Production of Peppermint Oil
A model of best practice for Tasmania and Victoria

A report for the Rural Industries Research and Development Corporation
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August 2000
RIRDC Publication No. 00/20
RIRDC Project No. UT-16A
Foreword

In July 1996, the Rural Industries Research and Development Corporation hosted a workshop for participants in the Tasmanian and Victorian peppermint and spearmint oil industries, in Melbourne. The group reviewed market opportunities for peppermint and spearmint oil, and concluded that there was substantial scope for increased production at present prices, stating that production targets of 100 and 15 tonnes of oil from each of Victoria and Tasmania were achievable.

A key conclusion of that meeting was that there was an urgent need for development of ‘useful models for the performance of peppermint under commercial conditions. This would provide a powerful tool for growers to determine management processes and predict outcomes because much is presently based on anecdotal evidence.

Beginning in July 1997, the Australian peppermint oil industry was reviewed, with particular attention given to agronomic benchmarks, management strategies and risk factors preventing good and consistent yields.

This report summarises the findings of that investigation, and proposes a crop management system designed to provide technical guidance for mint growers, documentation of farm practices and a data collection system to enable state- or industry wide planning.

This report, a new addition to RIRDC’s diverse range of over 400 publications, forms part of our Essential Oils and Plant Extracts R&D program which aims to support the growth of a profitable and sustainable essential oils and natural plant extracts industry in Australia.

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Acknowledgments

This work was made possible with funding from
• Rural Industry Research and Development Corporation,
• Natural Plant Extracts Cooperative Society Ltd and
• VicMint Partners Pty Ltd.

The Authors also acknowledge the contributions of Bernard Brain and Rob & Andrew Parsons in allowing trials on their properties, and Essential Oils of Tasmania’s support of the mint propagation project during the 1998 and 1999 seasons.
Contents

Foreword........................................................................................................................................... iii
Acknowledgements............................................................................................................................. Error! Bookmark not defined.
Executive Summary.............................................................................................................................. vi
Introduction ........................................................................................................................................ 1
1. Literature Review............................................................................................................................ 2
   1.1 Plant Material ......................................................................................................................... 2
   1.2 Nutrition ................................................................................................................................. 2
   1.3 Pest and Disease Control ....................................................................................................... 3
   1.4 Irrigation ................................................................................................................................. 5
   1.5 Harvest Management ............................................................................................................ 5
   1.6 General .................................................................................................................................. 7
   1.7 References ............................................................................................................................. 9
2. Industry Assessment ....................................................................................................................... 11
   2.1: Historical Performance and Statistics .................................................................................. 11
   2.2: Industry Potential ................................................................................................................. 12
   2.3: Peppermint Production and Trial Results 1997-1999 ......................................................... 14
3. A Checkpoint Model for Mint Managers...................................................................................... 32
   3.1 Introduction ........................................................................................................................... 32
   3.2: Overview ............................................................................................................................. 35
   3.3: The Model ........................................................................................................................... 36
   3.4: Implementation .................................................................................................................... 73
4.: References ....................................................................................................................................... 74
5. Appendices ....................................................................................................................................... 78
6. Recommendations .......................................................................................................................... 83
The Mint Best Practice Project was initiated to investigate the reasons for the failure of the Australian peppermint oil industry to consistently achieve yields regarded as normal in the large production areas in the US. The present yields are regarded as unsustainable for an industry of its size, with large investment required for harvest and distillation equipment and strong competition for suitable land from other irrigated cropping enterprises.

**Background and Review**
A brief review of the scientific literature as it bears on production and agronomic issues for peppermint production was conducted at the commencement of the project, revealing that general guidelines for crop inputs, IPM strategies, and harvest technology are available, at least for the US situation. In some cases the substance of these management guidelines differs substantially from current field practices in Australia.

The Australian industry employs the same varieties of peppermint (Todd’s Mitcham and Black Mitcham) as are used by US producers. Despite a very large annual expenditure on peppermint breeding research in that country, there have been no releases of significant new varietal material in recent times. However almost all US producers use nursery-grown stock to establish their plantings as commercial production areas suffer from, and usually succumb to Verticillium Wilt disease after four to five years.

This is not the situation in Australia and the usual practice is to dig propagation material from existing fields in autumn, when the storage reserves have been significantly depleted and physical damage to the stolons during harvest has increased the possibility of infection by otherwise non-invasive diseases. The difficulty of removing compacted soil from the stolon material also increases the prospect of spreading disease and pest agents with the plant material into new areas.

Industry statistics and yield performance over the two years of the project are documented in the report. As mentioned above, while some Tasmanian producers have achieved yields close to 90kg/ha on commercial areas, performance has been inconsistent, and the statewide average yields ranged between 32 and 60kg/ha in the ten years to 1999. Yields on the large, new plantings at Moyhu in Victoria remain below 40kg/ha overall, but again, some smaller Victorian producers have achieved yields close to 80kg/ha.

**Production Practices**
During the two years of the project attention focussed on introducing soil and tissue sampling for nitrate levels and monitoring of soil. In peppermint, irrigation and nitrogen are widely regarded as the two key inputs for manipulating herbage growth and oil quality. Prior to this project, producers employed a standard formula for setting fertiliser and irrigation regimes, without regard for the actual requirements of the plant. Economical technology is now available to enable monitoring of both inputs. During the two seasons of the project this technology was used to demonstrate the potential for cost savings, improved yields and reduced environmental hazard in both production areas.

**Mint Manager**
The obvious lack of user-friendly published technical advice and the problem of ‘decay’ in the quality of the advice available by word of mouth was addressed in preparation of the ‘Mint Manager’ a major outcome of the project in which best available technical guidelines (based in part on the findings of the irrigation and nitrogen monitoring trials) were combined with a set of recording and planning procedures. This is intended to improve the attention of the grower to...
critical details of the production cycle, improve data collection and record keeping and enable sharing of ‘best practice’ between growers.

The cropping cycle, commencing with the preparatory work during the year before planting is subdivided into discrete parts, culminating in an annual management loop wherein performance is reviewed at the completion of harvest, and a plan devised to manage the plantation in the subsequent year.

For each stage, a ‘Checkpoint’ is identified at which the situation in the field is reviewed, and data entered into a simple proforma. Growers then use a self-contained set of agronomic guidelines to devise a plan for the next stage of implementation. The plan is then agreed between the producer, farm manager, consultant agronomist and any other relevant party before implementation commences. Information gathered at each stage and by each grower is collated at the completion of the harvest and the technical guidelines and structure of the management package are reviewed before being re-released for the following season.

Supporting Information

During the conduct of the Best Practice Project many useful technical guides, extension literature and research reports were obtained from the US industry. Copies of a selection of this material have been prepared as an annexure to the main report and will be provided as a separate volume to the funding body and the industry partners as supporting reference material. A copy is also available from the authors of this report.
Introduction

The two year project 'Best Practice Procedures in Peppermint' was undertaken between 1997 and 1999 to address a perceived problem of poor yields in peppermint oil production, as experienced by producers over an extended period in both Tasmania and Victoria.

The conventional approaches involving field officers in the Tasmanian industry and Department of Agriculture support in Victoria have resulted in inconsistent performance - highly variable yields, confusion as to the cause of this, and a gradual drift in crop recommendations for basic inputs such as pesticides, water and nitrogen over a fifteen year period.

Furthermore, there was no broad system for documenting the practices, nor reviewing performance. As a result, producers were:
- unclear of the requirements of the crop,
- transposing US practices, unmodified, into their operations, and
- failing to identify disease, nutrition or irrigation problems as they occurred

The project was undertaken in two parts:
Firstly, a brief assessment of the industry was undertaken, reviewing production methods and yield expectations in both states. The two cropping cycles 97/8 and 98/9 were monitored with a view to identifying key issues for attention and shortcomings in current practices. As part of this, some trial investigations of moisture and nitrogen status in crops in Tasmania and Victoria were undertaken.

Secondly, a management system based loosely on procedures used in the Australian grains industry (Crop Check, Top Crop) was developed, to provide a framework for documentation and review. It is the absence of such a framework which has led to the problems mentioned above.

While the grain cropping system is arguably simpler than that of peppermint (perennial, complex harvesting procedure), the concept of the Crop Check management tool has been used to develop the management plan which forms the main part of this report.

The Crop Check system has evolved with the benefit of an enormous quantity of data gathered across all Australian production areas, a variety of cereal, seed and legume crops and over a lengthy period into a very focussed and precise system of management and documentation.

The 'Mint Manager' should be approached in the same fashion: it is a first draft, and as such lacks the focus of the grains system. To be properly implemented, it requires an annual review - collation of results across all producers, modification of the procedures and advice and refinement of the data collection requirements, all directed towards simplification.

This will require coordination by a person or organisation within the industry or associated with it, according to a strict timetable, and responsive to producer's feedback and commentary on the system as they find it.

An unstated, but implicit, objective of management plans such as this is to 'wean the producer off the handbook'. After several annual cycles of prescription, observation and response, the grower should develop a more intuitive approach to the health of the crop, and be less dependent on sample analysis, soil testing, etc.

Hopefully, by that time, the grower is persuaded of the value of the system and will remain committed to the documentation and review process - the sharing of experience and resetting of targets each year.
1. Literature Review

The following brief review is not intended to fully represent the scientific literature on the subject, but rather to summarise

- published information relevant to the commercial production of peppermint - agronomic recommendations and supporting reference material, and
- relevant institutional reports and some general commentary on crop monitoring etc.

Appended to this report are:
1) Mint Report 1998: Prof. Rob Clark
2) Copies of US extension service publications
3) Report of the harvest loss trial conducted at Uni of Tas 1993/4

1.1 Plant Material

To date the US industry mainstay remains the variety Black Mitcham, although this may include several phenotypically distinct selections, some of which are grown as named selections of the 'Black Mitcham' type, eg. Todd’s Mitcham, Murray Mitcham, and have demonstrated tolerance for 
Verticillium wilt disease. Nevertheless, of the approximately US$400,000 provided annually by the Mint Industry Research Council (MIRC) for mint research, about 50% is directed towards development of new varieties and propagation studies (Clark 1998: Appendix 1).


The purpose of these investigations is to assess performance of species and cultivars, breeding programs, propagation procedures and nurseries for a variety of parameters. These include growth in presence/absence of verticillium wilt, and measure hay yield, oil yield and quality and stand life. Material is grown in field plots and not surprisingly, each year seems to result in a different ranking of the available material.

The main issues for the researchers are the vigour of the material (with implications for winter survival in freezing conditions) and verticillium wilt resistance (determining the longevity of plantings).

Mitchell et al (1998) compared three methods for assessing the energy stored as carbohydrate in peppermint rhizomes. The capacity to grow vigorously in early spring will depend on the amount of such storage. Etiolated growth measurements, spectroscopy and determination of water and acid soluble sugars were compared with one another in samples collected during the growing season. With refinement, the same procedures might be suitable for assessing the vigour of propagation material prior to digging, enabling comparison of nursery stocks and refinement of the planting density at establishment.

For the Australian perspective, the key point is that all commercial mint production is based on material sourced from specialised propagators, not on material lifted from commercial fields after harvest and of unproven vigour and health status. Despite the obvious cost of this and short stand life due to progressive infection with verticillium wilt, mint producers have persisted with this approach and support several specialised mint propagators who draw their nuclear material on an annual basis from the authorised MIRC propagator Summit (Fort Collins, CO).

1.2 Nutrition
Nitrogen

The critical role of nitrogen in regulating peppermint dry matter and oil production is well documented in the scientific literature (Piccaglia *et al* 1993, Singh *et al*, 1992, Clark and Menary 1980).

Mitchell and Farris (1996) sought an optimum level of nitrogen application on Murray Mitcham mint over two years, and found that a total (soil inorganic + fertiliser) N of around 280kg/ha resulted in maximum oil yield and dry matter yields. This paper cited seven other reports over a long period (1957-93), and across a range of environments in the US and Tasmania, all of which found optimal rates between 180 and 270kg N/ha.

These results are incorporated in the extension guides of the Oregon State University Extension Service (Mitchell 1996) and University of Idaho College of Agriculture (Brown and LeBaron CIS 647) and Brown (CIS 714), the general conclusion of which is that an otherwise healthy peppermint crop will deliver optimum yields when a total of approximately 280 kg N per hectare is available. This includes soil N present at the commencement of the season, determined by pre-season soil testing, and assumes minimal losses through volatilisation, leaching etc.

Reference levels of soil nitrate and recommended split application schedules are provided by Mitchell (1996).

For the case of new peppermint crops, a 'ready reckoner' listing a variety of previous crops including grain and legumes and the probable nitrogen application rate required is provided in Brown and LeBaron (CIS647).

All three of these publications recommend monitoring N during the season, using periodic stem tissue or soil analysis, and caution against over-application of nitrate fertilisers in case of salt damage or leaching into groundwater or river systems.

Nitrate test procedures: Westcott and Wraith (1995) compared stem nitrate levels with leaf chlorophyll readings, attempting to correlate the two measurements to enable the use of a hand held chlorophyll meter to predict N requirements.

Wescott *et al* (1994) examined the validity of sap testing and dry matter analysis for monitoring soil N availability, finding that for peppermint, sap nitrate readings provided good agreement with their soil N uptake model. This was not the case with dry matter analysis of peppermint petioles.

Smersrud and Selker (1998) investigated factors influencing the validity of stem nitrate tests in peppermint (radiation effects, spatial and temporal variations, tissue type and the time in relation to soluble N application). They presented a method for field sampling which ensures reliable and consistent results and stressed the importance of reporting the method used.

Other Nutrients

Mitchell (1996) provided a guide to the requirements for phosphorous, potassium and sulphur using the soil test as a guide, and prescribed application rates for spring or autumn applications of each. Micronutrient applications (Mg, Zn, Fe, Cu, Bo) were not indicated for the production areas of eastern Oregon for which this publication is intended. Root zone pH levels of 5.8 or higher were regarded as satisfactory.

1.3 Pest and Disease Control
Insects and mites
US extension advice (Baird et al 1993), Baird et al (CIS 808) and Berry and Robinson, (1973) provide control recommendations for the main pests of mint fields in Idaho and Oregon.


Of interest to Australian producers are the grasshoppers, two spotted mite and cutworms, for which useful guides to recognition, treatment thresholds and management of beneficial predators are included in both the guide and the software package.

Nematodes

Ingham and Merrifield (1996) provide a detailed guide to nematode biology and management in peppermint. This report details feeding and reproductive behaviour of six groups of endo- and ectoparasitic nematodes known from US mint fields, relating growth cycles and levels of feeding activity to seasonal root growth cycles in healthy mint stands. Nematode damage is largely blamed for poor root development and stand decline and is predicted to be much worse on sandier soils.

Sampling methods are described and management strategies for pre- and post-plant nematode control are explained. Preplant fumigation, summer tillage and fallow, and choice of rootstock are given as options for preplant nematode control.

Postplant control methods employ Vydate (oxamyl) - a systemic nematistat to contain nematode feeding during the early spring root growth period. Nematodes will recover and resume normal activity later in the season, but establishment of a deep and vigorous root system early in the season enables the plant to tolerate the resulting higher midsummer and late season nematode populations.

The report addresses the problem of determining economic injury levels for an agent whose effects are highly dependent on other aspects of mint health and soil type.

Yahaya (1980) examined the pathogenicity of Phoma spp. isolates obtained from field soil at a site in Tasmania where peppermint was showing signs of root decline and reduced vigour. The fungus alone was not acting to invade root tissue, but when roots were inoculated by wounding, such as would occur during planting and harvesting operations or through the action of nematode feeding, growth was reduced and disease symptoms observed.

This thesis also cites literature references to the frequency of nematode infestations in American, Japanese, European and Russian mint plantations. Low levels of potentially pathogenic nematodes in soils of mint fields do not necessarily result in symptoms of decline. Detrimental effects only arise when some threshold nematode density is exceeded. Presence of some fungal agents in association with the nematode also appears to increase the liklihood of pathogenicity.

Disease

The most serious disease of peppermint in Australia is the mint rust - Puccinia menthae. The disease infects developing leaves and can cause severe leaf loss, particularly from the lower parts of the canopy. Infected leaves will drop readily, particularly when stressed by drought or infested by mites. Edwards et al (1998) report on environmental factors (temperature, leaf wetness and light intensity) affecting components of the life cycle of the fungus. Sporulation occurred over a wide temperature range (5 - 27°C), ‘summer spore’ (urediniospore) germination required at least 6hrs leaf wetness and lasted 4-6hrs at temperatures between 5 -25°C, but at 20°C growth of fungal structures began within a few hours of inoculation and after 24hrs, appressoria, substomatal vesicles and haustoria had been produced.
Essential Oils of Tasmania has produced a simple guide to the management of peppermint rust in Tasmanian fields.

Rust overwinters on mint stubble, begins to develop in spring and is usually first detected as yellow pustules on the undersides of leaves in early spring. The pustules release spores (aeciospores) as they mature. These spores are relatively few in number, but infect newly developing leaves causing the development of powdery brown pustules which in turn produce very large numbers of infectious spores, (urediniospores) initiating a cycle of reinfection which rapidly repeats itself over summer.

The Tasmanian guide targets the early aeciospore stage as the best opportunity for control of the disease before the formation of the rapidly self-replicating urediniospore stage. Small numbers of spores, cooler conditions and a more open canopy enable good chemical control of the disease at this point. The only registered fungicide available is Tilt EC (propaconazole), which is applied as two or three applications at 14 day intervals from the time of first detection of the infection in spring. Coverage and penetration of the canopy are stressed as is the importance of timely detection and response.

1.4 Irrigation

Clark and Menary (1980) obtained the highest yield of oil from crops irrigated with 50mm per week (2 applications) during the second half of the growing season and found that 25mm/wk in the first half of the season was adequate, but detected water stress (a degree of stomatal closure) at this level of irrigation during the second half of the season. High levels of N (ca 200kg/ha) were required to realise the benefit of increased irrigation, while increased N above this gave yield improvement only under the highest irrigation treatment.

Mitchell (1997) provides a straightforward extension note which explains the concept of Kc, a crop coefficient used to predict water use as the crop matures. This approach employs a locally available temperature coefficient - (Growing Degree Days Base 5C) to predict daily water use and irrigation requirements. Mitchell (1997) states that irrigation should commence when 35% of available water has been used. This approach is based on work reported in Mitchell and Yang (1998), a 4 year investigation of peppermint water use functions and crop evapotranspiration.

A simple guide to operating a 'chequebook' scheduling system is published by University of Nebraska Cooperative Extension (Yonts and Klocke 1997), and explains the principles behind the use of soil moisture measurements and crop water use. More background on Crop Water Use and Evapotranspiration as management tools is provided by Klocke et al in another publication by the same group (Klocke et al 1996).

The importance of post-harvest irrigation for maintaining carbohydrate reserves and survival through winter is stressed in Mitchell (1997), in which a comparison of between three and ten post harvest irrigations showed a benefit from increased application of approximately 12kg/ha in the subsequent crop.

1.5 Harvest Management


They found that vigorous growth led to lodging by mid January, flower buds were visible by mid January and full bloom was observed by the third week of February. Leaf development stopped when buds appeared and the laterals (arising after lodging) flowered later.
Peak herbage yield was 10.7t fresh weight/ha at early flower bud formation, and peak oil yield of 114kg/ha occurred two to three weeks later.

Clark and Menary (1979) compared harvest dates across four density treatments. The three higher density treatments (20, 30, 40 plants/m²) were indistinguishable after the first harvest. Yield of oil increased from harvest at 3 Jan to 7 Feb for the lowest density (10 plants/m²), but reached maximum by 13 Jan for the higher densities (>=30/m²) and remained so - approx 55kg/ha.

Court et al (1993) working with Black Mitcham in southern Ontario examined the effect of harvest date on oil yield and quality. Maximum yield was obtained when terminal flowering was complete and lateral branches in full bloom, while acceptable menthol levels were obtained during harvest periods coinciding with maximum yield of oil.

Oil yield was consistently about 1.4% of DM, falling in autumn with leaf loss due to frost. Hay yields rose to a maximum of about 4.3t/ha dry matter in the first and second years and 3.5t/ha dry matter in the third year.

Clark and Menary (1984) investigated the use of a double harvest to increase yield of saleable oil. The first harvest (at max. yield of 70kg/ha, 7 Jan.) produced an 'immature' oil containing only 39% menthol. A second harvest (also at a yield of 70kg/ha on 24 March yielded oil at 50% menthol, and high levels of menthofuran due to short days and advanced flowering.

An investigation conducted in Tasmania in 1993/94 revealed substantial losses of oil and herbage during harvest and identified the major problem as loss of broken, oil rich leaf during collection. Since the leaf contains most of the oil, but dries out more rapidly than stem, any loss of leaf will reduce the percentage oil in the distillation vessel, simultaneously increasing the average moisture content. It was this observation which enabled quantification of the losses in this case.

In that investigation, despite relatively favourable drying conditions, almost a third of the oil found in the standing herb crop was not recovered at the still. Sampling and measurements taken at each stage of the process showed that of 9.8g of oil/m² in the green crop, 0.15g remained in the stubble, 1.7g was lost during wilting and collection and 1.3g remained on the ground in uncollected herb, so that only 6.7g of oil was delivered into the vat. This result was confirmed in the commercial harvest of the same field 21% of dry matter, containing 27% of the oil was not collected.

Further losses with incomplete distillation and inadequate separation were also detected. A copy of the report of this investigation is included (Appendix 1).

Work by the mint group at Montana State University reported in their annual research report (MSU 1997) describes changes in 'mint hay' yield (and associated oil yield) of harvests taken weekly from early August (cf early February) when bloom commences. Oil quality did not meet the required composition until late September, by which time yield had begun to decline markedly due to lodging, leaf drop and senescence.

Ames and Matthews (1968) document field distillation practices and the basic parameters of still design and operation used in the production of (mainly) tropical and subtropical oils.

The only detailed investigation of the field engineering involved in distillation remains that reported by Hughes (1952), a comprehensive report in which still and separator design were given special attention.

**Sampling for Oil Yield and Composition**

Mitchell and Crowe (1996) compared mini ‘research’ stills with large commercial distilleries for results of oil composition and yield. They compared 4-6kg samples taken from windrows or direct
harvested, then air dried and distilled in a ‘mini-still’ with the ‘whole field’ result from a commercial still.

Despite care with sampling method, and relatively large numbers of samples (38 and 59 x 3-6kg from a 0.8ha field in 1992 & 93), oil composition predicted from samples was not very consistent with the commercial result in either year. The authors warn that use of mini distillations to predict oil quality and to select breeding lines or harvest date may be unreliable.

The mini distillations did, however provide good indication of oil yield, though the coefficient of variation was higher for dry matter than for oil in both seasons.

The general finding in the above report has not been tested in the Australian context, and indeed, the Tasmanian experience has been that it is yield, rather than composition which is difficult to predict by sampling, since crop maturity tends to be uniform over a field while density can vary greatly.

