolation process. Macro distillations require about 200g fresh weight (fw) of plant material. Micro and semi-micro distillations require less between 1 and 10g fw (6). The micro and semi-micro stills can accurately measure small quantities of oil, but solvents are required to wash the oil from all glass surfaces, which makes measurement difficult, as the evaporation of the solvent has the potential to remove the more volatile oil components. Micro-stills, which do not require the use of solvents use a series of complex procedures which are not suited to rapid repeatable yield analysis.

The system developed is based on the "Clevenger Trap" (1928) (cited by 7) and Kerven's system (8). Kerven et al (8), used a semi-micro steam-powered distillation unit for isolating oil from individual mint samples. This system was a direct flow distillation with no recycling of the distillation water. Recycling was not included as it was felt the recycling water would remove some of the oil. Recycling has been included on this system because the returning water prevents the still pot boiling dry.

Steam distillation has been shown to be more efficient than water distillation (9, 10). The difficulty with steam distillation and water recycling is that the returning water can interfere with the steam flow resulting in a cooling of the charge, thus increasing the oil isolation time.

This experiment was designed to develop a distillation method which would systematically isolate small volumes of plant material, and accurately measure essential oil yield to a minimum level of 5µL without affecting oil quality. A versatile system is needed suitable for either macro or micro distillations capable of measuring volumes of oil from 5 µL to 10 mL, while operating as a steam unit, a water unit or a combined water and steam unit. The system design required consistency between individual stills, and ease of multiple still operation. Finally, the system needed to provide a clean uncontaminated sample, easily available for GC analysis.

CONSTRUCTION: The system was designed in three pieces, the still pot, the condenser and the separator. Different boilers are used depending on the volume of material required for distillation and the type of distillation (steam or water). The condenser section is permanent and can be used for all three forms of distillation. The separator attaches to the condenser and separates the condensate into oil and water. The volume and oil character determines the type of separator. Three separators are available:

(I) Semi-micro for volumes of oil between 5 and 700 µL.

(II) Macro which is similar to the semi-micro but with a larger bore within the calibrated section, measuring between 1 and 10 mL.

(III) A heavier than water separator for high specific gravity oils; these calibrated sections can also vary between 5µL and 10mL.

The Still Pot

For water distillation round bottom flasks are used as with the modified Clevenger method. The size of the flask depends on the volume of material to be distilled, but the size of the neck must match the base of the condensing section.

The steam distillation still is designed around the plunger base of a two cup coffee pot. Flared glass tube the same diameter as the coffee plunger is sealed on one end and narrowed to a quick fit joint on the other (B24/29) (Figure 1). A drainage line and steam pipe are attached to the base section, and a threaded stainless steel rod enables the plunger base to be set at varying heights.

During operation the plunger base holds the leaf material above the steam which is supplied via the steam pipe. The system connects to the 'condenser section' just as the round bottom flask does. The drainage line allows 15mm of water to build up within the system and then removes this waste to avoid flooding the charge.

To operate the system as a steam and water unit the same vessel is used as in the steam distillation, but the steam inlet is blocked and the vessel is filled with water to the level of the drainage line, and heated on a hot plate.

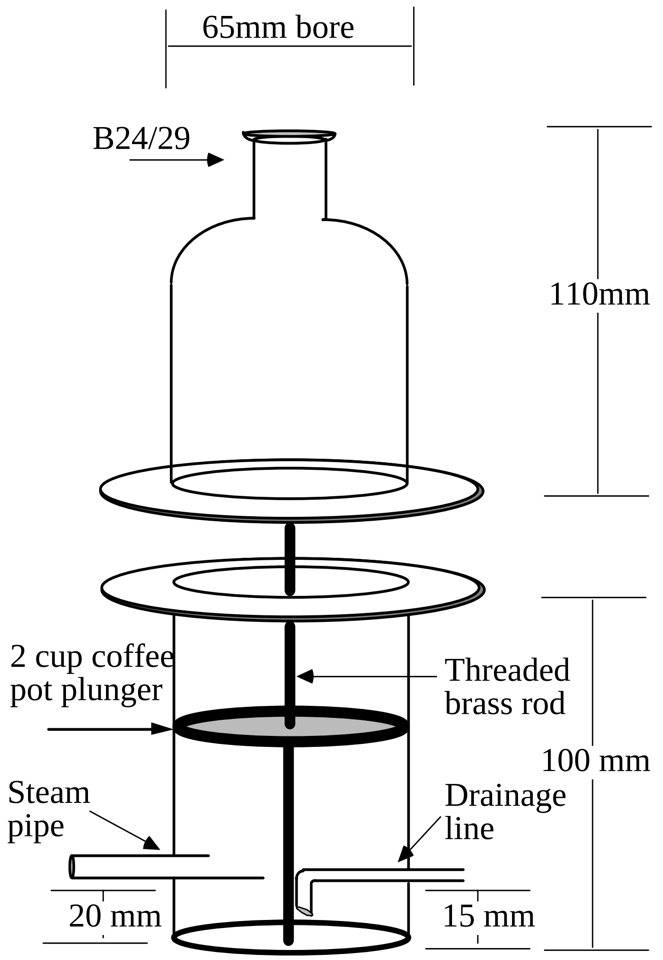

Figure 1. The Steam and Steam and Water Still Pot

The condenser section

The condenser section (Figure 2) consists of a 700mm long lead pipe and a 140mm condenser. The condenser inner tube is constructed from 6mm ID tube to reduce the oil and glass contact. At the top of the condenser is a stoppered opening which allows for easy cleaning. The outlet of the condenser has a drip tip to rest against the top of the separator which stops the condensate from dripping, maintaining an even flow through the system. The joint at A allows for recycling of the distillation water from the separator section.

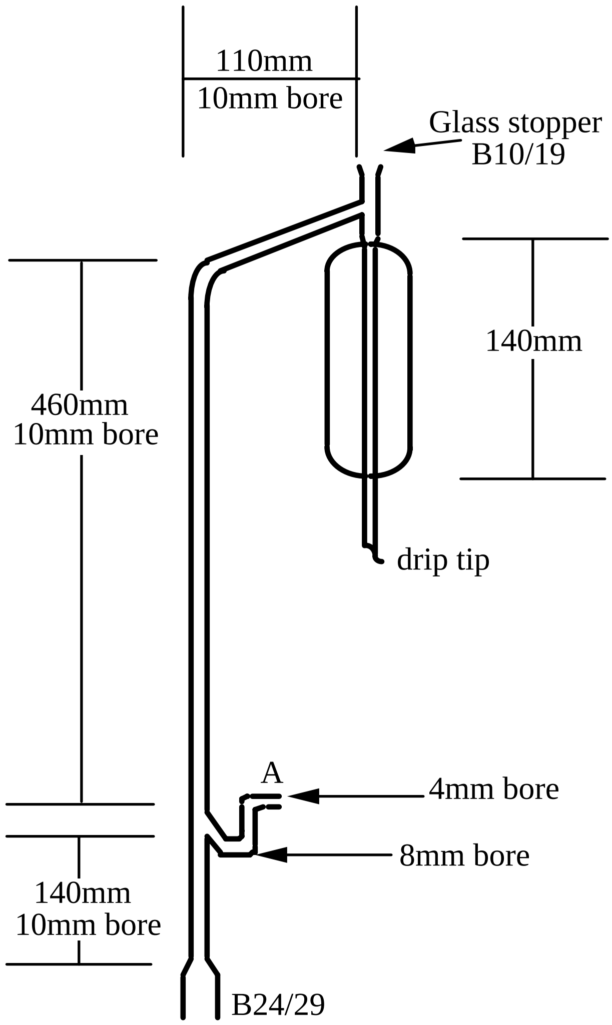

Figure 2. Condenser unit

The separation section

The separator (Figure 3) collects the condensate via the collection funnel which leads down to the separation cone via the calibrated section. The condensate moves down through the calibrated section and separates out in the cone below.

In Figure 3 the outlet at C relieves the steam back pressures created if the fluid flow should block the narrow graduated tube; thus, maintaining the flow in one direction. Outlet B attaches to the main still by a plastic tube which enables water recycling. At the completion of the distillation the plastic recycling tube can be removed. The level of the bent outlet B maintains the oil just below the calibrated section.

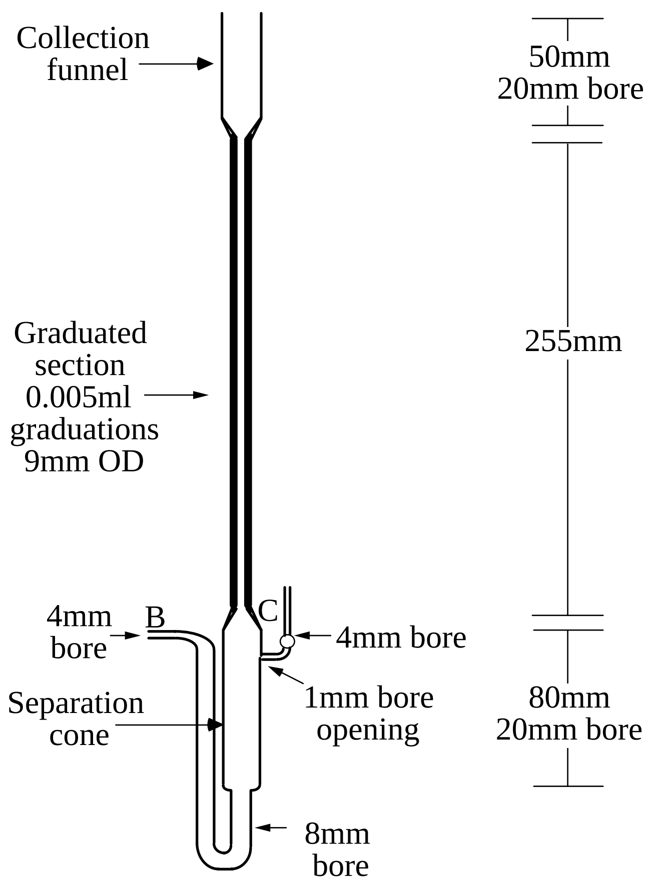

Figure 3. Semi-micro Separator

OPERATION:

Step 1

To operate the still the separator is connected below the drip tip of the condenser and the water recycling tubes of the separator and the main still are joined by a plastic tube (A, B Figures 2 and 3). The still pot is attached to the base of the condenser and distillation begins.

Step 2

At the completion of the distillation the glass stopper at the top of the condenser is removed and the condenser is flushed with water. The plastic water recycling tube is removed from the main still (A, Figure 2), and the oil level is raised by injecting water at point (C, Figure 3) . A rubber cap blocks the outlet at point (C), then a water reservoir is attached to the separator outlet point (B, Figure 3).

Step 3

The water reservoir pushes the oil up the calibrated section; enabling a quantitative measure of the amount of oil. Once this measurement has been made the reservoir can be re-opened to push the oil up into the collection funnel. From this point the oil can be collected in a micro-pipette and used for qualitative analysis.

EXPERIMENTAL : These results will be discussed separately in terms of uniformity of the stills and oil recovery

Uniformity of the stills: The aim of the semi-micro stills is to provide an accurate estimate of oil concentration in multiple samples. To fulfil this purpose the stills had to be accurate, but above all give repeatable results. To test the uniformity of the stills; repeated samples from an individual plant source were tested and the results analysed to determine the error.

Method

A leaf and twig sample (1000g) was collected from one tea tree shrub (*Melaleuca alternifolia.* Cheel). This sample was dried and prepared in the manner described by Whish (11). Twenty, 5 gram samples were weighed and prepared; 5 were oven dried (80°C for 24 hours) to determine dry weights with the remainder being distilled for two hours in four runs of the four stills (condensate flow rate 5 mL/min). Finally an analysis of variance on all treatments was used to determine the error between stills and between distillation runs.

Results and Discussion

The accuracy of the stills was very high. No significant difference was found between the 4 individual still or between the 4 repeated distillation runs. The mean coefficient of variation between the 4 individual stills was 1.65% and 2.03% over the repeated runs. The low coefficient of variation demonstrates the accuracy of this system for repeated sampling (Table I).

Table I. The Oil Yield (%v/dw) isolated by each still from each repeated distillation run

	Oil Yield %v/dw				
	Still 1	Still 2	Still 3	Still 4	**Mean**
Distillation Run 1	6.1	6.2	6.3	6.1	**6.2**
Distillation Run 2	6.1	6.0	6.0	5.8	**6.0**
Distillation Run 3	6.0	6.2	6.2	5.5	**6.0**
Distillation Run 4	5.8	5.8	6.2	5.9	**5.9**
Mean	**6.0**	**6.0**	**6.1**	**5.8**	

Oil recovery: It is not possible to make absolute measurements of a herbs' essential oil content. Thus, a stills' effectiveness can only be measured by a direct comparison with an existing system; such as the Clevenger trap.

