STUDIES ON THE VARIATION IN THE QUANTITY AND QUALITY OF OIL IN DIFFERENT PARTS OF PALMAROSA (*Cymbopogon martini Stapf. var. motia*) IN DIFFERENT SEASONS

BY

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THESIS

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DECLARATION

I hereby declare that this thesis entitled "Studies on the variation in the quantity and quality of oil in different parts of palmarosa (Cymbopogon martini Stapf. var. motia) in different seasons" is a record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

Vellanikkara,
10-7-1981.

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CERTIFICATE

Certified that this thesis is a record of research work done independently by Miss. Alice Kurian, under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

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We, the undersigned members of the Advisory Committee of Miss. Alice Kurian, a candidate for the degree of Master of Science in Horticulture with major in Horticulture, agree that the thesis entitled "Studies on the variation in the quantity and quality of oil in different parts of palmarosa (Cymbopogon martini Stapf. var. motia) in different seasons" may be submitted by Miss. Alice Kurian, in partial fulfilment of the requirements for the degree

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Introduction

INTRODUCTION

Essential oils are complex materials of diversified composition and are not related to the non-volatile glyceride oils. Aromatic plants have long been exploited for the essential oils they produce, in many parts of the tropical regions. They are profitable cash crops and their oils are valuable export products. Essential oils are one of India's traditional items of trade in both exports and imports and in palmarosa oil India has almost a monopoly in production and trade, earning foreign exchange worth over Rs.2.5 million.

The aroma of the oil of palmarosa resembles that of the oil of rose. Hence, it is also known as 'rose oil'. It is now an important perfumery raw material and is extensively used as a cheap base. It stands well in an alkaline medium and as such is an indispensable perfumery item in the production of high quality soap. It is used in flavouring of tobacco leaves and its products, and as a general perfume in cosmetic industry. It is a starting material for industrial production of high grade geraniol which has wide uses as an aromatic isolate in compounding different rose-like scents and allied preparations. Besides this perfumery value, oil of palmarosa has antiseptic properties also.

Palmarosa oil is obtained from the plant (Cymbopogon martini var. motia). This plant grows wild in the forests of Maharashtra, Madhya Pradesh and Uttar Pradesh. India's annual production is 40 M.T. whereas the total demand is 100 M.T. per annum. Hence, there is immense scope for the development of palmarosa cultivation.

Palmarosa was introduced at the Lemongrass Research Station, Odakkali a decade ago when the price of lemongrass oil registered a steady decline. The studies so far conducted with the cultivation of this aromatic plant have clearly shown that it is a suitable crop under the agro-climatic conditions of Kerala and is a more profitable crop compared to lemongrass. The oil produced at Odakkali is found to be of good quality and acceptable to the user industry. The price of palmarosa oil is about two and a half fold over the lemongrass oil.

The cost of production of the essential oil is comparatively much higher and the post-harvest operations contribute to more than 3/4th of the cost of production. Therefore ways to economise the distillation cost should be aimed at. One approach to the problem of high cost of distillation is to reduce the bulk, without detriment to the oil yield.

Investigations to assess the oil content in different parts of palmarosa plant were carried out and they showed that the oil content was maximum in the inflorescence, followed by the leaves and least in the stalk. So far, no systematic approach seems to have been made to study the oil yield from the different portions of palmarosa in order to find out whether the lower portions can be deleted before distillation.

Hence, the present study was taken up with the objectives of:

1. Determining the yield and quality of oil from different portions of palmarosa under the influence of season.

2. Working out the economics of distilling the different portions of the plant and the whole plant.

Review of Literature

REVIEW OF LITERATURE

The palmarosa (Cymbopogon martini Stapf. var. motia) is an important essential oil crop grown in Kerala and the factors affecting its yield, extraction and quality were investigated by several workers in this field, which is briefly reviewed below.

