

**SMALL SCALE STUDY OF
YIELD AND QUALITY OF
OILS FROM SIX HERB SPECIES**

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Contents	Page
1. Key Findings	1
2. Introduction	3
2.1 Overall objective	5
2.2 Detailed objectives	5
3. Materials and Methods	6
3.1 Sites	6
3.2 Herb crops	6
3.3 Layout of the plots	7
3.4 Individual cultural details	7
3.5 Assessments	9
4. Results	10
4.1 Germination of the herb seed	10
4.2 Crop development	11
4.3 Crop yield and quality assessments	11
4.4 Cold pressing	15
4.5 Economic returns	15
5. Discussion	16
5.1 General	16
5.2 The herbs oils in detail	17
6. Recommendations	19
7. References	21
Appendix I - Distillation facilities in UK	24
Appendix II - Layout of the herb oil plant herbarium in Pringle Drove field at ADAS Arthur Rickwood in 1997	26
Appendix III - Lavender, rosemary and chamomile plots on Meadow Ground field at ADAS Arthur Rickwood in 1997	27
Appendix IV - Minimum monthly temperatures, monthly rainfall and maximum monthly temperature at ADAS Arthur Rickwood in 1997 compared with long term (30 year) means.	28
Appendix V - Chemical components of oil of German chamomile on 3 September 1997	29
Appendix VI - Contacts referred to in the report	30

1. KEY FINDINGS

Six herb species were grown for their yield of essential oil at a site in Cambridgeshire in 1997. They were chosen for their likelihood of becoming a commercial success in the UK following on from reviews of the market (Runham, 1996; Verlet, 1993). The crops were German chamomile (*Matricaria chamomilla* or *recutita*), Roman chamomile (*Anthemis nobilis*), lavender (*Lavendula angustifolia*), rosemary (*Rosmarinus officinalis*), thyme (*Thymus vulgaris*) and yarrow (*Achillea millefolium*).

The oils extracted from the herbs, either in the laboratory or by pilot commercial distillation, were analysed for their component chemicals using chromatography. On the chromatogram, the individual chemical components are shown as 'peaks'. These chromatograms can be compared with those from oils traded on world markets and which may be considered as 'standards' for the quality required. Accepted chemical standards exist for many essential oils and these must be met for the oils to be traded on the world market.

The yield of German chamomile oil was low at 6.6 litres/ha. The quality was considered mediocre with 3.8% to 4.9% of chamazulene. The oil could attract a market in aromatherapy or for use in blends but this section of the German chamomile market is relatively small. The oil should contain 10-12% of chamazulene to be considered as suitable for the larger pharmaceutical trade. The overall productivity of the crop would need to be increased by using a cultivar with the correct chemotype (with high chamazulene and bisabolol oxides contents) to make the crop attractive to UK growers.

Roman chamomile had a good oil yield of 9.22 litres/ha, a pleasant fragrance and a good light blue colour. The oil had over 75 peaks on the chromatogram, 19 of which had values of over 1%, which indicated a 'well balanced oil'. When compared with oils on the world market, it had a rather high level of alpha pinene and low levels of angelates and butyrates. There is scope to produce this oil in the UK, but there is a need to improve the quality of the oil by seed source and selection.

The yield of lavender was 41.4 litres/ha on 29 July and 44.4 litres/ha on 19 August. The quality of the oil was reasonable but there is a need to increase the levels of linalyl acetate and linalool by over 50% in order for the oil to attract a premium price on world markets. This improvement in oil quality would be achieved by selection and breeding. There is likely to be interest in the oil from local outlets, from buyers who will blend the oil, or where there is a premium for oils from known sources (traceability of production of the oil).

The yield of oil extracted from leaves of rosemary was 11.5 litres/ha. The quality of the oil was acceptable for world trade. The content of alpha pinene (45.9%) was higher than the preferred range of 20-30%, and the 1,8 cineole (10.8%) was lower than the preferred range (20-30%). There is scope to develop niche market sales for this crop.

The yield of oil from thyme was high at 11.8 litres/ha and had a good quality with a high content of thymol and was assessed to have the correct percentages of other components for world trade.

The yield of oil from yarrow was low at 4.95 litres/ha. The quality was inferior to a comparative oil obtained from Holland which had been specifically bred for the essential oil market. There are no world standards for this oil and it may be acceptable to local buyers for the same reasons given for lavender.

The work has demonstrated that the quality of the oils from rosemary and thyme were deemed acceptable for world-wide trade whereas lavender, Roman chamomile and yarrow were considered more suitable for a known local outlet (determined by interchange with a buyer). This is because the local or UK markets do not require the specific standards set by the world markets. The work indicated that the likely returns for all crops, except German chamomile, were considered acceptable. There is scope to improve the yields of oils as variety selection, crop husbandry and extraction techniques progress, thereby improving the levels of return for the crops.

The prospects for the essential oil industry will be improved by underpinning new and recently-created enterprises with strategic research. There is scope to improve considerably both the yield and quality of crops by breeding. There is need for information on crop physiological development under a range of UK climatic conditions. There is scope to develop a form of decision support mechanism to help growers to chose crops suited to their soil type and location. The information, provided on the Internet, could display information on planting and growing schedules, the interaction of soil fertility and oil quality, and timing of harvesting. A further area of important research is that of evaluating new extraction techniques such as microwave or ultrasound to increase the output of oils per kilogram of material processed. All of these approaches will improve the competitiveness of UK enterprises.

2. INTRODUCTION

A large number of plant species contain secondary plant metabolites, which can be extracted by various methods including steam or hydro-distillation, solvent extraction and maceration. Essential or volatile oils belong to these natural chemical products (Deans and Svoboda, 1993). They form approximately 0.001 to 20% of fresh weight of a given plant species.

World trade in essential oils is increasing, with a 40% increase from 1984 (£475 M) to 1990 (£667 M) (Caiger, 1993). In addition, there is a trend towards the use of natural flavour and fragrance compounds; a market which was worth over £6.5 billion worldwide in 1994 (Somogyi, 1996). The Health Product Market was worth £800 M in the UK in 1995 (Anon., 1996). Of this, 48% was from non-food supplements, herbal remedies and complementary medicines.

Prior to the First World War, most herbs consumed in the UK were home grown. It gradually became uneconomic to produce herbs due to high labour costs, and the UK sourced its herbs from the European continent. There was a small revival of the industry during the Second World War in the search for natural medicines (Laura Hastings, Royal Botanic Gardens, Kew, pers. comm.). At its lowest, in the years after the Second World War, the total area of herbs grown outdoors in the UK was less than 1,000 ha.

The economics of growing crops for plant extracts in the UK can now be reconsidered in the context of modern cultural preferences for natural products (Horrobin and Lapinskas, 1993). There has been an increase in interest in the use of natural substances instead of synthetic chemicals. Aromatic plants and their essential oils are a source of natural medicines or plant protection chemicals. They contain secondary metabolic products which have biological activity such as antibacterial, antifungal or antioxidant (Deans and Waterman, 1993). For example, the volatile oil of thyme has been shown to prevent the age-dependent decrease of the polyunsaturated fatty acids in the livers of mice (Deans *et al.*, 1993).

The value of imports of essential oils ranged from £34 M in 1994 to £47 M in 1995 (MAFF, 1994; MAFF, 1995). The value of non-citrus imports, the oils most suited to UK production, ranged from £13 M in 1994 to over £26 M in 1995.