Methods

Estimate of effective oil recovery

Sufficient leaf was collected from 1 clonal tea tree shrub (*M. alternifolia.* Cheel) to give 200g of air dried leaf. The leaf was mixed and divided into four portions. Each portion was then divided into eight 5g and eight 10g samples. Four of the eight, 10g samples were distilled for two hours in a modified Clevenger trap water distillation unit. Four of the 5g samples were distilled for 2 hours in the semi-micro distillation unit in water mode (condensate flow rate 5 mL/min), and the other four, 5g samples were distilled in the semi-micro distillation unit in steam mode (condensate flow rate 5 mL/min). The remaining four, 10g samples were oven dried and used to calculate the percent yield for each distillation. At the completion of the distillation the oil from each still was collected and chemically analysed.

A 10µL oil sample was collected, diluted in 1mL of ethanol and analysed using a Varian Star 3400 GC fitted with an 8200 autosampler, star workstation computerised integrator and a capillary column [Econo Cap SE54, internal diameter 0.32mm, length 30m, and film thickness of 0.25µ]. Running conditions were initial column temperature, 50°C held for 3 min; temperature rise rate, 4°C per min to 100°C, held for 3 min, continued temperature rise, 15°C / min to 200°C; inlet temperature 150°C and detector oven temperature, 265°C; flow rate of 1mL per min.

The results were analysed by a two way analysis of variance using the statistical software package "Neva" (12).

Results and discussion:

Oil recovery

The stills effectiveness compared to the modified Clevenger trap was good. In this comparison no significant difference was recorded between the two stills, yet a 10g sample was required to obtain a reading on the modified Clevenger trap.

In the past it has been suggested, by Charles and Simon (10) that steam distillation is more efficient than water distillation; however, in previous comparisons the two stills have always been separate individual systems. This system, being a flexible form of distillation enables the steam still pot to be connected to the existing condenser and separator. There was no significant difference between steam distilled samples and water samples (Table II). So in this case there is no difference between steam and water distillation.

Table II. Comparison of Distillation Methods

Still type	Method	Oil Yield % v/dw	1,8, Cineole %	Tepinene-4-ol %
Semi-micro distillation unit	Steam	5.6	6.27	41.28
Semi-micro distillation unit	Water	5.7	6.48	43.22
Modified Clevenger Trap	Water	5.6	6.75	44.85
5% LSD		0.4	0.61	4.71

CONCLUSION: The above results show that this new distillation system is flexible, accurate and well suited to oil screening where quick results are required. The ability to easily remove small quantities of oil from the still makes it a useful research tool. A 10µL sample of oil can be removed directly from the still enabling a full oil analysis to be completed immediately after the distillation.

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THE EFFECT OF FIVE DIFFERENT MULCH FORMS ON THE PRODUCTION OF BASIL, THYME AND CHAMOMILE

INTRODUCTION

The control of weeds in high value herb crops is a major problem. Many herbs are eaten raw or with minimal preparation, or consumed as concentrated extracts, hence reduced chemical use is encouraged. Weed control is the predominant cultural practice in herb crops as the reduction of weeds is important to maintain high production levels, and to avoid product contamination. In order to achieve both a weed and chemical free product, various mulches are used.

Mulch is a covering layer of material that creates a buffer zone between the soil surface and the aerial environment. This buffer zone can change the microclimate around the plant improving plant growth. Many different substrates are used as mulch, and these can be classed as either organic or inorganic mulches. Organic mulches are mulch forms comprising of waste material: straws, manures, sawdust and woodchips. Historically, these materials have been applied to the soil with the aim of reducing weeds, retaining soil moisture and returning nutrients. In addition, the organic mulches improve soil structure by reducing soil crusting, compaction and erosion. Thick layers of mulch provide an insulting effect on the soil which reduces diurnal fluctuations.

Organic mulches utilising the byproducts of other agricultural practices have proven their worth over centuries; however, the use of organic mulch on broadacre, large scale production areas is impractical. For this reason synthetic inorganic mulches have been developed.

Various forms of plastic film are used to provide some of the benefits of organic mulch in a manageable form. A number of ancillary benefits can be gained from the use of plastic mulch, and these have been exploited to improve crop production. Despite these benefits the greatest drawback with the use of inorganic mulch is that it persists as an environmental contaminant after use.

The use of either organic or inorganic mulch can enable the manipulation of a plants micro-environment to enhance production. This manipulation is not always beneficial, however, and all aspects of the plant must be considered when choosing a form of mulch.

Temperature

Different plastic mulch forms are available varying from woven plastic, to smooth plastic and embossed plastic films. In addition to the surface structure, the colour and thickness of the mulch can vary. Each of these variations can have an effect on the microclimate around the plant, and in particular the soil temperature.

Plastic mulches have been shown to increase the soil temperature by 5 to 10°C when compared to bare earth (Decouteau *et al.*, 1989; Argall and Stewart, 1990; Asiegbu, 1991; Elmer *et al.*, 1991). This well documented temperature rise is often used as an explanation for increased production of crops grown in plastic mulch (Ricotta and Masiunas, 1991; Brown, 1992; Grubinger *et al.*, 1993; Davis, 1994). Each of the different coloured mulches used in the production of crops causes different temperature effects.

Black plastic film is the most common form of mulch, and has been shown to cause a significant temperature rise in soils (Decoteau *et al.*, 1989; Decoteau *et al.*, 1990; Ham *et al.*, 1993; Wien *et al.*, 1993). Clear plastic mulch is often used for soil sterilisation (Solarisation) - the plastic film is fixed over wet soil to trap solar heat which kills weeds and soil pathogens. Clear plastic is believed to achieve higher soil temperatures than black plastic (Argall and Stewart, 1990; Abu-Irmaileh, 1991). This happens because much of the incident radiation is absorbed by coloured films (Argall and Stewart, 1990) and does not pass through to the soil. Ham *et al.* (1993) showed that the placement of the mulch was important for these temperature rises to be achieved. Their results showed clear plastic heated soil less than black plastic, if it was placed tightly across the soil with good contact between the soil surface and the mulch. The suggestion is that if clear plastic mulches are placed loosely over the soil an insulating air layer develops, increasing the soil heat storage, and reducing heat loss.

The purpose of the mulch is not always to heat the soil, in some situations soil temperatures are high enough, and an increase in soil temperatures may reduce plant growth by damaging the plant root system, and pasteurising the soil microbes (Barker, 1990). White mulches have been shown to have a significantly lower heating effect compared to other coloured mulches (Decoteau *et al.*, 1989; Ham *et al.*, 1993). Silver mulch would be expected to reflect the greatest amount of light, and for this reason generate the lowest soil temperature. However, Decoteau *et al.* (1989) found silver mulch caused a soil temperature rise only 1.5°C lower than black plastic. This unexpected result may be explained in terms of the optical properties of the mulch. Silver mulch has a relatively high short wave transmittance, coupled with a relatively low long wave transmittance. The silver mulch could have heated the soil by initially transmitting and/or absorbing short wave radiation, while preventing the loss of emitted radiant energy in the long wave spectrum (Ham *et al.*, 1993). The type of reflective mulch and its thickness may be important when examining the soil heating properties of different reflective mulch forms. Schalk and LeRons Robbins (1987) showed aluminium and aluminised plastic to have similar soil heating properties to white plastic, contrasting with the work of Ham *et al.* (1993). The thickness, or the transmitted wave form, of the mulch used by Schalk and LeRons Robbins (1987) were not reported; however, Kalaielah (1988), cited in Abu-Irmaileh (1991), found that plastic thickness could significantly effect the temperature rise within the soil, and this may explain the deviation from the results of Ham *et al.* (1993).

The effect of mulch surface heating is also important when considering the growth of plants. Surface temperatures in excess of 84°C (Ham *et al.*, 1993) have been recorded over black plastic. At these temperatures leaf scalding can occur. Despite the high mulch surface temperatures, the air temperature in the growing regions 5cm above the mulch were uniform for all mulch colours, and only 4°C higher than the ambient temperature measured at 1.5m (Ham *et al.*, 1993). It must be remembered that the measurements quoted were recorded on small experimental plots and that fields covered with an unbroken layer of mulch may influence the temperature around the plants to a greater extent.

Improved plant yields from plastic mulched soils are often explained as a temperature effect, but the effect of temperature on the plant has not been examined. Wien *et al.* (1993) found plants transferred into black plastic mulch had a significantly higher root growth rate in the week following transplanting, compared to plants transferred into bare soil. This increased growth rate enabled the roots to reach the edge of the mulch within 3 weeks of transplanting. The growth of the roots in the first three weeks was significantly correlated with soil temperature. However, the growth rate of the plant tops was much slower than root growth. The tops of the plastic mulched plants only surpassed the growth rate of the bare soil plant tops two weeks after transplanting. This growth was not significantly correlated with soil temperature, suggesting that the increase in the yield of plants grown on plastic mulch is not controlled by soil temperature alone (Wien *et al.*, 1993).

The temperature effects caused by coloured mulches may diminish as the plants grow and shade the mulch surface. However, the effect of soil warming caused by a sealed plastic surface, and insulting layer of trapped air, would remain.

Organic mulches do not always display the same heating effect as the plastic mulches, in particular black plastic mulch. Black plastic has been shown to have a large diurnal temperature fluctuation only marginally different to bare soil. Organically mulched soils do not display this same degree of fluctuation (Asiegbu,1991). Asiegbu, (1991) used two grasses and cassava peel as his mulches. The cassava results were not conclusive, but the two grasses were light in colour, and showed an insulating effect on the soil. Many of the traditional mulches used are light in colour, hence the insulating effect described by authors when referring to organic mulches may simply be an optical effect with the straw mulches responding in a similar manner to white plastic. When dark coloured pine bark was placed as a mulch around crepe myrtle cultivars, a heating effect occurred. The surface of the mulch was 26°C hotter than bare soil, and the plants' water usage was increased (Zajicek and Heilman, 1991).

Despite the potential for increased temperatures, the insulating effect of organic mulch is useful in areas where high summer temperatures and cool nights may effect plant growth. One aspect of the insulating properties of organic mulch is the time of application, the mulch will prolong the soil temperature to that at the time of placement. For this reason the application of mulches to cold soil will keep the soil cooler for longer compared to bare soil (Barker, 1990).

Increasing soil temperatures can significantly improve the growth and development of plants, this improvement is only one aspect of the many different influences mulches can have on plant growth.

Soil moisture

Water is essential for growth and development. It is also a major cost in agricultural systems. The success of many agricultural forms relies on conservative and efficient use of water.

Moisture retention is undoubtedly the most common reason mulch is applied to soil. Mulch is used to protect the soil from direct exposure to the sun, which would evaporate moisture from the soil surface and cause drying of the profile (Barker, 1990). The protective interface established by the mulch stops raindrop splash by absorbing the impact energy of the rain, hence reducing soil surface crust formation. The mulch also slows soil surface runoff allowing a longer infiltration time. These features result in improved water infiltration rates, and higher soil moisture (Barker, 1990). An auxiliary benefit of mulch reducing soil splash is the decreased need for additional cleaning prior to processing of the herb foliage (Barker, 1990).

Organic and inorganic mulches have been shown to improve the moisture retention of soil. This extended water holding ability enables plants to survive during low rainfall periods.

Fluctuations of moisture within the soil are conducive to the development of Blossom-end rot in tomatoes, and the use of mulch to reduce the fluctuations can decrease the occurrence of this disease (Cook and Saunders, 1990; Elmer and Ferrandino, 1991). Plastic mulch can however, encourage the development of Blossom-end rot as it forms an impervious layer excluding rainfall, with water only reaching the soil through the plant holes and around the edges of the mulch. This impediment to water flow during heavy rains may explain the enhancement of early season Blossom-end rot under plastic mulch (Elmer and Ferrandino, 1991). The use of irrigation in combination with the mulches would reduce the occurrence of this disease.

However, the improved moisture retention under mulch can cause disease problems during wet years, especially on crops that are continually wounded by repeated harvests. The occurrence of soft rot in basil plants was more apparent in plastic mulched treatments than in either straw, wood chip or bare soil (Davis, 1994). Despite this disease problem the overall yields were highest in the plastic mulched treatments (Davis, 1994).