1.6 General

Victorian Peppermint Growers Manual

A production manual for peppermint funded by Austrade, and prepared by Macarthur Consulting, Victoria was provided to Victorian peppermint growers in June 1995.

This manual presents an overview of mint production in the US, Victoria and Tasmania and reviews the resources (natural and industrial) available to Australian mint producers.

It then goes on to develop what is called a 'Best Practice' procedure for mint production, incorporating US and Australian experience in management plans and flowcharts, supported by detailed tables and other summarised information relating to production inputs.

Despite presenting itself as a 'Manual' for producers, the report serves best as 'situation analysis' or 'resource assessment', and has not been used extensively by Victorian producers to modify production methods or benchmark their performance.

The TopCrop Model

Finally, it is worthwhile to briefly outline the crop management procedure developed for the Australian grains industry and referred to broadly as the 'Top Crop' system.

This is a constantly evolving crop management system which incorporates:
1) production guidance - agronomic advice and management procedures
2) a recording system for minimum essential crop observation and measurement
3) a system for benchmarking performance on-farm, across seasons and regions.

With each succeeding season, collation of data generated by the system enables refinement of the guidance information, adjustment of benchmarks and better understanding of the effects of management and edaphic factors on yields, etc.

Most important in the grain industry is the third component of the system which allows planning for production and sales on a national level, with part of the monitoring directed towards yield prediction as the season progresses.

The ‘Top Crop’ system depends upon a system of 'Checkpoints'. These are critical points in the production cycle at which attention to detail can maximise yield potential, and careful measurement of a few parameters can give excellent predictors of performance and crop requirements.
As the system has evolved, the complexity and detail required of these ‘Checkpoints’ has diminished, resulting in a lesser requirement for record keeping and data collection without compromising the effectiveness of the tool.
1.7 References


PNW (182) A guide to Peppermint Insect and Mite Identification and Management. *PNW 182. Oregon State University, OR*


Hughes A D (1952) Improvements in Field Distillation of Peppermint Oil. *Station Bulletin 525 Agricultural Experiment Station, Oregon State College, Corvallis, OR*


Mitchell A R (1996) Peppermint and Spearmint (East of Cascades) FG 69 *Oregon State University Extension Service, Corvallis OR*


Montana Mint Research Reports (1992- 1997) Reports for the Northwestern and Western Agricultural Research Centres: Montana State University Agricultural Experiment Station


Yonts C D and Klocke N L (1997) Irrigation Scheduling Using crop water use data Nebguide G85-753-A, University of Nebraska - Lincoln (www.ianr.unl.edu/pubs/irrigation/g753.htm

2.: Industry Assessment

2.1: Historical Performance and Statistics

Peppermint production in Tasmania underwent something of a renaissance in the early - mid 1980's, having commenced more than ten years previously. Problems of peppermint rust, and low yields had restricted expansion of production. A more intensive management regime, incorporating chemical control of rust, nursery grown propagation material and increased levels of nitrogen and irrigation application saw yields recorded from 85 - 95 kg/ha on several 'demonstration' plots around the state.

Expansion of production area, construction of several new distillation plants and concomitant establishment of a fennel oil industry saw total area under peppermint increase to more than 200ha by 1988.

The charts below, Figures 2.1 and 2.2 summarise the development of the Tasmanian industry and reveal several problems which remain with the industry to the present.

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Fig 2.1: Tasmanian Peppermint Oil Yields 1986 - 1998
A large proportion of small growers with little commitment to the industry, statewide average yields not exceeding 50kg/ha until the last two years, and in recent years declining overall production have combined to undermine the early enthusiasm of committed growers to the industry. This trend has also been accelerated by the availability of several alternative medium to broadacre crops (pyrethrum, poppies, peas) with very competitive gross margins, a high level of external management and similar requirements for land and irrigation.

Nevertheless, several long term producers remain in the industry, for example B W Brain and Sons, at Ouse who were among the original producers and still have 22ha under peppermint, and are expecting to expand to 30ha during 1999. The mean area/grower in 1999 includes a 2ha nursery plot, without which the mean area/grower would have been 14ha.

### 2.2: Industry Potential

Constraints to production of peppermint at present appear to differ between Victoria and Tasmania.

The Tasmanian industry (producers, still operators, EOT) and Victorian producers have both identified oil yield as the single 'unifying' problem for the industry. None of the Australian peppermint producers have ever managed to attain the yields often claimed by US producers, in the region of 110+kg/ha, and it appears that consistent yields of 75kg+/ha would be regarded as satisfactory to support a sustainable industry.
In Tasmania historical yields of less than 60kg/ha makes it difficult for peppermint to compete for suitable irrigated land with the available alternative crops. Specialised infrastructure (distillation and transport facilities, planting equipment, post-harvest blending and analysis) is all available and very under-utilised. Plant material of good quality is available sufficient to establish up to 100ha in the vicinity of distillation plants in two regions this year (1999) and there remains a reasonable level of experience and familiarity with the crop among potential producers and industry support personnel to quickly revitalise production if growers were convinced of potential returns. Essential Oils of Tasmania remains optimistic of selling up to 10 tonne of oil at prices equivalent to those of 1998/9.

In Victoria, the main scope for industry expansion rests with the VicMint operation at Moyhu, where very significant capital investment in land and infrastructure has been undertaken specifically for mint production.

Expansion of the Moyhu project continues into 1999, while the management continues to attempt to resolve several pressing agronomic problems. The present expansion will result in a total area of approximately 250ha, and if yield targets are met this will generate more than 15 tonnes of oil. To date the area has not yet returned this yield, although it is clear that the reasons identified for this are technically soluble, and there appears no reason not to aim for at least 70kg/ha in the future.

Note re: Plant Material

The US experience presented in the MSU reports from 1995-7 is that the source of plant material influences the production of mint ‘hay’ and oil in some seasons.

In those reports Welty and his colleagues compare stolons, meristem and nodal derived Black Mitcham from a number of regions, nurseries and selections, from 1995 - 7 and find that the result is a complex picture - they use hay yield (dw/ha) and oil yield (kg/ha) as their measures and don't show statistics for % yield. These experiments are often combined with harvest date, wilt infection and other comparisons and are sometimes hard to interpret. In any case, the majority of US peppermint plantations are established from nursery grown mint, not by the method usually employed in Australian production - stolon propagation from commercially grown and harvested fields. The imperative for US producers is the need to minimise pest and disease buildup in their fields, and in many areas, crop cycles of 5 -7 years are the norm.

US production is based on plant material generated through a certification program and on-farm nurseries. Farmers buy 7 - 10000 nuclear plants as plugs or open rooted plants for about US$50c and grow these on in an unharvested nursery from which they multiply approximately 15 times into a production site.

There is at least some evidence in US that the “mother blocks” of peppermint which are held at Fort Collins in CO by the Mint Industry Research Council authorised propagator ( Summit) are either not genetically uniform or have varying levels of a “factor” which contributes to phenotypic variation (mostly vigour). For example, the Summit material released in 1992 is thought to be more vigorous and is especially sought by one propagator of stolons in Idaho, who multiplies and produces stolons which are then sold to mint farmers who don’t wish to do the original propagation. A very high proportion of farmers choose this option and there is a concern that the more vigorous type might be producing more stolons and hay but less oil.

During 1997-8, a project was initiated in Tasmania in which clean tip cuttings were taken from a commercial field (Parsons, Hamilton) in spring, grown in speedling plugs under nursery conditions then planted into a commercial field nursery in October. Here it was subjected to close and careful management, with regular irrigation and nitrogen applications, rust control etc. to ensure vigorous growth throughout the summer.
This material was lifted and moved in winter 1998 to two clean farm sites (3ha in total) in the Derwent and Fingal River Valleys, where it was grown-on for multiplication to commercial areas (30ha) in autumn/winter 1999. Once again, these ‘farm nurseries’ were planted and monitored carefully, with the result that the southern plot produced a dense mat of stolons and vigorous top growth, while the Fingal plot, after an initial setback with cutworms prior to emergence, produced good stolon and top growth over most of the area. Both sites were harvested in February 1999, and the Derwent Valley site was used to establish approximately 10ha of new planting in an adjacent area.

Simultaneously, meristem material, originating from the same commercial field (Parsons) was used to initiate a set of tissue cultured material at the University of Tasmania. This material was planted out in a field nursery in late 1998 and transferred to a small commercial site in winter 1999. A report on this part of the work is included in Appendix 1.

2.3: Peppermint Production and Trial Results 1997-1999

Following is a summary of the trials and observations conducted on commercial crops during the two years of the project. Limited data collection and sampling was undertaken, together with collection of statistics relating to the production performance of several mint growing operations.

As the investigation was intended to identify those issues presently constraining production levels in the Australian industry, presentation of trial results has been confined to those issues which

- provide benchmarks against which commercial production practices may be measured,
- identify agronomic risks and threats to viable production and
- reveal current practices which may be outdated, or based on misleading information

2.3.1: 1997/98:

Yields:

Average yield for the Tasmanian production was 58kg/ha, on approximately 35ha. In Victoria, an average yield per property was reported of 53kg/ha, although the overall average (total production /total area) would have been very much lower (40 kg/ha).

The inadequate soil moisture conditions in the large King Valley (Moyhu) plantation, combined with patchy establishment and difficulty in collecting the light crop resulted in a yield of 32.5kg/ha from 88 of the 100ha planted. Peter Nankervis was reported as having produced 74kg/ha on 80ha, the best result among the other growers in this season.

In Tasmania, in the fields examined, good quadrat yields (the equivalent of 6.5 - 7t dry herbage/ha) were obtained in the vicinity of irrigator paths. This might be expected to deliver 90-105kg oil/ha (at typical oil percentages in dry matter of about 1.4-1.5%). However average yields over the whole field at completion of harvest were in the order of 55 - 60kg/ha, resulting from the unevenness of the herbage and losses occurring during harvest.

Irrigation

During 1997/8 a soil moisture monitoring program was undertaken at Parsons, to try to provide guidance for the irrigation manager. The key observation to emerge was that, while irrigation levels and rainfall provided adequate soil moisture in the vicinity of the monitoring tubes, the vigour of herbage growth across the fields reflected closely the observed uneven distribution of irrigation water (and nitrogen, after Christmas) delivered by the irrigators.

In Victoria, 180ML of irrigation water was delivered in 11 irrigation passes over 88ha (one every 8-9 days) - effectively 18.5mm/pass delivered at the nozzle, (irrigator malfunction was a contributing factor in the low application rate). Even assuming 100% efficiency (80-90% is more likely for irrigation during the day in warm weather), this falls well short of the 'conventional wisdom' suggesting about 25mm water/week for peppermint in Tasmania. In addition to this, evidence of
localised wet and dry patches suggested that infiltration may be a problem with the soil type at Moyhu.

Establishing a starting date for irrigation is particularly important when the capacity of the system to deliver sufficient water may be marginal. In this case it seems likely that the upper soil layers may have been in serious water deficit even before irrigation commenced in mid November.

**Nitrogen Sampling**

As the first stage in an effort to manage the application of nitrogenous fertilisers, a comparison of soil and tissue nitrate analysis was conducted on samples collected from the two Parsons paddocks and the Victorian planting at Moyhu. Sap nitrate testing offers the advantage of being commercially available and providing a rapid result, provided the results can be correctly interpreted and shown to relate well to tissue levels.

The procedures used are described in Appendix 2, and the key results shown in the Figures 2.3 - 2.5.

A comparison of laboratory whole tissue analysis, sap nitrate analysis and the topsoil testing for nitrogen and nitrate levels (Fig 2.3) shows the relationships between the methods. Whole tissue and sap nitrate procedures showed a weak linear relationship, as shown in the first figure. On the other hand, topsoil nitrate concentrations, as might be expected, showed strong, non-linear relationships with the tissue procedures. Interestingly, topsoil N concentrations above about 1mM determined by this procedure had very little effect on levels of tissue nitrogen.
Figure 2.3: Comparison of nitrogen test procedures used in Tasmanian and Victorian mint fields, Nov 1997 Feb 1998. Soil measurements refer to soil samples taken from 0 - 150mm.

Regarding sap nitrate results for the whole season, (Figure 2.4 ) all three sites followed a pattern typically reported for peppermint in US literature - highest prior to the period of ‘grand growth’ and falling steadily as the plant approaches flowering and maturity. Significantly the very high levels of soil nitrate in the Victorian samples did not prevent sap nitrate levels from dropping sharply prior to harvest, when the plants were experiencing severe water stress.
Soil samples were taken at three depths (0-150, 150-300 and 300-500mm) and the effects of nitrate application on three of the measured parameters can be seen in the charts below (Figure 2.5). Note particularly that the levels of soil nitrate present in the Moyhu topsoil samples were more than ten times those at the Parsons site, that pH remained below 4.5 throughout at Moyhu, and conductivity rose sharply towards the end of the season at this site. The implication here is that high initial levels of soil nitrate, supplemented by fertiliser additions and not drawn down by the crop have contributed to salting and acidification of the top 150mm of soil.
Lastly, for the Tasmanian sites, three 0.25m$^2$ quadrat samples of fresh stem material were collected from within each field at each date, and subsamples of ten shoots per quadrat were used to estimate dry matter yield, ratio of leaf to stem (fresh weight) and the number of leaf pairs remaining on the stem. These results are shown in the charts below in Fig 2.6. These results confirm observations in the field that

- dry matter yield in the established crop reached a maximum in early January, after which leaf loss began to erode the benefits of continued stem and leaf production. This was not so apparent in the rejuvenated crop which continued to increase yield of herbage up to harvest.
- leaf loss from lower nodes progressively reduced the proportion of leaf to stem, most seriously in the established crop.
**Fig 2.6: Herbage results for triplicate quadrat samples gathered from Parsons 'Lucerne Paddock', 1997 - 1998**

**Harvest Procedures**

In both states areas for improvement were identified during the 1998 harvesting operation, despite an apparent understanding of the broad objectives and particular requirements by most people concerned. Without reviewing these in specific detail, it should be noted that difficulties were observed in several areas:

- inefficient herb collection due to a failure to obtain a smooth finish to fields at planting
- prevention of damage to mown and unmown herb by traffic
- mowing/collection of lodged herb or light and uneven crops
- matching mowing rate to collection rate and regulating crop moisture
- establishing appropriate chain of responsibility for starting and stopping harvest
- harvest losses through machinery design & moisture management
- mechanical problems with old vats
- inadequate control or monitoring of condensation/separation temperatures
- no detection of distillate concentration, separator bypass or vat yields
- possible incomplete exhaustion of vats
All of the above have the potential to detrimentally effect yield of oil - particularly serious because the oil has been brought to the brink of collection (and even in some cases delivered to the still and distilled from the herbage!) before these losses occur.

2.3.2: 1998 / 99 Season

The 1998/9 season was characterised in Tasmania by unusually warm conditions. Data collected by Bernard Brain shows that the 20 year average mean monthly temperature for December is 14.5°C while the same figure for December 1998 was 15.2°C. Similarly January (16.5/17.5) and February (16.5/17.8) were also warmer than the average for that period. The increased average in each case was largely caused by higher than average night-time minima.

Secondly, production areas received unusually large falls of rain leading up to harvest in mid to late February. Brains recorded a total of 95mm in three large falls to 24/2, the largest they have recorded for the month, and following only one fall of more than 5mm after 28/11.

By contrast, Victorian conditions prior to and during the harvest were very hot and dry.

Yields
The average yield of Tasmanian mint production areas was 59.7kg/ha, including the yield from two small nursery plots. One field of 6ha was not harvested due to weed problems and an (unsuccessful) attempt was made to take a second cut at two sites.

Data for Victoria show that for the large (220ha) site at Moyhu, an average yield was obtained around 32.5kg/ha. On small parts of this crop (where irrigation approached ‘adequate’), yields of 62kg/ha were recorded with a best result on a 4ha portion of 75kg/ha. A chronic water shortage across the whole area limited overall growth and acute shortages during January together with some rust infection appears to have caused major loss of mature leaf at this time.

A single crop at Myrtleford returned 78kg/ha, while the Nankervis crops at Corryong were severely affected by flooding during spring, with the result that the major part of this area yielded only 48kg/ha. This crop averaged 70kg/ha in 1998.

Crop Agronomy
1) Irrigation
Use of the 'Gopher' moisture probe was extended to include the Moyhu plantation and Brain's Willow paddock (soil and sap samples were also gathered from the vicinity of the probe tube sites). The objectives during this season were to;
• demonstrate the monitoring of soil moisture in the whole root zone
• aid in determining a 'start date' for irrigation
• estimate effective rooting depth in each soil type
• determine typical 'crop factors' and daily water use for peppermint

Summed histographs for the root zone in Parsons (deep black clay) and Brains (loam over clay at 300mm - duplex type soil) for the 1998/9 growing season are shown at Figures 2.7a and 2.7b respectively.

The Parsons site shows the consequences of positioning a tube between two overlapping irrigation runs, so that for most of the season the root zone remained close to field capacity. Tubes located on the outer edge of the irrigator runs frequently showed excessive dryness.

More typical of all the other sites is the 'Brain 2' plot, in which total available water in the root zone fluctuated more widely, and irrigation did not commence until well after the first drying cycle had
reduced moisture levels to about 50% of field capacity. In this case, the operator was able to retrieve the situation with a heavy irrigation.

At Moyhu, the equivalent results for a root zone 300mm deep (refill point 72mm water) showed moisture levels fluctuating between 12 and 40mm water throughout the month of January - clearly in serious deficit during a critical period. Readings taken in early to mid-November showed the root zone already showing a moisture deficit, warning that irrigation should have been underway by this time.

Figure 2.7a: Summed Histograph Gopher Soil Moisture Readings: 0 - 400mm depth, Parsons
Figure 2.7 b: Summed Histogram Gopher Soil Moisture Readings: 0 - 300mm depth, Brains.
The probe measurements for the Brain site are displayed as 'multi-slice' graph in Fig. 2.8, (above) indicates an effective root zone of 300mm in the duplex soil. This is recognised as the depth beyond which negligible water depletion occurs even during deep drying cycles (eg 7/12 - 18/12). A similar observation was used in the choice of 400mm as a suitable depth for summation of available water at the Parsons site.
Use of a ‘water budget’ for irrigation scheduling (described in US literature as a 'chequebook' system) incorporates an estimate for the rate of water consumption: daily water use. This can be determined from probe measurements by calculating total water used during a drying cycle, correcting for rainfall or irrigation and dividing by the number of days.

At Brain 2, in Fig. 2.7a, the water available in the root zone fell between 28/12 and 16/1 by 63mm, despite the addition of 50mm irrigation and 3mm rainfall. Total water use, then, was 106mm over a period of 19 days - a daily water use of 5.6mm. A similar calculation for the period 5/12 - 15/12 results in a daily water use of 5.7mm.

At Moyhu, using the January data mentioned above, a water use of only 3mm per day was calculated for three prolonged drying cycles. This very low usage rate confirms that the crop was probably seriously stressed at these soil moisture levels. In the very hot conditions during January a water use of more than 6mm per day would have quite normal, equating to a usage of about 50mm per 8-9 day cycle.

Similarly, crop water use can be compared with pan evaporation data to estimate a 'crop factor'. This factor (the ratio of crop water use to open pan evaporation) will vary as the crop matures, and will be sensitive to extremes of temperature and windspeed, as an indicative figure, the open pan evaporation at the Brain site between 28/12 and 16/1 was recorded as 109mm, suggesting a 'crop factor' of 0.97.

A critical issue at all sites was the effectiveness of the irrigation application.

The irregular watering pattern of gun irrigators is clearly shown in the chart below (Fig. 2.9), depicting the result of sampling across the irrigator path during a moderate crosswind. The grower in this case assumed that he was applying approximately 32mm per pass, based on specifications for the gun itself.

![Irrigation pattern - Irrigator at 32m (Parsons irrigator, east-west, easterly conditions)](image)

**Fig 2.9: Delivery from gun irrigator during single irrigation pass in moderate cross-wind. Irrigator positioned at arrow.**

At Moyhu, notwithstanding difficulties with the reliability of the lateral move system used, a key concern remains the rate of infiltration of water delivered to the soil surface. Ponding and localised dry areas both contribute to stress patterns in the mint plant, and the relatively shallow root zone could not have provided an adequate buffer for the long irrigation cycles dictated by the system, had the crop been growing vigorously.

2) Nitrogen

A pilot nitrogen management plan was devised in which soil nitrate N and sap nitrate levels would be sampled systematically through the 1998/9 growing season both in Tasmania and the King Valley, Victoria. The intention was to use the analyses to regulate nitrogenous fertiliser application, (the ‘demand feeding’ model) and attempt to minimise the possibility of over-application.
As shown in the table below, (adapted from the US extension literature for peppermint production), a total soil nitrate-N supply of approximately 290kg/ha is obtained by topping-up the 'native' levels detected in the soil during the winter, in two or more applications during the growing season. The aim is to maintain levels of available nitrate-N at approximately 100 - 150kg/ha during this time. Splitting the application is advised as this ensures a more measured delivery and reduces the possibility of short term acidification or salt damage to the growing mint.

<table>
<thead>
<tr>
<th>Winter Soil Test : NO₃ - N: kg/ha</th>
<th>Early Spring: Sept - Oct (kg N/ha)</th>
<th>Summer : Nov - Dec.(kg N/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>90</td>
<td>195</td>
</tr>
<tr>
<td>45</td>
<td>45</td>
<td>195</td>
</tr>
<tr>
<td>90</td>
<td>45</td>
<td>150</td>
</tr>
<tr>
<td>140</td>
<td>0</td>
<td>150</td>
</tr>
<tr>
<td>&gt;140</td>
<td>0</td>
<td>retest soil N</td>
</tr>
</tbody>
</table>

*University of Idaho, Extension Series CIS 647*

In Tasmania, the Parsons site (Figure 2.10a) commenced the season with adequate levels of soil nitrate. Modest applications totalling about 100kg of nitrogen, kept soil and sap nitrate levels within the required range. This crop maintained vigorous growth throughout, suffering, if anything, an overabundance of herbage where irrigation was in luxury supply.

The Brain Site, (Figure 2.10b) on the other hand exhibited low levels of soil nitrate N and associated low sap levels in mid-spring. Two applications of ammonium nitrate in November were used to...
address this problem and the effect was obvious. A total of about 170kg of N were applied during the growing season.

Figure 2.10b: Soil and Sap nitrate results (means) for Brain peppermint site. Arrows show date and quantity (kg) of N added as ammonium nitrate.