The UK imports essential oils of many plants which could be grown here, particularly mint and lavender but also chamomile, thyme, rosemary, clary sage, rose, coriander, angelica and others. In addition, there is scope to export extracts of those species which yield reliable quantities of oil under UK climatic conditions. English production of these oils still gains a premium on the market, although volume is small. There is a premium for 'English chamomile' and 'English clary sage', for example (C Wells, Essentially Oils Ltd, pers. comm.).

There are no official statistics for the area of herb crops grown in the UK, although in 1992, the area was estimated at 1,262 ha. This comprised 992 ha of culinary herbs (mainly parsley, coriander, mint, sage and lower acreages of thyme, dill, basil, chives, horse radish, rosemary and tarragon), with 270 ha of medicinal herbs (mainly

chamomile, with lower areas of lavender, witch hazel and fenugreek; S Perkins, ADAS, pers. comm.). These figures are an underestimate because they do not include evening primrose or borage. These two crops were estimated at 1,500 ha in 1995 (M. Askew, Central Science Laboratory, pers. comm.). There appears to be an increase in the crops grown for medicinal purposes with some additional 200 hectares of rosemary, chamomile and thyme recorded (W. Symonds, ADAS, pers. comm.). It is estimated that there may have been a further 250 ha established during 1996 and 1997 for essential oil extraction (A. Winter, ADAS, pers. comm.). In addition, it is thought that some 200 ha of coriander has been established in 1996/97 (P. Turner, National Herb Centre, pers. comm.). Thus, the total herb acreage is now more than 3,000 ha. This is low compared with the production in other northern European countries. For example, Spain grows 28,500 ha and France grows 23,000 ha (Verlet, 1992).

There is limited capacity for the processing of these 3,000 ha of crops in the UK (Appendix 1). This is due to lack of investment in both the capital and research required to establish and sustain the processed herb industry. However, the demand for essential oils, pharmaceuticals and herbal extracts from UK crops is such that the production area could be increased to up to 15,000 ha within the next ten years (based on discussion with potential buyers of essential oils from UK sources and with consultants working with growers on new enterprises).

Recent reviews (for example Runham, 1996; Verlet, 1993; Verlet and Svoboda, 1996) have determined that there is a demand for essential oils from the UK. More than 70% of the world's volatile oils are consumed by only 15% of the world's population such that there is scope for growth, and, in particular, there is burgeoning interest from Far Eastern markets. This is particularly the case for Roman chamomile and lavender from England (termed 'English' chamomile and lavender respectively), where the oils are of an acceptable quality to particular buyers and the production is reliable and supply regular.

The research done for this report aims to provide some base-line information on UK crop productivity in terms of oil yield and quality as a foundation for further research and development. The crops assessed were grown from plots at ADAS Arthur Rickwood in Cambridgeshire. Lavender and rosemary had been established in 1996 by ADAS in order to gain information on herb husbandry to support a range of projects. The other four herbs were established in 1997 within this project.

The techniques used to grow the crops were based on discussion with a range of specialists in the industry because there are scant research data from elsewhere in Europe which give specific husbandry guidelines, although some information on the culture of chamomile does exist. Chamomile was evaluated in Finland and compared with crops grown further south in Europe. It was found that the quality of the flower and essential oil of the Finnish crop were as good as the Southern Europe product provided it was dried properly (Galambosi and Szebeni-Galambosi, 1992a). The development of chamomile plants depended upon the climate. For example, chamomile flowers took less time to complete the flowering cycle in Ethiopia than in temperate regions of Europe (Letchamo, 1992a; Letchamo and Vomel, 1992). The mean yield components, essential oil and straw yields of different genotypes of chamomile varied in the seasons grown, and favoured by increased nitrogen levels

(Letchamo, 1992b). A search of the literature showed a large influence of agronomic factors on essential oil composition. For example, the planting date, nitrogen fertilisation and timing of crop harvest all affected yield or content of essential oils of peppermint (Piccaglia *et al.*, 1992).

Herb seed is frequently difficult to germinate for a range of reasons such as dormancy and limited breeding for uniformity (Collins *et al.*, 1994.). These problems could be overcome by research into seed treatments such as priming techniques that have been used for other vegetable crops (for example, Gray *et al.*, 1992).

Timing of harvest affected the concentration of essential oils of chamomile in experiments in Germany (Letchamo, 1992b). There are differences between the oil collected from the leaves of *Achillea millefolium* during the flowering period and the oil from the leaves collected during the vegetative phase of the plant (Figueiredo *et al.*, 1992).

2.1 Overall objective

To determine the yield and quality of essential oils and the economic returns of a selection of UK herb crops which may be commercially viable if produced in the UK.

2.2 Detailed objectives

- i) To grow crops according to best agronomic practice and to harvest at flowering (or post-flowering for rosemary).
- ii) To extract the oils by commercial distillation and by cold pressing (lavender).
- iii) To analyse the oils in the laboratory.
- iv) To produce yield and quality data and prepare an estimate of the economic returns for the production of the herbs for oils in the UK.

This work supports the policy of the Ministry of Agriculture, Fisheries and Food to develop alternative industrial crops on set-aside land and the creation of new enterprises in rural locations.

3. MATERIALS AND METHODS

3.1 Sites: ADAS Arthur Rickwood with a Grade I peaty loam soil and with irrigation available.

Pringle Drove field for Roman chamomile, thyme and yarrow, see field plan in Appendix II. A partially sheltered site but with no shading from trees. The previous cropping was wheat.

Meadow Ground field for German chamomile, lavender and rosemary, see field plan in Appendix III. An exposed site with no shading from trees. The previous cropping was carrots.

The soil fertility and lime requirement at the start of the 1997 season is shown in Table 1.

Table 1. Soil nutrient indices and lime requirement.

Field	pH	lime (t/ha)	P mg/l (Index)	K mg/l (Index)	Mg mg/l (Index)	N (estimated index)
Pringle Drove	6.5	5	58 (4)	358 (3)	145 (3)	1
Meadow Ground	6.9	Nil	47 (4)	329 (3)	113 (3)	1

Fertiliser

Nitrogen was applied to Meadow Ground at 30 kg/ha (as 87 kg/ha of Nitram @ 34.5% N) in 1996 and to both fields at 30 kg/ha (as 87 kg/ha of Nitram @ 34.5% N) in 1997.

3.2 Herb Crops

Roman chamomile

Anthemis nobilis

cv. Lawn Chamomile

Source: CN Seeds Ltd.

German chamomile

Matricaria chamomilla (recutita)

cv. Wild Chamomile

Source: CN Seeds

Lavender

Lavandula angustifolia

Source: Muntons Microplants

Rosemary

Rosmarinus officinalis

Young plants of 'Sudbury Blue' as young plants from Yorkstock. Propagated in Israel.

Thyme

Thymus vulgaris

cv. English winter

source: CN Seeds

Yarrow

Achillea millefolium

Source: CN Seeds

3.3 Layout of the plots

The herbs were established in single large non-replicated plots (Appendices II and III). All crops were raised as young plants in modules in a glasshouse but were grown-on in the field. All crop harvests were taken from within large plots with a minimum of 2 m discard on either side and at each end of the plots. Climatic data were recorded throughout the season and these are presented in Appendices IV.