The use of plastic mulch can be improved if under-mulch irrigation is used in combination with soil moisture monitoring. The influence of rainfall events are not as great when plastic mulch is used, necessitating active irrigation management. Under-mulch irrigation of vegetable crops has been shown to improve crop yields more than overhead irrigation systems (Clough *et al.*, 1990).

Mulch enables the soil moisture levels to be maintained for longer periods. In some cases while providing improved moisture conditions within the soil, the mulch changes the plants microclimate so that it uses more water (Clark *et al.*, 1991; Zajicek and Heilman, 1991), thus negating the initial benefit. However, Mulches are dynamic and can reduce competition by weeds for the crops resources. In more general terms, mulches suppress weeds and in so doing they improve the soils' water and nutrient reserves for the desired crop plant.

Weed control

Weed control in crops is a difficult, time consuming and expensive task. These difficulties are compounded when the crop is a low growing succulent plant which cannot successfully compete with weeds, is eaten raw, and grown as a minor crop. These characteristics are found in herb crops grown for the medicinal and culinary industries. Also, premium prices can often be achieved if a chemical free herb is produced. Being minor crops, the registration and development of selective herbicides is impractical, hence soil mulching is one method with which weed control can be achieved on small and large scale plantings. Mulches laid across the soil and around the crop reduce the amount of light reaching the soil, and thus inhibit weed germination, and smother emerging weeds. Mulching for weed control can take a number of forms: inorganic or organic mulches can be applied and left *in situ* to control the weeds; living mulches can be grown to choke out weeds, before planting the mulches are either killed with chemicals or complete their life cycle before the growing season of the herb; Solarisation uses an inorganic mulch and solar energy to disinfect the soil, the mulch being removed prior to planting.

Black plastic mulch has been shown to successfully control weeds and to enhance the growth of basil and rosemary plants (Ricotta and Masiunas, 1991; Davis, 1994). Despite the success of black plastic, its disposal at the end of crop production can cause environmental problems. Some photodegradable plastic films have been developed, but the buried portion of the mulch will not break down, and remains in the field as a pollutant (Ham *et al.*, 1993). Black plastic has also impeded production of some herbs, as the lateral shoots grow underneath the mulch instead of above it (Galambosi and Szebeni-Galamosi, 1992).

Organic mulches come in various forms the most common being: straw residues from cereal crops, sawdust, wood chips and legume hay. Some disadvantages occur with each of these forms, but the greatest drawback with the use of organic mulch is the introduction of weed seed (Barker, 1990). Organic mulches must be applied thickly, and continually reapplied as decay occurs, so that they stop light reaching the soil surface. The large volumes of material required to successfully impede weeds can be costly, and discriminate against the use of these mulches (Barker, 1990).

Davis (1994) found organic mulch successfully controlled weeds, and the yields achieved with basil were not significantly different to black plastic. Similarly Asiegbu (1991), compared two straw mulches, black plastic and Cassava peel. The results showed that the mulch treatments, with the exception of Cassava peel, reduced weed growth. However, black plastic was the most efficient weed control method.

The addition of mulches for weed suppression does have drawbacks. Black plastic must be removed at the end of the season, while organic mulches will break down during the season and may need to be replenished. Organic mulches can be either long lasting (wood chips, sawdust) or short lived (legume hay) lending themselves to annual, or perennial herb culture. The use of long lasting mulches on annual crops will cause a build up of the mulch in the soil and effect soil composition.

The difficulty with using organic mulch is the need to apply large volumes of material over large areas. Living mulch is one solution to this problem. Living mulches can either be living during the growing season of the crop, or dead due to herbicide application or life cycle end. This form of mulching is suited to annual herb production. A quick growing cereal or forage is grown during the off season, and flail mown to produce a mulched layer for the annual herbs. Tomatoes have been successfully produced in this manner following wheat and rye in a no till mulch (Drost and Price, 1991). This form of *in situ* green manuring is a successful method of applying mulch to large areas; however, it is important to achieve an adequate cover of mulch. If the cover is not adequate weed infestation will occur through the bare spots (Mohler, 1991), resulting in a need to rely on chemicals. Increased chemical volumes will be required as the mulch will adsorb the applied chemicals thus reducing their effectiveness (Hodges and Talbert, 1990). Additional benefits such as weed and disease control may be gained from the use of cover crops if allelopathic inhibitors are present in the mulch (Freyman, 1989; Mohler, 1991).

The use of a low growing seasonal cover plant is another method of mulching large areas. The use of living mulch has been trialled on maize crops (Enache *et al.*, 1990), between the rows of raspberry crops (Freyman, 1989) and as an interplanting system within vegetable production

(Abdul-Baki and Teasdale, 1993). These cases indicate a benefit from the use of the mulch. A yield increase often occurred if the mulch was a legume, as it supplied additional nitrogen while the crop utilised (Freyman, 1989; Pool *et al.*, 1990). Competition between the mulch and the crop can occur, and the best management strategy is to suppress the growth of the mulch (Wiles *et al.*, 1989). The application of a knockdown herbicide prior to planting the crop, or matching a cool season mulch with a warm season crop, are the most suitable methods. Both the crop and the mulch must be managed concurrently, so additional inputs of water and fertiliser may be necessary.

The addition of mulches for the growth of some herbs may not be practical. Many herbs are short, ground covering plants which can grow under and through mulches. Solarisation can control weeds in these situations without the use of chemicals, provided sufficient solar energy is available. The soils to be solarised are covered with clear or black plastic and sealed. Clear plastic is considered to produce higher temperatures in soil so is the most commonly used (Stevens *et al.*, 1990). The soils are left for a period of time after which the soil is uncovered and planted. Solarisation of soil for 98 days has been shown to control weed populations of purple nutsedge, southern crab grass, barnyard grass, beauvois, florida pusley and pigweed (Stevens *et al.*, 1990). Solarisation has also been shown to significantly reduce the presence of soil borne diseases (Sarraf and Farah, 1989; Stevens *et al.*, 1990; Abu-Irmaileh, 1991). Abu-Irmaileh (1991), found black plastic mulch could effectively solarise soil, and then remain in place as a plastic mulch. This method of mulching would help prevent plant disease, and reduce the occurrence of weeds through the plant holes in the mulch.

Plant growth

Mulching soil with either organic or inorganic mulches influences the crop in a number of ways. The combined effects of soil temperature, soil moisture and weed suppression may work to improve crop growth. The mulch colour, and the effect that mulching has on the soil structure, also influence crop growth and development.

The advent of inorganic plastic mulches has enabled the colour of the mulch to be easily changed. Plastic mulches can be made in a multitude of colours and even change their colour during the growing season. The different colours of the mulch reflect and adsorb different wavelengths of light, and this filtering of the light can influence plant growth. The difference in plants grown on light mulches and dark mulches has often been explained by the dark mulches changing the soil temperature. This is true, but the reflected light from the mulch has also been shown to influence plant growth (Brown *et al.*, 1992). Decoteau *et al.* (1989, 1990) examined the influence of coloured mulches on the growth of bell peppers and tomatoes. In both cases significant morphological differences occurred as a result of the mulch colour. Tomato plants grown on silver, and white mulches had more foliage compared to red or black mulched plants, yet the red and black mulched plants had the highest fruit yields. When the same experiments used insulation under the mulch to reduce the effect of heat, similar results occurred. Plants grown on the lighter coloured mulches were also shorter than plants grown on the darker (black and red) mulches (Decoteau *et al.*, 1990).

The use of silver and reflective mulch has also improved crop growth. This improvement is not only a result of the mulch reflecting the light back to the plant, but the reflected light reduces the number of aphids and thrips on the mulched plants (Enache and Ilnick, 1990; Greenough *et al.*, 1990; Lamont *et al.*, 1990). Reduced insect numbers may also lower the incidence of plant disease.

The optical properties of organic mulch may affect plant growth in a similar way, but no information was found during this search. Organic mulches do influence the soil structure. The addition of organic mulch to the soil increases the organic components and microorganism populations. Structural changes to the soil can increase the soils water holding capacity and rate of infiltration, while the mulch cover protects the soil from surface water movement, and wind erosion. The combination of physical changes created by the addition of inorganic mulch will improve crop production. Sawdust applied to lowbush blueberries significantly increased the fruit yield primarily because of the improved soil structure (Sanderson *et al.*, 1991).

Disadvantages of using mulch

Despite the added benefits of using mulch outlined above, a number of disadvantages do exist. The use of mulch reduces the options for field establishment, as conventional direct seeding technology does not work with mulch. A number of seeding systems that allow plants to be sown through the mulch have been developed, although these systems are expensive and due to the increasing cost of seed have only limited use. Improved and hybrid seed has increased the cost of direct seeding plants, and eliminated the option of overseeding as a means of establishing uniform plant stands (Hartz, 1994). The use of transplants has simplified the establishment of uniform plant stands during unfavourable environmental conditions, and new machinery has enabled transplants to be sown at low cost (Hartz, 1994). More recent developments have been the use of machines that will sow transplants through plastic mulch, however, such machines are rare and in many cases handsown transplants are used with mulch.

Despite the fact that mulch helps maintain moisture within the soil, some form of irrigation is often required. The use of organic mulches does not influence the type of irrigation, but plastic mulch can reduce the efficiency of overhead and channel irrigation (Hartz, 1994). Drip under mulch irrigation is the most suitable form to be used with plastic mulch, although it is an expensive form of irrigation (Hartz, 1994).

The use of plastic mulch is the easiest and most suitable form of mulch for large areas. The drawback with this mulch is its disposal at the end of the season. Photodegradable plastics are being used (Ham *et al.*, 1993), however, as already described, the buried portions of these plastics will not break down making photodegradable plastic difficult to remove.

Organic mulches can also cause problems when used. The use of straw and other crop residue materials can increase rodent populations. Field mice will breed within the straw and can reduce profits by collaring plants or contaminating the final product (Barker, 1990). The addition of organic mulches may also introduce weeds and diseases. The volume of material required is large and in most cases must be bought off farm, thus increasing the risk of introducing problems.

The production of herbs on mulch is not without its problems, but provided the mulch can be obtained for a price that will allow a suitable profit, and the plants will grow successfully above the mulch and not through or under it, then plant growth and management will be assisted by its use.

Many authors, when comparing the growth of plants on mulches, only examine the effects of yield. If any changes occur this is described as a result of the mulch, but not caused by any particular feature of the mulch. In our experiment four forms of mulch are examined, and the effects of temperature, moisture, weed suppression, and plant nutrition are all examined for their individual effects on the yield of the herb crop, and the quality and quantity of secondary products produced by the plant.

METHODS

Five mulch treatments were laid out in a complete randomised block design. The mulches were "no mulch" a control plot consisting of a 1m wide ploughed earth bed, "*in situ* mulch" an unploughed 1m wide bed covered with flail mown winter forage to a depth of 3 cm, (forage was sprayed prior to mowing with 1.6 L/ha of Glyphosate-360g/L), "plastic film" (VP. Industries Pty Ltd) 200µm black polyethylene film placed over a 1m wide ploughed bed, "weedmat" (VP. Industries Pty Ltd) a woven polyethylene film placed over a 1m wide ploughed bed, "wool mulch" (Higgins Wool Company) 350g per m^2 needle felted wool fabric placed over a 1m wide ploughed bed. The mulches were buried along the edges of the ploughed beds to hold them in place.

Basil seedlings (Yates, F1030HH3), Chamomile Seedlings (Eden Seeds, 1993) and Thyme cuttings were germinated/struck and raised in individual cell trays (100 cell "Kwikpots" Rite Gro Australia) inside a plastic hoop house. Eight week old seedlings were transplanted into the field through the mulch with the aid of a mulch punch which cut a 3cm diameter hole and left a dibble hole the same size as the seedling plug in the soil bed. The weedmat required cutting before the mulch punch could be used. Seedlings were placed by hand into the prepared holes and watered in by an overhead sprinkler. Basil plants were sown 20 cm apart with a 25 cm row spacing, thyme and chamomile plants were placed on a 15cm square.

No under-mulch irrigation was provided. All plots were watered by an overhead sprinkler and natural rainfall events. Irrigation was used for plant establishment, and when rainfall was inadequate.

Plant growth

Basil

Each plot was harvested twice during the season. The first harvest occurred 80 days after the seedlings had been transferred to the field (10/2/94). At this point 50% of the plants had set flower. The second harvest occurred 137 days (8/4/94) after transplanting and was chosen because of the onset of cool conditions. At the 2nd harvest flower initiation had occurred, but no flowers were set. The plants were harvested with a cutter bar which cut them 10cm above the mulch. The harvested material from each plot was collected in 5kg plastic bins, weighed, and dried at 30°C using a hydronically heated, forced air drying unit (Branco Australia; Morgan and Judd,1992). Drying was deemed complete when the plant water content had reached 9%. In general this took 72 hours. Once dry, the plant samples were weighed and then rubbed through a $1cm^2$ mesh to remove the leaves from the stems. The rubbed material was then weighed to determine dried leaf and dried stem weight for each plot.