1. FACTORS INFLUENCING YIELD AND QUALITY OF OIL

1.1. Growth characters

Dutta and Sahoo (1977) studied the variability in growth characters in palmarosa and reported a range of 83.0 to 166.9 cm in plant height, 13.2 to 56.8 cm in the length of the inflorescence and 40 to 153 in the number of tillers per stool.

Virmani et al. (1977) reported that palmarosa plants attained a height of 300 cm and that the panicles were 10 to 30 cm long.

Investigations were conducted by Gupta et al. (1978) on the influence of transplanting versus direct sowing on the growth and yield of palmarosa. They observed that the plant height ranged from 1.43 m to 2.41 m; length of inflorescence from 34.00 to 55.00 cm and number of tillers

from 35 to 115 per stool. An analysis of the growth characters contributing to yield revealed that the number of tillers per plant made a significant contribution towards yield. It was also noted that the increase in plant height did not correspondingly increase the length of flowering shoot; on the contrary a slight reduction in the size of floral shoot was noticed in the taller plants particularly in the autumn crop.

Nair et al. (1980) while studying the varietal differences on the growth parameters found that ODP-2 had an average 162 cm height, 50 cm in the length of the inflorescence, 16 tillers out of which 14 were productive as compared to 110 cm height, 30 cm in inflorescence length; 25 tillers out of which only 9 were productive in the case of ODP-1.

1.2. Stage of harvest

According to Virmani et al. (1977) maximum yield of palmarosa oil was obtained when the plants were at full flowering stage.

The Kerala Agricultural University recommended that palmarosa grass should be harvested one week after flowering when the essential oil content was at its maximum (Anon, 1978). Gupta and Jain (1978) observed that the

oil yield was maximum when it was harvested at the flowering stage and that the quality of oil was also better when harvested at this stage than at a later stage.

Nair and Mariam (1978) were of the opinion that the stage of harvest was the most important factor contributing to optimum yield of oil with high geraniol content. The study conducted on this aspect at the Lemongrass Research Station, Odakkali revealed that the sixth or seventh day after the full flowering of the crop was the optimum stage for harvest.

Gupta et al. (1978) conducted studies on the effect of direct sowing versus transplanting in palmarosa and reported that the crop was best harvested at a stage between 10 and 21 days of opening of flowers.

1.3. Height of cutting the herbage

According to Burger (1958) harvest of the palmarosa plants at 20-30 cm above the ground level for the first as well as the second cutting and just above the ground for the third were the optimum.

Kashyapa and Jain (1977) observed that for best results, the upper two-third portion of palmarosa plant was harvested and used for extraction of oil.

Virmani et al. (1977) cut the palmarosa grass at a height of 5-8 cm from the ground level and used the whole plant for distillation.

While conducting a fertilizer trial on palmarosa, Gupta et al. (1978) observed that the plants were cut 15 to 25 cm above ground.

A survey on this aspect was conducted by Gupta et al. (1980) on the palmarosa growing tracts of Madhya Pradesh and Maharashtra. They reported that the plants were cut at a height of 0.6 to 0.8 m from the base. They also observed that the average length of the flowering tops cut for distillation were around 50 cm and the tops had 4 to 5 floral leaves only.

1.4. Number of harvests

The number of harvests during an year was found to vary depending upon the climatic conditions of the place of cultivation. In West Africa, Burger (1958) obtained two cuttings in an year normally and additionally a smaller crop, if there was late rain.

According to Singh (1958) palmarosa crop gave two cuttings in an year (July and October-November) in Dehra Dun and Punjab.

In Burdwan, Ghosh and Chatterjee (1976) observed that motia grass yielded one crop (October) in the first year and two harvest (May and October) from the second year onwards.

Virmani et al. (1977) observed that under Lucknow conditions one crop could be taken during October-November in the first year, whereas two to three crops were obtained in the subsequent years.

Under Kerala conditions, only two harvests were obtained during the first year of planting (September and November). From the second year onwards three to four harvests (May, September, November and January) were possible, depending upon the rains received during the North-East Monsoon (Nair and Mariam, 1978).