Results for the Victorian site at Moyhu were dramatic (Figure 2.10c). Only two reliable results for sap nitrate were obtained, the first on 22nd December showed adequate levels of nitrate in the sap, the second in mid January indicated low levels of the same parameter. Since water shortages were a continual feature of this crop, sap nitrate concentrations are difficult to interpret and probably of little use in this context.
Figure 2.10c: Soil and Sap nitrate results (means) for Moyhu peppermint

The first of four soil samples, taken in late November, showed extremely high levels of nitrate N (>200kg/ha) at both Moyhu 1 and 2, after one application of 200kg urea, in early November. These levels rose still further, >1000kg N/ha after two more applications (200 and 180kg/ha of urea) in late November and mid December. Disbelief at the analysing laboratory prompted an additional set of samples which gave significantly lower results: 4-600kg/ha N, more consistent with the application rates, but still four to six times higher than published recommendations. The difference was attributed to problems with the handling and mailing of samples during the hot weather in late January. (Note: Laboratory results for the nitrate sampling are included at Appendix 2 of this report)

Herbage production in both these crops was limited by the availability of soil moisture, and nitrate uptake during the sampling period would have been low. **Results of this scale suggest certain acidification of the soil and potential salt damage to the crop.**

3) Herbage

While no formal measurements of herbage production are reported here for the 98/9 crop, several important observations were made towards the end of the season, which have led to some of the focus in the 'Mint Manager' strategy on the last part of the growing season, characterised as a 'vulnerable fortnight'.

In the Parsons crop in which the nitrate measurements were collected, vigorous growth and the resulting volume of the crop in areas where irrigation was adequate to 'luxury' resulted in lodging and, towards the end of January, significant losses occurred due to senescence of lower leaves.
This observation (that these levels of irrigation and nitrogen combined resulted in a vigorous and
difficult to manage crop) provided a 'benchmark' for tissue and soil nitrate levels in the situation where
water is not limiting.

Elsewhere in the field, where irrigation application was less reliable, crop growth was suppressed
despite the same rates of nitrogen application, soil types, crop density etc.
In the perfect situation, some middle ground should be sought - adequate nitrate and adequate soil
moisture.

Several problems combined during the last days before collection to reduce the final yield of oil:
• Heavy rains and overcast weather during the planned harvest period (early February) delayed
  harvest by almost two weeks.
• Part of the crop was mown prior to one of the rain periods and remained on the ground for around
  a week before being collected.
• Rust, which was evident by the end of January, benefitted from the wet conditions and the delay in
  harvest to spread rapidly and with devastating results in some parts of the crop.

At Moyhu, in late January, about two weeks before harvest commenced, there was evidence of
substantial leaf loss on large parts of the crop, despite the better irrigated areas having produced good
stem growth and large numbers of nodes. This loss appeared most likely due to a combination of an
earlier rust infestation an the more recent severe dry conditions

These examples demonstrate the problem of vulnerability of crops and managers to external factors
during the last critical stages of production. This vulnerability applies equally to vigorous and poorly
grown crops, but for different reasons.

4) Harvest Procedures

a) Monitoring:
An effort was made to trial a data collection protocol with the Moyhu harvest, using simple datasheets
at the still and in the field.
Data from the sheets was to be collated on a daily basis, to enable constant monitoring of area yields,
mower, harvester, transport and boiler performance, and to allow checkback procedures in the case
that expectations were not met.
This approach works best when oversight is provided by management, and pre-harvest targets are
explicit.

The trial was drafted immediately before harvest, and several issues were not addressed in sufficient
detail in planning the recording system - for example, the value of temperature measurements on
distillate and separation water, and in monitoring boiler performance through gas consumption and
distillate flow rates etc were probably not put strongly enough.
Similarly, there was no provision on the forms to allow for measurement of distillate enrichment
during the distillation period on a small number of distillations.
Routine checks of herb moisture content and testing of the marc and separator outflows for oil
residues would also have been useful and could have been included on the sheets.

All this information is routinely collected at many stills, and, with the benefit of rapid computer
analysis can quickly identify opportunities for improved efficiency or warn of sudden changes in
harvest performance.

In this trial, sheets relating only to the first few days of harvest were available. Nevertheless, from the
small amount of information available, some simple graphical comparisons of several parameters was
possible, as shown in the charts (below), revealing some interesting trends.
(Note that these results have been presented without statistical analysis, only to illustrate the opportunity for analysis of the harvest when relatively simple data is collected at the time. Results are tabulated in detail in Appendix 2B)

Higher average oil flows (vat yield/ distillation time) were clearly associated with better yielding crops, implying higher proportions of leaf vs stem in those crops, an inference which is reinforced by the positive relationship between vat yield and yield per hectare.

The datasheets also enable a comparison of vats for mean yields and flow rates, which will help detect problems with filling, steam distribution and so on, particularly if supplemented by gross weight readings on a regular basis.

In this case, the four vats (trailers) gave the yield results listed in the table below, and using the estimate of 8 tonnes herbage per vat provided by VicMint, we appear to be recovering approximately 0.4% oil of wilted weight.

<table>
<thead>
<tr>
<th>Vat No</th>
<th>Oil Flow Rate (kg/min)</th>
<th>Vat Yield (kg oil)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Std dev'n</td>
</tr>
<tr>
<td>1</td>
<td>0.33</td>
<td>0.055</td>
</tr>
<tr>
<td>2</td>
<td>0.34</td>
<td>0.027</td>
</tr>
<tr>
<td>3</td>
<td>0.33</td>
<td>0.049</td>
</tr>
<tr>
<td>4</td>
<td>0.34</td>
<td>0.048</td>
</tr>
</tbody>
</table>

This is an extremely low result, mint oil percentage in fully dry herb is typically in the order of 1.1 - 1.3%, and in mint at 45-55% dry matter (ideal for harvest) we expect about 0.65% oil.

Possible explanations include:
- poor leaf to stem ratio in the harvested herb
- high moisture contents / inadequate wilting
- incompletely filled vats
- high level of oil loss prior to collection
- incomplete recovery by distillation.
Without more detail it is impossible to conclude which of the above might be contributing to the result, and this is an area in which closer monitoring of procedures is clearly warranted.

b) Harvest Losses
As noted during the 97/98 season, and determined in earlier work (see Appendix 1), the potential for undetected losses during harvest is very large, possibly up to 30% of the oil present in the standing crop in some instances comprising losses at all stages from mowing to distillation. A large part of this potential problem resides in the management of the wilting process - judgement of the balance between too green and brittle-dry.

With heavy crops, such as those gathered in the Tasmanian fields this year, there is considerable leeway, since mown windrows dry more slowly, and are less prone to 'teasing out' during collection. Furthermore, where high pressure steam is available, collection can err on the side of 'green', resulting in less leaf shatter and gland loss.

Light standing crops of mint, however, or crops in which much of the leaf has been lost due to environmental stresses prior to mowing are most prone to harvest losses. Rapid drying of thin or stalky windrows provides no buffer against unexpected hot or windy conditions, making it difficult to match the rates of mowing and collection.

5) Distillation

While there was very little input during this project on the issues surrounding distillation design, it is important to comment on two concerns raised in discussions at several operating distillation plants.

1) Separator design.
In the early 1950’s a lengthy investigation of the separation of mint oil and water using glass equipment and oil soluble dyes concluded that it was essential to interpose a baffle between the distillate entry and water outlets of separator tanks.

The key observation was that for short periods during each distillation, (the time of largest temperature discrepancy between separator water and distillate) substantial quantities of oil passed directly across the tank and out with the wastewater. This loss usually only occurs for short periods and is difficult to detect or is quickly diluted by subsequent flows.

The resulting design of tank ensured that the oil/ water mixture was required to move up, then down before arriving at the outflow, overcoming problems of temperature differential, and accounting for the rate of vertical movement of oil drops in water.

The important point here is that the distillate arriving during the first few minutes of a mint run can contain 12 - 15% by volume of oil, but is often 10 -15°C below the optimum temperature for separation, so that direct discharge of even a small proportion of distillate has serious implications for yield and composition (refer also Appendix 2).

While temperature measurement of cooling water and separator tank water gives a good general guide for distillation operation it does not warn of short term changes in disillate temperature resulting from very low or high flows at different times during the run.

2) Distillate Sampling.
A facility for trapping distillate as it leaves the condenser provides an important opportunity to monitor two key issues:

a) oil flow profile: confirmation of the profile of oil delivery during a distillation directly demonstrates the evenness of packing of the vats and the appropriateness of the steam flow (with opportunities for reducing it as the distillation proceeds), and allows operators to better understand the nature of the distillation process.
b) **cooking time**: while in general it is convenient to nominate an *optimum period* for distillation, this should only be done after the range of delivery rates for herb of different moisture contents has been determined, by determining the flow profile for a number of herb qualities.

More flexible is the *spot sample* approach, in which a predetermined percentage ‘oil in distillate’ has been nominated as the economic cutoff point, and this is confirmed for every distillation - a 30 sec. task which allows documentation of another performance measure.
3. A Checkpoint Model for Mint Managers

A Working Manual for Farm Managers and Enterprise Operators

3.1 Introduction

Peppermint oil production in Australia has long failed to meet the expectations of producers and researchers who look to US industry for productivity benchmarks. There is plenty of historical evidence of producers in all the mint growing areas in Tasmania and Victoria, meeting or exceeding these 'benchmarks', in some years, or in some fields. What is lacking is a consistent result.

Reasons for this are many and complicated, but at an agronomic level, it is clear that in most cases, the limitations should be overcome by increased attention to detail.

This attention must be focussed in three areas, specifically,

1) informed observation of the crop,
2) careful interpretation of the evidence and
3) timely management responses,

and the intensity of this attention must be increased during the last weeks leading to and including harvest.

This may appear self evident for any cropping enterprise, but the ‘recipe’ approach, taking little account of specific soil and seasonal conditions or changes in the disease, nutrient and moisture status of the plant, has proved particularly unreliable in the case of peppermint.

The Mint Manager has been developed to

- improve the focus on critical points during the cropping cycle,
- provide 'starting point' guidelines for producing high oil-yielding crops
- identify risk indicators
- provide a framework for data collection and performance checking.

The simple scheme below shows a series of check phases, (red boxes) followed by planning phases (blue boxes).
The Checklists record the minimum basic information required to plan the next phase of production and to allow useful comparisons between crops, seasons and districts.

The Plans provide a brief guide to good practice and record an agreed strategy for each stage of establishment and management. These Plans represent an understanding between the operators of the enterprise and other interested parties (agronomic consultants, field operators, managers, research interests, others?). Deviation from the plan by the operators should be justified by detailed explanation, supporting information and agreement between the parties.

Important Notes to Field Officers and Consulting Agronomists

1) Reference Material:
The Grower Manual is a self contained document. As such it does not include references to other literature either scientific or extension. Consultants and other advisors, and some growers will need to look further to resolve specific problems or to obtain background on certain aspects of mint production.

Much of this material is to be found in the RIRDC report on Best Practice in Peppermint Oil Production (1999), in the ‘Literature Review’ part of that report, copies of some of which are appended to the report. Additional reference material and scientific literature as well as the US
Extension Guides and other relevant reports used in preparation of the ‘Mint Manager’ are included in the Bibliography of the report.

2) Implementation of the Mint Manager
The ‘Mint Manager’ is not designed simply as a technical support for producers. It requires the establishment of a feedback loop which will ‘breathe life’ into the system - an annual collation, review and revision of the package. The industry must identify which parties are to be responsible for this coordinating role.

Data drawn from each of the Checkpoint stages is summarised and compared between producers, regions, states and seasons to
- monitor progress in improving yields (or reduced variability between seasons),
- further the technical guidance for mint production,
- identify opportunities to simplify the data collection and documentation,

The Crop Checklists (below) for each grower are collected, and basic data extracted and entered into a database upon which the following parameters can be investigated.

Checklists:
1: Prior Season: New Plantings
2: Site Preparation: New Plantings
3: Crop Establishment: New Plantings
4: Growth Cycle
5: Harvest
6: Post Harvest

Parameters:
Data should be arranged so that results and history for each crop (for each grower) can be extracted if necessary. The most important analysis is the comparison of yield results with the key crop records (previous crop, soil type, plant density, degree days, water use, nitrate nutrition, disease control, harvest management, gross margin).

Preface: ‘The perfect Crop: 90kg oil/ha every year’
- Healthy vigorous stolon material is planted into moist weed free soil, covered within 30 mins and the smooth, finished surface is sprayed within 2 days with Sinbar.
  The operation is completed more than 1 month before mint commences growth in the district (usually early spring).
- Basal fertiliser was incorporated prior to planting, as indicated by soil analysis.
- The site experiences ideal aspect, soil type and spring/summer climatic conditions.

The manager ensures good control of cutworms/cockchafer, rust, leaf hoppers and other pests from planting to harvest.

Growth commences in early spring, soil moisture is maintained above refill point throughout, and nitrogen application commences in late spring.

Soil nitrate levels are maintained as adequate, monitored through soil analysis and supplemented with sap analysis at 3-5 times during development.

Peppermint first produces primary shoots at each node, quickly followed by stolon development above and below the soil surface, aerial shoots proliferate, each quickly giving rise to vigorous laterals at the first 6-8 nodes above ground.
Full canopy closure occurs in mid December, and aerial shoots continue to develop, achieving 10-12 nodes each by end December. By this time the canopy is supported by an extensive mat of stolons, all rooted firmly in the top 150mm soil, with root development (and water depletion) reaching at least 300mm in loamy soils.

Leaf area achieves a maximum towards the end of December and leaf loss due to moisture or disease stress is kept to a minimum thereafter.

In hot climates leaves will tend to be smaller, bearing a full complement of full glands, allowing for the possibility of higher yields than might usually be obtained in a cooler situation, where leaves will be larger.

Harvest commences when sample analysis indicates an oil composition appropriate to the requirements of the market. Herbage yields are in the order of 6-7 tonnes dry matter/ha, containing 1.3-1.5% oil.

The crop is mown close to the ground and the herbage laid in a compact windrow with the minimum of bruising.

Average moisture content at the time of collection is 45-50%, and collection is carried out to avoid teasing out the windrow or otherwise damaging leaves. The mint is chopped and blown into the distillation vessel. In windy conditions harvest is suspended or only conducted on moist (>60%+) herbage. Distillation occurs within 2 hours of harvest, and all oil is condensed and separated from the water.

**The crop yields at least 90kg/ha.**
3.2: Overview

Mint Manager

Below is a schematic guide to the application of the mint manager.

The general approach is:
- Information gathering: Checklists - Red Boxes, Pink Pages
- Planning: Plan Phases - Blue Boxes, White Pages

Each planning phase is supported by a set of notes which identify the key issues and provide a concise agronomic guide for each stage of the cycle.
3.3: The Model

1. Prior to Season - New Plantings

- This checklist should be completed in the spring prior to planting, and discussed with the coordinator/agronomist, with whom
- a 'Leadup Program' should be prepared, incorporating fertiliser and cultivation strategies, irrigation requirements, propagation plan etc.
- Implement Program, then move to II: Site Preparation

<table>
<thead>
<tr>
<th>Property</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Paddock Name/Reference</td>
<td></td>
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</table>

Paddock Statistics

- **Paddock Plan:** Sketch paddock in plan view, showing major dimensions and noting the method of determining these (eg. pacing, distance wheel, ute odometer). Use GPS identifiers if possible.
- **Monitoring pathway:** To ensure consistent sampling; avoid atypical parts of the field (headlands, minor soil types, old fencelines, firebreaks, previous trial sites, irrigation fixtures). The pathway should be identified by permanent markers at the edges of the field (eg painted posts), and marked on the plan.

Previous Crop history:
Crop/pasture type* for previous two seasons

<table>
<thead>
<tr>
<th>Season</th>
<th>Comment (vigour etc)</th>
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<tbody>
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</table>

*eg cereal/poppies/canola/legume crop/legume pasture/grass pasture/fallow/other; high/med or low productivity?

Weed Status

- Annual and perennial weeds presenting a problem during previous crop cycle - list by species and severity. Mark local infestations of problem** perennials on paddock plan.

<table>
<thead>
<tr>
<th>Date Inspected</th>
<th>by Whom</th>
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<tbody>
<tr>
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</table>

<table>
<thead>
<tr>
<th>Weed Species (a/p)</th>
<th>widespread/localised?</th>
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** sorrel, californian thistle, flatweeds- all types, ....other??

Soil Conditions

- **Uniformity of topsoil type:** plot two main soil types on paddock plan and estimate % area of each*). Mark also any problems and estimate area of each. Photo after cultivation might be helpful.
- **Predominant soil types:** describe the predominant soil types by texture, depth
- **Subsoil description:**
- **Soil Samples:** record results of soil sampling for pH, soluble salts, N, P, K, S, Ca, Mg.

* This may have to await initial cultivation in the case of old pastures
Parameter Results Test Procedure

pH
P
K
Available Nitrate - N
S
Ca
Mg

Date Sampled:_______________

Local Geography:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aspect (circle one or two as necessary)</td>
<td>N  E  S  W  N  FLAT</td>
</tr>
<tr>
<td>Site elevation (asl),</td>
<td>Metres</td>
</tr>
<tr>
<td>Topography (flat, undulating, etc)</td>
<td>Flat  Undulating  Steep</td>
</tr>
<tr>
<td>Exposure to prevailing winds (H, M, L)</td>
<td>High  Medium  Low</td>
</tr>
<tr>
<td>Proximity to still (km)</td>
<td>&lt;1km  1-5km  &gt;5km</td>
</tr>
</tbody>
</table>

Local Climate:
Obtain basic records from nearest meteorological recording station, at_____________________(name), ___________km from site

<table>
<thead>
<tr>
<th>Rainfall totals (mm):</th>
<th>Accumulated degree days:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Av:</td>
<td>August</td>
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<td>August</td>
<td>September</td>
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<td>February</td>
<td>March.</td>
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</table>
**Preplant: Guidelines/Leadup Plan**

**Weed Control:** High populations of 'flatweeds' (*Hypochaeris spp.*, *Taraxacum officinale*, *Leontodon spp.*) and any stoloniferous weeds (eg. couch grass, sorrel, whiteweed (*Carderia draba*), Californian thistle,) should be treated with appropriate translocated herbicides before any cultivation or livestock introduction. Seek professional advice as to the best approach.

**Nutrition and Soil Amendments:** Results of soil samples should be reviewed by a professional agronomist / other. Mint is vulnerable to salt damage, and fertilisers of all kinds should not be used without evidence that they are necessary.

Lime should be incorporated in the plough layer if the pH is less than 6.0. A target pH of 6.5 will provide some buffer against the effects of acidifying nitrogenous fertilisers during the life of the crop. Advice as to the neutralising capacity of available liming materials and soil buffering capacity should be sought before devising recommendations.

The following table* provides a guide for P and K application:

<table>
<thead>
<tr>
<th>Soil P (ppm)</th>
<th>Phosphate (P&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;5&lt;/sub&gt;) required (kg/ha)</th>
<th>Soil K (ppm)</th>
<th>Potash (K&lt;sub&gt;2&lt;/sub&gt;O) required (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-20</td>
<td>110 - 170</td>
<td>0 - 100</td>
<td>130 - 225</td>
</tr>
<tr>
<td>20-40</td>
<td>70 - 110</td>
<td>100 - 200</td>
<td>65 - 135</td>
</tr>
<tr>
<td>&gt;40</td>
<td>Nil</td>
<td>&gt; 200</td>
<td>Nil</td>
</tr>
</tbody>
</table>

* Adapted from Oregon State University FG 15

Sulphur levels of less than 10ppm should be redressed by application of 25 - 45 kg/ha of S, unless this will be achieved through application of superphosphate prior to planting.

**Cultivation Program:** Program should result in moist, weed free tilth appropriate to seedling transplantation by time of planting. Deep ripping is only recommended in special circumstances and with professional advice.
### Weed Management: Spray Program

| Herbicide (ai, rate, special comments): |   |
| Time of Application: |   |
| Review Date: |   |

### Nutrition and Soil Amendment Program

| Lime Type and Application Rate: | Complete By: |
| Fertiliser Type and Application Rate: | Complete By: |
| Other: |   |

### Cultivation Plan:

| Cultivation Type: | Complete by: |
| To be complete by: |   |
| Cultivation Type: | Complete by: |
| To be complete by: |   |
| Cultivation Type: | Complete by: |
| To be complete by: |   |
| Cultivation Type: | Complete by: |
| To be complete by: |   |
II. Site Preparation- New Planting

- Implementation of the Leadup Plan (devised in consultation with the agronomist) should be complete by late summer prior to planting.
- This checklist is then used prior to planting to record the degree of preparedness of the site, which is discussed with consultant, and
- a 'Planting Plan' is developed, to assess risks with the site and infrastructure and to set targets for implementation during planting.
- Plan to be signed off before commencement of planting
- At completion of planting, move to III: Crop Establishment

Soil Preparation
1) Indicate condition of soil prior to planting, and note any problem areas eg stoney, boggy or cloddy parts of the site (use the paddock map):

<table>
<thead>
<tr>
<th>1) Tilth description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2) Soil Moisture</td>
</tr>
<tr>
<td>3) Site problems:</td>
</tr>
<tr>
<td>See paddock map</td>
</tr>
</tbody>
</table>

2) Fertiliser and Lime Applications:

<table>
<thead>
<tr>
<th>Amendment: Type and Rate</th>
<th>Date Completed</th>
</tr>
</thead>
</table>

Weed Control
Indicate effectiveness of weed control programme prior to planting:

<table>
<thead>
<tr>
<th>Viable seedlings</th>
<th>Species if known</th>
<th>Distribution over field</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viable pieces of perennial weed: sorrel, dock, flatweeds...</td>
<td></td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Propagation Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield stolons*: g m⁻²</td>
</tr>
<tr>
<td>Area of Nursery m²</td>
</tr>
<tr>
<td>Stolon Vigour**</td>
</tr>
</tbody>
</table>

* Use dig a 50 x 50cm patch to 100mm depth, remove all non-rooting above ground material, and shake out as much dirt as possible. Record Fresh Weight in grams

**Qualitative description of stolon material: thickness, proportion of dead or diseased stolon, or determine DW of shoots produced/metre of stolon in dark.

Irrigation Capability

<table>
<thead>
<tr>
<th>Water Available</th>
<th>ML/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pump and supply system</td>
<td></td>
</tr>
<tr>
<td>Irrigator design</td>
<td></td>
</tr>
</tbody>
</table>
Planting Guide/Plan

Site Conditions:
1) Tillage:
Preparation should result in a tilth roughly equivalent to that required for seedling transplantation. Note - pre-emergent herbicides do not work well on lumpy and irregular surfaces, or where clods continue to weather and break apart.

2) Soil Moisture:
Peppermint stolons are live plant material, as vulnerable as vegetable speedling transplants. Stolons collected from on or just beneath the soil surface may have well developed roots, short shoots and sometimes leaves. Handled properly, they will develop one or two new shoots and roots from nodes along their length, so that the minimum effective unit for mint planting is a short length of stolon with one viable node.

In dry conditions, however, any small lateral shoots and roots will dessicate rapidly, followed by drying of the stolon itself, at a rate depending on the size of the material, air movement and soil adhering to it. It may take as little as an hour to irreversibly damage the material, but even partial drying will reduce the number of viable nodes present.

Planting into wet sites is not recommended. Damage to the soil and plant material will result, and in most cases it is better to delay planting until conditions are suitable. Mint stolon material can be cool stored but specialist advice should be sought before this approach is contemplated.

3) Weed Control
All perennial weed material should have been controlled by this point. Seedlings present as cotyledons-only at planting will normally be destroyed during the procedure. However, use of a dessicant immediately prior to disturbing the soil at planting will improve the efficiency of post-planting pre-emergent treatment. The standard of weed control in the nursery should be assessed at this point.