Thyme

The thyme plants were transferred to the field on the 5/11/93. Being perennial they grew more slowly than either the basil or chamomile. Only one harvest was possible in the first season, the plants were cut with a mechanical hedge trimmer 124 days (11/3/94) after transplanting.

Chamomile

The chamomile plants were harvested twice during the season, further harvests may have been possible but the onset of dry conditions reduced plant growth. The plants were transferred to the field on 23/11/93 and the first chamomile harvest was when the majority of plants had open flowers, 65 days (27/1/94) post transfer. The flowers were combed from the plants using a wide toothed comb and a collection tray. The second harvest occurred 15 days after the first, 80 days (11/2/94) post plant transfer .

Oil yield determination and composition

Basil

Three 30g samples were taken from the dried broken leaf. One 30g sample was weighed and placed in an 80°C oven for 48 hours to determine the oven dry weight. The two remaining samples were steam distilled using a semi micro hydro distillation unit (Whish, 1994). A 20µl oil sample was collected, diluted in 1ml of ethanol and analysed using a Varian Star 3400 Gas Chromatograph fitted with an 8200 autosampler and star workstation computerised integrator.

Thyme

Three 10g samples were taken from the dried leaf. One 10g sample was weighed and placed in an 80°C oven for 48 hours to determine the oven dry weight. The two remaining samples were steam distilled using a semi micro hydro distillation unit (Whish, 1994). A 20µl oil sample was collected, diluted in 1ml of ethanol and analysed using a Varian Star 3400 Gas Chromatograph fitted with an 8200 autosampler and star workstation computerised integrator.

Chamomile

The chamomile samples were not examined for oil quality and quantity.

Table 9. G.C. Parameters

Stationary phase column	Econo Cap SE54
Length	30m
Internal diameter	0.32ml
Film thickness	0.25µ
Detector	FID
Oven temperatures Initial	60°C
Ramp	3°C / minute to 150°C
Ramp	20°C / minutes to 250°C
Injector temp	220°C
detector temp	265°C
carrier gas	Helium
retention time Pinene	5.20 minutes
retention time Limonene	7.89 minutes
retention time 1, 8 - Cineole	8.01 minutes
retention time Linalool	10.63 minutes
retention time methyl chavicol	14.29 minutes

A third distillation for oil yield was conducted should the first two differ by more than 0.015 ml.

The volume of essential oil measured in the still was related to the oven dried sample and the oil concentration was recorded as percent oil yield v/dw.

Weed control

Basil

The ability of each mulch treatment to suppress weeds was determined by continual harvests of the weed burden. Weeds were harvested three times during the growing season, at 21, 58 and 98 days from the time of transplanting. The time of weeding was selected by the size of the weeds and the degree of weed infestation, with the aim of removing the weeds before any detrimental effect occurred to the crop. The degree of weed infestation was determined by photographic records of the plots recorded over the season.

Thyme

As with the basil plants weeds from the thyme plots were harvested at different times, the harvest at 39 days after transplanting (14/12/94) and 76 days post transplanting (20/1/94) were the largest. Following these harvests only spot weeding was necessary as the thyme plants had closed their canopy and were successfully preventing weed growth.

Chamomile

The chamomile plants were weeded at the same time as the basil plants (21, 58 and 98 days from the time of transplanting) the quick growth of the chamomile plants reduced the time to harvest, but did not help to reduce the weed population. Following the final harvest, weeding of the chamomile plants was stopped and the plots were soon invaded by broad leaf weeds.

Soil nitrogen mineralization under the different mulch treatments

Open intact cores

The effect of the mulches on soil mineralization was measured using intact soil cores buried in the soil under each mulch

50, 3cm diameter x 5cm high, intact soil cores were collected from within a 1m^2 area. These cores were sealed and returned to the laboratory. 20 cores were cut vertically in half, half the soil (by weight) was dried at 105°C for 48 hours for moisture content determination . The remaining soil was immediately extracted in 200ml of 1N KCL, shaken for 2 hours and filtered through a Whatman No. 42 filter paper. The extract was analysed for nitrate and ammonium using Bremners (1965) steam distillation method.

The remaining 30 cores were attached to leachate collectors. These consisted of a funnel filled with glass wool and a glass wool wick leading down to a collection bottle (Whish, 1988). These cores were randomly placed under each mulch treatment, and incubated for 94 days. Following removal the cores were cut in half, one half was weighed and extracted for nitrate and ammonium as before. The second half was divided into two parts, one part was weighed and oven dried to determine moisture content, the second part was air dried, and a 5g sample taken and diluted 1:5 with water for pH and conductivity measurements.

Laboratory Incubations

A 30cm^{2}x 3cm deep section of top soil was collected and bulked. This soil was air dried and sieved through a 2mm mesh. The <2mm soil fraction was brought to field capacity (13% moisture) and 8 x 33.9g samples (equivalent to 30g oven dry soil) were weighed into glass incubation jars. The jars were sealed with Gladwrap (polyethylene film 0.013mm thick permeable to CO_2 and O_2 manufactured by Union Carbide Pty. Ltd.) and placed in controlled temperature incubators for 2 weeks. Two incubation temperatures used were 25°C to correspond with the mean maximum summer temperature of soil under wool mulch, and 35°C to correspond with the mean maximum summer temperature under black plastic. At the completion of the incubation the soil was extracted with 100ml of 1N KCL, shaken for 2 hours, filtered through a Whatmans No. 42 filter paper and analysed for nitrate and ammonium nitrogen using Bremners (1965) steam distillation method.

Constant Moisture Field Incubations

Soil samples were prepared as above with 33.9g of soil being placed in resealable plastic bags, the bags were sealed, and buried within the top 5cm of soil under the 5 different mulch types. The soil was allowed to incubate for 160 days and was then removed and analysed for nitrate and ammonium nitrogen as above.

Soil mineralisation data was only collected under the basil plants and extrapolated to the other plant species due to time and equipment limitations .

Temperature difference between mulches

To measure the temperature difference between the 5 mulch treatments, copper constant thermocouples were placed 1cm below the soil surface and covered with mulch. Each plot had a thermocouple, thus replicating the temperature measurements across treatments. Two air probes were placed at plant canopy height (30cm above the ground) to measure the ambient air temperature. The thermocouples were connected to a data logger which recorded the temperatures every 30 minutes. Temperatures were recorded throughout the season in 6 x 10 day blocks.

Both the basil and the thyme plots had temperatures monitored.

RESULTS

Plant growth

Basil

The five mulches showed varying effects on plant growth at the first harvest. The three covering mulches (plastic film, weedmat, and wool mulch) gave significantly higher yields than the *in situ* mulch treatment (Fig. 8). The no mulch control had a lower production than the three coverings; although, this was only significantly less than the plastic film. At the second harvest no significant differences existed between any of the mulch treatments. The production of leaf material was similar to the whole plant production, but showed greater definition (Fig. 9). The covering mulch treatments produced significantly greater quantities of leaf compared to the *in situ* and no mulch treatments at the first harvest (Fig. 9). The second harvest showed that the low yield of the *in situ* mulched plants had continued. There was no significant difference between the three covering mulches. The no mulch and the weedmat were significantly different, but no difference occurred between the other covering mulches and the no mulch control. No significant difference was observed between the stem material yields or the leaf to stem ratios (data not shown).

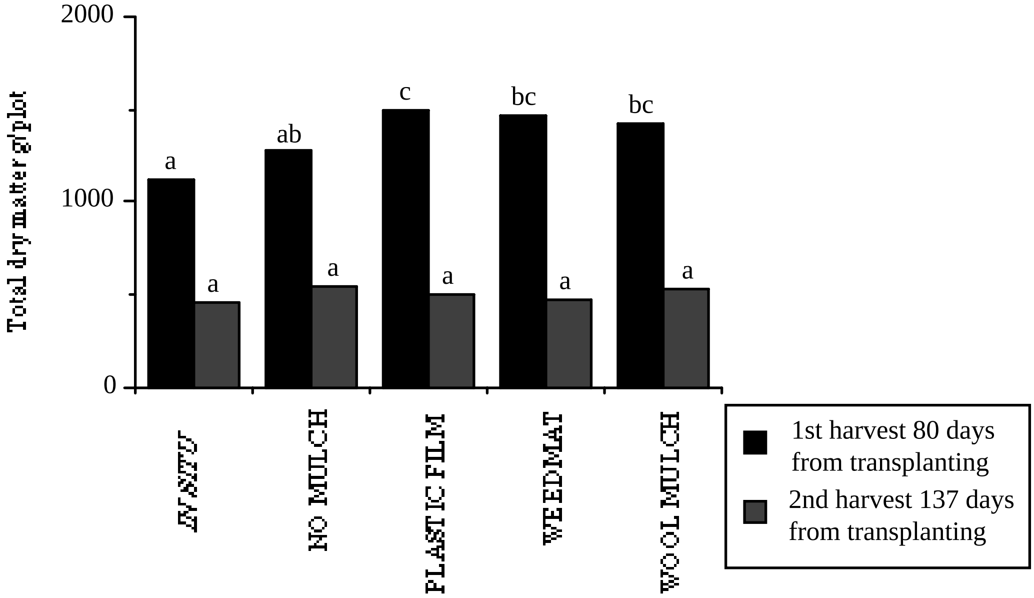

Fig. 8. Total dry matter production of basil plants (g/plot) grown on five mulches (*In situ* , no mulch, plastic film, weedmat and wool mulch). Plants were harvested twice over the growing season. Letters indicate least significant difference at P•0.05

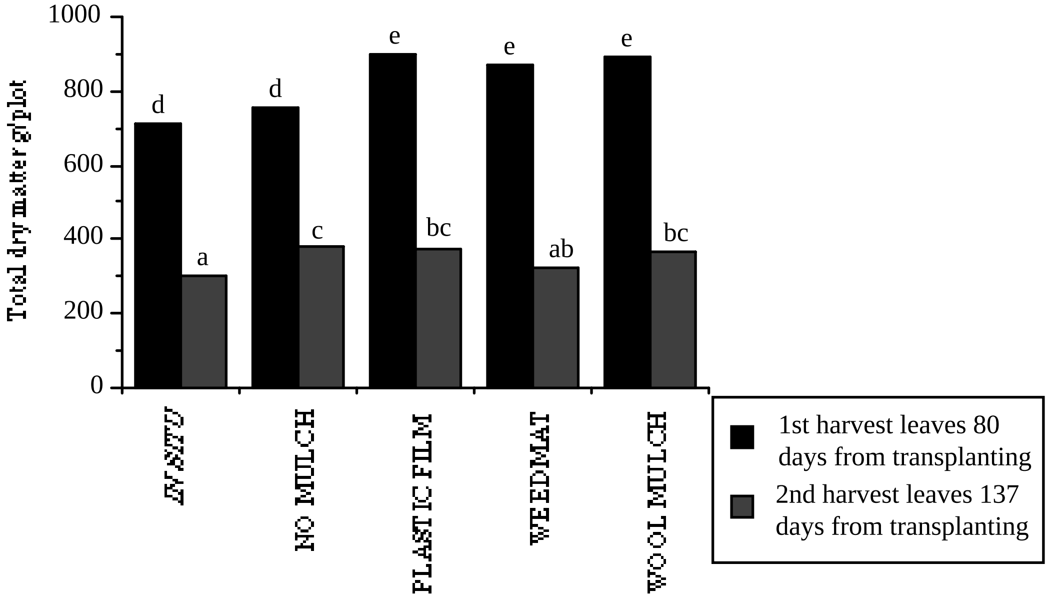

Fig. 9. Total leaf production of basil plants (g/plot) grown on five mulches (*In situ* , no mulch, plastic film, weedmat and wool mulch). Plants were harvested twice over the growing season.

Letters indicate least significant difference at P•0.05

Thyme

The results from the first thyme harvest (Table 10) shows there to be no significant differences between any of the treatments.