1.5. Wilting or drying the grass

For economical production of oil, Virmani et al. (1977) suggested that the harvested material should be wilted for a short time.

Gupta and Jain (1978) recommended that in the case of Cymbopogon grasses, the harvested material may be cut into small pieces so that more quantity could be charged into the still thus saving steam and fuel. They found

that the time required for drying the grass depended upon the weather conditions, about 3-4 hours in bright sunlight and 24 hours or more in shade or a longer period during the rainy season. They recommended that during drying, the grass should be turned over frequently to prevent fermentation.

From the studies conducted on the wilting of grass after harvest, Nair and Mariam (1978) reported that distilling the cut grass 24 hours after harvest increased the oil recovery. They suggested that the cut grass should be stored under shade with provision for good aeration.

1.6. Method of extraction of oil

Ghosh and Chatterjee (1976) employed steam distillation method for extraction of essential oil from motia.

According to Virmani et al. (1977), the extraction of palmarosa oil in India was generally by hydro-distillation and that the quality of oil obtained from this method was inferior. They recommended the adoption of steam distillation to get maximum yield of good quality oil.

Gupta and Jain (1978) were of the opinion that the Cymbopogon grasses could be distilled by steam. They found

that directly fired stills have adverse effect on oil yield and quality. It was also observed that increase in pressure increased the yield of the oil; but prolonged distillation at high pressure reduced its quality. They suggested that pressure should not exceed three atmospheres in any case.

The Kerala Agricultural University recommended that extraction of palmarosa oil could be done by steam or water distillation (Anon, 1978).

According to Nair and Mariam (1978), steam or water-cum-steam method could be employed for the distillation of palmarosa grass.

1.7. Seasonal variation

Seasonal variation of the active principles in essential oil bearing plants was recorded from very early times. Variation in the concentration of the active principles may be, to a considerable extent, due to climatic conditions of the area from which the materials were collected (Chakravarthi, 1970).

In Mysore, Kulkarni (1959) observed that for lemongrass the yield of oil was 0.2 to 0.3 per cent of the fresh weight of grass during the rainy season whereas in

the summer season the yield of oil rose to 0.4 to 0.5 per cent.

Investigations by Yoshida (1959) over two years with Pelargonium roseum indicated that the atmospheric temperature was the major environmental factor controlling the percentage of oil. He also observed that the oil percentage was higher in October and November than in May and June owing to secondary factors of humidity, rainfall and temperature. A parabolic relationship was observed between a rise in air temperature and oil percentage with a maximum yield occurring at a temperature of 28 to 29°C.

Keterson and Hendrickson (1966) reported that the aldehyde content of expressed orange oil varied considerably from one season to another. They found that rainfall influenced the aldehyde content of the oil, the higher the rainfall the greater the aldehyde content in the oil.

Hotin (1968) suggested that atmospheric temperature had the greatest effect on essential oil accumulation. He observed that in menthol mint and East Indian basil leaves and clary sage and lavender inflorescences, a rise in the temperature to 23-25°C increased the essential oil

content, but reduced the menthol content of the mint essential oil. At very high temperatures the essential oil content of coriander fruits was sharply reduced during ripening whereas in anise, fennel, ajovan and caraway fruits it changed only slightly. The linalool, carvone and anethole contents of the essential oils were increased by high temperatures.

Gas liquid chromatography conducted by Adams (1970) revealed that significant differences occurred from summer to winter in the relative composition of the volatile terpenoides.

Ahmed and Jacques (1975) reported that high temperatures encouraged flowering and reduced the time to flowering during inductive long day treatment.

Ghosh and Chatterjee (1975) studied the effect of photoperiod on growth, development and essential oil content of palmarosa. The results established that palmarosa, possees characteristics of long day plants and different inductive cycles of long days hastened flowering and increased the reproductive growth. Promotive effects of light on biogenesis of essential oil formation under long day condition was accompanied by increased foliar growth and accumulation of dry matter.