Planting Procedure:
1) Planting Equipment:
Detail the digging, transport and planting equipment to be used.

2) Planting Density:
A minimum of 10 viable pieces per square metre (determined after planting using a rake, or digging by hand) is required to ensure full yield in the first year of planting. Large clumps and very vigorous stolons allows slight reduction of this target only if planting conditions are ideal. A strategy to ensure uniformity of planting should be discussed and documented. Under typical conditions of planting and crop management, a lower density or uneven distribution of plant material will result in a reduced yield.

3) Handling of Stolon Material:
Every effort must be made to minimise exposure of freshly dug stolons to drying conditions. The intended strategy should be noted in the box below. Similarly, under no circumstances should dug stolons be stockpiled for long periods: field heat and respiration will result in very rapid spoilage and composting may commence.
Tillage: Additional cultivation / exclude some areas/ other
Action:

Soil Moisture: Over wet/ moist / over dry
Action: Delay harvest till:
Commence planting on:
Irrigate ___ mm and plant from ________

Weed control: Spot applications required/preplant dessicant?
Action:

**Planting Procedure:**
Target Density: ___________ pieces m⁻²

Proposed Multiplication: ___________

Planting target: _____________ ha day⁻¹

Digging and Planting Equipment:

Distance and time to planting site: _______ km; _________ mins

Covering and Levelling Strategy:

Target maximum exposure time for stolons:
**III: Crop Establishment**

- The Planting Plan devised in consultation with the agronomist should be implemented by *early winter*, unless wet conditions force a delay.
- This Checklist to be completed immediately after completion of planting and discussed with the agronomist, with whom
- the 'Growth Cycle Plan' should be developed, addressing risk areas identified to date, proposing monitoring methodologies, target parameters and management responses.
- The plan to be signed off prior to the commencement of spring growth.

<table>
<thead>
<tr>
<th>Planting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start Date and Time</td>
</tr>
<tr>
<td>Finish Date and Time</td>
</tr>
<tr>
<td>Weather Conditions</td>
</tr>
</tbody>
</table>

**Actual Planting Density**
Drag a garden rake through a square metre of soil to determine the number of *viable* pieces of peppermint in five samples following the covering pass.

Count large clumps as '2' and *exclude* single nodes, severely damaged or diseased pieces.

<table>
<thead>
<tr>
<th>Sample</th>
<th>No Pieces</th>
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<tbody>
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<td>1</td>
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<td>3</td>
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<td>4</td>
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<tr>
<td>5</td>
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</tbody>
</table>

**Paddock Finish (Circle)**

- Loose  2 3 4  Compact **TOPSOIL**
- Smooth 2 3 4  Irregular **SURFACE**
- None  2 3 4  Many **EXPOSED PLANT PIECES**

**Herbicide Application**

<table>
<thead>
<tr>
<th>Herbicide</th>
<th>Rate &amp; volume/ha</th>
<th>Application date</th>
<th>Weather conditions</th>
</tr>
</thead>
</table>

**Post-Planting Irrigation?**

<table>
<thead>
<tr>
<th>Application method/ rate</th>
<th>Date of completion</th>
</tr>
</thead>
</table>

In developing a management plan for the annual growth cycle (the period from about September till harvest), attention must be given to four main issues:
• crop water use and irrigation management
• managing nitrogen availability
• management of Pests and Disease
• herbage growth and oil production

The following discussions are intended as 'background papers' for use in devising strategies for managing each of these issues. They are not intended to provide comprehensive coverage of the subject and management plans should be tailored to the specific site and management capability and should particularly address any perceived weaknesses in the operation.

*******************

1: CROP WATER USE AND IRRIGATION MANAGEMENT

General
Assuming average rainfall during winter/ early spring, the soil profile beneath the crop should be at or close to field capacity in late September.
At this time, datum levels for soil water holding capacity must be established using probes, soil samples or other methods.

In addition to plant use (transpiration), a small quantity of moisture will evaporate directly from the soil surface whenever the surface is wet, until plant cover reduces air movement and soil temperature in this zone. As soon as the surface dries out, however, little more moisture will be lost until transpiration takes over as the main pathway for water use. In newly planted mint crops, this will occur when temperatures begin to rise and leaf area begins to increase rapidly in mid spring.

Water will be drawn from the root zone in order of increasing water potential - upper parts of the profile will dry somewhat, raising water potential and causing the roots to begin removing water held less strongly, but from further down the profile. Until more water is added to the surface of the soil, this process will continue, removing water from further and further down the profile, until the full extent of the root zone is affected and the plant's ability to withdraw water exceeded.
At that point, the plant will begin to wilt. However, for the last part of the cycle of increasing dryness, the plant experiences increasing difficulty in supporting maximum transpiration rates, and growth (and yield) are reduced, (see diagram below).
The root zone must therefore contain 'surplus' water for maximum productivity, and managers can set an arbitrary 'refill point', usually halfway between field capacity and wilting point, at which plants continue to function at close to maximum transpiration rate. These points can be estimated for the whole of the root zone, by multiplying values for each, expressed as mm water/100mm soil, by the depth of the root zone.
Irrigation and rainfall arriving at the surface will wet soil on a 'front', moving roughly downwards as each layer achieves field capacity. **Water will not move from wet to dry parts of the profile unless the soil in the wet area exceeds field capacity ('saturation').**

If the water added doesn't match the rate of consumption, only the upper part of the profile will be raised to field capacity again, and some proportion of the lower areas will remain drier. After removing this available water from the wetted soil, the plant will resume drawdown on deeper parts of the profile.

One can envisage the situation where the water 'budget' is moving further and further into debt, more and more of the profile remaining dry after each irrigation, and the zone of active root activity ultimately limited to the upper region wetted during each rain or irrigation event. The implications for nutrition and water balance, and therefore growth and yield are obvious.

**Irrigation Management**

Several issues must be addressed in choosing an irrigation method for mint:

a) **Delivery requirement:** irrigation facilities must be capable of meeting average demand of a full-grown crop during typical summer conditions. Peak demand can be met either by direct water application or by drawing down the reserve within the root zone.

The root zone can be used as a buffer against the situation where hot dry conditions prevail over a full canopy for several days at a time, provided this can be refilled before the plant begins to 'shut down'. Soil type (depth and texture) will determine the capacity of the moisture 'buffer', and this must be determined either by sampling and analysis or using a moisture probe.
b) Infiltration: the application system must allow for the minimum infiltration rate across the range of soil types, so as to avoid localised drought and waterlogging. Specialised advice should be sought if there is any doubt regarding this, and before expensive cultivation and soil amendments are used.

c) Efficiency: large irrigation guns throw water high into the air and are vulnerable to high evaporative losses (up to 45% in warm windy conditions). They may also cause physical damage to the soil and crop. On the other hand, lateral move and centre pivot systems deliver water close to the crop, and are less liable to evaporative loss, but lack flexibility in exceptionally drying conditions, where crop consumption may exceed design application rates. Irrigator efficiency can be estimated simply by strategic placement of collection vessels across the irrigator path. Actual delivery to the soil or crop surface may be compared with pump delivery to obtain % efficiency.

d) Distribution: In the case of gun irrigators, particularly in irregular fields, and when irrigation is carried out in hot or windy conditions, uneven distribution of water can seriously affect crop performance. Simple checks with multiple collectors will help, but very careful planning of irrigation cycles, and ample capacity to cover the area required in less than the available time are essential for a good result.

e) Scheduling: Water budgets can be used provided good local data for evaporation and crop demand are available. Following is a typical balance sheet for irrigation management. The schedule should be initiated prior to the growing season, (assuming soil is at field capacity), and used to predict the time at which water deficit will arise in the crop. This allows the irrigator to initiate irrigation sufficiently early to avoid limiting plant growth. The essential basic requirement is for some means of measuring soil moisture and crop water use.
Schedule Form:

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<tbody>
<tr>
<td>eg day 7</td>
<td>58</td>
<td>+ 5</td>
<td>+ 0</td>
<td>- 10</td>
<td>= 53</td>
<td>- 45.5</td>
<td>= 7.5</td>
<td>/ 1.5</td>
<td>= 5</td>
<td>58</td>
<td>- 53</td>
<td>5</td>
</tr>
<tr>
<td>day 14</td>
<td>53</td>
<td>+ 0</td>
<td>+ 20</td>
<td>- 14</td>
<td>= 59</td>
<td>- 45.5</td>
<td>= 13.5</td>
<td>/ 2.0</td>
<td>= 7</td>
<td>58</td>
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</table>

eg: in sandy loam:

500mm assumed root depth at maturity
Min water balance (wilt point) = 6.7*mm/100mm (*potatoes used as an example)
Field capacity = 11.6 mm/100mm
Min. balance (wilt): 5.0 x 6.7 = 33.5mm
Field Capacity in root zone: 5.0 x 11.6 = 58mm
Nominal Refill point (50% of available water): 45.5mm

Season commences (assume) with the rooting profile at field capacity.
Crop water use may be calculated by dividing the total water use (e.g. as determined from consecutive moisture probe readings) by the number of days elapsed, or by referring to published local data for the crop.

Note in the example, that under the crop water use figures used (about 2mm/day), soil at field capacity only contains enough water for 6-7 days uninhibited growth, without supplementary rainfall or irrigation. This would not be untypical of a vigorous mint crop in warm conditions.
f) Monitoring
• A simple but essential tool in irrigation management is the rain gauge - providing a measure of the amount of rain or irrigation water landing on the soil surface. A cheap solution is to use one gauge and a series of cans or containers of similar diameter, placed so as to check irrigator delivery across or along the irrigator path. Conditions such as temperature and windspeed and direction should be noted when these checks are conducted. Uneven, or less than expected delivery suggests that a change in irrigation strategy should be considered.
• After irrigation, attempt to drive a length of 3/8" rod into the soil by hand. This will show the depth of wetting provided by the irrigation event. *(It will not demonstrate how deeply the profile has been dried below this depth).*
• A spade can be used to dig test holes before and after irrigation to estimate soil moisture at various depths beneath the crop. If the root zone is estimated to be say, 400mm, then by the time the mint has achieved full canopy, it may be necessary to dig the full depth to determine the reserve of water available to the crop.
• Tensiometers can be inserted to various depths and calibrated for the soil type to indicate available moisture.
• Moisture probes (using various means to measure moisture content of the soil surrounding buried tubes) can provide continuous readings for soil at predetermined depths, or point readings for various depths (usually 100mm intervals) beneath the crop. By coupling these devices to recording instruments and employing computer analysis, 2- and 3-D representation of moisture changes beneath the crop can be produced. In particular, *rates of change* in soil moisture can indicate 'daily water use', and allow development of a water budget, estimation of available water and prediction of 'days to irrigation' - the time available for the irrigator to complete the next irrigation.

**Crop Requirements**
As a simple rule of thumb, in southern Australia, most mint crops appear to require at least 32mm of water per week after development of the full canopy, although demand will be greater during periods of hot windy weather

This requirement can be fulfilled by:

1) Rainfall. Falls of less than about 5mm are unlikely to refill the root zone to any useful extent, while very heavy falls may result in runoff, so that the nett increase in available soil water *may be less than that recorded as rainfall.*

2) By drawing down water available within the root zone. The quantity of water available from this source depends upon on soil type, and the depth of penetration of mint roots.

3) Irrigation. Schemes should be designed to provide at least 32mm per week, and preferably include some reserve capacity in case of prolonged extreme demand, or temporary breakdown.
2: MANAGING NITROGEN AVAILABILITY

General
All soils contain natural levels of nitrogen containing compounds. Bacterial degradation of plant and animal proteins in the soil, fixation of atmospheric nitrogen by symbiotic and free living bacteria, and dissolved nitrogenous compounds arriving with rainfall, all contribute to the natural nitrogen resource in the soil.

On the other side of the ledger, nitrogen and ammonia gas are lost to the atmosphere, nitrate is washed from the soil by drainage or runoff, and plant uptake of nitrate and ammonia all combine to remove available nitrogen from the root zone. These processes are all influenced by factors such as pH, soil moisture, temperature and C/N balance in the soil.

During a peppermint growing season, plant uptake becomes the major factor in influencing soil nitrogen availability, and nitrogen present prior to the growing season is depleted, unless more is added. This continues until the crop is removed or winter dormancy begins, at which point a new, basal level of nitrogen in the soil can be established, and the other processes mentioned above become more important.

Nitrogen is recognised as the nutrient most often responsible for limiting oil yields in peppermint crops. A shortage will reduce total yield of herbage, and in most cases yield of oil. It can also alter the balance of oil components in the whole plant, altering oil quality and therefore affecting 'maturity' date. Usually, a shortfall in N will result in reduction of growth as the season progresses, and therefore early development of a 'harvest-ready' oil.

On the other hand, there are several important reasons to avoid excessive levels of N, both during and at the completion of the growth cycle:

- excessive nitrogen can pose an environmental hazard, resulting in high nitrate levels in soils and groundwater,
- excess nitrogen in the root zone can induce deficiencies in other nutrients,
- excess nitrate levels can result in an overabundance of leafy vegetative growth which may contain a low percentage of oil, and add to the cost of transport and distillation,
- lush, leafy growth may be more susceptible to disease and pest attack, and
- nitrogenous fertilisers are expensive, so losses to the atmosphere or via drainage water represent an unnecessary waste of inputs.

The single most important factor influencing N availability is the 'cropping history' and many guides provide estimates for N application based simply on previous crop history - fallow /crop; legume / non-legume; stubble incorporated /removed. Nitrification during a fallow season, or a preceding legume crop or pasture will augment nitrate levels, while incorporation of straw and stubble will alter the soil microbial environment and reduce the availability of nitrogen. This is particularly important during the first year of the crop.

The table below* gives a guide to the likely requirement for added nitrogen for peppermint established after a variety of preceding crops.
This table should be seen as a general guide only - it does not account for situations in which excesses of nitrate remain at the completion of a crop cycle, nor where an unusually heavy crop may have drawn down the reserve of soluble N more than usual.

The best approach is to analyse the soil prior to planting or at the end of winter and before crop growth commences. This will give a 'baseline' N from which a strategy can be developed.

The following table, adapted from the US Extension literature* gives a simple guide to managing split applications of nitrogen during the summer growing season, based on the actual levels of nitrate N present in the soil at the beginning of the season.

<table>
<thead>
<tr>
<th>Winter Soil Test : NO₃ - N (kg/ha)</th>
<th>Early Spring: Sept - Oct (kg N/ha)</th>
<th>Summer : Nov - Dec.(kg N/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>90</td>
<td>195</td>
</tr>
<tr>
<td>45</td>
<td>45</td>
<td>195</td>
</tr>
<tr>
<td>90</td>
<td>45</td>
<td>150</td>
</tr>
<tr>
<td>140</td>
<td>0</td>
<td>150</td>
</tr>
<tr>
<td>&gt;140</td>
<td>0</td>
<td>retest soil N</td>
</tr>
</tbody>
</table>

*University of Idaho, Extension Series CIS 647

This advice is based on work which shows that optimal levels of peppermint oil and dry matter are produced when the crop has approximately 280kg N available to it during the growing season, and it does not experience any other limiting stress. More nitrogen is either wasted or serves to simply add unproductive vegetative material, while less may restrain the growth of the crop if all other requirements are met.

The purpose of dividing the application into two or more parts is to minimise the chance that N will be lost through leaching, or volatilisation, and to try to maintain a steady adequate supply to the plant right through the season.

Three commonly used nitrogenous fertilisers are listed below, each contributing a different percentage of N by weight, as shown. A cost per kg of nitrogen applied can be calculated using the %N shown and the local cost of each ($/t 1000 %N). The cost of applying (whether broadcast or fertigation) should be included. Most commonly used in Australia is ammonium nitrate, less acidifying than sulphate of ammonia and less subject than urea to losses through volatilisation if not washed into the soil. Urea is well suited, however, to application through irrigation water, (although for foliar application biuret should not be higher than 0.4%).

<table>
<thead>
<tr>
<th>Nitrogenous fertiliser</th>
<th>% N</th>
<th>$/100kg N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urea</td>
<td>45</td>
<td></td>
</tr>
</tbody>
</table>
Ammonium nitrate 34
Sulphate of ammonia 21

Monitoring Nitrogen Use
While the general recommendations above will give an adequate result in most cases, the high
cost of nitrogen suggests a more precise 'demand feeding' approach to its use.
Measuring available N in the soil, or levels in the plant several times during the season will
help guide the timing and quantity of each application.
Ultimately, it may reduce the total amount of fertiliser required, particularly if
• very high levels exist before the commencement of growth
• soil type and irrigation pattern enable exploitation of a larger than expected root zone
• crop uptake is reduced for any other reason.

In practical terms, two methods for monitoring available N can be used.
1) Soil nitrate N - rapid (<36hr) procedures are available for estimating kilograms of nitrate
   N per hectare. The procedures involve specific sampling and handling methods, but
   provide an accurate indication of available N, and exclude the effects of microbial
   activity in the sample, etc. The results can be compared with those in the table above, and
   fertiliser applications managed accordingly.
   Details of the sampling procedure, costs and interpretation of results will be available
   from fertiliser suppliers and agronomic advisers.
2) Sap nitrate provides a 'snapshot' of nitrate concentration in the xylem, but as with the soil
   analysis above, sampling procedure is critical. Provided the correct procedure for
   sampling and despatch of material is followed, then ‘adequate’ sap nitrate levels will
   indicate at least adequate uptake from soil reserves. Low levels are more difficult to
   interpret in isolation, since they may indicate inadequate supply, some other factor
   restricting uptake, or simply excessive dilution of the nitrate due to high rates of
   evapotranspiration.
   Sap nitrate levels should be high at the beginning of the season and fall steadily as the
   mint matures up to harvest.

The example below shows the results of soil and sap nitrate testing on a healthy, vigorous
Tasmanian crop, taken during summer 1998/9. Results are the mean of two or three
samples, and the arrows show the dates and quantities of nitrogen applied as ammonium
nitrate. In this case good spring soil reserves enabled low application rates throughout the
season, without soil reserves ever falling below 100kg/ha.
Postharvest nitrogen nutrition
Work published in the US shows clearly the benefit of encouraging growth in peppermint after harvest, enabling the mint to develop some carbohydrate storage in roots and stolons. While some reports show very large increases in yield in the subsequent season, after post-harvest applications of nitrogen and frequent irrigation, part of this is due to improved survival of these crops in the extremely cold winter conditions of the main production areas in the US.
Nevertheless, the Tasmanian experience with loss of stolon vigour in established crops suggests that some autumn growth might be helpful in invigorating the remaining herb, which in turn will help minimise the effects of winter active pests and diseases on growth in spring.

3: SOIL FERTILITY

As with any crop in which large amounts of dry matter are removed in the course of harvest (eg lucerne) particular attention must be paid to maintaining adequate reserves of macronutrients in the root zone.
While annual topdressing can serve to replace nutrients removed with the crop, or by leaching, it is less effective than preplanting application in providing nutrient throughout the root zone of the plant.
Nevertheless, annual soil analysis and fertiliser application should be part of the management plan. The guide presented in 'Preplant Guidelines' should be referred to in relation to P and K requirements.
Suspected micronutrient deficiencies should be addressed using expert advice. Tissue analysis of affected plants and comparison with healthy plant material provides one of the best means of detecting specific nutrient deficiencies. However, sampling technique and handling of the samples must be carefully planned if these results are to be meaningful.

4: MANAGEMENT OF WEEDS, PESTS AND DISEASE

Weed Control
The ideal situation for weed-free peppermint production begins with use of weed and seed-free planting material in a planting bed from which all the perennial weed material has been destroyed. Timely pre-emergent herbicide application supplemented by limited hand control of escapes should exclude most weeds, most of the time.

The standard recommendation for pre-emergence weed control in peppermint in Australia is for terbacil (“Sinbar”) applied at the rate of 2.0 kg/ha over the dormant mint in late winter. Terbacil will control most annual broadleaf weeds and grasses in mint, provided that soil moisture is adequate at application, or post-application irrigation is used to ‘activate’ the chemical.

If seedlings are present at spraying, inclusion of a wetting agent will improve the result. As always, pay close attention to label recommendations.

Inevitably populations of hard-to-kill weeds will develop, and it is this which usually brings on the demise of most mint crops in Australia. Some weeds pose a particular threat: sorrel seems to be particularly antagonistic towards mint; species containing essential oils could contaminate the oil; weeds resistant to terbacil control as seedlings can set seed and rapidly spread.

The best opportunity to deal with these hard-to-kill weeds is in winter, when the mint is relatively dormant and less likely to be damaged by broad spectrum control measures, and the weeds have recovered from the harvest.

Unregistered herbicides should not be used on peppermint. Specialised advice should be sought and where necessary, provision for off-label use of unregistered herbicides may be arranged by application to the relevant authorities.

Established broadleaf perennials which have established during the previous season should be allowed to retain their leaves (i.e. avoid grazing) and treated either by hand or 'patch' boom applications of suitable herbicides. Close attention to weed condition, soil moisture etc. is essential, no matter what herbicide treatment is used.

An important supplementary control measure is the hoe - limited outbreaks of resistant weeds can be contained by early mechanical removal.

Pests of Peppermint
During the pre-emergent and early emergence stages, particularly in new mint stands, cutworm species can inflict severe damage, destroying shoots before or shortly after they appear above the ground. Detection is difficult since the insect feeds at night, most of the damage occurs out of sight and the first warning may come too late as parts of the crop may fail to emerge altogether. Clues are the occasional wilting or damaged shoot and patchy emergence of the new crop during the first few weeks of spring. Close inspection of buried stolons in these areas may reveal 'nipped - off' shoots.

US extension literature advises use of Lorsban in new fields if ten samples of 250mm x 250mm of soil to a depth of 50mm yield an average of one or more cutworms each.
Outbreaks of two spotted spider mite are well known in mint crops. At this stage there is no IPM program designed to address this problem in Australian mint crops. Mites tend to build in numbers as the season progresses, building webbing on the underside of leaves, causing dry or silvery marks on the surface of the leaf and in dry conditions causing severe damage, although often only in localised areas. US literature advises application of suitable miticides only when an average of more than five mites per leaf are found, using a hand lens on a sample of 50 leaves. The use of predatory mites, as occurs in other crops affected by mites may prove useful if the problem is localised and care is taken with use of 'predator safe' chemicals. Since there are no insecticides or miticides presently registered for use in mint crops it may be necessary to obtain special licences for chemical use, for which specialised advice should always be sought.

Nematode infection of roots and stolons is implicated in 'decline' of peppermint. This is subject to a range of exacerbating conditions such as waterlogging, mechanical damage to the underground parts, herbicide or nutritional stress, high densities of nematodes in early spring (either native to the site or imported with propagation material). No active treatment of nematodes in peppermint is advocated at this time. Use of clean planting material, and maintenance of a vigorous stand through other cultural means provides the best strategy for minimising the effect of this agent.