Plant density

Plant densities were selected after discussion with specialists and from the literature based on European herb production. The optimum densities for production of these crops in the UK are not yet known. The herbs were established using the vegetable bed system based on a tractor width of 1.8 m. There were two rows of lavender on the bed width, three of rosemary, thyme and yarrow and four of each type of chamomile.

All crops were harvested fresh and taken to be distilled in the laboratory or for commercial distillation.

3.4 Individual cultural details

German Chamomile

These were grown from seed at ADAS Arthur Rickwood. They were sown on 14 March 1997 into Hassy 228 trays with Levington F1 compost. The seed was germinated at 20°C then moved to 12°C to grow on. The germination was low to moderate giving small plants on 17 April 1997. The crops were planted on 1 June 1997. A 1,800 m² plot of chamomile was established using a Veg-row transplanter machine at 30 cm in-row and 30 cm between the rows giving a population density of 74,074 plants/ha. Sequential harvests were sampled manually on 29 July (10 m²) and by machine using an Allen scythe on 1 September (44 m²).

Roman Chamomile

These were grown from seed at ADAS Arthur Rickwood. They were sown on 14 March 1997 into Hassy 228 trays with Levington F1 compost. The seed was germinated at 20°C then moved to 12°C to grow on. The crop was planted by hand on 1 June 1997 and spaced at 30 cm in-row by 30 cm between the rows (74,074 plants/ha). There was 100 m² of chamomile, of which 18 m² was sampled on 19 August.

Lavender

This crop was bought in as plug plants in 1996 and planted that year. A 1,350 m² plot of the lavender was established at a density of 18,519 plants/ha, achieved by using 90 cm row spacing and with the plants at 60 cm in the row. The crop was not harvested in 1996. In 1997, the crop was maintained and had increased its cover of the ground. Sequential harvests of 10 m² were taken manually on 29 July, 19 August and 18 September 1997. A larger sample of 88 m² was cut using an Allen scythe harvested on 1 September.

Rosemary

Seed was put to germinate on 22 April 1996 but it failed to do so. Consequently, plants which had been propagated in Israel were obtained from Yorkstock. These were planted on 7 July 1996. There was 450 m² of rosemary plants, from which 10 m² was sampled by hand on 14 November 1997. They were spaced at 60 cm in-row and with rows at 60 cm (27,400 plants/ha).

Thyme

Seed was sown in Hassy 228 trays on 14 March 1997 using Levington F1 compost. The seed was germinated at 20°C then moved to 12°C to grow on. The crop was planted by hand at 50 cm in-row and 50 cm between the rows (33,333 plants/ha) on 1 June 1997. There was 100 m² of thyme plants, from which 18 m² was sampled when the crop was harvested manually at flowering on 29 July.

Yarrow

The seed was sown in Hassy 228 trays on 14 March 1997 using Levington F1 compost. The seed was germinated at 20°C then moved to 12°C to grow on. The germination was good with small plants on 17 April 1997. The crop was planted on 1 June 1997. The crop was planted by hand at 50 cm in-row and with 50 cm spacing between the rows (33,333.plants/ha). There was 100 m² of yarrow, from which 18 m² was sampled when the crop was harvested manually on 29 July.

The plant populations are summarised in Table 2.

Table 2. A summary of spacing (cm) and crop density(plants/ha)

Species	cm (in row/between row)	plants/ha
Roman chamomile	30 by 30	74,074
German chamomile	30 by 30	74,074
Lavender	60 by 90	18,519
Rosemary	60 by 60	27,400
Thyme	50 by 50	33,333
Yarrow	50 by 50	33,333

All crops were grown with 50 mm of irrigation. The herbs grew vigorously but control of weeds was required before harvest. For rosemary, lavender and German chamomile, there was a large area which warranted the use of a single application of chlorpropham + pentanochlor as Atlas Brown under the specific off-label approvals

0249/93 and 0602/93 applied by tractor-mounted sprayer. The other herbs were kept clear of weeds by hoeing.

3.5 Assessments

Germination

An indication of the germination of the seed was obtained using 20 seeds of each herb which were placed in a petri dish and put into an incubator at 18°C (not an official seed test). The number of seeds germinated was assessed daily and recorded for 13 days. This period was rather short as herb seed is often assessed for germination over four weeks due to its prolonged germination phase, and lack of uniformity, when compared with more rigorously selected vegetable seeds.

The growth stages at which the herb crops were sampled for oil extraction are shown in Table 3.

Table 3. Growth stage at which the crops were sampled

Species	Stage of harvest (material harvested)
German chamomile	flowering in summer of first year
Roman chamomile	flowering in summer of first year
Lavender	flowering in summer of second year
Rosemary	leaves in autumn of second year
Thyme	flowering in summer of first year
Yarrow	flowering in summer of first year

The stages of growth shown above were prolonged allowing more than one harvest within the growth stage period, shown in Table 4.

Table 4. Dates of sampling

Species	Date of sampling
German chamomile	29 July, 1 September (whole crop, flowers sub-sampled),
Roman chamomile	19 August (whole crop, flowers and tops of stems sub-sampled)
Lavender	29 July, 19 August, 1 September, 18 September (whole crop, flowers and tops of stems sub-sampled)
Rosemary	14 November (leaves and stems)
Thyme	29 July (flowers, leaves and stems)
Yarrow	29 July (whole crop)

Laboratory analyses

The harvested herbs were posted (one-day delivery) to the Scottish Agricultural College for extraction and analysis in the laboratory. The plants were dried at 38°C in a drier adapted for herbs (similar to commercial scale adapted grass driers with shelves). The oil quantity was measured using the British Pharmacopoeia distillation apparatus (BSI 1985) and Gas Chromatography analysis (Svoboda *et al.*, 1990a, 1990b). The components of extracted herbs oils can be confirmed using Gas Chromatography and Mass Spectrometry. This is the process used for all commercial essential oils to verify their authenticity and quality. An example of a chromatogram is shown at Appendix V. This shows the 'peaks' which can be related to the chemical components by a consultant analyst.

Pilot commercial steam distillation

German chamomile and lavender oils were extracted from fresh herbs in bulk (50 kg) using steam distillation in a pilot commercial scale plant (still by Stern Engineering Ltd, and steam generation by Wanson Ltd) at the National Herb Centre in Warwickshire. The extracted oils were analysed using Gas Chromatography as above.

4. RESULTS

Assessments of the extracted oils were made at the Scottish Agricultural College and by the National Herb Centre. The opinions were based on Martindale (1993) and on discussion with contacts in the essential oil trade.

4.1 Germination of the herb seed

The germination of the rosemary was poor in 1996 and the crop plants were bought in instead. Lavender was also purchased in 1996 as it was reported to be difficult to achieve germination. The germination of the other species is shown in Table 5.

Table 5. Germination (%) of the herb seeds after 13 days at 18°C.

Species	Germination %
German chamomile	40
Roman Chamomile	35
Thyme	75
Yarrow	75

The thyme and yarrow gave very good germination. Chamomile gave very slow and poor germination over the assessment period.

4.2 Crop development

Once the crops had been planted in the field they established and grew away well (Table 6).

Table 6. Ground cover at harvest.