El-Din et al. (1976) stated that in Eucalyptus camaldulensis essential oil content varied greatly, being highest in January (0.31%) and lowest in June (0.14%). Cineole content was lowest in January/February and highest in May/June.

From the studies conducted on the cultivation aspects of Java citronella, Singh et al. (1976) reported that harvests during the rainy period of the year gave higher yield of leaves than harvests during comparatively dry periods. They further reported that there was hardly any difference between the quality of oil obtained during the dry and wet periods of the year, although a slight increase in the percentage of oil was obtained in the dry season.

Alexander et al. (1977) noticed that climatic factors strongly influenced the growth of bush and yield of flowers and oil in roses. They observed a positive correlation ($r=0.8$) between essential oil percentage and night air temperature.

Investigations by Rai et al. (1977) on the effect of nitrogen deficiency and seasonal variations on growth and essential oil content of mint under sand nutrient condition revealed that seasonal variations improved the growth, nutrition, metabolism and biosynthesis of monoterpenes. They observed that plants grown during rainy season

were most vigorous as compared with those of the summer and winter seasons. The mint oil concentration in leaves was maximum in summer season followed by in rainy and winter seasons. Total production of oil per plant was highest in the rainy season. They found this to be associated with largest production of leaves in this season. The higher content of mint oil during summer and rainy seasons was possible due to increased number of oil glands per unit leaf area.

Bradu et al. (1977) stated that the ratio of linalool to linalyl acetate in the oil of Mentha citrata was affected somewhat by the maturity of the plant, the time of harvest and environmental or seasonal variations.

According to Basker and Putievsky (1978) the volatile contents of dried leaves of Marjorana hortensis, Melissa officinalis, Ocimum basilicum, Origanum vulgare, Salvia officinalis and Thymes vulgaris reached maximum values in summer.

In Java Citronella, Ganguly (1978) noticed a slight increase in oil and citronellal content of the oil in the dry season, compared with harvests in the dry and wet seasons. It was also noticed that both citronellal and geraniol remained unaffected by the season of harvest.

According to Gupta et al. (1978) the oil of palmarosa obtained in different harvests generally conformed to ISI specifications although the summer harvests contained higher ester content.

Hazarika et al. (1978) studied the effect of N, P, K fertilizers on the yield and quality of oil of palmarosa under the influence of seasonal variations and reported that for the same treatment, variation of oil and geraniol percentage was due to variation of seasons (months) in the same year. Interaction between season and treatments was found to be highly significant.

Investigations by Adams (1979) on the diurnal variations in terpenoides of Juniperus scopularum revealed that there were significant differences in the samples taken during winter and summer.

2. YIELD OF GRASS AND OIL

Rao et al. (1948) raised motia grass experimentally from seed and reported that the yield of grass and oil on a fresh weight basis were 13,418.6 kg and 21.5 kg per acre, respectively.

Burger (1958) observed that the cultivation of palmarosa lasted for two to three years and that one hectare yielded from 30 to 60 kg of oil per annum.

According to Singh (1958) Rosha grass gave two cuttings per year. He observed that the yield of fresh herbage was 2220 kg and 4440 kg and that of oil 4.54 kg and 8.16 kg in the first and second cuttings respectively.

Ghosh and Chatterjee (1976) reported the results of a fertilizer trial on palmarosa, in which they obtained 36.8 tonnes of green herbage and 194.4 kg of essential oil per hectare per year from plots fertilized with N,P,K at the dosage of 60-30-30 kg/ha.

In the Cymbopogon species trial conducted, Gupta (1976) observed that the green yield was minimum in Cymbopogon martini (11553 kg/ha).

In a population of fortyfive different parental clones of palmarosa, Dutta and Sahoo (1977) observed that the herb yield per clump varied from 0.318 kg to 0.825 kg while the oil yield per clump ranged from 0.41 ml to 4.38 ml.