Management of insect, mite and nematode problems in US production areas is well documented in the software package by Coop et al (1995), guides available from Oregon State University (PNW 182, Berry and Robinson (1973) and Ingham and Merrifield (1996)), and the University of Idaho (Baird et al 1993).

Disease
The most serious disease threat to peppermint in Australia is Puccinia menthae - peppermint rust, a common and infectious disease of leaves and stems, a prolonged infection of which can almost completely defoliate the plant. Almost any level of infection can make infected leaves vulnerable to temperature or moisture stress. As with all rusts, spread and infection are affected by environmental conditions - particularly high humidity and moderate temperatures. Early detection and the use of systemic fungicides forms the basis of control programs, while in the case of an unmanageable outbreak, early harvest is an option. The life cycle of peppermint rust is complex, and may include up to five spore stages, not all of which are present in any year, although all have been detected in mint crops in Australia. Hot conditions found in Victorian fields during midsummer may reduce the germination of spreading spores during the day, but will not destroy established colonies, nor prevent further spread during irrigation events or at night. The apparent disappearance of rust infection after hot periods is actually due to the complete loss of infected leaves rather than destruction of the pustules themselves.

The key components of the controls strategy are
• timeliness - frequent close observation during spring and early summer,
• hygiene: - ensure no untreated material exists in or around the field, and coverage: - good penetration of the canopy, good spread over the leaf.

The fungicide Tilt (propaconazole) as 2 -4 applications of 500 - 750ml/ha is used to prevent spread of rust. The first application should occur at the time of first detection of pustules on the underside of lower leaves, usually in mid-spring, followed by repeat applications at 14 day intervals. This is the best opportunity to break the life cycle of the fungus before rapid multiplication and spread gets underway, and while the plant is smaller and coverage more assured.
5: HERBAGE GROWTH AND OIL PRODUCTION

High oil yields in peppermint will occur when the crop has
• maximum number of leaves per hectare
• maximum number of glands per leaf
• maximum fill of oil glands
Total oil yield increases until the rate of oil loss in fallen leaves outstrips the accumulation of oil in young leaves.

Oil composition in a given leaf changes as the leaf ages, and the composition of oil produced by distillation of the whole plant reflects the proportions of young and old leaves present (stems contribute very little to the oil yield from the whole plant). Old leaves contain mature oil with higher levels of menthyl acetate and menthol. Flowers contain high levels of menthofuran.

Leaf loss is caused by a large number of interacting factors. Moisture stress, disease or pest damage, high temperatures and nutrition problems can all cause leaves to drop prematurely. Leaf loss can be rapid, the combination of rust affected leaves, moisture stress and warm conditions can cause loss of most leaves on the plant in a matter of days. The objective is to retain as many healthy leaves as possible until the maximum leaf area is attained, and then to wilt, collect and distill them all.

Predicting Harvest Date
Sampling prior to harvest, taking typical samples of the whole plant and distilling in the laboratory will provide an indication of the relative maturity of the crop. Users of peppermint oil are usually quite specific in their requirements of oil composition and this should be considered when determining harvest timing.

In order to follow the change in maturity, a minimum of three samples should be taken before the anticipated harvest date, about two weeks apart. This will reveal trends, and allow the manager flexibility if an early harvest is required due to a pest or disease outbreak. (It is difficult to obtain estimates of yield by sampling, because while crop maturity may be reasonably uniform all over the field, the density of the crop can vary much more widely from place to place.)

The Vulnerable Fortnight
During the two to three weeks prior to harvest, many crops are particularly vulnerable to rapid changes in the quantity and 'maturity' of the oil. These changes usually involve the loss of parts of the leaf canopy, and are caused by the convergence of a variety of factors.

The Mechanism
1) The number and composition of leaves on the whole plant dictates the yield and quality of the oil. At early flowering a very large part of the canopy is composed of fully mature leaves.
2) These leaves (formed during the period of rapid growth, and on the plant for more than 5-6 weeks by this time) require only the slightest stress to cause them to rapidly senesce and fall.
3) Transpiration demand of a full canopy, combined with midsummer weather conditions, hastens the shift from adequate to stressful soil moisture levels.
4) Leaves experiencing lower light levels will be lost preferentially in the case of stress.
5) Diseases (rust, moulds etc) tend to flourish beneath a closed canopy, are hard to detect, impossible to control and will result in premature leaf loss.

The Problem:
• The decision to commence harvest is usually made close to the time of optimum oil yield, but in very many cases, actual start of harvest lags the decision by 3-5 days.
• After the decision is made, surveillance and management of the crop usually lapses (or at least diminishes greatly).
• Close to the time of harvest the scope for management intervention in disease or soil moisture problems is extremely limited or zero.
• Even with smaller cropping areas, the period to complete harvest is significant in relation to the 'vulnerable period' - days or even weeks.

_It is difficult to stress sufficiently the need to make the 'start' decision in advance of the optimum harvest date._

**Growth Cycle Plan**

<table>
<thead>
<tr>
<th>Irrigation Capability:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application Equipment:</td>
</tr>
<tr>
<td>Quantity applied per event: (estimate) mm (q)</td>
</tr>
<tr>
<td>Efficiency Factor (estimate) % (e)</td>
</tr>
<tr>
<td>Min. Cycle Period (estimate) Days (f)</td>
</tr>
<tr>
<td>Number of irrigations (estimate) (n)</td>
</tr>
<tr>
<td>Total Area ha (a)</td>
</tr>
</tbody>
</table>

| Irrigation Capacity: (7qe 100f) mm/week |
| Water Requirement: (nqa 100) MI |
| Water quality: Conductivity MEq |
Irrigation Scheduling:

Moisture Monitoring Strategy:

Baseline Establishment: ________________ (Date)

Rainfall Monitoring: ____________ (freq.) at ________________ (location of guage)

Root Zone: ____________ mm (initial estimate)

<table>
<thead>
<tr>
<th>Soil Type*</th>
<th>Field Capacity</th>
<th>Refill Point</th>
<th>Available Water/100mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>______________</td>
<td>____________</td>
<td>_________</td>
</tr>
<tr>
<td>B</td>
<td>______________</td>
<td>____________</td>
<td>_________</td>
</tr>
<tr>
<td>C(eg)</td>
<td>38</td>
<td>23</td>
<td>15</td>
</tr>
</tbody>
</table>

* If more than one soil type exists, provide estimates for each. Indicate locations on paddock map.

Nitrogenous Fertiliser:

Pre-season Soil Nitrate Nitrogen: _________ kg/ha

Spring Application: _______ (type) ________ kg/ha, or _________ kg N/ha

Summer Applications: ________ kg/ha ie ________ kg N/ha split as ______ applications

Sampling: ______ soil tests; ______________________ (frequency or dates)

________ sap tests; ______________________ (frequency or dates)

Analysing Laboratory: __________________________
**Weeds, Pests, Disease:**

1) Chemicals licenced for Spot Weed Control:

3) Pest Management:
   - Spring: Cutworm Monitoring/ Treatment Plan:

   ________________________________________________________________
   ________________________________________________________________
   ________________________________________________________________

   Summer: Mite and Insect Monitoring/ Treatment Plan:

   ________________________________________________________________
   ________________________________________________________________

3) Rust Control:
   - Monitoring period and frequency: ____________________________
   - Chemical Response (a): ________, @ _______l/ha, in _____l water
   - Chemical Response (b): ________, @_______l/ha, in _____l water
   - Spraying capability: Complete application in _____Hours/Days

---

**IV: Growth Cycle Checklist**

- The Growth Cycle Plan is implemented during the spring and summer, leading to determination of a harvest date in early February*.
- This Checklist is to be maintained during the season as the main record of growing conditions and management actions.
- A Harvest Plan is to be prepared in consultation with agronomist and agreed with management prior to the commencement of harvest.

* In some circumstances a case can be made for taking two cuts of peppermint. In almost every case, this is only feasible when the first cut can be taken before the end of December. US reports indicate that the practice is beneficial only in warmer than average years, and when good rust control in both crops is assured.

**Irrigation**

1) Application Rate at Soil Surface: _________________mm.
   - Date of determination: __________ Method: __________

2) Efficiency of Application:_______% (water pumped/water delivered to soil surface)

3) Irrigation Events:
Prepare tables on the following format, for each irrigation run, with week-commencing dates starting with the earliest anticipated irrigation, and with provision for recording post - harvest irrigation.

<table>
<thead>
<tr>
<th>Area:</th>
<th>Rainfall (mm)</th>
<th>Irrigation (mm)</th>
<th>Total for Week (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<tr>
<td>11</td>
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</tr>
</tbody>
</table>

4) Effective Rooting Depth: ________ mm
5) Daily Water Use: Use the notes in the previous section to make at least two (mid and late season) determinations of daily water use.
   Determination period: 1) ______________ 2) ____________
   Daily Water Use: 1) _______mm/day 2) _______mm/day

6) Soil Moisture Records
   If a soil moisture probe has been used, attach a copy of the results (preferably a graph) showing available soil moisture in the root zone.

**Nitrate Nutrition:**

1) Monitoring. Record the results of soil or sap readings in copies of the table below:

<table>
<thead>
<tr>
<th></th>
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<td>4</td>
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<td></td>
<td>5</td>
<td></td>
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</tr>
</tbody>
</table>

2) Applications:

<table>
<thead>
<tr>
<th>Area Name</th>
<th>Date / Application Rate (kg N)</th>
<th>Total N Applied</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

**Other Nutrition Issues:**
Briefly note any suspected nutrient disorders and the action taken.

**Weeds, Pests and Disease**

1) Weeds:
   - Mark localised outbreaks of problem weeds on the Paddock Map, and note action taken.
   - Estimate the area of the infestation (square metres, hectares) and the yield depression (in percentage terms) resulting from the outbreak.

2) Pests:
   - Mark localised outbreaks on the Paddock Map, and note action taken.
   - Estimate the area of the infestation (square metres, hectares) and the yield depression (in percentage terms) resulting from the outbreak.

3) Rust Control:
   - Time of Commencement of Monitoring _______________
   - Time and distribution of first visible rust activity:
   - Spray Program:

<table>
<thead>
<tr>
<th>Area</th>
<th>Application Dates</th>
<th>Application Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tbody>
</table>

**V: HARVESTING**

**Commencement of Harvest**

Much has been published regarding the effect of harvest date on composition of peppermint oil.

The composition of the oil is the result of syntheses and conversions occurring in the leaves and glands, and is controlled mainly by temperature conditions, so that seasonal factors such as nighttime average minimum temperatures and daytime maxima will alter the exact rate of oil maturation and the ultimate yield.

Equally important is the mix of mature and immature leaves on the plant, each with their own characteristic oil composition, since at harvest it is the collective composition which determines the final oil quality.

This mix of leaf maturities is less the result of seasonal factors, and more due to management practices which alter the rate of shoot development and the longevity of the leaves.

The simplified scheme below shows the general trends which can be detected in peppermint oil during the last part of the growing cycle, with the optimum period in the shaded block.

Note the drop-off in oil yield after this period, when leaf senescence begins to outstrip new leaf formation, while oil in all leaves continues to mature.
Market standards for peppermint oil demand certain proportions of each of the major components, and in the major Australian production areas, these proportions are to be found in healthy crops towards the end of January.

**Trends** are more useful than spot samples and crop sampling should be arranged to provide at least three 'snapshots' of crop development before harvest is anticipated.

While composition is of most interest at this stage, an experienced person can take area-based samples to give an indication of yield. This information is particularly useful during the harvest itself, providing some early warning of unreasonable losses or declining yield. Quadrat samples of 0.5 or 1.0 m$^2$ should be cut to ground level from representative parts of the crop, placed in bags and delivered promptly to the analysing laboratory, from where results should be available within 2-3 days. Unexpected results may warn of impending disaster - an immature oil usually indicates accelerated loss of lower leaves, in which case, paradoxically, immediate harvest might be the appropriate action.

From the point of view of the ‘Mint Manager’, the important issues are:
- monitor oil composition by sampling at least three weeks prior to likely harvest
- plan commencement of harvest to manage disease and moisture stress factors
- anticipate stress factors which will cause sudden loss of mature leaf
- correctly interpret trends and unexpected results – there will be a rational explanation

Lastly, it is important to be aware that by three weeks before harvest, most of the oil is already present, but highly vulnerable to sudden loss. A large proportion of mature leaves are close to senescence, experiencing low light levels and humid conditions beneath the canopy. The slightest stress will quickly trigger loss of these leaves particularly moisture stress or rust infection. Field experience over many years shows that crops are rarely if ever harvested too early. Even if the decision is made at the right time, the implementation almost always lags, due to weather, mechanical problems or logistics. The fragile state of the mature crop dictates that in most cases, a decision should be taken to start earlier rather than later, and that delaying harvest in order to gain a few kilograms of oil is rarely a wise decision.

**Harvest Procedures**
Fresh peppermint herb contains 80 - 85% water, and in typical field distillation equipment, it is difficult, if not impossible to recover all the oil from fresh herb. Refluxing of distillate within the vat will dissolve part of the oil. This oil can only be recovered by prolonged redistillation, if at all. However, the hot liquid environment can alter the chemical composition of some of the oil components rendering them non-volatile, and often undesirable in any case.

The conventional solution to this problem of moist herb is to wilt the mint in the field, before loading it into the distillation vessel. Typically, wilted mint averages between 45 and 55% with the stems tending to dry more slowly than the leaves. In most cases, leaves containing less than 50% moisture are crisp and brittle, and are extremely prone to shattering while the glands on them are easily damaged.

At mowing, mint is delivered into a windrow from which it is collected, chopped and delivered directly into the distillation vessel* using a forage harvester.

Thick windrows from heavy crops, or formed using a 'cutter-rower' or similar machine dry more slowly, and from the top down. Sparse windrows, on the other hand, dry evenly but change rapidly from green to over-dry in hot or windy conditions. This may appear self evident, and beyond the control of the harvest operator - obviously the former is preferable - it indicates a well-grown crop. However, every effort should be made in light crops especially where warm or windy weather is anticipated to provide machinery which will produce as thick a windrow as possible. This will provide the maximum flexibility for the harvest operation - less likelihood of a sudden change from 'wilted' to 'crisp' whereupon losses of shattered leaf and oil will escalate and harvesting should be suspended.

The importance of managing the wilting and collection procedure cannot be over-emphasised. In trials undertaken in Tasmania in 1992-3, it was shown that despite relatively favourable drying conditions, almost a third of the oil found in the standing herb crop was not recovered at the still. Sampling and measurements taken at each stage of the process showed that of 9.8g of oil/m² in the green crop, 0.15g remained in the stubble, 1.7g was lost during wilting and collection and 1.3g remained on the ground in uncollected herb, so that only 6.7g of oil was delivered into the vat. This result was confirmed in the commercial harvest of the same field 21% of dry matter, containing 27% of the oil was not collected.

* Separate transport systems have been used in Tasmania and in the US, but generally increase the opportunity for loss of leaf and oil, or overheating of the herb during storage. Any analysis of such a system should accommodate these problems and the associated costs.

Beside the obvious problems with losses arising from bruising of the herb during mowing/windrowing and failure to cut and collect all the herb from the ground, the single major contributing factor to this serious loss was the disintegration of leaves and glands due to overdrying. Dust generated during harvesting originates mostly from the oil rich leaf - not only is herb material lost, but it is the oiliest part of the herb which goes first.

Deciding when wilted herb is ready for collection requires fine judgement, accounting for weather conditions and the likely time to complete the task. Average moisture contents of more than 50% should be regarded as a minimum, with high pressure boilers enabling distillation at moisture levels up to 60%. Typically herb in this condition has soft, not crisp, leaf and pliant stems.

Operational targets are as follows:
• close mowing of herb
• delivery into consolidated windrow
• nil bruising, traffic damage or windrow disturbance
• wilting consistent with requirements of distillation plant, but as brief as possible
• efficient collection, chopping and delivery into distillation vessel
• minimal loss of dust
• distillation within 4 hrs before any composting can occur

In order to provide good management of the harvest operation a minimum level of record keeping is essential.

Paddock records, showing by vat the area (location and size) harvested, time since mowing and wind conditions during collection, should be maintained by the harvester operator. These will enable
• mapping of yield performance for the paddock
• improved management of mowing operation
• monitoring of loading and transport times
• early warning of low yields or unexpected losses

The still operator should be versed in simple analysis of these records, to assure himself of operating efficiency etc., but in any case the records should be collated with distillation records on a daily basis.

Distillation Operations
This discussion will not focus on details of distillation technology. Still design and construction has been approached from as many angles as there are practitioners, and although most follow a few basic rules, the hardware involved, the match between components and the logistics of operation are usually specific to the site concerned.

Several issues should be brought to the attention of the operator, however, to ensure efficient operation and again, careful record keeping enables helpful oversight by managers and inform decisions about plant upgrades.

Several studies of distillation in the US and Tasmania have demonstrated savings of 20-25% of steam by using high steam flows up to breakthrough and gradual reductions thereafter. There is no advantage in diluting the oil in large amounts of distillate, once the initial flush of oil has been delivered, and frequent checking of oil/water ratios enables steady reduction of steam flows as oil delivery falls during the last part of the distillation.

Most large distillation operations in Australia use the simple vapour-in-tube condensers which allow precise control of distillate temperatures and efficient use of cooling water for boiler feed. Visual evidence of distillate temperature ensures optimum separating conditions and early warning of overheating, coolant problems, pump failure, etc.

Distillation cut-off should be determined for every distillation, using a predetermined minimum oil delivery per 5 minutes or per litre of distillate. A basic minimum oil delivery should be established notwithstanding field and transport issues, based on cost of still labour, fuel and power only and compared with the price of oil less cost of sales. Operators will be able to use this cutoff for all distillations unless uncooked vats await distillation or transport back to the field is held up.

Operators should be warned against using a fixed distillation time throughout the day, with all distillation vats, over long periods of harvest or from field to field. Crop
composition (leaf vs stem), time since chopping, packing density and ambient temperature all affect the rate of oil delivery and significant quantities of oil per vat can be left in the marc if distillations are ended prematurely.

Minimum record keeping in the case of distillation operations includes vat arrival, steam on, distillation start and end times, boiler operation time and fuel consumption, oil flow profile for at least one vat per day (oil flow readings at 5 minute intervals from breakthrough). This enables determination of

• yield/hectare and yield/vat and sudden changes in either yield measure,
• monitoring of transport times,
• monitoring of boiler efficiency,
• calculation of fuel consumption,
• adjustment of distillation cutoff times

**Harvest Plan**

<table>
<thead>
<tr>
<th>Field Operations:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target Oil Composition:</td>
</tr>
<tr>
<td>Menthol: _________</td>
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<tr>
<td>Menthone: _________</td>
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<tr>
<td>Menthofuran: _________</td>
</tr>
<tr>
<td>Target Oil Yield: _________</td>
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<tr>
<td>Anticipated Start Date: _________</td>
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<tr>
<td>Mowing Equipment: Type:</td>
</tr>
<tr>
<td>Est. Mowing Rate: ______ ha/hr</td>
</tr>
<tr>
<td>Harvester: Type:</td>
</tr>
<tr>
<td>Est. Harvest Rate: ______ ha/hr</td>
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<tr>
<td>No. Vats: _________</td>
</tr>
<tr>
<td>Est. Vat Capacity: ________ tonnes wilted herb</td>
</tr>
<tr>
<td>Target Harvest Duration: ________ days</td>
</tr>
<tr>
<td>Record Sheets Prepared? Yes / No</td>
</tr>
<tr>
<td>Paddock Map / Grid system Provided? Yes / No</td>
</tr>
</tbody>
</table>

**Distillery Operations**

| Est. Cost Boiler Fuel, Power: ______ $/hr |
| Labour + On Costs: ______ $/hr |
| Total: ______ T$/hr |
Oil price less cost of sales: \( \text{OS/l} \)

Est. Distillate Flow Rates: \( \text{Dl/min} \)

<table>
<thead>
<tr>
<th>Cutoff Oil Flow* (16.7T÷DO) ml/litre distillate</th>
</tr>
</thead>
</table>

Target Distillate Temperature:__________

Target Minimum Separator Temperature:__________

Record Sheets Prepared? Yes / No

V: The Harvest Checklist

- The Harvest Plan is implemented as described.
- The following checksheets (1 & 2) are maintained by the field and still operators throughout, and the results collated on a daily basis and entered in a format similar to that below (3).
- At the completion of the harvest, a review of the season's activity and a post-harvest management plan are prepared.

1) Field Records:

<table>
<thead>
<tr>
<th>Location</th>
<th>Date</th>
</tr>
</thead>
</table>

FIELD RECORDS:

Harvester operator to maintain the following records.
This sheet to be delivered/faxed at the end of each day to the manager/other??

- 'Weather' - mild/hot/very hot; calm/light breeze/windy
- Estimate the area mown in hectares and note the location on the map provided
- Estimate the area and location of the harvest for each vat using the Paddock Map provided
- Note the time the vat departs the paddock.

<table>
<thead>
<tr>
<th>WEATHER CONDITIONS:</th>
<th>MID MORNING:</th>
<th>MID AFTERNOON:</th>
</tr>
</thead>
</table>

Area Mown Today

<table>
<thead>
<tr>
<th>Harvest Number</th>
<th>Vat Number</th>
<th>AREA Estimate</th>
<th>DEPARTURE TIME</th>
<th>Notes</th>
</tr>
</thead>
</table>

65
Paddock Map: Attached?
2) Distillery Records

<table>
<thead>
<tr>
<th>DISTILLERY RECORDS:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(Location)</td>
<td>(Date)</td>
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</tbody>
</table>

**STILL OPERATOR:**
Please keep the following records, using a new sheet each day.
The sheet is to be faxed/ forwarded to the manager at the end of each day.

- Weather refers to temperature and wind conditions
- Include in boiler times any prolonged downtime
- With gas supply*, note times and quantities of gas deliveries, litres and approximate change in % full, as shown on tank
- Vat number refers to the identity of the vat/trailer
- Note the approximate time of vat arrival from the field
- Temperatures at time of peak oil flow will help track possible losses and vat performance

*other fuel will require different records

<table>
<thead>
<tr>
<th>WEATHER CONDITIONS:</th>
<th>MID MORNING:</th>
<th>MID AFTERNOON</th>
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<thead>
<tr>
<th>BOILER START TIME</th>
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<tr>
<td>BOILER SHUTDOWN</td>
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<thead>
<tr>
<th>GAS SUPPLY:</th>
<th>% START:</th>
<th>% END:</th>
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<thead>
<tr>
<th>VAT/ TRAILER NO.</th>
<th>TIME OF ARRIVAL</th>
<th>STEAM ON</th>
<th>DISTILLATION BEGINS</th>
<th>STEAM OFF</th>
<th>DISTILLATE TEMP @ 15MINS</th>
<th>SEPARATOR TEMP @ 15MINS</th>
<th>VAT OIL YIELD (KG)</th>
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</table>
Oil flow Profile:
A minimum of one sample run should be conducted per 10 distillations. Time and collect, without spillage, one litre of distillate, allow to settle and estimate the quantity of oil collected.