Table 10. Dry matter production (g/plot) of thyme plants grown on five mulches (*In situ* , no mulch, plastic film, weedmat and wool mulch). Letters indicate least significant difference at P•0.05

Treatments	D.W. Plant g/plot	D.W. Leaves g/plot	D.W. Stem g/plot	Leaf : Stem g/plot
In situ	647.25 a	425.00 a	245.50 a	1.79:1 a
No mulch	638.25 a	375.75 a	247.75 a	1.64:1 a
Plastic film	700.50 a	458.25 a	260.00 a	1.78:1 a
Weedmat	753.75 a	380.50 a	295.00 a	1.31:1 a
Wool mulch	474.75 a	302.50 a	158.25 a	1.90:1 a

Chamomile

The five mulch treatments (*In situ* , no mulch, plastic film, weedmat and wool mulch) had no effect on the production of chamomile flowers at either the first or second harvest. However the yield from the two harvests was significantly different, with the second harvest yielding more flowers than the first (Table 11). An interaction between the treatments and the time of harvest did occur with the plants grown on plastic mulch producing significantly more flowers in the second harvest compared to the first (Table 11).

Table 11. Dry weight of chamomile flowers (g/plot) produced on five mulch treatments (*In situ* , no mulch, plastic film, weedmat and wool mulch).

Treatments	Harvest 1	Harvest 2	Mean of Harvests	Significance
In situ	42.91	38.8	40.85	
No mulch	52.08	53.81	52.94	
Plastic	25.93	62.61	44.27	
Weedmat	46.17	53.15	49.66	
Wool mulch	50.58	47.32	48.95	
Significance	ns	ns	ns	
Harvest time	43.53	51.14		*

Treatments vs Harvest				**

Oil yield and composition

Basil

The oil yield was measured as the percent oil within the plant leaf (concentration), and no significant difference (P•0.05 or P•0.01) existed between the treatments at either of the two harvests (Fig. 10). The second harvest resulted in a lower oil concentration than the first. An LSD of 1% is used to compensate for the error associated with the use of micro-distillation equipment.

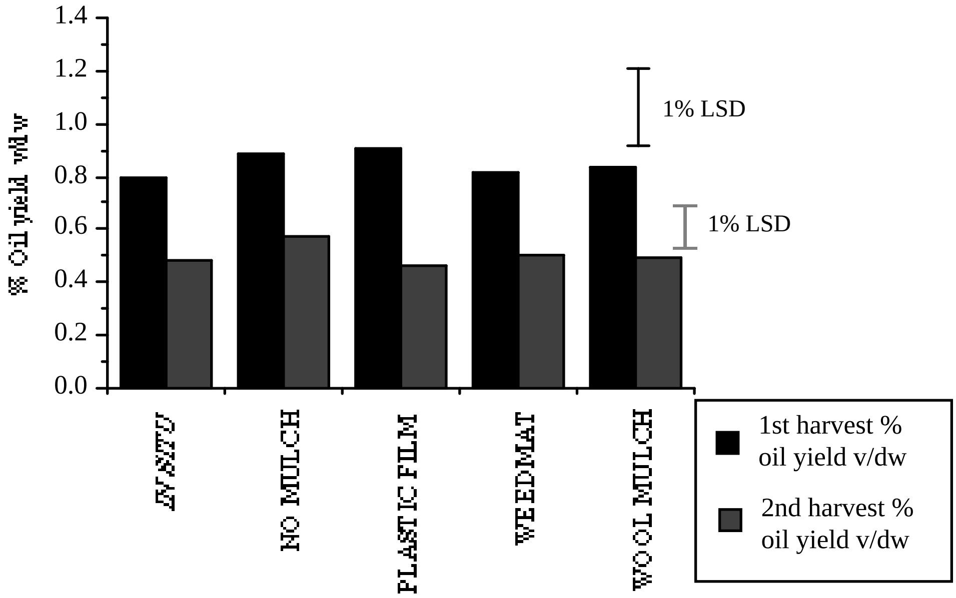

Fig. 10. Oil concentration in basil leaves (volume of oil /g dry weight of herb leaf) grown on five mulches (*In situ* , no mulch, plastic film, weedmat and wool mulch). Error bars indicate least significant difference at P•0.01

The five different mulch forms had no significant effect on the production of essential oil components at either harvest (Table 12), however, a difference did exist between the two harvest times for some components within some treatments.

Table 12. Effect of the five mulch treatments (*In situ* , no mulch, plastic film, weedmat and wool mulch) on the composition of Basil oil over 2 harvests

Component	Pinene % of oil	Limonene % of oil	1, 8 - Cineol % of oil	Linalool % of oil	methyl chavicol % of oil
Retention time	5.201	7.893	8.012	10.635	14.298
Harvest 1					
in situ	0.53 a	9.88 a	1.132 a	44.88 a	11.13 a
no mulch	0.475 a	9.14 a	1.04 a	43.65 a	17.05 a
plastic film	0.555 a	10.3 a	1.04 a	43.07 a	16.17 a
weedmat	0.522 a	9.76 a	1.11 a	46.06 a	9.517 a
wool mulch	0.557 a	10.71 a	1.03 a	43.6 a	13.657 a
Harvest 2					
in situ	0.495 b	8.83 b	0.39 b	45.08 b	13.587 a
no mulch	0.432 b	7.49 b	0.44 b	46.18 b	18.592 a
plastic film	0.431 b	8.11 b	0.32 b	46.38 b	15.758 a
weedmat	0.465 b	8.89 b	0.4 b	45.1 b	15.13 a
wool mulch	0.46 b	8.19 b	0.402 b	44.67 b	14.97 a
harvest diff	***	***	***	*	-

Letters within a column indicate least significant differences at P•0.05.

Thyme

The five mulch treatments had no effect on the percent oil yield (v/dw) (Table 13). The majority of oil components were also unaffected by the types of mulch. Plastic film produces the greatest quantity of π-cymene. Thymol also showed significant variation between the mulch treatments, plants grown on weedmat produced significantly more thymol than plants grown on either black plastic, *in situ* or no mulch.

Table 13. The percent oil yield (v/dw) and percent component in oil of thyme plants grown on 5 different mulches (*In situ* , no mulch, plastic film, weedmat and wool mulch)

Treatments	oil yield % oil /dw	α-Pinene % in oil	π-cymene % in oil	γ-terpinene % in oil	thymol % in oil	carvacrol % in oil
In situ	2.64 a	1.28 a	12.24 a	12.86 a	51.2 ab	2.61 a
No mulch	2.64 a	1.21 a	12.48 a	13.35 a	49.54 a	3.15 a
Plastic	2.65 a	1.30 a	14.03 b	12.72 a	50.49 ab	2.67 a
Weedmat	2.72 a	1.23 a	12.24 a	11.19 a	55.06 c	2.78 a
Wool mulch	2.37 a	1.26 a	12.26 a	11.42 a	53.42 bc	3.11 a

Letters within a column indicate least significant differences at P•0.05.

The effect of weeds

The covering mulches clearly demonstrated their ability to suppress weeds (Figs. 11, 12, 13). The no mulch and *in situ* mulch treatments had a significantly higher weed burden than the covering type mulches. The occurrence of woody weeds in some plots and not others caused a large variation in dry matter yields between replicates, and hence a large LSD.

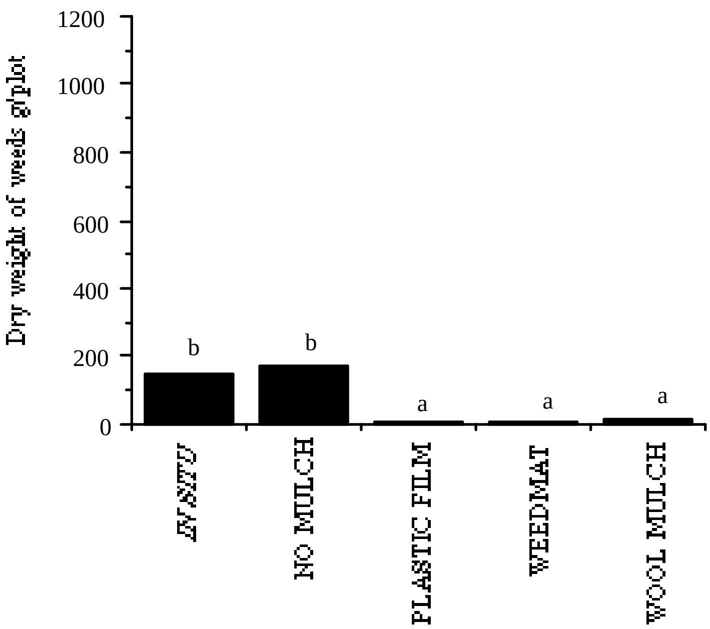

Fig. 11. Total dry weight of weeds (g/plot) removed from basil plots grown on five mulches (*In situ* , no mulch, plastic film, weedmat and wool mulch). Plants were weeded 3 times over the growing season. Letters indicate least significant difference at P•0.05

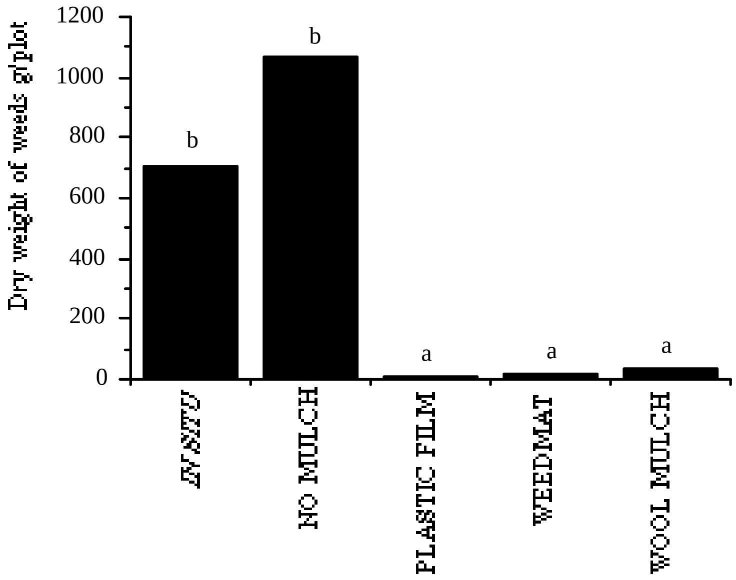

Fig. 12. Total dry weight of weeds (g/plot) removed from thyme plots grown on five mulches (*In situ* , no mulch, plastic film, weedmat and wool mulch). Plants were weeded 3 times over the growing season. Letters indicate least significant difference at P•0.05

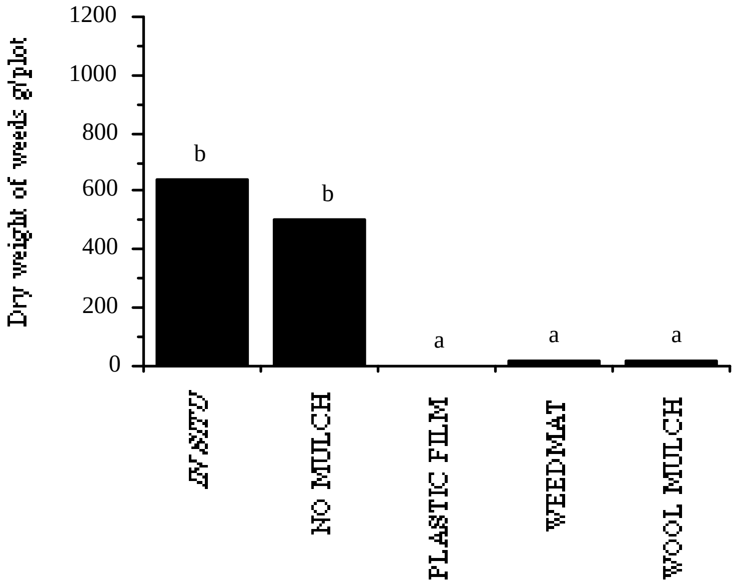

Fig. 13. Total dry weight of weeds (g/plot) removed from chamomile plots grown on five mulches (*In situ* , no mulch, plastic film, weedmat and wool mulch). Plants were weeded 3 times over the growing season. Letters indicate least significant difference at P•0.05

Soil nitrogen mineralization

Open intact cores.

During the process of mineralization two reactions occur, ammonification catalyzed by ammonifying bacteria, and nitrification catalyzed by nitrifying bacteria. The soil examined in this trial could be described as easily nitrified as all the ammonium produced in the first reaction was nitrified for all treatments except the plastic film under which a non significant amount of ammonium remained unconverted. Plastic film and wool mulch showed the lowest net mineralization, with wool mulch mineralizing the least (Table 14).