Species	% of ground covered at harvest
German chamomile	100% with one-year-old plants
Roman chamomile	100% with one-year-old plants
Lavender	80% with two-year-old plants
Rosemary	80% with two-year-old plants
Thyme	80% with one-year-old plants
Yarrow	60% with one-year-old plants

4.3 Crop yield and quality assessments

German Chamomile

The crop yield of biomass and oil is shown in Table 7 from two sample dates.

Table 7. Yield of crop and oil of German chamomile.

Component	Yield
Whole crop fresh herb on 29 July (small sample)	26,400 kg/ha
Oil on 29 July	6.6 litres/ha
Whole crop fresh herb on 1 September from 44m ²	20,861 kg/ha
Oil on 1 September	6.9 litres/ha

The yield of the oil from the whole crop was about 0.025 % (a figure which is considered normal for a whole crop harvest). The yield of oil from just flowers and tops of stems was 0.5 - 1%.

The principal constituents (those specifically sought as measures of the biological activity of the oil, e.g. its medicinal or pesticidal properties) are chamazulene, farnescene and bisabolol oxide. These components were present in the oil extracted on 29 July 1997 (Table 8). The levels of chamazulene and bisabolol were considered to be approximately half the required levels acceptable for trading on the world market.

Table 8. Chemical components of the oil after pilot commercial distillation (source National Herb Centre).

Constituent of the oil	Percentage present on 24 July	Percentage present on 3 September
1,8 cineole	1.8	0.5
Thujone	0.3	5.86
Alpha farnesene	0	1.9
Beta farnesene	38.7	1.4
Bisabolol oxide B	0.3	2.0
Bisabolol oxide	10.1	0.5
Chamazulene	3.8	4.9

Roman chamomile

A single sample was taken from this crop on 29 July 1997, when the crop was in flower. The sample was sent for laboratory distillation only. The whole fresh herb was harvested and this gave a yield of 9,500 kg/ha. The leaves, stems and flowers together contained 0.097% of extractable oil which equated to 9.22 litres/ha.

The oil had a light blue colour and pleasant fragrance. The plant produces an essential oil containing chamazulene, coumarin, flavonic heterosides and esters of angelic acid. The chromatogram trace showed that there was a total of 75 peaks, of which 19 peaks exceeded 1%. This constitutes a well-balanced oil. However, it had a rather high content of alpha pinene when compared with oils on the world market, which usually have less than 4%. The oil did not have large enough peaks of angelates and butyrates which should form over 70% of the total oil (Table 9).

In additional tests at Scottish Agricultural College, the plants were separated into flowers and stems and distilled separately. There was very little difference between the two components apart from a higher yield in the flowers and the stems gave a slightly darker blue colour.

Table 9. Chemical components of the oil of Roman chamomile from 29 July harvest after laboratory distillation (source Scottish Agricultural College).

Oil constituent	Percentage present on 29 July
Alpha pinene	18.0
Beta pinene	3.2
1,8-cineole	1.1
Angelates/butyrate	43.1

Lavender

The yield of the crop biomass and oil is shown in Table 10.

Table 10. Yield of crop and oil of lavender during 1997

Component	Yield
Whole fresh herb on 29 July 1997	16, 513 kg/ha
Oil on 29 July 1997	41.3 litres/ha (0.9% of sub-sample of flowering stems)
Fresh crop flowers only on 19 August	4,938 kg/ha
Oil on 19 August	44.4 litres/ha
Fresh flowers (and 6 cm stem) on 18 September	4,784 kg/ha
Oil on 18 September	43.05 litres/ha (flowers contained 0.9% of oil)

The 29 July sample had a good profile of oil components but the linalyl acetate and linalool were considered rather low for world trade standards (Table 11). For linalyl acetate, the level should be in the range of 30-43 % and for linalool the level should be in the range of 36-43%.

Table 11. Selected chemical components of oil from a sample of lavender on 29 July after laboratory distillation (source Scottish Agricultural College).

Oil component	Percentage present in a standard oil	Percentage present in the trial sample
Linalyl acetate	12.4-45.3	18.6
Linalool	10.0-49.9	22.1
Limonene	1-11.0	1.0
Terpinene-4-ol	1.8-11.8	1.6
Alpha terpineol	1-7.9	1.1
1,8 cineole	1-2.3	1.1
Myrcene	0.3-2.0	0.1
Alpha pinene	0-1.0	0.5
Beta pinene	1-1.3	1.2

Rosemary

The yield of fresh crop on 14 November was 4,795 kg/ha. The crop was sent for extraction in the laboratory where the percentage of oil extracted from the leaves and stems was 1.2% based on the dried plant (0.24% of the fresh plant). This was

considered low as some samples can be as high as 2-4%. The overall yield of oil was 11.5 litres/ha. The rosemary oil had a pleasant strong smell. The constituents of the rosemary oil are shown in Table 12. The proportion of alpha pinene was rather high (20-30% preferred). The proportion of 1,8-cineole was low (should be 20-30%). The level of camphor was acceptable at under 4% of the oil constituents.

Table 12. Components of rosemary oil after laboratory distillation (source SAC).

Oil Constituent over 1%	Percentage present in the trial sample
Alpha pinene	45.9
Camphene	6.3
Beta pinene	5.0
Alpha terpinene	2.7
1,8 cineole	10.8
Camphor	3.6
Alpha terpineol	6.2

Thyme

The yield of the crop harvested on 29 July, when in full flower, was 5,325 kg/ha. This crop was sent for laboratory extraction and analysis when the percentage of oil extracted from the fresh plant was 0.22%, giving a yield of 11.8 litres/ha.

The oil was of a good quality with a high thymol content and the correct percentage of other components for world trade (source Scottish Agricultural College).

Yarrow

The yield of fresh crop on 29 July was 16,513 kg/ha. The percentage of oil extracted in the laboratory was 0.03% giving a yield of 4.95 litres/ha. The range of constituents compared with the sample is shown in Table 14.

Table 14. Selected chemical components of the oil of yarrow after laboratory distillation (source Scottish Agricultural College).

Oil constituents	Preferred percentage range in world-traded oil	Percentage present in trial sample on 29 July
Alpha pinene	8-23	3.1
Beta pinene	6-23	10.2
Borneol	3-19	9.7
Chamazulenes/azulenes	2-15	2.5
Sabinene	12-40	8.4
Caryophyllene	10-31	1.5
1,8 cineol		2.6
Linalool		1.2

4.4 Cold pressing

The crops were considered unsuitable for cold pressing due to their very low levels of oil content. A list of oils more suited to this method of processing is given in the Discussion.

4.5 Economic returns

An estimate of the gross margins for the crops grown, based on oil yield and quality is presented in Table 15.

Table 15. The estimated gross margins for herb oil enterprises based on yields and quality in 1997.

Crop	Crop oil yield l/ha	Crop price# £/kg	Output from trials in 1997 £	Variable costs* £/ha (years of production)	Gross margin# £/ha
German chamomile	6.6	470 (high)	3,102	420 (1)	2,682
German chamomile	6.6	100 (low)	660	420	240
Roman chamomile	9.2	250	2,300	725 (4)	1,575
Lavender	41.3	85 (high)	3,511	454 (14)	3,057
Lavender	41.3	50 (low)	2,065	454	1,611
Rosemary	11.5	250 (high)	2,875	470 (10)	2,405
Rosemary	11.5	100 (low)	1,150	470 (10)	680
Thyme	11.8	250 (high)	2,950	520 (10)	2,430
Thyme	11.8	100 (low)	1,180	520	660
Yarrow	5.0	500 (high)	2,500	717 (3)	1,783
Yarrow	5.0	250 (low)	1,250	717	533

*The variable costs include seeds or bought-in young plants, fertiliser, irrigation, labour but assumes that the weeds will be controlled using herbicides, and that the crops are mechanically harvested using specialist equipment (A Winter, ADAS, pers. comm.). The variable costs take into account the number of years of production of the individual crops (shown in parentheses). The costs of distillation are not included in the variable costs. The costs depend upon the method and scale of distillation.