Virmani et al. (1977) noticed that the yield of oil in palmarosa was low in the first year and it increased with the age of the plantation. The yield of oil obtained during the first four years were 20, 60, 70 and 70 kg per hectare, respectively.

Observations were made on the cultivation and

improvement of medicinal and aromatic plants in Orissa region by Regional Research Laboratory and reported the herbage yield of 46 different clones, selected from a heterogenous population of palmarosa. It was found to vary from 2.2 to 16.5 tonnes, 1.1 to 5.0 tonnes and 0.15 to 4.25 tonnes per hectare in the first, second and third cutting respectively (Anon, 1978-79).

Nair and Mariam (1978) obtained a yield of 60 kg of oil per hectare from a rainfed crop of palmarosa from the second year onwards to fifth year.

Nair et al. (1980) made a comparative study of two varieties of palmarosa and obtained a herbage yield of 10.410 tonnes and 29.197 kg of oil per hectare from the variety ODP-2 as compared to herbage yield of 13.240 tonnes and 21.186 kg of oil per hectare from the variety ODP-1.

Pareek et al. (1980) evaluated the palmarosa accessions under cultivation and they found that fresh herbage varied from 6.6 to 55.0 tonnes per hectare and essential oil from 41.67-163.60 litres per hectare.

3. OIL CONTENT

Iall (1935) reported that the leaves of palmarosa grass yielded the maximum amount of oil (1.39%) in October, when the plants began to bloom. He also observed

that after flowering period the oil content of the plant diminished steadily to the minimum (0.77%) in the beginning of March. Further it was stated that the top of the grass contained most of the oil; but it was not advisable to cut only the tops for distillation because the grass will then get exhausted by too rapid regrowth.

According to Narain and Das Gupta (1948) the yield of oil from fresh or carefully dried grass of palmarosa was about 1.0 per cent.

Burger (1958) found that in palmarosa, bulk of the oil came from flower leaves growing on 2 m high stalks. The yield obtained was 1.5 per cent calculated on fresh weight basis.

Virmani et al. (1967) observed that the oil content in the whole plant varied from 0.12 to 0.28 per cent, on a fresh weight basis and that the flowers and leaves contained the maximum quantity of oil.

Gupta (1976) observed that the percentage of oil ranged from 0.10 in August to 0.70 in November.

As per the package of practices recommendations of Kerala Agricultural University the average recovery of oil from palmarosa was 0.60 per cent (Anon, 1978).

Preliminary studies conducted at the Lemongrass Research Station, Odakkali revealed that the oil recovery from the wilted herbage ranged from 0.35 to 0.40 per cent, depending upon the season (Nair and Mariam, 1978).

From the studies conducted on the cultivation of palmarosa, Regional Research Laboratory stated that the average oil content of palmarosa varied from 0.07 to 0.73 percent (Anon., 1978-79).

According to Nair et al. (1980) ODP-2 recorded 0.28 per cent oil recovery while ODP-1 had only 0.16 per cent oil recovery.

Rakshit and Dutt (1947) noticed that the yield of oil varied within the following limits - whole plant (before flowering tops appear) 0.13 to 0.21 per cent, flowering top 0.70 to 0.98 per cent and lower portion 0.39 to 0.61 per cent.

Rao et al. (1948) reported that in motia grass the yield of oil on a fresh weight basis was 0.16 per cent from the whole plant, 0.52 from the flower top, 0.20 per cent from leaves and 0.12 per cent from stalk. A similar trend in the oil yield from different parts has been reported by Deshmukh et al. (1976), Dutta and Paul (1976) and Virmani et al. (1977).

Screening of palmarosa from a population of 1000 plants was carried out on the basis of morphological characters by the Central Indian Medicinal and Aromatic Plants Organisation, Lucknow and they reported that the selected clones contained more than 1.0 per cent oil in the whole plant, 1.5 per cent in the flowering tops with 93.0 per cent geraniol (Anon., 1977-78).