Table 14. Net nitrogen mineralization during intact core incubations under the five different mulch types (*In situ* , no mulch, plastic film, weedmat and wool mulch). Letters indicate least significant difference at P•0.05

	Net mineralization	Temperature 23/11/93 to 8/4/94			moisture * at core collection
	µg/g	max	min	ave	%
IN SITU	219.8 c	33.83 b	15.95 b	23.25 b	42.78 b
NO MULCH	188.2 bc	32.35 b	16.25 b	22.55 b	39.08 b
PLASTIC FILM	71.1 ab	34.25 b	17.17 b	24.25 c	6.66 a
WEEDMAT	171.2 bc	30.83 b	16.37 b	22.38 b	38.89 b
WOOL MULCH	31.6 a	25.92 a	17.78 b	21.43 a	9.95 a

*soil moistures very high due to heavy rainfall during collection

Laboratory Incubations

The optimum temperature for mineralization of this soil appeared to be closer to 25°C than 35°C (Table 15).

Constant Moisture Field Incubations

The constant moisture incubations (Table 16) occurred during the cooler months. Little variation occurred between the treatments with the no mulch treatment mineralizing the least nitrogen. The *In situ* plots were not measured because the mulch had decomposed making the plots similar to the no mulch control.

Table 15. Content of available ammonium and nitrate mineralized during laboratory incubations at two temperatures 25° and 35°C.

Incubation Temperature	Net Mineralization	significance
	µg/g	5% LSD
25°C	24.5	23.92
35°C	58	

Table 16. Content of available ammonium and nitrate mineralized during constant moisture field incubations under the five different mulch types (*In situ* , no mulch, plastic film, weedmat and wool mulch). Letters indicate least significant difference at P•0.05

	Net Mineralization	Temperature 25/3/94 to 2/9/94		
	µg/g	max	min	ave
IN SITU	-	13.89 a	1.82 a	6.20 b
NO MULCH	14.2	16.16 a	0.55 a	5.95 b
PLASTIC FILM	23.5	21.13 a	-0.55 a	7.13 b
WEEDMAT	27.05	14.87 a	2.89 a	7.44 b
WOOL MULCH	28.27	15.97 a	-0.65 a	5.66 b
AoV	*			

* Significant at P•0.10

Growing season temperatures

Basil

Significant variation existed between the five mulch treatments (Fig. 14, Table 16). Average temperatures for Plastic film were significantly higher, and wool mulch was significantly cooler, than the other treatments. The minimum temperatures show no significant difference occurring between the treatments. However, there is a trend showing wool mulch to have a higher minimum temperature than the remaining treatments, and hence display a smaller diurnal variation (Fig. 14). If an arbitrary figure of 15°C is used as the minimum temperature below which growth does not occur, then the degree days above this temperature are significantly in favour of the plastic film (Fig. 15).

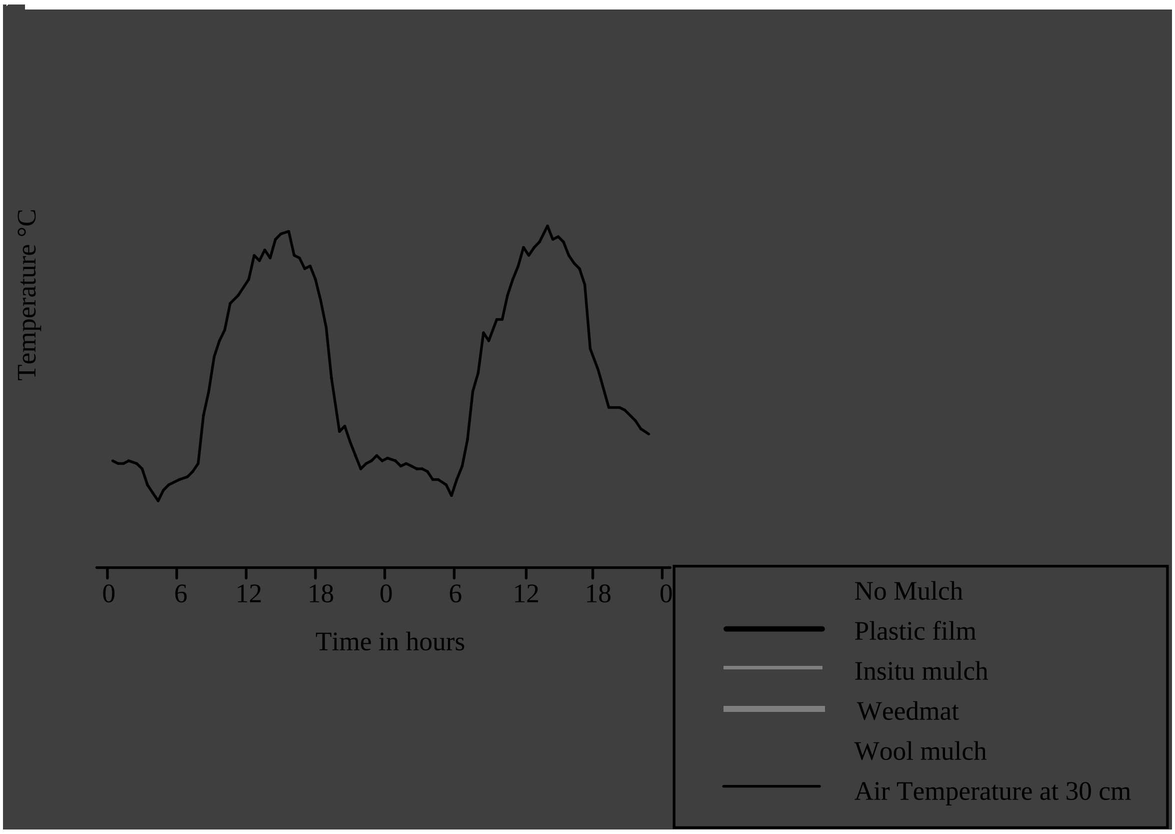

Fig. 14. Diurnal temperature variation beneath the five mulch treatments (*In situ* , no mulch, plastic film, weedmat and wool mulch). For two 24 hour periods recorded from the 30/11/93 to 2/12/93

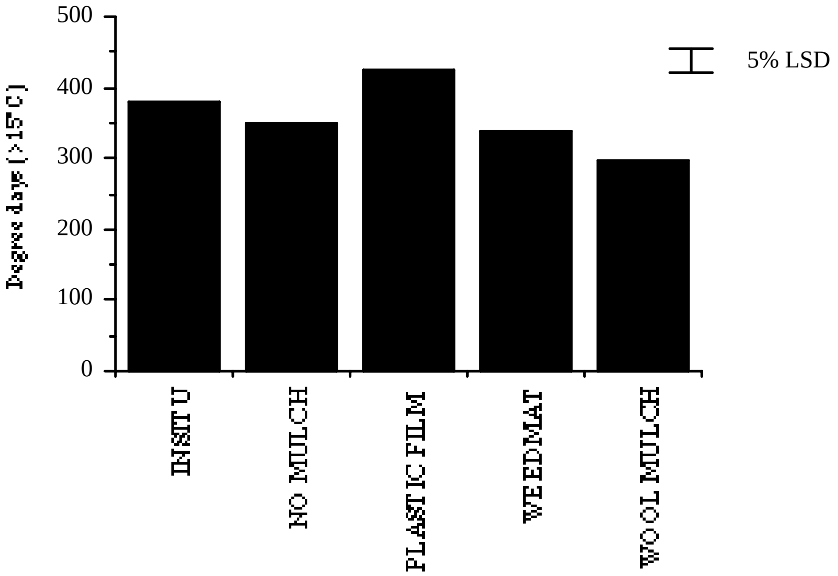

Fig. 15. The sum of degree days greater than 15°C recorded 1cm below the soil surface of the basil plots under the five mulch treatments (*In situ* , no mulch, plastic film, weedmat and wool mulch) over the growing season. Least significant difference at P•0.05

Thyme

The temperature data recorded under the thyme plants follows the same trend as the temperature data recorded under the basil plants (Table 17). Plastic film imposes the greatest heat load having the largest maximum temperature and the greatest number of degree days above15°C . The temperatures recorded under the thyme plants are less than those recorded under the basil plants,with no significant difference occuring between treatments.

Table 17. Under-mulch temperature from the thyme plots recorded under the five different mulch types (*In situ* , no mulch, plastic film, weedmat and wool mulch) between 23/11/93 and 8/4/94. Letters indicate least significant difference at P•0.05

Treatments	maxima	minima	average	degree days >15°C
In situ	28.75 a	14.57 b	20.19 b	181.92 b
No mulch	26.71 a	14.52 b	20.39 b	189.49 b
Plastic	31.69 a	13.81 b	20.74 b	201.49 b
Weedmat	27.98 a	14.46 b	20.27 b	188.83 b
Wool mulch	25.02 a	15.46 b	19.81 b	172.47 b
air	29.34 a	11.67 a	18.61 a	133.84 a

Temperature during the constant moisture field incubations basil plants

The temperatures during this incubation were much cooler than during the growing season of the plants (Table 16). No significant differences existed between the treatments. However, plastic film had the highest mean maximum temperature, and examination of the diurnal fluctuations (Fig. 16) shows plastic film to have the largest fluctuation.

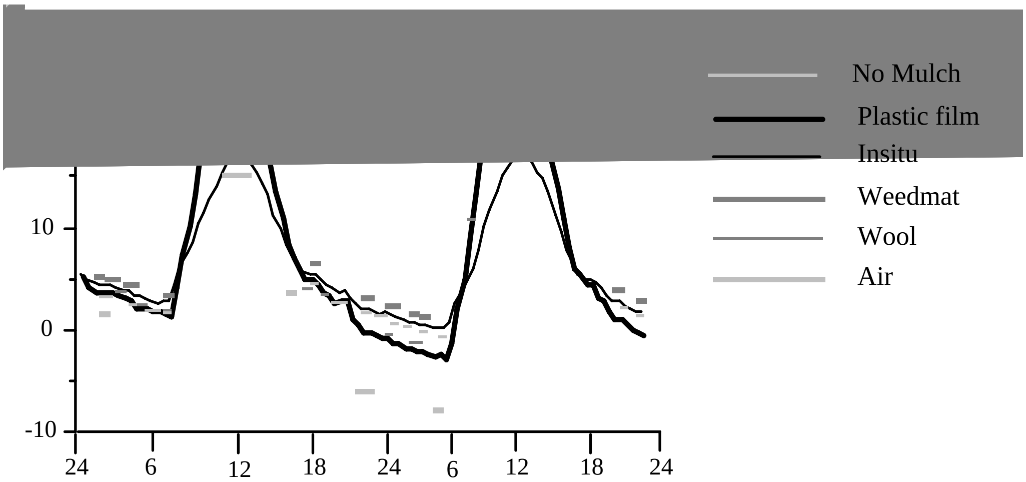

Fig. 16. Diurnal temperature variation beneath the five mulch treatments (*In situ* , no mulch, plastic film, weedmat and wool mulch) for two 24 hour periods recorded from the 15/6/94 to 17/6/94.

Leaching Estimate

These measurements represent an estimate of the degree of nitrate leaching. No plants were included, and hence only a representation of water movement and leaching through the incubation cores was obtained. No leaching took place under the plastic or the wool mulch (Fig. 17) indicating low water movement in these treatments. The greatest leaching occurred under those mulches which transferred the greatest volume of water through the mulch to the soil. The water content in Table 14 highlights this.

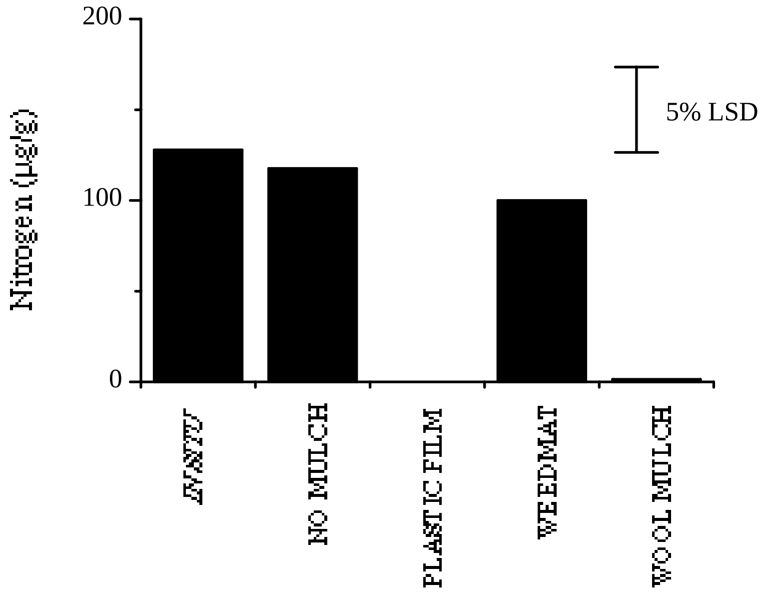

Fig. 17. The potential loss of nitrate nitrogen by leaching from the top 5cm of soil under different mulch treatments (*In situ* , no mulch, plastic film, weedmat and wool mulch). Leaching was from soil cores 3cm diameter x 5 cm high. The least significant difference at P•0.05 is indicated

Soil conductivity varied under the three mulches in inverse proportion to soil moisture (Fig. 18). Both wool mulch and plastic film had significantly higher soil conductivity levels than the remaining treatments. This again reflects low water percolation.