The higher figure given is for high quality oils which can be traded on the world market. Lower quality oils may give higher returns if the buyer is prepared to pay a

premium for them because they are from a known (local) source. The higher prices could also apply where the grower sells the crop direct to the public.

5. DISCUSSION

5.1 General

Six herb species were grown for their yield of essential oil and assessed for quality from a site in Cambridgeshire in 1997. The industrial crops were chosen for their likelihood of becoming a commercial success as an 'alternative non-food crop' in the UK following on from reviews of the market (Runham, 1996; Verlet 1993). The crops were German (Wild Chamomile) (*Matricaria chamomilla* or *recutita*), Roman or Blue Chamomile (*Anthemis nobilis*), Lavender (*Lavendula angustifolia*), Rosemary (*Rosmarinus officinalis*), Thyme (*Thymus vulgaris*) and Yarrow (*Achillea millefolium*). In addition, Clary sage (*Salvia sclarea*) was grown in 1997 but will be harvested at flowering in 1998 (an updated report will cover this yield). All of the crops have been requested by buyers of essential oils.

For all novel crops, there is a pre-commercial stage of development. During this phase, growers produce the crops using the best available guidelines. This study provided some information on relative ease of germination and establishment. The initial establishment of the crops in the glasshouse, before planting out, was difficult for all except thyme and yarrow. Lavender and rosemary were consequently bought in as plug plants (in 1996). Both types of chamomile and yarrow gave poor germination in 1997, but enough material was obtained for the evaluation. It should be possible to improve the germination of herbs by selecting higher quality seeds. Currently, good germination for herbs is in the order of 75-80%, which is lower than for highly-bred vegetable seed. Germination of herbs also tends to take place over a longer period of time than for vegetables which have been bred for uniform germination over as short a period as possible. Once planted out all crops established well. They grew vigorously but needed some weed control before harvest.

The study used information from research and discussion with a range of specialists to estimate the best time of harvest of the herbs to maximise the production of oil. In the ideal situation, several samples should be taken for laboratory analysis at around the optimum crop growth stage (usually at around flowering, but, for rosemary, either at flowering or later). Most producers of oils equip themselves with laboratory facilities to support this quality appraisal. The crops were harvested at peak flowering except for rosemary which was harvested for its aromatic leaves in autumn. A change in composition of essential oil with harvest date was observed for both German chamomile and lavender and this showed the importance of choosing the best time for harvest. In both cases, the earlier harvest at peak rather than at post-peak flowering proved more appropriate.

Even when the biomass production of the crop is high, not all of the parts of the plant yield valuable oils and consequently the oil yield is low. For rosemary, taken in autumn, the leaves proved to contain some useful components. The profile of the oil was acceptable and it had a nice aroma. For other crops, the flowers contain the

highest yield of oil. The ease of harvesting flowers alone has still to be ascertained in the UK. In some other countries, machines to selectively harvest the cut flowers and tops of stems and vacuum them into a collection chamber are under development (R Cole, National Herb Centre, pers.comm.).

The value of the oils could be considerably enhanced by knowledge of their source and the methods of production used. The value could be improved further by the adoption of a certification scheme which indicates that the crops have been produced using protocols. This would be similar to the produce assurance scheme developed for vegetable crops.

Lavender was also sent for cold pressing extraction but this was not successful due to the inherently low level of oil in the crop. All other species have oil contents which, on the basis of the lavender results, would be too low for cold pressing extraction to be economic. The species more suited to the use of cold pressing include the following:-

borage
nettle
calendula
spurge
coriander
caraway seed
evening primrose
mustard seed

(Peter Sedgebeer, Statfold Seed Developments, pers. comm.).

This small-scale study was undertaken in a year of unusual rainfall patterns, particularly in June and August (see Appendix III). The crops also are perennial (except the German chamomile) and may be harvested in later seasons giving a different result for yield and quality of oil. The results from this trial should be treated as a guideline only and interpreted with some caution by prospective producers.

5.2 The herb oils in detail

German chamomile

The yield of German chamomile oil was low at 6.6 l/ha on 29 July 1997 and the quality mediocre with 3.8 to 4.9% of chamazulene compared with world standards. This low level of required constituents reduces the value of the oil which, together with the low yield of oil, means that this crop would probably not be economic to produce. However, the value of the oil may be enhanced by the knowledge of its source and the method of production used. It is only as the grower develops a dialogue with the potential buyer that the markets for oils develop. The oil may attract interest from buyers in a niche market but the overall productivity of the crop would need to be increased to make the crop attractive to UK growers. It is worth pursuing the development of this crop which meets a world market estimated at £3.6M (Verlet, 1993). The yields of oil should increase in the future, as variety selection and crop husbandry techniques progress, thereby improving the level of return for the crop.

Roman Chamomile

Roman chamomile had a good yield of oil with 9.22 litres/ha on 29 July 1997. The oil had a pleasant fragrance and good light blue colour. The oil had over 75 peaks on the chromatogram which indicated a 'well balanced oil'. When compared with oils on the world market it had a rather high level of alpha pinene, and low levels of angelates and butyrates. There is scope to produce this oil in the UK, but there is a need to improve the quality of the oil by seed source and selection. The value of this oil on the world market has been estimated at £2 M (Verlet, 1993). There is interest in developing 'English chamomile' strains. There may be a market for this product because it is English and from a traceable source (of value on some markets). However, there is a problem with attempting to sell on the world market against traditional sources.

Research is required to establish standards for this oil. It is possible to use those which have become available recently to make an estimate of the quality of the oil with respect to other oils on the market. The oil resembled a locally available oil (from elsewhere in East Anglia) which is 'one of the best' according to a USA buyers guide (K. Svoboda, pers.comm.). The oil grown at ADAS Arthur Rickwood differed in that it had high alpha pinene (12-19% instead of 3-7%), probably from the leaves of the chamomile. The oil had low levels of butyrate and angelate (40%) compared with the world-traded normal levels of 60-70%. The high level of pinene on its own does not present a problem as it is harmless at this concentration, but it can make the smell and taste more bitter than if it were at a lower percentage of the constituents. This, and the low levels of angelates and butyrates, would mean that the oil needs to be dealt with by a specific buyer. There is no statutory regulation about quality of the oil.

Lavender

The yield of lavender was 41.4 litre/ha on 29 July 1997, and 44.4 litre/ha on 19 August 1997. This quality of the oil was reasonable but there is a need to increase the levels of linalyl acetate and linalool to improve the viability of the oil for world markets. This would be achieved by selection and breeding (Rabotvagov and Akimov, 1987). There is likely to be interest in the oil from local outlets, from buyers who will blend the oil, or where there is a premium for oils from known sources (traceability of production of the oil). The value of this market has been estimated at £12 M (Verlet, 1993).