<table>
<thead>
<tr>
<th>Time after breakthrough (mins)</th>
<th>Time per litre distillate (secs): T</th>
<th>Oil Yield ml per litre distillate (m)</th>
<th>Distillate Flow (F/(60÷T)) l/min</th>
<th>Oil Flow Rate (mF) ml/min</th>
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</table>

3) Harvest Summary

The following may be set up as a spreadsheet in which columns 1-7 are entered each day, and columns 8 - 12 calculate the results shown.

<table>
<thead>
<tr>
<th>Date</th>
<th>Harvest Location</th>
<th>Area Harv. (ha) A</th>
<th>No. Vats N</th>
<th>Total Oil (kg) O</th>
<th>Boiler hrs H</th>
<th>Fuel (kg) F</th>
<th>Area/vat A/N</th>
<th>Oil/vat O/N</th>
<th>Oil/ha O/A</th>
<th>Boiler vat H/N</th>
<th>kg Fuel/kg Oil F/N</th>
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VI: POST HARVEST REVIEW and MANAGEMENT

Review of Performance
The crop should be assessed in terms of **average yields** and **yields on specific areas / paddocks / growers / districts**.

The purpose of this is to identify:
• areas which can be regarded as setting a benchmark for future yield targets, and
• areas which perform in the lowest range of yields, to be appraised for removal or special attention, etc.

Each grower is required to address the question of paddock and area performance, and a forum should be in place for a non-threatening review of grower and district performance at the completion of each season. This allows 'district benchmarks' to be discussed.

**As far as possible reasons for less than expected performance, the extent of the problem and the degree to which the problem area fails to meet the target should be documented.**
This may require outside support in the form of soil analysis, pathology advice, aerial surveys, or simply 'brainstorming' by a small group of experienced individuals, including the agronomist or consultant.

On the other hand it is important to analyse why top-performing sites are so, and to attempt to incorporate these findings in the subsequent management plans for the whole operation.

Financial analysis
An essential measure of performance of the crop is Gross Margin Analysis.
In brief, this is an estimate of the difference between gross income (yield x farm gate price) and the variable cost of production (establishment, operational expenses and harvesting costs). Usually calculated as $/ha, the Gross Margin does not account for fixed costs, but provides a very useful indication of the performance of the enterprise for comparisons between alternative enterprises, between seasons and between peppermint crops at different locations.
Post-Harvest Management
All areas to be managed for mint production in the following season should be subjected to close attention post harvest and leading up to winter. As with most perennial species, peppermint herb depends to a large extent for its winter survival and initial spring growth on storage tissue laid down during the growing season.

This is not simply a question of early season vigour, which might be compensated for later in the spring. There is plenty of evidence from the US that mint in poor condition at the start of winter is particularly subject to attack from otherwise benign agents during winter and early spring. The inevitable soil compaction and poor aeration, depletion of macronutrients in the root zone, winter frost damage or waterlogging and damage to the aerial parts during harvesting all constitute major stress factors for the harvested stand. Soil dwelling nematodes and the fungus *Phoma spp.* in particular are able to attack unthrifty, damaged or weakened peppermint, apparently in combination, and it is these agents which have been most often implicated in 'peppermint decline'- the sometimes rapid deterioration of healthy stands of peppermint.

It is critical therefore to allow the herb to recover as far as possible before it moves into its winter dormant phase, recognisable by the recumbent stems, small leaves appressed to the stem and dark colouring.

Postharvest irrigation regimes should continue to maintain adequate available water for normal growth. Demand will fall after removal of the top growth, but in most cases significant depletion of the root zone occurs during the time taken to harvest the crop and an immediate full irrigation is usually required just to return the root zone to the 'available water' level. Similarly, a well managed crop will have drawn down the available nitrogen substantially by the time of harvest. Unless soil tests indicate otherwise, a postharvest nitrogen application is usually required.

Refurbishment of poorly performing or problematic areas within the crop may be undertaken at this time. Soil moisture conditions are more manageable at this time (with the aid of irrigation) than in spring, so that drainage, replanting and subsoiling operations are best conducted prior to winter.
VI: Post Harvest Checklist

Irrigation / Rainfall

<table>
<thead>
<tr>
<th>Area:</th>
<th>Rainfall (mm)</th>
<th>Irrigation (mm)</th>
<th>Total for Week (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week</td>
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<td>Commenc e.</td>
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</table>

Rainfall and irrigation should be monitored until field capacity is reached in the root zone and / or winter dormancy is evident.

Pre-Winter Nitrate analysis:

In order to assess the effectiveness of the fertiliser program in matching application to removal by the crop, a pre-winter soil analysis is useful, since excess nitrate will be leached from the soil during winter.

Sample Date:

<table>
<thead>
<tr>
<th>Sample Location</th>
<th>Soil Nitrate - N (kg/ha)</th>
</tr>
</thead>
</table>

Regeneration:

Location and Area (ha):

Procedure Employed:
**Gross Margin:**

<p>| | |</p>
<table>
<thead>
<tr>
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<tbody>
<tr>
<td><strong>Total Yield (kg):</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Farm Gate Price($):</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Area Harvested (ha):</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Revenue ($/ha):</strong></td>
<td></td>
</tr>
</tbody>
</table>

### Preplant Expenses:
- Weed Control
- Cultivation
- Fertiliser
- Other (fencing, drainage)

### Planting Expenses:
- Supply of Rootstock:
- Digging:
- Transport:
- Planting:
- Herbicide:
- Irrigation:

### Operations ($/ha):
- Fertiliser N:
  - Herbicides:
  - Fungicides:
  - Insecticides:
  - Irrigation:
  - Water Cost:
  - Monitoring and Sampling:
  - Mowing:
  - Harvester:
  - Transport:
  - Distillation:

<table>
<thead>
<tr>
<th>Total Costs</th>
<th>$/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross Margin</td>
<td>$/ha</td>
</tr>
</tbody>
</table>
3.4: Implementation

To extend the usefulness of the ‘Mint Manager’ beyond simple technical support for producers, and to initiate the feedback loop which will 'breathe life' into the system, an annual process of collation, review and revision of the package is essential.

Each grower must forward copies of the Checklists (listed below) to the nominated coordinator, and basic data will be extracted from these and entered into a database from which the following parameters can be investigated.

Checklists:
1: Prior Season: New Plantings
2: Site Preparation: New Plantings
3: Crop Establishment: New Plantings
4: Growth Cycle
5: Harvest
6: Post Harvest

Parameters:
Data will be arranged so that results and history for each crop (for each grower) can be extracted if necessary. Besides this, the important analysis is the comparison of yield results with the key crop records (eg previous crop, soil type, planting density, growing degree days, weekly water use, nitrogen nutrition, disease control, harvest management, gross margin).
4. References

A guide to Peppermint Insect and Mite Identification and Management. PNW 182. Oregon State University


Hughes A D (1952) Improvements in Field Distillation of Peppermint Oil. *Station Bulletin 525* Agricultural Experiment Station, Oregon State College, Corvallis


Mitchell A R (1996) Peppermint and Spearmint (East of Cascades) FG 69 *Oregon State University Extension Service, Corvallis OR*


Montana Mint Research Reports (1992- 1997) Reports for the Northwestern and Western Agricultural Research Centres: *Montana State University Agricultural Experiment Station*


Muni-Ram, Ram D, Singh S and Ram M (1995) Irrigation and nitrogen requirements of Bergamot Mint on a sandy loam soil under sub-tropical conditions. *Agricultural Water Management* **27** 45-54


PNW (182) A guide to Peppermint Insect and Mite Identification and Management. *PNW 182. Oregon State University, OR*


Yonts C D and Klocke N L (1997) Irrigation Scheduling Using crop water use data Nebguide G85-753-A, University of Nebraska - Lincoln (www.ianr.unl.edu/pubs/irrigation/g753.htm
5. APPENDICES

1: Research Reports
   L M Falzari and R C Menary (1999): Mint Propagation - Meristem Culture
   RJ Clark (1998):
       Mint Report: Report on Peppermint Production and Research in the US.
   C D Read (1992): Peppermint Harvest and Distillation Losses

2: Methods and Raw Results:
   A. Nitrate Sampling Procedures and Results
   B. Harvest Monitoring Results: Moyhu
Appendix 1

Production of Disease-Free Nursery Stock of *Mentha piperita* through Meristem Culture.

Dr L. M. Falzari
Professor R. C. Menary

2/11/2005

Introduction and Objectives:
Field grown mint shows a decline in oil yield with increasing age. It has been hypothesised that this due to a systemic disease such as a mycoplasma or virus, nematode infection, *Phoma* (or a complex of the two). It may be related to physiological aging of the crop, or to plant nutrition. The nutrition problem could be a micronutrient deficiency or the unavailability of phosphate due to fertilisation techniques used after establishment.

The objective of this work was to produce disease-free stock plants, through meristem culture. These would be used to establish a field nursery, for the production of material for comparative trials with a tip cutting nursery and current commercial crops.

Methods and Media:
Two mother plants were taken from a commercial field and transferred to the glasshouse. These were grown under conditions of natural light intensity and photoperiod, with a daily average temperature of 26°C and a night temperature of 15°C. They were fed weekly with normal Hoagland’s solution (see appendix 1). Under these conditions the plants grew rapidly. Each plant was multiplied by tip cuttings to produce approximately 300 plants from each mother plant. These were grown on, under conditions producing the rapid growth of material, ideal for use as sources of meristems.

*In vitro* cultures were established from the apical buds of these plants. Approximately 30 buds from each original parent (designated P1 and P2) were handled at one time. The bud, including the expanding apical leaves were excised into a screw top container and sealed, for transport to the laboratory. There they were washed under running water for two hours and surface sterilised in 1% sodium hypochlorite for two minutes. This was followed by three, five minute rinses in sterile distilled water. A preliminary trial showed that sterilisation times of greater than two minutes did not improve decontamination rates but did decrease the rate of culture establishment.

The meristems were aseptically transferred to sterile MS medium (see appendix 1) at a rate of 5 meristems per flask. The cultures were incubated in a controlled environment growth cabinet for 14 to 21 days. Cultures received a photoperiod of 16 hours with 22°C days and 15°C nights. Light levels during the photoperiod were approximately 50mE.

Following the establishment period, surviving meristems, showing no sign of superficial contamination, were selected for propagation. The rate of culture establishment was approximately 2%. These cultures had generally produced a stem approximately 3mm in length. This was excised in the laminar flow, the meristem removed with minimal cutting and transferred to fresh medium. These meristems took approximately four to six weeks to establish. The success rate was approximately 30%. A total of 24 lines were produced in this manner.

These cultures were periodically sub-cultured, at which time the shoots were cut into single node pieces, with the exception of the apical tip which contained one node plus the apical bud. Each flask contained a maximum of ten explants. Sub-culturing took place when the explants had put on sufficient growth to reach the top of the flask. After the initial establishment phase, there were two sub-culturings before weaning began.
On this medium, the cultures produced roots from most nodes. At sub-culturing these roots were generally trimmed or removed. Cultures were weaned directly from this medium without the need for a specific root induction medium. Cultures were weaned when the explants had put on sufficient growth to warrant sub-culturing i.e. they had reached the top of the flask.

At weaning the plants were removed from the flasks and the agar removed by washing the explants in a solution of 2ml/L Previcur®. This also served to protect the plants from fungal pathogens during the weaning phase.

The potting mix used was an open, free-draining mix of sand and composted pinebark (see appendix 1). Plants were placed in this medium, in 48-cell speedling trays, under mist, for one week. They were then transferred to the glasshouse with a natural photoperiod and ambient temperature, with a maximum daily temperature of 25°C, i.e. with no heating but with coolers cutting in at 25°C. The plants were weaned in two batches.

Following weaning, plants from the first batch were multiplied by cuttings to increase the number of plants to the maximum number possible for the glasshouse. These cuttings were taken as “splits” with each cutting having roots present. Neither mist, nor other special conditions were used.

Weaned plants were fertilised regularly with a modified Hoagland’s solution (see below). This modification was a reduced nitrate, increased ammonium concentration and was only carried out for ease of handling. Other plants in the glasshouse required this solution and it was not deemed to be detrimental to the mint plants.

The glasshouse propagated material required remedial treatment for rust and was regularly treated with a mixture of Dithane® and Tilt®. It was also treated with Pirimor® for aphids.

The field nursery occupied an area of approximately 0.25ha. Soil preparation included fumigation with Nemacur® at a rate of 800ml/ha and treatment with Sinbar® at a rate of 1.5kg/ha. N:P:K fertiliser (9:14:17) was applied at a rate of 200kg/ha. The mint was planted in beds 1800mm wide with three rows per bed. They were planted with a speedling planter. Inter-row spacing was 450mm and intra-row spacing 350mm. The plants were irrigated with overhead sprinklers. The plants received regular treatment with Tilt® and Dithane® for the rust infection and treatment with Omite® 200g/100L water for two-spotted mites. It will receive 100kg Nitram® in 20kg applications over the growing period.

**Potting medium**
10L coarse river sand
40L composted pinebark
200g dolomite
200g Osmocote plus®
25g FeSO₄
25g Micromax®

**Normal Hoagland’s solution**

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<tr>
<td>MgSO₄</td>
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<td>KNO₃</td>
<td>0.505g/L</td>
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<td>Concentration</td>
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<tr>
<td>--------------</td>
<td>--------------</td>
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<tr>
<td>Ca(NO₃)₂</td>
<td>1.180g/L</td>
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<tr>
<td>KH₂PO₄</td>
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<tr>
<td>MnCl</td>
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<tr>
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<td>H₃BO₃</td>
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For the modified version, KNO₃ was replaced with KCl and (NH₄)₂SO₄ as follows.

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MS medium

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<tr>
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<tr>
<td>Glycine</td>
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<tr>
<td>Difco Bitek Agar</td>
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Results and Discussion

A total of 9264 plants were produced through a combination of tissue culture plants and cuttings. Tissue culture produced 3582 plants in batch 1 and 2042 plants in batch 2. The number of cuttings produced was 3640.

The \textit{in vitro} multiplication rate was calculated using the formula for compound interest (see Table I below). This gave a weekly multiplication rate of approximately 0.2. Based on this figure the cultures would double every four weeks.

No experiments were carried out to find the optimum cycle time for sub-culturing. In calculating the multiplication rates, no estimate of the age of the cultures was taken into account. It is probable that those cultures with low multiplication rates were younger and had not yet reached their maximum multiplication rate. A further observation is that the multiplication rates are generally lower for the second batch of cuttings. This suggests that the 14 week cycle was too long.

The plants, particularly the first batch were held for too long in the glasshouse. Plants from the first batch were weaned in April and not planted in the field until October. Once the plants became root bound, they succumbed to rust. Weekly application of Tilt® and Dithane® did not control the infection. This has led to the field nursery having a systemic infection, which could not be controlled in the current season. The second batch of cuttings, weaned in July and planted in October, were somewhat better but were still root bound at the time of planting out. In hindsight, these plants should have been used to produce cuttings and then discarded. This would have left young, actively growing material, possibly free of rust, in the glasshouse.
6. Recommendations

If future field trials show meristem culture to improve field oil yields, it is recommended that the following programme be used to produce the field nursery.

Ten lines of mint should be initiated in culture. This requires the excision and sterilisation of approximately 2000 buds, given a 2% success rate of surviving sterilisation and a 25% success rate of culture establishment from the sterile buds. The cultures should then be multiplied to produce a total of 1000 explants, which can be weaned into 48 cell speedling trays. These parents can then be used to produce one generation of cuttings and subsequently the parent material discarded. The parent material should not be held in the 48-cell trays for longer than eight weeks. These cuttings then become the parent material for the next generation of cuttings and the procedure may be repeated until the required number of plants produced for transfer to the field nursery. Rejection of the parent material, results in the quality of material transferred to the field nursery being enhanced.

Summary:
The objective of this work was to produce disease-free stock plants, through meristem culture. These would be used to establish a field nursery, for the production of material for comparative trials with a tip cutting nursery and current commercial crops. Meristems were taken from cuttings produced from two original parent plants. A method was developed to multiply these through tissue culture to produce disease-free explants ready for weaning. These plants were weaned and further multiplied by cuttings to produce a total of 9264 plants. These were transferred to the field nursery.

The aim, to produce disease-free plants, was achieved to the point of weaning. Under the glasshouse conditions, rust became a severe problem and this was carried over into the nursery. In future, it is recommended that plant material not be held under these conditions for longer than eight weeks. If glasshouse storage becomes necessary, it is suggested that cuttings be taken at regular intervals and the parent material discarded. This will maintain a population of actively growing plants and rust should be more easily controlled. No results are available, as yet, on the comparison of this physiologically younger stock with the current commercial nursery Astock. The benefits of taking plants through a tissue culture phase to rejuvenate the stock material, is yet to be established.
Report on aspects of the US peppermint oil industry reviewed by Professor Clark during study tour May - August 1998.

Mint Production and Research in Montana

• Some industry information;

Spearmint
Both native and scotch spearmint are grown in Montana but native is considered to be more winter hardy than scotch (both more susceptible than peppermint). Price and yield of spearmint is as follows;
Scotch - US$12/lb with 110lbs/acre with 2 harvests
Native - US$10/lb with 90 lbs/acre with 2 harvests

Peppermint
Significant production commenced in about 1960’s and area increased to ~ 9000 acres, in the mid 1990’s - now about 6300 acres. The decline in acres has been largely due to
- the weak market for peppermint oil (current prices only about $US8/lb and NWARC and growers suggest a price of ~ $US11 to 12 is needed for break even at a yield of 60lbs/acre)
- expiry of sales contracts with the major mint companies - Todd, Callison, Leman. New contracts for peppermint are being offered at about $US8 to10 /lb but growers are not signing
- few have contracts for ‘98 production and many are considering or already have ploughed some fields out.

The average yield for peppermint is about 60lbs/acre with best yields reaching 100 lbs and there is some suggestion that average yields have declined since the early 1990’s - from about 75lbs/acre while hay yields have continued to be very good. Crops are generally very vigorous and there is some suggestion that the maintenance or increase in hay yields and decline in average oil yields - corresponded with the planting of vigorous planting material - some arising from meristem culture and nodal cuttings. While the main peppermint variety grown is Black Mitcham - there is reasonable evidence to suggest that there may be several selections of Black Mitcham, all showing different phenotypes especially with respect to
vigour. In addition to this phenotypic variation in the mainlines of Black Mitcham, there are several named selections of “Black Mitcham” grown either commercially or in plots - including Murray Mitcham and (Don) Roberts Mitcham. Currently germplasm or mother plants of all mint, for all States, are held by a Mint Industry Research Council authorised propagator (Summit - Fort Collins, CO). Material is released from Summit to other propagators, generally as in vitro rooted plantlets. These propagators may then offer stem, nodal or meristem propagated nuclear plants to growers who plant into their nursery fields in spring, grow through the first season - usually without harvest (perhaps some hilling to increase stolon and rhizome production) and then lift and fall plant into their fields. Nuclear propagators include two at Ronan, MT - Lake and Starkel

Roger Starkel
Starkel Plant Lab
4284 N. Foothills Drive
Ronan, MT 59864
Phone 406 675 8231

Jan Lake
SPUDMAN@RONAN.NET

Planting Material

Considerable confusion exists with respect to type of planting material available for growers. Both propagators source material from MIRC. Both retain stock plants from previous MIRC releases as well as other introductions (e.g. UK) and neither use the Corvallis Germplasm Repository. Much of the reported difference in available material relates to the different ways growers handle material supplied to them from MIRC.

Generally propagators receive in vitro plantlets of mint from MIRC but sometimes small rooted plants. Regardless of the type of material, Starkel’s heat treat the material (34oC to 36oC for 6 days) and then surface sterilise with a weak chlorine based sterilant followed by distillate water. Starkel’s then excise the apical meristem along with no more than the first leaf pair and place this tissue on a “filter paper bridge” in a 150mm long by 20mm diameter test tube containing a standard liquid culture media. If successful the meristem grows over several weeks to the point where it can be transferred to solid media for growth. Should callus appear at any time during the process the culture is rejected. The risk of somatic mutations in callus is considered too great to risk propagation from callused cultures. The shoot which is transferred from the liquid culture grows and the stem produces nodes. These nodes, which are about 1mm x 10mm stem segments are cut and put on to culture - and the process repeated. Once sufficient material is available, node cuttings are allowed to root in media and then planted as open rooted plants into soil beds in a glasshouse. Once established in the glasshouse these plants are lifted as open rooted nuclear plants and supplied to growers (about 7,000 to 10,000/acre at about US 50 cents/plant. Propagators continually cut and renew their specimens of each “strain” and use this material to start subsequent bulking up programmes. Starkel’s produce some 300,000 plantlets/year and deliver to several US States, including stolon propagators in Idaho - who eventual ends up selling material back into Montana. The above material is referred to as MERISTEM MINT. Lake’s follow almost an identical procedure with the exception of the meristem cultures. Lake’s do not heat treat or return to meristem but take nodal cuttings from material supplied by MIRC. Lakes finally transfer the in vitro cuttings to small cell trays rather than open rooted into glasshouse soil beds. The Lake’s material is referred to as NODAL MINT and they produce some 100,000 plantlets per year. Both propagators have their checked for verticillium wilt and general cleanliness by the plant pathologist at Western Montana Agricultural Research Station and
both use clear “punnet” type trays with an aeration hole covered with filter tape. Trays are poured 10 days before use and any contaminated trays are discarded.

* Pests and diseases include verticilium wilt, powdery mildew, rust, mites and bud worms
* Spearmint is frequently double harvested with first harvest taking place in early to mid July.
* Peppermint is seldom double harvested - mostly due to problems with winter kill.
* Winter kill (temperatures can reach - 25 to - 30oF below) can be a very significant problem and there is some evidence that the more vigorous meristem and in some cases nodal mint - is more winter hardy.
* Terbacil remains the main stay for weed control. Tilt is not registered for mint and Rally is the approved fungicide.
* Harvest date tends to be based on grower observation of their crops, calendar date and the presence or absence of pest and diseases - usually takes place in early to mid August and to avoid excessive winter kill harvest should be completed by mid to late September. Harvests is usually scheduled for about the same date every year even though data reported by NWARC shows “growing day degrees” in Kalispell varied from 1376 to 1853 (Mean 48 year Average = 1683.5) from May 1 through to Sept 15. GDD calculated as ([Temp Max + Temp Min] div 2)-50, when min temp less than 50 substitute with 50
* There are about 13 distillation units in the valley and many growers choose to have their crops “custom distilled” - at a cost of $US3/lb for all operations except swathing. Swathing is also often done by contractors - and hay is left in large swaths for 4 to 14 days depending on the weather. Ideally moisture is reduced to about 30% before collection.
* Distillation times vary with distillation units but are typically 20 to 25 minute break through followed by 40 to 50 minutes cooking time. Distillate temperature is maintained at about 105 to 110oF (and is considered critical) and one distillation unit - reported distillate flows of 6 quarts/minute as being reasonable - about 1 vat per acre of spearmint, yielding ~85lbs of oil - and it was costing $US26/vat for fuel and labour - not including the still operator, the chopper driver or the owner manager’s wages (Source of information = Farmer named Clyde Fisher (Montana representative on MIRC) near junction highway 35 and road to Columbia Falls).
* There is some evidence that returning the mint waste to mint fields increases stolon decay!
* Post harvest irrigation and fertilisation is vital to subsequent years’ crop yields!
Some comments, questions and conclusions from reading the MSU 1997 Report, inspecting field plots and discussion with Leon Welty

Over the last 6 or so years much research has been done at the NWARC by both Leon Welty and Mal Westcott. This work has focused on nutrition (Westcott) and variety, winter kill, source of planting material, etc. (Welty). While the standard of maintenance and attention to detail in field experiments is the very highest - for a variety of reasons including lack of uniformity within plots (e.g. 1998 N Trial) and the fact that data was collected from one harvest only - despite recognition that maturity often varied with treatment, and as a result of quite significant confounding within trails (mostly relating to sources of planting material) - care is needed in interpreting data presented in annual reports and much of the work should be extrapolated with much caution - in many cases it should not be seen as the definitive work, that at first it may appear from reading abstracts, etc. This difficulty of working with mint and the complexity of source of material, etc. was openly recognised by Leon Welty. Despite the above problems much useful data can be drawn from work completed and under way at NWARC.