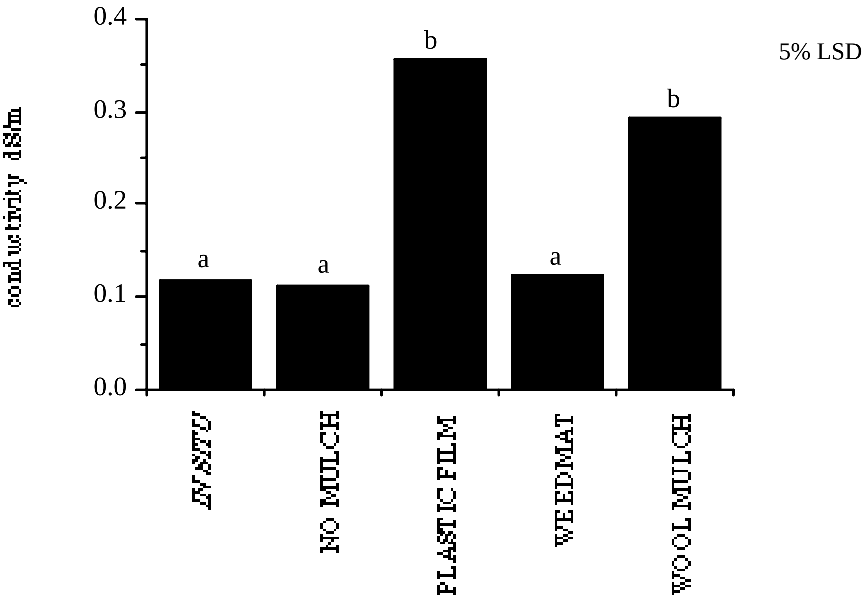

Fig. 18. Soil conductivity (dS/m) in the nitrogen incubation tubes following a 94 day incubation under the five mulches (*In situ* , no mulch, plastic film, weedmat and wool mulch). Letters indicate levels of significance at P•0.05.

Hand weeding costs

These figures were estimated from the time it took to weed the plots during the experiment, they are not a true representation of actual cost as they include collecting the weeds and placing them in sample bins (Fig. 19).

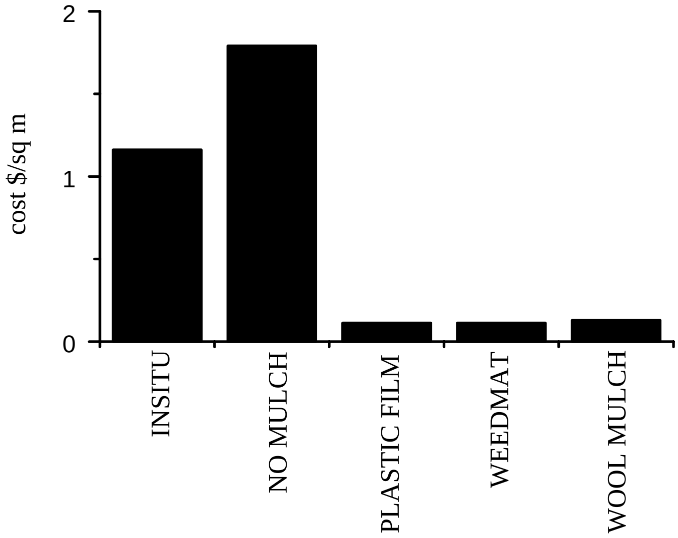

Fig. 19. Estimated cost of hand weeding the five mulch types (*In situ* , no mulch, plastic film, weedmat and wool mulch) costs calculated as $ per m^2 for hand hoeing weeds.

DISCUSSION

Plant growth

Basil

The *in situ* mulch affected the basil plants immediately after transplanting. This may have been as a result of nitrogen immobilisation caused by the mulch, or the result of water stress. The plants were transplanted into an untilled bed using the mulch punch, and the dibble hole produced by the punch may have restricted root development during the initial stages, thus limiting the supply of water and nutrients. The growth of the *in situ* plants was severely impeded for 2 to 3 weeks, although, following this time the plants which survived grew at a normal rate.

The plastic film improved plant growth for the first harvest (Fig. 8), although this growth was not significant when compared to weedmat or wool mulch. However, when this trial was harvested all treatments were at the same ontogenetic stage i.e. in 50% flower. Observations of the crop over the growing season showed the plastic mulched plants reached harvest size earlier than the other plants, yet all plants set flower at the same time. The delay between reaching a harvest size and flowering would explain the small difference between treatments. The improved growth of basil when grown on black plastic film (Ricotta and Masiunas, 1991; Davis, 1994) did occur in this experiment, but the delay between reaching a harvest size and flowering decreased this effect. Leaf production at the first harvest was significantly improved by the use of covering mulches (plastic film, weedmat and wool mulch). The soil moisture content was not measured throughout this period, but an increase in the available soil moisture due to reduced evaporation of initial moisture may explain this improved growth. The temperature response often used to describe improved plant growth of plastic mulched plants (Ricotta and Masiunas, 1991; Brown, 1992; Grubinger *et al.*, 1993; Davis, 1994) was not the cause here, as the three mulches (plastic film, weedmat and wool mulch) all created significantly different soil temperatures (Figs. 14 and 16).

At the second harvest no significant difference in dry matter production occurred between any of the treatments (Fig. 8). However, the leaf production at the second harvest (Fig. 9) showed some significant differences. The *in situ* mulched plants are again the least productive, despite not showing any difference in total growth compared to the other treatments. This may be explained as a carryover effect from their establishment, mentioned above. The dry weight of leaves at the second harvest showed the weedmat and no mulch treatments to be significantly different, but no explanation can be offered for this from the results available. Yields from the covering mulches (plastic film, weedmat, wool mulch) were not significantly different from each other.

Thyme

The five mulch treatments (*In situ* , no mulch, plastic film, weedmat and wool mulch) had no significant effect on the production of thyme plants (Table 10). However, examination of the results shows some interesting trends. Weedmat produced the greatest dry matter, yet when this production is broken down to its components, leaves and stems, the improved yield is not consistent. Weedmat produced the greatest quantity of stem material but only a moderate quantity of leaf giving a low leaf to stem ratio (Table 10). The black plastic produced the greatest quantity of leaf which may be attributed to the slightly higher temperatures observed under the film. Yet overall there was very little difference seen in the temperature recordings (Table 17). The reduced affects of temperature under the thyme plants compared to the basil plants may be attributed to the slightly earlier planting time, and the speed with which the thyme plants grew and covered the mulch insulating the soil and decreasing the influence of the mulch. From the results of the basil plots it can be assumed that there is no nitrogen differences between the mulch types making it difficult to explain the difference in leaf and stem production. One explanation may be the influence of mulch colour provoking a similar response in thyme as that described in tomatoes (Ham *et al.*, 1993). Further work controlling the variables of temperature and moisture would be required to test the influence of light on thyme production. The commercial part of thyme is the leaf and any method which may increase the production of leaf would be beneficial.

Chamomile

The five mulch treatments had no effect on the production of chamomile flowers (Table 11). However, the two harvests produced significantly different yields. The second harvest was the larger of the two, and would have been a result of increased flowering following the earlier harvest.

The interaction between the mulch treatments and the harvest date can be explained by the plastic film harvest difference. The first harvest produced a low yield while the second harvest was much higher. The plastic film produced a high surface temperature which was observed to cause leaf burn on the young chamomile seedlings. Many of the chamomile seedlings did not survive transplanting into the plastic mulch as the small soft plants were easily lost beneath the mulch and cooked by the high temperatures. The second harvest produced more flowers than the first, because the plants which survived the transplant shock grew well and filled the space of the lost plants, these larger plants flowered well and produced a greater quantity of flowers in their second harvest.

Oil yield and composition

Basil

The oil concentration in basil leaves was unaffected by the different forms of mulch (Fig. 10). Both harvests showed a similar response with respect to the different treatments. However, different yields were recorded for each of the two harvests. The harvests took place at different ontogenetic stages of plant growth, and as Basker and Putievsky (1978) found, different oil yields were achieved. Flowering changes the oil concentration in basil plants, and the later the harvest is conducted after flower initiation, the higher the oil content (Basker and Putievsky, 1978).

The oil quality (Table 12) also remained unaffected by the different mulch treatments suggesting that the different wavelengths of light, or the different temperatures produced by the mulches, had no effect on the production of secondary products within the plant. The nitrogen mineralization results (Table 14) show that plastic film nitrified ammonium at a lower rate compared to the other mulches. Different forms of nitrogen have been shown to effect the production of essential oil and influence the composition of that oil when applied individually (Adler *et al.*, 1989). This experiment does not show such a result, however it may be that when some nitrate nitrogen is present, the effect noted by Adler *et al.* (1989) does not occur.

Low soil moisture readings were recorded under the plastic film and the wool mulch (Table 14), but despite this the plants did not show signs of water stress. When basil is water stressed the oil content in the leaves increases, and the concentration of methyl chavicol will change (Simon and Reiss-Bubenheim, 1992). No difference was observed between the mulch treatments in this experiment, suggesting that the plants were not sufficiently water stressed.

Thyme

The five mulches (*In situ*, no mulch, plastic film, weedmat and wool mulch) had no affect on the production of oil within the thyme plants (Table 13). However, the components in the oil did show some variation with respect to mulch type. The percent π cymene in the oil was increased when the plants were grown on the black plastic. This response was only significant at the 10% level and may be due to the slightly higher temperatures recorded under the black plastic. Further research will be needed to see if this is the cause. The dense planting of the thyme meant that the temperature influence of the mulch type and colour is greatly reduced. This suggests that a second harvest of these plants would not be influenced in the same way or to the same extent.

Thymol also showed a significant variation across mulch types with weedmat producing significantly more of this compound (Table 13). This result is difficult to explain as the weedmat does not have any individual characteristics. Weedmat temperatures and moisture contents were consistent with the no mulched plots. The colour of the weedmat was similar to the black plastic making it difficult to identify a reason why the thymol content was increased.

Weed control

The covering mulches (plastic film, weedmat and wool) significantly reduced the weed burden for all plant types (Fig. 11, 12 and 13). The *in situ* mulch successfully controlled weeds at the beginning of the season, but once the thin layer of mulch began to break down, weed invasion soon followed. The no mulch treatment resulted in the greatest weed burden. However, this weedload was collected predominantly during the first weeding, after this, relatively few weeds established. This low rate of subsequent weed infestation would suggest that had the beds been formed and then fallowed, the weed burden of the no mulch plots may have been greatly reduced.

Soil moisture

Both the black plastic and wool mulch showed the lowest soil moisture content at the time of sampling. As the plots were watered by overhead sprinklers, in order for water to enter the soil under the plastic film it had to move through the plant holes or in from the edges. The plant growth in the wool and plastic mulches was not affected by the low moisture content, yet the soil under the mulch was significantly drier (Table 14) and had a higher conductivity suggesting that less water percolation had occurred (Fig. 18). Wien *et al.* (1993) found that root growth under plastic mulch was correlated with increasing temperatures and that within 3 weeks of transplanting roots had reached the edge of a 1m mulched bed. Assuming the basil plants in this experiment behave in a similar fashion to the tomato plants studied by Wien *et al.* (1993), the plants would have been able to take up adequate water from the edge of the beds and maintain a similar growth rate to the plants in the other mulch treatments.

Wool mulch is a permeable substance so should not have impeded the flow of water into the soil. However, wool is a highly absorbent material and may not have allowed the water to pass through to the soil. Despite the lower soil moisture recorded under the wool mulch, the plants showed no signs of water stress. It must be assumed that the plants grown in the wool mulch received adequate water despite the lower soil moisture and higher soil conductivity.

Soil moisture was not measured under the thyme or chamomile plants as it was assumed that the influence the mulches had on soil moisture would be the same and independent of the plant species.