Rosemary

The yield of oil extracted from leaves of rosemary was 57.5 litre/ha. The quality of the oil was acceptable for world trade. There is scope to develop niche market sales for this crop, worth an estimated £3.4 M (Verlet, 1993).

Thyme

This crop was established at a relatively late planting date for a harvest in 1997. The preferred technique is to overwinter the crop prior to harvesting by which time it has increased in biomass and yield. It was observed that the thyme had increased in size considerably at an assessment in January 1998. It is anticipated that the yield of biomass and oils will be higher in 1998 when the crop is harvested at flowering. The yield of thyme was high at 11.8 litres/ha and the oil had a good quality with a high content of thymol and the 'correct percentages of other components' for world trade, which has been estimated at £750,000 (Verlet, 1993).

Yarrow

The yield of yarrow was low at 4.95 litres/ha. The oil was of inferior quality to a comparative oil obtained from Holland which had been specifically bred for the essential oil market and which contained 21% of chamazulene, and 33% of beta pinene (compared with 2.5% and 10.2% respectively for the trial sample). There are no world standards for this oil. There is likely to be interest in the oil from local outlets, from buyers who will blend the oil, or where there is a premium for oils from known sources (traceability of production of the oil). There may be an advantage in oils of low chamazulene content, which is an astringent component of the oil, but this depends on the outlet.

The development of new enterprises based on growing and processing crops of these essential oils will lead to a greater diversity of cropping in rural locations. The on-farm processing of these, and other suitable candidate oils (e.g. mint, sage and hypericum) will increase employment in rural areas and contribute towards meeting the objectives within the Agenda 2000 policy of the EU.

6. RECOMMENDATIONS

Increased production of essential oils in Europe will require the introduction of modern technology in the production and extraction phases. Further research work is needed in the following areas:

Breeding for high oil content and adaptation to UK climate. Most producers will need to have a their own crop selection and improvement programme. For most herbs crops grown in the UK, breeding for the production of essential oils is in its infancy. There is considerable scope for simple genetic improvement to crops to increase the contents of essential oils.

Seed selection and seed treatment to improve germination. There have been considerable advances in seed improvement within mainstream vegetable crops which technology can be developed for herb seeds.

Planting and growing schedules. There is a need to determine crop cultural requirements on a range of soil types and in several locations. This work will show the potential for producing crops economically in the UK.

Detailed development work on the interaction of soil fertility and fertiliser use on oil quantity and quality. There is scope to adapt computer models for vegetable production (such as Well-N and Manners developed by Horticulture Research International and ADAS respectively with MAFF funding)) to enable growers to determine crop fertiliser need and to prevent exceeding the optimum amount for oil yield and quality.

Sustainable methods of production of the crops. For example, in Finland, the use of agro-chemicals is not permitted for herb production. There are two methods of non-chemical weed control; the use of either black plastic mulches or ridges as for potato growing. The use of both the mulching and ridging techniques assisted weed control

in herb production (Galambosi and Szebeni-Galambosi, 1992b). Where the use of herbicides is permitted, the quality of aromatic oils from herbs has not been affected provided the crop is tolerant of the herbicides and, in some cases, the quality of the oil has improved (Pank, F., 1992; Zheljazkov and Topalov, 1992a).

Harvesting timing and method. For example, timing of harvest affected the concentration of essential oils of chamomile in experiments in Germany (Letchamo, 1992b). There were differences between the oil collected from the leaves of *Achillea Millefolium* during the flowering period and the oil from the leaves collected during the vegetative phase of the plant (Figueiredo *et. al.*, 1992). The mechanisation of herb crop production for essential oils or dried herbs in the UK will be a key to the economic viability of production. For example, hand-harvesting of chamomile flowers only may be too time consuming, and it may be more worthwhile to harvest the stems, leaves and flowers together by machine (M Gahagan, pers. comm.).

Development of extraction technology to maximise the oil extracted and minimise distillation time. There are several recent advances in extraction of essential oils at the laboratory scale, for example in using ultrasound to assist the solvent or steam distillation extraction processes (T Mason, Coventry University, pers. Comm.). These should be tested using UK-grown essential oils and using pilot commercial-scale equipment if the results in the laboratory prove worthwhile.

The prospects for UK produced essential oils will be improved by the setting up of a certification scheme based on source of crop, method of crop production and quality of oil, and by the adoption of crop production protocols.

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Appendix I

DISTILLATION FACILITIES IN THE UK.

Advanced Phytonics Ltd

Leeming, N Yorkshire

Tel: 01677 425655

This company undertakes solvent extraction using a new 'environmentally-friendly solvent'.

Bush Boake Allen Ltd Longmelford Sudbury, Suffolk

Tel: 01787 880833

Distill for fragrance and flavour

Camstar Herbs Ltd,

Eye, Suffolk

Tel:01379 870669

Firth Farms Ltd,

Basingstoke, Hants.

Tel: 01635 298355

This small company recently set up produces chamomile oil. They have 3 stills.

James Barn Farm Estate,

Naunton, Cheltenham

Tel: 01451 850787

The company undertakes supercritical carbon dioxide extraction of herbs for high quality extracts.

John K King and Sons Ltd

Coggeshall, Essex

Tel: 01376 561543

This company processes oils, mainly industrial.

Lionel Hitchen,

Winchester, Hants.

Tel: 01962 760815

This company produces essential oils in the UK. A multi-national company which makes their own essential oils on a small scale.

Neals Yard Ltd,

Battersea, London

Tel: 0171 498 1686

The company buys herbs from abroad and does its own processing.

Norfolk Lavender, Norfolk

Tel: 01485 570384

This company steam distills lavender from its own farm.

Peter Jarvis

Hadleigh, Ipswich

Tel: 01845 523452

Process by maceration to obtain essential oils for cosmetics.

Ransomes,

Hitchin, Hertfordshire.

Tel: 01462 437615

The company purchases dried herbal products from which extracts are made.

R C Treatt & Company Limited

Bury St. Edmunds, Suffolk

Tel: 01284 702500

The company imports essential oils, re-distils and fractionates them if required to standardise quality.

Weleda -

Ilkeston, Derbyshire.