Source of Planting Material and Crop Vigour, Hay and Oil Yield

Trial 1 Evaluation of Cultivars in the Presence and Absence of Vert Wilt
* The Black Mitcham stocks came from different sources;
Nodal = Lake’s, Meristem = Starkel’s and Stem Cut = Robert’s (Summit)?
Lake’s and Starkel’s source their material from MIRC but there is little evidence that the MIRC a “clonal” collection. To the contrary, as suggested from later work where there was shown to be differences between individual plants from MIRC and “bulk” or MIRC plants - the MIRC stocks of Black Mitcham - might be a collection of genotypes/phenotypes!

Summary of Data - 3 years data to 1997
1. Stem - cut (77) outyielded meristem (65) and nodal (70)
2. Black Mitcham (77) out yielded Robert’s (71), M 837 (70), T845 (65) or Murray Mitcham (67)
3. Meristem produced more hay!
4. There are quality differences between the sources of material at mid bloom but R3 site had very high menthofuran (7 to 9%) and low menthols (37 to 39%)
5. Potential confounding of this trial includes - variation in source of planting stock(genotype/phenotype), variation in harvest date - all harvested on same even though there were observed differences in vigour/growth and subsequently yield and quality - should have established yield and quality profiles with time!!
Trial 2. Black Mitcham Peppermint Propagation Trial

Comments - again the confounding between sources of material - Lake’s and Summit Labs.

Trial 3 Black Mitcham Peppermint Propagation Trial

Source of material
* Single plant form MIRC Black Mitcham Mother Block
* Random Selection from MIRC Black Mitcham Mother Block
* A contaminated culture from Lakes

Comments - while reasonable efforts were made to eliminate the confounding effects due to source of material with all coming from “known” sources some other confounding effects were introduced to this trial, namely
* meristems plants from the single and random selection differed in their production - with the latter not being heat treated.
* at the time of planting there would have been significant differences in the physiological age of plants and their vigour and stage of development.
* only one harvest date!

Conclusions drawn from this trial were that there was a difference between meristem and stem - cut material in oil yield and hay yield - with the meristem yielding more hay and less oil. There was a difference between stem cut from a single plant compared with from the random selection with the random selection yielding more oil. That this difference didn’t exist between plant origins when nodal or meristems were used - it was hypothesised that the nodal and meristem culture technique may have eliminated the factor and that the single plant choose was “free” of the factor relative to the random selection.

(To Steve Lommel from North Carolina University in collaboration with Dr Fred Crowe from OSU at Central Oregon - are working on the identification of the factor)
* Unlike one of the previous studies - menthofuran was very low (1 to 2%). The harvest date trial (Trial 4. Peppermint Fall Harvest Date Trial) showed that in 1997 both yield and quality varied dramatically over the harvest period - yet in 1996 this wasn’t observed - more reason to think that preharvest sampling would be worthwhile. Perhaps the earlier trial with high menthofuran was harvested too late.

Trial 5 Early Season N Fertilisation of Peppermint

* Are the leaf nitrate measurements of any value given that they didn’t show much change between 0 and 240 lbs N/acre?
* Large variation in stem nitrate between seasons
* Why is it necessary to use different methods of application of urea and urea - ammonium nitrate, latter being sprayed onto foliage?
* Why would Treatment 2 be expected to have such a bad result?
* Comment on danger of excess rain

Other questions - effective rooting depth? Is 4ft too deep for active root N uptake?

When the 1998 nutrition experiment was inspected there was very severe burn from the Urea-Ammonium Nitrate treatment and there appeared to be a very large variation across the trial site, both of which would make it very difficult to draw many conclusions regarding oil yield. Similar burning has been observed in the past and so data needs to be interpreted with some caution.

Some observations, conclusions - RJC
1. Commercial Production

All crops appeared to be very vigorous with large leaves, little lateral branching, very thick stems and lots of senesced leaves - even at a stage judged to be about 3 weeks before harvest. This is all quite consistent with the seemingly very fertile, alluvial sandy soil, good husbandry and very adequate N and irrigation applications - combined with a very mild/cool growing environment with long summer days. Some crops which were “neglected” with respect to N and irrigation show signs of stress but have also been observed to yield good oil and not too much hay. All this is consistent with the model of “producing and retaining the maximum number of small oil rich late produced leaves” - in order to maximise oil yield.

2. Miscellaneous

- Oil Analysis is performed by oil buyers - even experimental samples
- No yield or quality determinations before harvest
- No QA on quality before submitting to buyers
- No regional association between growers to address issues of marketing, QA, etc.
- Fields were irrigated using either central pivots or rolling aluminium lines. Some details on rolling Al lines is as follows; 1/4 mile long, 4” x 40ft pipes, irrigates 10 acres in 6 shifts at 3 hrs per shift. To ensure adequate irrigation capacity one line is usually assigned to 10 acres. The cost of a 1/4 mile unit is ~US$7000.
- NWARC has recently commissioned an experimental still, based on the Lewis McKellup/Hacher model. Seems there are now three of these stills in US (McKellup - Idaho, NWARC Kalispell, Montana and Prosser, Washington. The still cost US$40,000 with open shed and second hand boiler, with much of the construction and commissioning being in kind from NWARC staff. (While the plumbing, condensers, temperature control are quite elaborate - the stills process little more than UTas lab stills and the separators are more likely to introduce errors with smaller samples. It is difficult to see the advantage of these stills over the UTas lab stills. (Experimentally oil yields are measure as a volume in a collection arm of the separator - not very precise!)
- Montana growers levy all mint US8 cents/lb - six of which goes to support MIRC research initiatives and projects and two remains with the Montana growers to fund local initiatives. There is also a growers association in Montana who collect an annual membership from growers (a few hundred $/yr/grower) and this fund is used to support Montana R&D - such as a $25,000 contribution to the experimental still.

Reference
Mint Industry Research Council (1998) - Public Information

General Industry Information
Commercial mint was introduced to the US in the early 19th century. Commercial production in the Pacific NW started around 1920. Mint is grown primarily in eight states - Idaho, Indiana, Michigan, Montana, Oregon, South Dakota, Washington and Wisconsin, where an average of 62500 hectares of mint are produced annually. 80 to 85% of this area is peppermint, with the balance being spearmint. Annual production of mint oil is approximately 5 to 6,000 tonnes of oil. This accounts for 70% of the world’s peppermint and spearmint production. On average the Midwest States produces 40 kg/ha and the Pacific NW approximately 80 kg/ha.

The MIRC provides about US$400,000 /annum on mint research with about 50% directed to developing new varieties, pest management (25%) and integrated pest management (25%).
Commercial Information

Oil Yields

- Peppermint prices in traditional higher priced production areas have decreased recently from a position where growers in Montana were operating on 3 year contracts at a price of about US$15/lb to a position now where few growers in Montana have any contract and prices are US$8 to 10/lb. There is tremendous opposition to this price, growers are reluctant to enter contracts at this price, some will hold oil and others will leave the industry. The area in Montana which increased rapidly in the early 90’s from 1000 ha to a maximum of about 4000 ha, over the last year or so the area has reduced to 2700 ha, largely as a result of price and non contract renewal. It has been suggested that the rapid expansion which was encouraged by buyers through offering 3 year contracts to growers (very attractive to growers and their financiers since few crops are grown on contract in Montana), may have been too rapid and have selected some lower performing growers. Many of the lower performing growers have now left the industry. The average yield of oil decreased from the early 90’s to late 90’s. Some attribute this decrease to the entry of new lower performing growers, others attribute this to introduction of more vigorous varieties of Black Mitcham.

Oil Prices

- Traditionally in the US, large users of mint oils (e.g. Colgate, Wigleys and Proctor & Gamble) preferred to purchase oils from buyers (e.g. Todd, Callison, Leman) on the basis of “district identity” (e.g. Midwest, Madras, Willamette, Columbia Valley, Idaho, Yakima, Montana, South Dakota) and all blending and “engineering” of oils was done by the users of oils. It is claimed that this reliance upon district identity meant that to satisfy users needs, buyers depended on a reliable supply of oil from all identified districts - requested by users. Buyers had almost no flexibility in sourcing oils and competition between buyers maintained oil prices at a high level in districts where supply was most limited (e.g. Madras, Willamette, Midwest, Montana). It is claimed that this situation has changed and now buyers do the “engineering” of oils and supply to the users on specification and not on the basis of “district identity”. It is considered that this gives the buyers more flexibility to purchase and blend oils and makes them less dependant upon any one district oil type. Hence competition for oils from higher priced districts has weakened. This weaker competition has resulted lower prices in these districts.

Oil Quality

Buyers generally offer a standard price for oil coming from a district but occasionally have the provision to discount on high menthofuran levels. But in districts such as Montana where menthofuran is not generally an issue within the district, no premium is offered above the district price, for lower menthofuran levels. Similarly in the Yakima Valley where high menthofuran levels are usual, the district price reflects this and growers are seldom penalised for higher menthofuran. In fact buyers expect to receive a range of oil qualities - within the general district descriptions, and actively discourage growers and distillers from blending to “improve quality” or to ensure oils meet district specifications. This practice would in the opinion of the buyers, reduce their flexibility to blend and “engineer”. Consequently district specifications are set very wide with little incentive for growers to manipulate harvest date or production strategy to control quality. Therefore production and harvesting strategies focus on maximising oil yield with little emphasis on quality - apart from ensuring oil is free from taints, caused through weeds or poor distillation.

Reference
Scott Bolton felt that given the flexibility and capability of buyers to “engineer” oil blends, that there would never be a return to past higher prices for districts such as Montana, Madras, etc. (He also included Australia and Canada in this higher priced category). He felt that growers would need to base long term projections on US$11 to US$12/lb and maybe lower and not US$15 and higher. He suggested that producers such as Mick Brown, Royal City, Washington in the Columbia Valley who has 10,000 acres has a production cost of less than US$9/lb. This is obviously a “buyers position” and fails to recognise that in order to “engineer” buyers need a range of oil qualities. Should any quality type become in shorter demand, the laws of supply and demand will again prevail and price differentiation return, albeit possibly to a lesser degree due to the buffering ability of buyers “engineering”.

Production Issues

• Autumn plantings were considered higher yielding than spring plantings

• Crop scouting, irrigation (application method and rate), nitrogen nutrition, rust control and establishment from nuclear planting material were all considered to be of utmost importance to high yields. These were considered to be areas where Australia needed to focus - if yields were to improve.

• Winter kill in Montana is still considered the major district problem.

• It is generally recognised that there are different “strains” of Black Mitcham that have arisen through the MIRC mother block system and subsequent propagator multiplication system. MIRC requires that propagators return to MIRC for new mother plants each year and discard all previous releases or generations of material. However, propagators visited have retained almost all releases and continue to offer clients past MIRC released strains. For example, the 1992 Black Mitcham strain is considered most vigorous and is in demand from stolon growers - perhaps all for the wrong reasons since whilst it grows vigorous stolons, it may be low oil yielding.

A.M. Todd, International

Todd has an international programme in India (UP and Punyup Districts ??) and China (Chenshe District ??) and possibly some in Argentina. In India, especially in the Punyup) Todd has replace many of the 15 or so “middlemen” in the supply chain by establishing contracts with distillers, providing distillation equipment and technology and nuclear nursery material. The company has been operating in India for about 5 years and this year expects about 1000 acres of production. Peppermint is grown as an annual crop after cereal and before rice and so fits well into existing rotations.

The situation in China is reported to be much more difficult. In the areas where mint grows best, mint would need to replace wheat within the rotation. Wheat is an “official food crop” and its production closely regulated by the government. It is Todd’s opinion that given the culture in China where farmers are much more controlled by and look to the government for advice and assistance and have significant resistance to producing non food crops ( - little point selling mint oil for money to buy food in a famine if there is no food to buy!) - there will always be difficulty reliably expanding production.

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Report Of An Investigation Of Losses Of Oil And Herb Dry Matter And Changes In Oil Composition During Peppermint Harvest And Distillation Undertaken During The Harvests Of 1991 And 1992.

Chris Read, School of Agricultural Science, University of Tasmania, Hobart

INTRODUCTION

In 1992, three trials relating to the harvest and distillation of peppermint were undertaken. The first of these set out to determine the fate of oil and herb dry matter during the mowing, harvest and distillation of peppermint using the standard equipment widely used in the Tasmanian industry. The harvest and distillation procedures at a site in the Derwent Valley were examined in detail, revealing losses of oil and dry matter and changes in oil composition at each stage of drying, harvesting and distillation.

The second, established that the composition of peppermint oil changed dramatically during harvest in the commercial situation, and the third showed that changes in composition occurred in the course of the distillation, and that regulation of the first and last parts of the distillation may have an important bearing on oil quality. Recommendations for efficient mowing, harvesting and distillation are provided together with some useful statistics for harvest planning and management.

I: Losses of Oil and Leaf During Harvest and Distillation of Peppermint in Tasmania

MATERIALS AND METHODS

Herb samples were collected from the site at Fenton Forest during the month preceding harvest, at mowing and at harvest. Three samples (1 m² quadrat) of standing herb were collected on two occasions (17/1 and 27/1) in January and once immediately before mowing (7/2). Three samples each of mown, harvested and distilled herb of roughly equivalent size were collected from the mown windrow (16/2), the spout of the harvester and from within the three vats during harvesting. Dead, fallen leaf beneath the canopy at mowing, unmown mint stems, and wilted herb left on the ground after forage harvesting were collected and dry matters determined. For all other samples, oil content was assessed by laboratory distillation for a minimum of two hours and dry matter content assessed on a subsample by drying in a forced air draught oven to constant weight.

During the commercial harvest, nett weights of herb, oil recovery and samples of the marc were taken for three vats and the area harvested for all three vats recorded. Samples of cooked herb were collected from each vat and distilled in the laboratory for a further 2 hours to ensure complete exhaustion of the oil. A simple solvent trap was installed after the separator for one distillation as a guide to oil losses in the discharged distillate.

The sampling at harvest was repeated for two other harvesting operations to examine the condition of the herb at harvest, and to detect changes in moisture and oil content.
RESULTS

Results are expressed as means for three replications unless otherwise indicated. Dry matter and oil yields of standing crops (17/1, 27/1, 7/2) are given in Table 1. The mean dry matter yield metre\(^2\) for these three dates (727 g m\(^{-2}\)) is used to estimate dry matter remaining in the windrow and entering the harvester. From these estimates, the dry matter and oil yield per square metre of the material collected by the machine may be estimated. These calculated results are given in bold type in the Table I.

### Table I: Dry matter and oil yield /metre-2

<table>
<thead>
<tr>
<th>Sample</th>
<th>% DM</th>
<th>% Oil by DM</th>
<th>DM g m(^{-2})</th>
<th>Oil g m(^{-2})</th>
</tr>
</thead>
<tbody>
<tr>
<td>17/1</td>
<td>18.38</td>
<td>1.42</td>
<td>711</td>
<td>9.96</td>
</tr>
<tr>
<td>27/1</td>
<td>18.1</td>
<td>1.38</td>
<td>775</td>
<td>10.1</td>
</tr>
<tr>
<td>7/2</td>
<td>22.92</td>
<td>1.36</td>
<td>696</td>
<td>9.33</td>
</tr>
<tr>
<td>9/2 windrow (wilted)</td>
<td>32.87</td>
<td>1.23</td>
<td>613</td>
<td>7.56</td>
</tr>
<tr>
<td>16/2 Harvest w’row</td>
<td>49.6</td>
<td>1.30</td>
<td>613</td>
<td>7.99</td>
</tr>
<tr>
<td>16/2 Harvest spout</td>
<td>52.47</td>
<td>1.16</td>
<td>564</td>
<td>6.54</td>
</tr>
<tr>
<td>16/2 Harvest vat</td>
<td>51.03</td>
<td>1.18</td>
<td>564</td>
<td>6.66</td>
</tr>
<tr>
<td>LSD P&lt;0.05</td>
<td></td>
<td></td>
<td>0.16</td>
<td>1.68</td>
</tr>
</tbody>
</table>

Uncut material remaining after mowing (stem only) accounted for 114 g DW m\(^{-2}\). Experimental separations and distillation of mint leaf and stem material revealed that in general, leaf representing 40% of fresh weight of herb (at 70% moisture), contained about ten times as much oil as stem on a dry weight basis and accounted for about 73% of the oil in the plant. Stem material contained only about 0.12% oil by dry matter and the loss of the uncut stubble should have increased average oil content in the remaining material. In fact, oil content fell significantly after mowing suggesting that a substantial but unidentified loss of oil occurred after mowing and prior to harvest.

The assumption that the mown windrow still contained 613 g DW m\(^{-2}\) was used to calculate oil yield metre\(^2\) for the windrow. Similarly samples of wilted herb remaining after harvesting were collected, adjusted for dead leaf material lost before mowing and used to estimate total dry matter gathered by the machine (564 g DW m\(^{-2}\)), and therefore oil yield metre\(^2\) passing into the machine. The uncollected herb, predominantly short leafy stems and broken leaves represented about 8% of the dry matter in the windrow at harvest and a substantial loss of some of the best material, although the results do not show a statistically significant drop in oil content at harvesting.

The result of the commercial distillation conducted on three vats is summarised below

- Total area harvested: 9283 m\(^{2}\)
- Total DM in three vats: 5358 kg = 577 g DM m\(^{-2}\)
- Total Oil Recovered: 68.4 kg = 7.36 g oil m\(^{-2}\) (or 1.28%)
- Oil present in cooked herb: 0.03% by DM; < 0.2 g m\(^{-2}\)

The trial results and the commercial harvest are compared in Figure I. Although difficulties were experienced with the solvent trap, (the trap was inadequate for the distillate flow and much solvent was lost from the trap during the distillation), a total of 415.5 grams of oil were recovered in one distillation - the equivalent of about 1.3 kg ha\(^{-1}\).

DISCUSSION
During the 1991 harvest, samples of windrow, spout delivery and material from within the vat were collected and revealed substantial losses of dry matter, particularly leaf, which took with it a higher than average percentage of oil. This was estimated to amount to almost 30% of the oil present in the windrow at the time of harvesting. The crop concerned was typical of those harvested during the season, producing about 490 g dry matter m\(^{-2}\) and 6.52 g oil m\(^{-2}\) and at the time of harvest the windrow contained 29% moisture.

During the 1992 trial the circumstances of the harvest at the experimental site were very different, and far more favourable for minimising losses of oil and dry matter. Dry matter and oil yield per square metre were almost 50% higher than in the 1991 experiment (727 grams and 9.8 grams respectively), but most importantly, the windrow contained almost 50% moisture at harvest and losses during the collection and delivery of the windrow into the vat were not of the order of those recorded in 1991.

Nevertheless, this trial suggested that of the 9.8 g metre\(^{-2}\) oil in 727 grams of dry matter per square metre at mowing, only about 6.7 g of oil and 564 grams of dry matter are ultimately collected in the vat. The order of this loss is confirmed by the commercial collection of material from almost one hectare at the site, totalling 577 g dry matter metre\(^{-2}\) and delivering about 7.4 g oil metre\(^{-2}\). This represents the successful recovery of about 76% of oil from the field (see Fig I).

Stem material represented 60% of the dry matter of typical samples in this field at the time of mowing, and the stubble amounted to 25% of this - a significant benefit to the harvesting operation with minimal loss of oil.

However, after mowing and during drying of the herb, oil content in the windrow fell very significantly (p<.05) to 7.99 grams metre\(^{-2}\) despite the exclusion of this stubble. The long delay to harvest (nine days - the very heavy windrow was slow to dry in the prevailing cool conditions) may have been a factor here.

The results also show a significant (p<0.1) drop in percentage oil in the herb during the harvest itself, probably due to the failure of the harvester to collect some leaf and, but implicating other losses of oil without associated dry matter, since total loss oil exceeds that found in even the leafiest of material (2.7% - see Fig I).

Negligible differences between dry matter and oil contents of herb delivery from the spout, and herb collected and lying uncovered in the vat suggests that loss of water and oil due to the draught passing over the chopped herb was not detected in this experiment.

Failure to collect good quality leaf and stem at harvest is a serious problem, and clearly there is room for improvement and careful attention to the condition of fields, the harvester pickup and the matching of ground and reel speeds as well as the direction of windrow mowing and collection is required to keep these losses to a minimum.

It should be stressed that in the crop in question, the ground surface, the efficiency of the mowing and the moisture content of the material would have favoured efficient collection, and that the circumstances of many sites and harvest operations would certainly result in greater losses than those observed here. In particular, overdrying the crop, as often happens, can seriously worsen losses at all stages of the harvest operation, as indicated by the 1991 trial.

The use, in this case, of a cutter/rower for mowing the herb resulted in negligible losses of oil in uncut herb, greatly reduced harvest time (travel in the field) and steady, if slow drying of the crop. In hot, dry conditions a windrow such as this provides harvest operators much flexibility, avoiding the frequent situation in which crop harvested later in the day becomes too dry, complicating mowing and distillation strategies. A similar satisfactory result has been achieved using disc mowers with long crop dividers and homemade swathe boards. The importance of setting up a mower to avoid running the tractor on uncut herb or on the
previous swathe cannot be stressed sufficiently. Bruised herb rapidly loses moisture and oil, drying to shattering point long before undamaged. The collection of the windrow with reel type pickups should, if possible, be carried out in the opposite direction to the mowing, and at speeds which avoid 'teasing out' the swathe.

The residue of oil obtained from the cooked herb in this experiment amounted to less than 2% of the total recovered and distillation times were all less than 45 minutes. Harvesting at less than 50% moisture cannot, therefore, be justified for reasons of distillation efficiency and is likely to result in much more serious herb losses as shown above. On the other hand the small quantity of oil retrieved from the separator outflow using the simple (and inadequate) solvent trap represents a loss of oil which has been successfully harvested, distilled and condensed, and indications from this and previous work with solvent extraction of separator discharge shows the possibility of 1.5 to 2 kg of oil per hectare being collected using relatively inexpensive solvents and a simple trap design. The oil is of a distinctive composition (see Part II) and may have specific uses. The choice and supply of solvent, and the design of the trap should be given careful consideration, with regard to the operating parameters of the stills concerned.