The effect of temperature

Basil

No significant difference occurred between the *in situ*, weedmat or the no mulch treatments. The maximum, minimum, average temperatures (Table 14), and degree days greater than 15°C (Fig. 15) are all similar for these mulches. Black plastic and wool mulch showed significantly different results from all other treatments. The maximum and minimum temperatures recorded by four of the five mulches were not significantly different, wool mulch maximum temperature was significantly lower. The average temperatures also show some difference, black plastic as expected had the highest average temperature, and wool mulch the lowest. These results are mirrored in the degree days greater than 15°C (Fig. 15).

The soil heating effect caused by black plastic was similar to that observed by other authors (Decouteau. *et al.*, 1989; Argall and Stewart, 1990; Asiegbu, 1991; Elmer *et al.*, 1991). Black plastic significantly raised the soil temperature above the bare soil control and all other forms of mulch. It is suggested that black plastic can raise the average soil temperature by 5-10°C when compared to bare soil. This was not the case in this trial. The basil transplants were transferred to the field in late spring (23/11/93), and as at this time the soil temperature is relatively high, this reduced the effect of the plastic film. The late spring planting may be responsible for the lower average temperature rise recorded by the black plastic.

The wool mulch showed a significantly lower maximum temperature compared to all other treatments (Table 14). This ability to reduce soil heating is similar to the affect of white plastic (Ham *et al.*, 1993). The optical properties of white plastic explain this low heat input, and the wool mulch used in this experiment was of an off-white colour, suggesting its optical properties may also explain the reduced heating effect. The diurnal pattern of white plastic described by Ham *et al.* (1993) shows the night temperatures of the soil to be cooler compared to other mulch forms. In this work, the wool mulch did not show this same trend. It appeared to insulate the soil against the cool night temperatures (Fig. 14 and 16). The wool did not maintain the night soil temperatures at a level higher than the other mulches, but the diurnal variation of the wool was far less. As with plastic, the colour of wool can be easily changed and further work is necessary to investigate if changing the optical properties will increase the temperature rise during the day, and the insulating properties maintain this rise during the night.

The temperatures taken under the thyme plants were similar though less pronounced than the basil. This was a result of the thyme plants quickly establishing and closing the gaps between them, thus reducing the amount of exposed mulch surface. The basil plants were spaced further apart and only covered the mulch prior to harvest. For this reason the temperatures under the basil mulch were influenced by the exposed mulch surface for longer.

Soil nitrogen mineralization

Open Intact Cores

The open intact cores showed the rate of nitrification to be less under the black plastic mulch. Ammonification is caused by heterotophs and can occur over a temperature range of 0°C to 70°C (Richards *et al.*, 1985), with an optimum temperature around 30°C (Richards, 1987). The temperature readings recorded during this experiment showed plastic film to have a mean average temperature of 25°C and a mean maximum temperature of 35°C. Such temperatures would favour the production of ammonium. The soil used in this experiment readily converts ammonium to nitrate, as seen in the bare soil results (Table 14). The high levels of ammonium in the plastic film treatment suggests that nitrification is inhibited. Nitrification is temperature sensitive as the *Nitrosomonas* and *Nitrobactor* microbes involved have a very narrow temperature range (between 20°C and 35°C, Richards *et al.*, 1985). The mean maximum temperature of the plastic film was 35°C which may explain why the ammonium pool under the black plastic was not nitrified.

Hartz and Holt (1991) suggest that the application of plastic mulch increases the soil CO_2 concentration. Such an increase could reduce the oxygen tension within the soil, thus reducing the production of nitrate by the obligate aerobes (*Nitrosomonas* and *Nitrobactor*) (Richards, 1987).

Wool mulch and black plastic film mineralized less nitrogen than the other treatments. They also had the driest soil and for active mineralisation to occur an adequate supply of moisture is necessary.

Laboratory Incubations

The laboratory incubations show 25°C to be a more suitable temperature for nitrogen mineralisation than 35°C in this soil (Table 15). 35°C is the upper limit for survival of many soil microbes (Richards, 1987). During the open field incubations the soil under the black plastic had an average maximum temperature of 35 °C while the daily average was 25°C. Hence, the soil was maintained at the optimum temperature for microbial mineralisation, and one may assume that provided moisture does not become limiting, the plastic film would have a higher mineralization rate than the other forms of mulch.

Constant Moisture Field Incubations

No significant differences in net mineralization were found between the plastic film, weedmat and wool mulch (Table 16). The no mulch treatment produced significantly less nitrate nitrogen than these treatments. However, during the experiment it was observed that some plant growth occurred in 2 of the no mulch sealed bags which may have been responsible for this difference, and in reality no practical difference may have occurred between the treatments. The improved levels of mineralisation occurring in the wool and black plastic treatments suggests that the low nitrogen production experienced in the intact open core incubations was as a result of reduced moisture under these mulches.

Cost of mulching and hand weeding

The three mulches used in this experiment have a range of prices and functional life expectancy.

Mulch	cost per m^2	life expectancy
plastic film 200 µm	$0.56	2 years
weedmat	$0.96	5 years
wool mulch	$1.30	1-2 years

Thinner, cheaper forms of plastic film are available, but their life expectancy is less. The estimated costs of weeding from this experiment are very high. The average cost of hand weeding a cotton crop is between $50 and $70 per ha. Cotton is planted into well prepared fields which have experienced a chemical fallow and a residual herbicide application at the time of sowing. In this experiment there was no fallowing and no residual chemicals applied. Better pre-planting preparation may have reduced the weed burden in this crop, and thus reduce the cost of hand weeding. However, the cost would be unlikely to be reduced to that of cotton crops, which is around $0.07 a m^2, the proper preparation of the site may reduce the cost of hand weeding to around the same price as the more expensive mulch forms. It must be remembered that although a mulch form will reduce the weed population, weeds will still appear and manual weeding may still be necessary; this weeding will be slower and more difficult because of the mulch.

CONCLUSION

Basil

Black plastic film was found to improve the dry matter production of basil and to increase the soil temperatures. High levels of ammonium were found in soil under black plastic, although this did not affect the oil concentration or composition. All covering mulches (plastic film, weedmat and wool mulch) improved weed control in basil crops. The *in situ* mulch was too thin to successfully impede weed development, and the basil plants were not suited to direct drilling into unprepared soil. Thicker layers of *in situ* mulch and continual irrigation following transplanting may improve the growth of basil, planted in this manner. Wool mulch and black plastic had the lowest soil moisture content, yet plant growth was unaffected. However, the use of under-mulch irrigation would be necessary to maintain production in dry years. Mulch is an additional production expense for a herb crop, but provided the crop returns are adequate it is a successful method for basil production.

Thyme

The mulches had no significant effect on the production of thyme. The thyme plants were planted at a close spacing and quickly filled the gaps between plants, such quick coverage reduced the growth of weeds and made for a strong uniform sward of thyme. The limited weeding required prior to the closing of the crop, and the reduced weeding required following canopy closure, suggests that the use of covering mulch is unnecessary when growing thyme plants.

The *in situ* mulch and direct sowing of the plants is probably the most suitable approach, as the *in situ* mulch gave some weed protection while the plants were establishing. A well prepared soil with low weed burden would also give such protection. The covering mulches were not the most suitable for thyme plants. The spreading tendency of thyme meant that some plant growth occurred under the mulch, and low growing plants could be lost under the mulch during establishment.

The black plastic and weedmat appear to have influenced the oil spectrum, and this may be useful if thyme oils with specific oil characteristics are desired, but, this aside the growth of thyme plants on covering mulch is not necessary provided adequate weed control measures are taken prior to planting.

Chamomile

The chamomile plants had high weed burdens yet the different mulches had no affect on their growth. Observations showed that the high surface temperatures of the black plastic and the weedmat did cause some leaf burn during the growth of the plants. Following the final harvest the plants continued to flower and much of the seed germinated. The unmulched and the *in situ* mulched plots re-established from this seed. The plastic mulches caught the seed which was later blown off onto the paths at the edge of the mulch, thus reducing the effectiveness of this mulch when continual chamomile culture is planned. Due to the re-establishing ability of chamomile and the poor success of plants grown on the covering mulches, it would be more cost effective to control the weeds by pre-planting cultivation and management, not mulch.

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RESEARCH OUTCOMES *VERSUS* OBJECTIVES

Overall the research outcomes were largely as hoped for in the design of the project. The expected outcomes were:

* an integrated herb production and processing system
* technology packages for sale to new participants
* extension service for new participants (with or without the above packages)
* technical services for growers (quality control monitoring)

The extension and technical services are available through New England Natural Products Pty. Ltd. (NENP, formerly NPG) and the University of New England on a fee-for-service basis. Information on the technology is also available on an *ad hoc* basis as new participants request them. The industry partner (NENP) purchased a purpose built dryer part way through the project, and together with the work carried out on agronomical and cultural techniques, harvesting and handling, processing, storage and packaging, and financial planning have provided, in my view, as complete an integrated system as is possible in current circumstances. This information is available to new or existing participants in the herb industry as an extension service, on a fee-for-service basis.

At the planning stage perceived threats to the benefits of the project being realised included slow rates of uptake by commercial growers resulting in insufficient material to market and delayed commercialisation. This was in fact realised despite an initially large, enthusiastic group of potential growers. We believe that now however, we have a small band of dedicated, experienced growers who are beginning to enlarge their field sizes with more plantings of herb types they are familiar with, and new test varieties. NENP provides guidance for all crops grown for this group.

Now that the project is complete, the results will be extended to industry via publication of the final report, to be followed by a more comprehensive book. Also, articles in industry journals and papers in scientific journals are in preparation. NENP is now a limited liability company, working with a small group of contract growers who are continuing to undertake cooperative field trials. NENP has also taken on the role of processing/packaging, and marketing. As the industry partner, NENP considers much of the intellectual property of the researchers to be propriety information, and distribution of the findings is at the discretion of the Project Director and the Directors of NENP.

The original time frame planned for the project was probably greatly underestimated, but the eventuality of a severe drought held up adoption of trial plots by growers, the lack of funding for a dryer (originally estimated at $1,500 but on further investigation this unit proved very unsatisfactory) prevented trial runs of processing until the project was well started, and continues to hamper the development of realistic harvesting implements.

IMPLICATIONS AND RECOMMENDATIONS

The implications are that the problems associated with commercial production of medicinal and aromatic plants are relatively easy to overcome, if research money is directed into clearly defined areas. Agronomic and cultural problems such as seedling propagation and transplanting, weed and pest control, harvesting, handling and cleaning are all solvable in time. The one factor restricting the development of an Australian herb industry is the people involved in it. Specifically, it is the herb growers themselves who are the key.

I believe that while some growers are risk averse and will always wait until someone else has been successful before they will take on a new production system, we need to instil a sense of confidence into the growers prepared to try a new crop. The herb industry can become successful with a relatively small number of growers as long as they are growing and harvesting large herb fields. In fact, the technology and extension service providers cannot handle large numbers of growers, particularly if new ones are coming into the industry all the time, as the knowledge needed to grow herbs successfully is so diverse it can take a great deal of time to follow through adequately with each grower.

We critically need significant investment into the industry, for example to develop harvesting machinery and weed cultivators designed for the relatively small areas likely to be sown to herbs, and to allow these to be accessible to every grower. We also need to see some sort of standardisation in germplasm. The variability of material available at present is causing hesitation amongst growers and processors as there is no guarantee that seedlings grown one season will be chemically the same as seedlings grown in the next season. In fact, there have been cases of the grown plant not being the one thought to be sown, leaving the grower with no market at all. If we can offer advice with confidence on readily available machinery and lines to be grown, along with the agronomic and marketing advice we have access to, we will instil confidence into our growers and see their numbers, or the field sizes, begin to expand.

TECHNICAL SUMMARY

The project covered basic and strategic research to overcome the lack of technological knowledge in a range of processes. These included:

1] Seedling production on a grand scale - the development of a small easily operated vacuum seeder, useful for a grower wishing to produce his/her own planting material in large numbers, and the determination of potting mixes suitable for a variety of plant types.

2] The development of a punch to allow direct seeding of plants into field areas through plastic films, and other covering mulches. Again, the punch was designed with the grower in mind in terms of cost, and usefulness.

3] The mulch section outlines weed control measures for use in the herb crops.

4] The fertiliser section covers application rates of nitrogen and phosphorus on three crop types.

5] Harvesting techniques and handling methods were investigated as part of the grower managed field trials. This work is, and will continue to be, ongoing as more information and equipment becomes available. At present an harvester based on a mechanical hedge trimmer, with catch bag attached is being constructed for field testing over the coming growing season.

6] Processing techniques for dried material was investigated. This information is very crop type specific, and dryer specific.

7] Storage requirements were determined from the literature and potential buyers, as was

8] packaging requirements of potential buyers.