Tel: 0115 9448200

Distillation for natural medicine

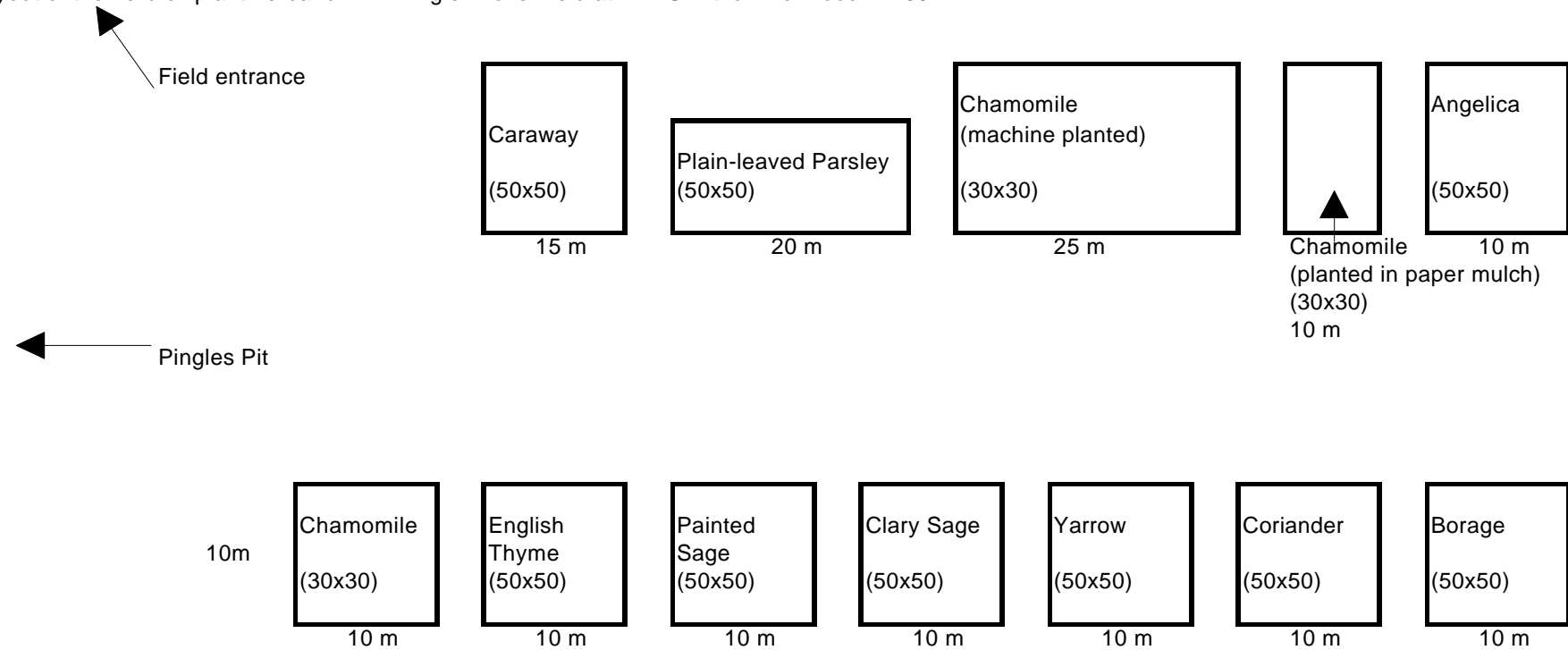
Wessex Impex Ltd

Stonebridge Farmhouse, Breadsell Lane, Crowhurst, St Leonards, E Sussex

Tel: 01424 830659

Appendix II

Layout of the herb oil plant herbarium in Pringle Drove Field at ADAS Arthur Rickwood in 1997



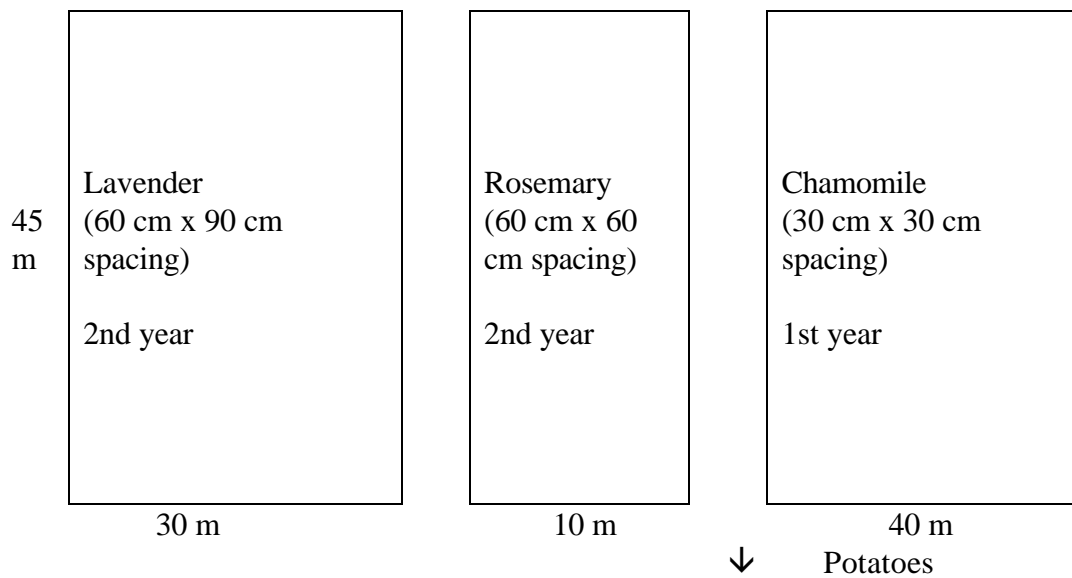
All plant spacings are in cm.

Appendix III

Lavender, rosemary and chamomile plots on the Meadow Ground field at ADAS Arthur Rickwood in 1997.