II: Detection of Changes in Oil Quality During Harvest and Distillation

Materials and Methods
Peppermint herb collected during the harvest loss trial was distilled in the laboratory and the resulting oil analysed by GC. The results are shown below (Table I).

The sharp change in oil composition after forage harvesting found in the laboratory samples prompted a further, brief study of oil composition changes in the herb after chopping. A sample of fresh herb (collected 22/4/92) was divided into five portions and one distilled immediately. The remaining four portions were finely chopped and bruised using a low speed food processor, and then distilled immediately, 19 and 27 hours after chopping respectively. The chopped material was held in a shallow tray, at room temperature (approx 180°C) and away from direct sunlight before distilling. These results are given in Table II.

Results

<table>
<thead>
<tr>
<th>Sample</th>
<th>% Menthone</th>
<th>% Menthofuran</th>
<th>% Menthol</th>
</tr>
</thead>
<tbody>
<tr>
<td>17/1</td>
<td>34.04</td>
<td>0.58</td>
<td>33.37</td>
</tr>
<tr>
<td>27/1</td>
<td>26.55</td>
<td>0.71</td>
<td>37.0</td>
</tr>
<tr>
<td>7/2</td>
<td>20.22</td>
<td>2.31</td>
<td>44.43</td>
</tr>
<tr>
<td>windrow(1/2 dry)</td>
<td>18.84</td>
<td>2.42</td>
<td>45.16</td>
</tr>
<tr>
<td>Harvest windrow</td>
<td>19.32</td>
<td>2.21</td>
<td>45.08</td>
</tr>
<tr>
<td>Harvest spout</td>
<td>18.27</td>
<td>0.66</td>
<td>48.46</td>
</tr>
<tr>
<td>Harvest vat</td>
<td>16.97</td>
<td>0.69</td>
<td>49.43</td>
</tr>
<tr>
<td>LSD P&lt;0.05</td>
<td>4.36</td>
<td>0.66</td>
<td>3.11</td>
</tr>
<tr>
<td>Cooked herb</td>
<td>1.37</td>
<td>0.66</td>
<td>14.44</td>
</tr>
<tr>
<td>Separator Discharge</td>
<td>13.86</td>
<td>0.47</td>
<td>54.55</td>
</tr>
<tr>
<td>Distilled oil *</td>
<td>18.39</td>
<td>1.58</td>
<td>49.08</td>
</tr>
</tbody>
</table>

* Result from bulk recovered for whole field.

Table II: Yield and Composition - Chopped Material prepared in the laboratory.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Oil Yield</th>
<th>% (DM)</th>
<th>% Menthone</th>
<th>% Menthofuran</th>
<th>% Menthol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unchopped Herb</td>
<td>1.25</td>
<td>5.17</td>
<td>2.76</td>
<td>55.91</td>
<td></td>
</tr>
<tr>
<td>Freshly Chopped</td>
<td>1.47</td>
<td>5.07</td>
<td>1.34</td>
<td>58.1</td>
<td></td>
</tr>
</tbody>
</table>
### Discussion

Changes in oil quality with maturation of the crop are well documented but the behavior and losses of peppermint oil during harvest and distillation has not been examined in detail. Experiments conducted in 1990 and 1991 showed a strong shift in oil composition during the distillation itself, the first and last parts of any distillation resulting in oils of significantly different compositions. These trends are the result of the relative solubility and volatility of components in the oils at distillation temperatures. During the drying and harvest of peppermint, although temperatures are much lower, exposure to the atmosphere of oil glands and free oil surfaces may be very great, and loss of some volatile components may still be of concern. At the time of mowing the crop had achieved a satisfactory analysis for the three principle components - 45% menthol, 2.4% menthofuran and 19% menthone. Sampling at harvest generated a set of windrow samples and two sets of finely chopped material - one for the spout, and one from within the vat. Both of these chopped samples, upon distillation in the lab several hours later revealed greatly reduced menthofuran levels, while the commercial distillations produced oil with menthofuran levels substantially lower than the field samples but much higher than the lab distillation of the chopped material. The laboratory chopping and distillation trial confirmed the direction of these changes (falling menthofuran and menthone levels) suggesting that exposure of the chopped herb and free oil to the atmosphere during chopping and transport and before distillation could be influencing composition outcomes. The increase in menthol and decrease in menthofuran content of the oil in all cases tends towards a favourable final overall composition. The composition of oil remaining in the herb after distillation included a very small proportion of the menthol, menthone and menthofuran (and a large proportion of pulegone and other less volatile components). This reinforces the suggestion that this loss of oil is of less significance than that in the separator discharge, which contained almost 55% of menthol and very little (less than 0.5%) menthofuran. This oil, if collected in useful quantities, could prove to be a valuable by-product of distillation.

### III Compositional Changes In Mint Oil During Steam Distillation

#### Introduction

During steam distillation of peppermint in commercial stills in Tasmania it has been suggested that the length of distillation can influence the quality of the oil and that premature completion of the distillation or careless management of the early flow of steam and oil vapour can significantly alter the final composition of the product. This study examined changes in composition of oil during the distillation, and reinforces the view that the beginning and end of each distillation are critical in this regard.

#### Methods

During commercial distillations of wilted Mentha piperita, at the distillation plant at Gretna, one litre samples of distillate were collected at the outlet of the condenser. The oil/water mixture was allowed to settle for approximately three minutes, oil yield per litre of distillate measured, and an oil sample removed from the surface of the water. The rate of distillate discharge corresponding to each sample was measured by recording the time for delivery of five litres of distillate, collected immediately after the sample was taken. Timing of the sampling was established in the light of local experience with the usual pattern of oil and water discharge rates for distillations of this type, and required more frequent samples during the first part of the distillation.
Results
The Table below gives estimates of average oil delivery for each sample period (inferred from flow rates and oil delivery), corresponding to an oil of the type described by the accompanying analysis. Using this data a 'theoretical' composite oil is described which corresponds quite closely to the analysis of the final blended bulk for the distillation. The nine major components (expressed as a percentage in the oil) are abbreviated as follows:

1- limonene  2 - cineole  3 - t-sabinene hydrate  4 - menthone
5 - menthofuran  6 - iso-menthone  7 - menthyl acetate  8 - menthol
9 - pulegone

<table>
<thead>
<tr>
<th>Period (mins)</th>
<th>Vol. Litres</th>
<th>Oil Component</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>0-2</td>
<td>1.5</td>
<td>3.40</td>
</tr>
<tr>
<td></td>
<td>1.29</td>
<td></td>
</tr>
<tr>
<td>2-4</td>
<td>3.1</td>
<td>1.98</td>
</tr>
<tr>
<td></td>
<td>1.81</td>
<td>3.7</td>
</tr>
<tr>
<td>4-6</td>
<td>3.7</td>
<td>2.20</td>
</tr>
<tr>
<td></td>
<td>1.56</td>
<td></td>
</tr>
<tr>
<td>6-8</td>
<td>3.9</td>
<td>1.34</td>
</tr>
<tr>
<td></td>
<td>1.76</td>
<td></td>
</tr>
<tr>
<td>8-10</td>
<td>3.0</td>
<td>0.87</td>
</tr>
<tr>
<td></td>
<td>1.99</td>
<td>2.55</td>
</tr>
<tr>
<td>10-12</td>
<td>2.1</td>
<td>0.67</td>
</tr>
<tr>
<td></td>
<td>2.13</td>
<td>3.18</td>
</tr>
<tr>
<td>13-16</td>
<td>1.0</td>
<td>0.57</td>
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<tr>
<td></td>
<td>2.55</td>
<td>3.18</td>
</tr>
<tr>
<td>17-20</td>
<td>1.0</td>
<td>0.67</td>
</tr>
<tr>
<td></td>
<td>3.18</td>
<td>3.18</td>
</tr>
<tr>
<td>21-24</td>
<td>0.6</td>
<td>-</td>
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<tr>
<td></td>
<td>3.90</td>
<td></td>
</tr>
<tr>
<td>25-36</td>
<td>0.8</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>6.18</td>
<td></td>
</tr>
</tbody>
</table>

Actual Yield 1.67 4.47 1.96 13.04 5.92 2.05 3.56 49.61
Theoretical 2.27
Actual Total Yield of oil - 19.5 litres (approx).
Estimated total yield from delivery pattern, above - 20.7 litres

Discussion

Decisions relating to distillation management are often the responsibility of the operator, and analysis and product blending often occur only after completion of the harvest by which time oil composition is essentially fixed. It is important, therefore, for operators to realise the extent to which collection of the first and last parts of the distillation can alter the composition of the final product.

As can be seen from the data above, the composition of the accumulated oil yield will reflect the progressively decreasing proportions of the more volatile components in favour of those of higher boiling points, and removal of oil from the collector at different times will produce oils of very different composition.
In practice, of course, the delivery of oil from a commercial still reflects the gradual exhaustion of various parts of the charge, depending upon the evenness of steam passage through it, and any distillation will exhibit a ‘tailing-off’ of oil delivery not necessarily representing the last oil vaporised from each part of the herb charge. For this reason the profile of composition of oil during the distillation will depend (as does the degree of tailing-off) upon the performance of the vessel itself and the distribution of steam within it. Nonetheless, in the experiment described here, strong trends were evident in the overall delivery throughout the distillation, and care must be exercised to avoid producing oil of a very different composition to that required by the industry or even that present in the herb charge in the vat.

APPENDIX III - STATISTICS

| Dry Matter Content of Fresh Mint | 18-20% |
| Dry Matter Content of Harvestable Mint | 45-55% |
| Dry Matter Content of Overdry Mint | 65-75% |
| % Leaf in typical fresh sample | 40% by weight |
| % Oil by Dry wt in typical mint | 1.3% |
| % Oil by Dry wt in harvestable mint | 0.65% |
| % Oil by Fresh wt in typical mint | 0.26% |

Yield mint at 50% moisture (sample site) 14 tonne ha-1

= 1.4 kg metre-1

Approximate volume of chopped herb 300 kg metre-3
Milestone Reports: Best Practice in Peppermint: 1997-9

RIRDC MILESTONE REPORT: December 1997

Project Title: EO197-03: A model of best practice in peppermint oil production -Tasmania and Victoria.

Research Organisation: University of Tasmania

Principal Investigator: Professor Robert Clark

Milestone Report: December 1997

Since the commencement of the project in July 1997, production areas in Victoria have been visited by Professor Clark (twice) and Dr. Read (once), and a number of discussions conducted relating to production methods in Tasmania, Victoria and the USA.

A recurrent theme in these discussions has been concern regarding the poor quality of planting material or the short productive life of commercial plantations. While the reason behind this is not clear, it appears that a complex of primary and secondary infective agents, management methods and soil factors may all be involved.

As a first step in addressing this problem, a plant pathologist (Dr. Calum Wilson) has conducted a series of procedures to determine whether a virus or similar agent may be limiting vigour in the vegetatively propagated plant material used for all commercial plantations.

Secondly, Professor Menary has initiated production of tissue culture plantlets from greenhouse grown peppermint material and we will be devising a means of comparing the vigour of this with the normal propagation material during 1998.

Thirdly, the Tasmanian production group NPE have agreed to participate in a propagation scheme devised by EOT and the Researchers, to generate a quantity of high quality propagation material relatively free from nematode and disease infestation, for use in establishing fresh on-farm multiplication beds. Tip cuttings, taken from a commercial field have been sprayed and drenched, grown in speedling cells, and planted into nematicide-treated soil in a commercial nursery. This material will be lifted, washed and transported to a farm site in autumn 1998, where it will be grown under supervision for use as planting stock for commercial fields the following year.

With respect to the development of a management model for peppermint, a review of the available literature has been completed, and a broad outline of the intended approach has been prepared. At this stage the model to be most closely followed is that employed in the grains and some vegetable industries - the Crop Check system in which key check points during the establishment and growth cycle are identified, and the producer (or consultant) assesses a set of crop growth and health parameters at each time.

One object of this approach is to minimise the number of checkpoints and parameters necessary to direct the manager in decision making. This should help to focus attention on those critical aspects of crop development which will affect yield and budget outcomes, and help the manager acquire an 'intuitive' feel for the problems and potential of the crop.

A scheme for a crop check system has been devised and draft checklists prepared for three of a probable six checkpoints have been completed for discussion.

The last area of research activity at present is the clarification of moisture and nitrogen monitoring methods.
Discussions and experience confirm that nitrogen and irrigation applications are the most effective management tools available for increasing oil yield, but are (in the local context) the least well-managed and understood.

Commercial consultants offer a range of nitrogen monitoring methods, growers use a variety of nitrogen fertilisers and application systems, and appear to aim for anything between 100 and 400 units of N during the season. Many growers use mostly anecdotal information to devise their program, some of it from the experience of US producers.

While sound basic recommendations do exist, a 'demand - application' approach implied by use of sap analysis and other techniques would allow savings in crop management and environmental risk.

Similarly, irrigation can represent the largest capital and operating expense in the production of a crop, prior to harvest. Discussions with producers suggest that a more rigorous approach to soil moisture monitoring and irrigation management may bring significant savings in some cases and reveal infrastructure shortcomings in others.

A sampling program in a Tasmanian field and the large new King Valley plantation has been devised to assess the value of sap, tissue and soil assessments of plant nitrogen status.

A soil moisture monitoring facility has been installed in the Tasmanian field and has already provided opportunities for savings in water and irrigation costs.

This program will continue through harvest and should allow more definitive guidance as to nitrogen and irrigation management for next season.

Losses in oil during harvest have been identified in previous work and a study of the problem is planned for the 1998 harvest in late January.
Progress Report: May 1998

Project Title: UT-16A: A model of best practice in peppermint oil production -Tasmania and Victoria.

Research Organisation: University of Tasmania

Principal Investigator: Professor Robert Clark

Work in the Best Practice Project has progressed on three fronts:

1) Assessment of the benefits and costs of using elite propagation material for plantation establishment. US producers purchase plant material from specialist providers to ensure freedom from pathogenic agents. Essential Oils of Tasmania has established a tip cutting nursery project under the guidance of the research team and tissue culture techniques have been used to produce a second line of meristem material. These will be compared for yield and vigour with commercially (stolon) propagated material in field trials during the coming year.

2) Following study of the progress in commercial production during the 97/98 season, the research group has focussed on the importance of enabling producers to measure and regulate irrigation and nitrogenous fertiliser use during the summer. These two matters alone we believe account for the largest proportion of crop failures, and offer the best opportunity to lift yields in the short to medium term. There are a number of commercially available methods for determining nitrogen and water status in commercial crops and we hope to develop a pilot monitoring project on at least one commercial field during the coming season. Another management issue requiring serious attention is the harvest itself. We have ample evidence (and the concurrence of producers) that the harvest operation may be responsible for losses of up to 30% of available oil, and propose to develop a simple 'Harvest Managers Guide' for use in 1999, to be incorporated in the crop management system described below.

3) Incorporating the problems mentioned above, and following the model of the grain production management systems such as 'TopCrop', 'MEY-Check' and others, we hope to develop a checkpoint - based management system for peppermint in southern Australia. This would provide basic management guidance for individual growers, helping them develop an intuitive understanding of mint growth and oil production, as well as establishing a framework for measuring and collating performance indicators across growers, districts and seasons.

With respect to the development of the model, a review of the available literature is complete, and a broad outline of a scheme has been devised with draft checklists prepared for three of a probable six checkpoints presently completed for discussion.
RIRDC ANNUAL PROGRESS REPORT: December 1998

Project Title: EO197-03: A model of best practice in peppermint oil production -Tasmania and Victoria.

Research Organisation: University of Tasmania

Principal Investigator: Professor Robert Clark

1) May 1998: commercial trials complete in Tasmania and Victoria and outcomes communicated to growers.

1) Review of 1997/8 season: At the completion of the mint production season, the performance of the Tasmanian and VicMint projects were reviewed and compared with the US and Tasmanian yield data for recent years. The results generated from tissue, sap and soil sampling programs during the season were analysed and presented to a meeting of producers and research personnel in Melbourne in May. A summary of this information and commentary on industry performance is attached to this report.

The key observation at that time was that despite historical yields of more than 80kg/ha having been achieved in Tasmanian fields in some seasons, by some growers, and US producers claiming yields of more than 100kg/ha on large areas, consistent yields of more than 70kg/ha have eluded the Australian industry.

2) Implementation:

Crop Monitoring

While there is already adequate scientific support to allow definition of water and nitrogen requirements for peppermint during the growth cycle, practical experience, and the analytical results of the past season strongly suggest that it is irrigation and nitrogen management which most usually contribute to the poor yield results.

For this reason, it was agreed that a vital part of the second year of the project would be a careful soil and plant nitrogen sampling program designed to identify appropriate fertiliser management based on a 'demand feeding' model. This program began in mid October and will continue up to harvest (early February), supplemented by pre- and post- season soil samples.

The objective is to detect changes in soil nitrate-N using recently developed test procedures which enable accurate and relatively cheap determination of this parameter, and to tailor fertiliser application to maintain levels established in the literature as adequate for peppermint growth. At the same time, sap nitrate levels, a 'derivative' measure of nutrient status will be monitored. This procedure is sensitive to sampling method and moisture status as well as growth stage, and while relatively simple and cheap, needs careful interpretation. The two procedures will be compared during the season.

Soil moisture status will be monitored in both states using a capacitance-based moisture probe and software capable of generating simple graphic explanation of progressive drying and refill of moisture in the root zone of the plant.

RIRDC has helped fund the moisture sensing program, the cost of the analytical work will be met by growers, EOT and VicMint are jointly meeting the installation and sample collection costs and Dr Read will collate results, and prepare interpretative material for use by growers.

This exercise will provide immediate practical guidance for growers, and enable the researchers to assess the sampling program and the responsiveness of growers and the crop to the feedback.

Propagation
A second area of attention is in the matter of mint propagation. Traditionally, Australian producers use harvested mint stock for replanting. This procedure is suspected of contributing to the lack of longevity of many mint plantations, possibly distributing soil borne pathogenic agents (nematodes and fungi) together with the mint.

In a major departure from this convention, this project has assisted the implementation of a tip cutting propagation exercise by industry partner Essential Oils of Tasmania, in which a special nursery area of clean, vigorous material was grown for the purpose of establishing new propagation plots in the Derwent and Fingal Valleys in Tasmania. This material has been planted and is growing well at both sites. The 3ha of material is expected to provide for at least 30ha to be planted in June 1999.

It is hoped that by using vigorous material, washed and treated with fungicide before planting, the resulting stand will remain healthier and free from damaging levels of pathogenic agents for longer.

A second propagation initiative, undertaken by Professor Menary, has involved production of a batch of propagation stock by tissue culture. The objective of this work was to produce disease free stock plants, through meristem culture. These would be used to establish a field nursery for the production of material for comparative trials with tip cutting propagation and commercial crops. Meristems were taken from glasshouse-grown plants arising from cuttings of two parent plants from a commercial field. Disease free explants were weaned and multiplied to produce over 9000 plants for establishment in a field nursery.

Model Development

A major objective of the project is to develop a management model which combines appropriate record keeping with accessible technical advice. The need for this management support is underlined by the experience of the past season.

In Victoria, poor growth resulted from inadequate or uneven irrigation application, and nitrogen fertiliser applications were not adjusted to suit.

In Tasmania, several fields showed promising yields in parts but extremely irregular irrigation patterns and the use of nitrogen application through the irrigation water resulted in wide variations in crop vigour within fields and reduced average overall yields to the typical 55-60kg/ha level.

Development of a 'checkpoint' system for establishment and harvesting continues, wherein a minimum of parameters are monitored and kept with predetermined limits. During the growing season a set of simple flowcharts will be used to guide managers in irrigation, nitrogen and disease management, supported by a basic level of technical monitoring - soil or sap analysis, moisture probes and timely 'scouting'.

The initial parts of this system were completed during the first year of the project and the more detailed, 'grower information' notes are being developed during the summer 1998/9 season. The latter will address the critical areas mentioned above - nitrogen and water management, and attempt to simplify and combine the information presently available in US extension guides, the Macarthur Consulting report to Victorian growers, and the results of the current pilot sampling and water monitoring program.

Key themes are:

- matching management actions to crop requirements, rather than 'recipe recommendations',
- debunking a number of mistaken concepts prevalent among irrigation managers, and
- minimising the amount of peripheral information directed at growers, while retaining the core information essential for good decision making.
Appendix 2: Raw Data and Methods

A) Nitrate Sampling

1997/8 Nitrate Sampling Procedures

Soil and tissue samples were collected early in the day on four dates (26th Nov, 17th Dec, 8th Jan and 31st Jan) at each of three sites - two Tasmanian fields and at Moyhu in Victoria. Triplicate soil samples of approximately 250g were taken from three depths: 0-150mm, 150-300mm and 300-500mm, by combining soil taken from two or three locations in the sample area. Each sample area corresponded with a tissue sample collection - in the vicinity of the probe tubes in Tasmania and in three positions along the length of the irrigator at Moyhu. Hence at each date and site, triplicate soil, sap and tissue samples were obtained, in the case of soil, for three depths.

Fresh shoots of ten or more nodes length were collected at the same time. All material was kept cool until despatch later the same day. Sap analysis samples of 10 shoots per replicate were posted overnight to Servag Pty. Ltd, (6181 Frankford Rd, Devonport TAS 7310), and the results of the analysis (sap nitrate concentration, ppm) were received within two days. A second set of ten shoots per replicate was dried (65°C, 2 days) and stored at -18°C. At the end of the season, these samples were hammermilled and analysed for total tissue nitrogen, using the semi micro Kjeldahl digestion method (Reuter and Robinson, 1986). Soil samples were analysed for NH$_4$ and NO$_3$ concentrations in paste extract (Smethurst et al 1997). Phosphate concentration, pH and conductivity of the paste extracts were also determined.

For the Tasmanian sites, dry matter yield, proportion of leaf and stem fresh weight and number of leaf pairs remaining on the stem were estimated using triplicate 0.25 m$^2$ quadrat samples of herb taken adjacent to each probe tube on each date.

1998/9 Nitrate Sampling Procedures

Topsoil was collected from 0 - 150 mm using an auger fitted to a cordless drill. Fifteen to twenty 'cores' were combined for each sample of 200g of soil. Samples were packed immediately (<15 mins) into a chilled container and transported to a refrigerator (<4°C), where they remained until late in the day, then packed into an Express Post bag, with an 'Ice Pack' and mailed to the laboratory.

(The laboratory advised that freezing before despatch would improve the prospect of the soil not exceeding the 8°C at which nitrification begins to occur. Use of 'chillchecker' discs which may be activated prior to mailing was recommended.) Results were returned by Fax or phone within 36hrs. The results of the 1998/9 analyses are provided below.
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