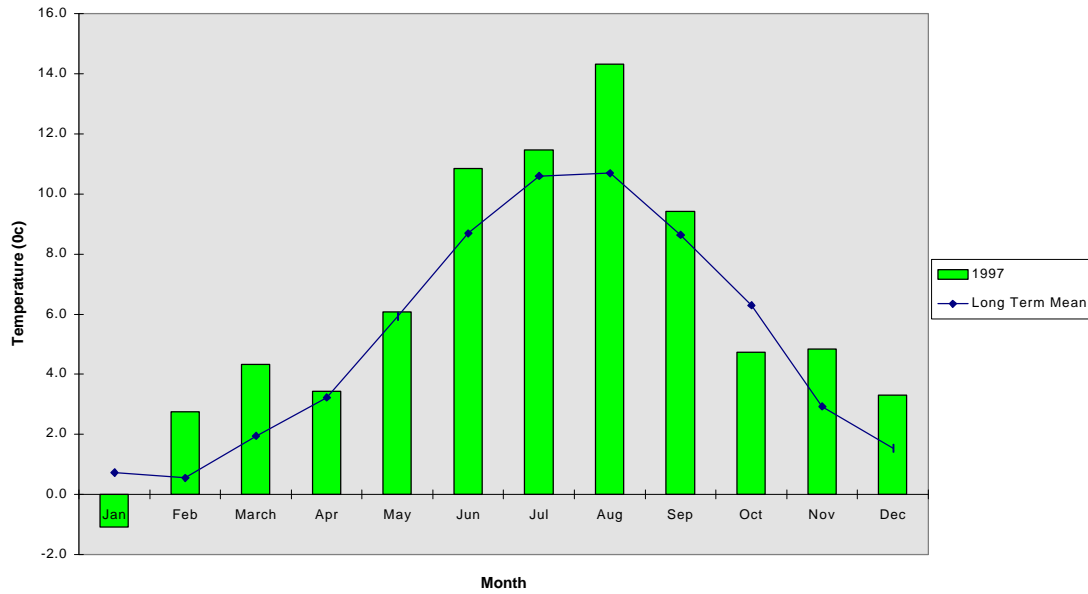
X Telegraph pole

↑ Road

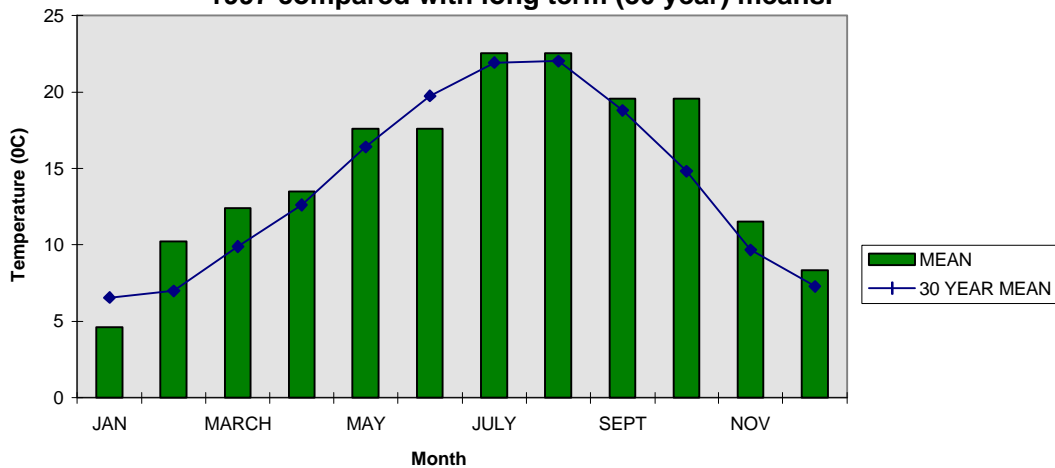


Appendix IV

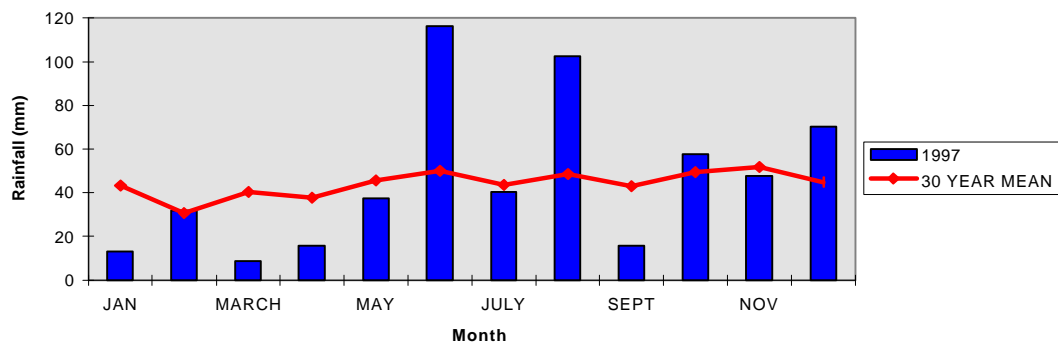
Appendix VI: Minimum monthly temperatures at ADAS Arthur Rickwood in 1997 compared with long term (30 year) means.



Maximum monthly temperatures at ADAS Arthur Rickwood in 1997 compared with long term (30 year) means.

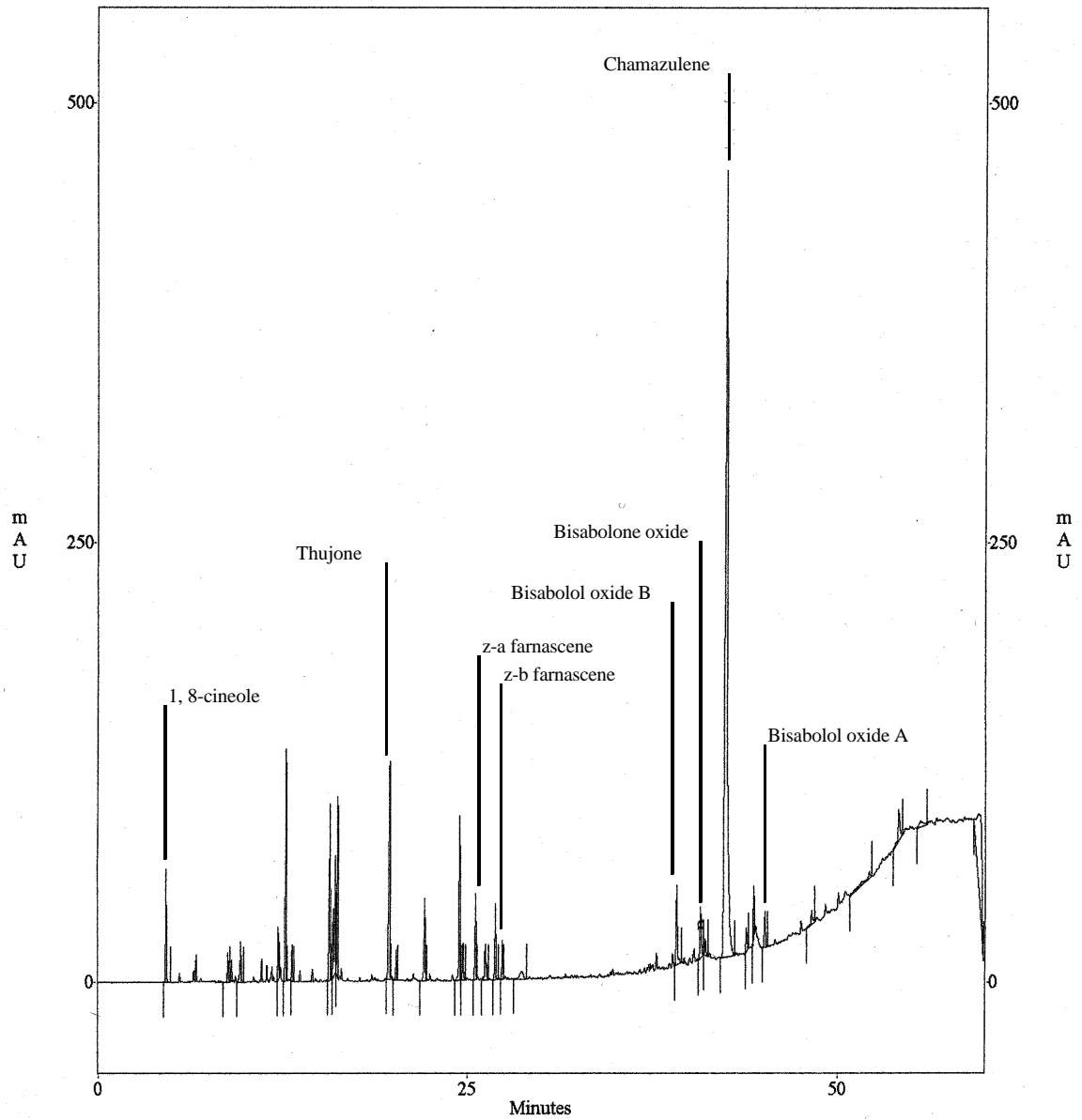


Monthly rainfall for ADAS Arthur Rickwood in 1997 compared with long term (30 years) mean



Appendix V

Chemical components of oil of German chamomile on 3 September 1997



Appendix VI
Contacts referred to in the report:-

CN Seeds Ltd

Ely, Cambs.

Tel: 01353 699413

Muntons Microplants Ltd

Stowmarket, Suffolk.

Tel: 01449 677800

National Herb Centre

Warminton, Banbury, Oxon.

Tel: 01295 690999

Scottish Agricultural College (SAC) Auchincruive,

Ayr, Scotland

Tel: 01292 520331

Statfold Seed Developments Ltd

Tamworth, Staffordshire

Tel: 01827 830871

Stern Engineering Ltd, Canvey Island, Essex.

Tel: not listed

Wanson Company Ltd, Borehamwood.

Tel: 0181 9537111

Yorkstock Ltd

Wetherby, West Yorks

Tel: 01937 541387