Chandra (1978) made observations on palmarosa grown in saline alkaline soils and found that the crop raised in alkaline and normal soil differed considerably in their oil content. He observed that the oil content in different parts of the plant grown in saline alkaline soil was 1.90 per cent in flower top, 0.80 per cent in leaves and 0.04 per cent in stalk as compared to 1.7 per cent, 1.32 per cent and 0.40 per cent in the respective tissues of the plant grown in normal soils.

Gupta et al. (1978) in his studies on the effect of fertilizers on yield, oil content and oil composition of palmarosa found that the flowering shoots contained maximum oil content of 1.06 to 2.72 per cent and the leaves 0.88 to 1.18 per cent at zero moisture. It was also noted that the maximum oil content in the leaves synchronise with the appearance of flower buds in the crop.

Pareek et al. (1980) studied the extent of variability in palmarosa accessions under cultivation and they observed that the essential oil percentage varied between 0.27-2.04.

4. PHYSICO-CHEMICAL PROPERTIES OF OIL

The earliest research on the chemical composition of palmarosa oil derived from true Cymbopogon martini Stapf. var. motia was carried out by Jacobsen (1871) who identified an alcohol $C_{10}H_{18}O$ as the main constituent and assigned to it the name geraniol. Later, Semmler (1890) confirmed the validity of the formula $C_{10}H_{18}O$ and found that this terpene alcohol belongs to the aliphatic series. Indian palmarosa oil contained from 75 to 95 per cent of (free and combined) geraniol about 3.0 to 15 per cent being present in the form of acetic and N-caproic esters (Guenther, 1950).

Narain and Das Gupta (1948) reported the following properties of pure palmarosa oil from India - specific gravity 0.886 to 0.889, optical rotation -3° 0' to +5°0', refractive index 1.4720 to 1.4780, acid number upto 30, ester number 12 to 50, total geraniol content 78 to 94 per cent and solubility-soluble in 1.0 to 3.0 volumes of 70 per cent alcohol.

Guenther (1950) stated that the properties of Indian palmarosa oil varied within the following limits. Specific gravity at 15°C 0.887 to 0.900, optical rotation + 6°0' to -3°0', refractive index at 20°C 1.4730 to 1.4760, acid number 0.5 to 3.0, ester number 12 to 48, ester number after acetylation 226 to 274, total alcohol content as geraniol 84 to 94 per cent and solubility soluble in 1.5 to 3.0 volumes and more of 70 per cent alcohol.

Guenther (1950) reported that the shipments of Indian palmarosa oil received and examined by Fritzche Brothers, Inc., New York had properties varying within these limits - specific gravity at 15° 0.887 to 0.895, optical rotation -1° 34' to + 2° 45', refractive index at 20°C 1.4730 to 1.4760, acid number 0.7 to 1.1, ester content calculated as geranyl acetate 3.3 to 12.6 per cent, total alcohol content as geraniol 84 to 94 per cent and solubility-soluble in 3.0 to 4.0 volumes and more of 60 per cent alcohol.

On analysis of palmarosa oil from Angola, Burger (1958) obtained the following constants. Specific gravity at 20°C 0.8875, optical rotation ± 0°, refractive index at 20°C 1.4745, acid number 2.8, ester number 61.6, ester number after acetylation 268.8, total geraniol content 93 per cent and solubility-soluble in 1.5 volumes and more of 70 per cent alcohol.

Indian Standards Institution's specifications for Indian Palmarosa oil (Anon, 1968) were as follows: Colour light yellow to yellow, odour - rosaceous with a characteristic grassy background, specific gravity at 30°C 0.8740 to 0.8860, optical rotation -2° to + 3°, refractive index at 30°C 1.4690 to 1.4735, ester value 9 to 36 (Geranyl acetate (%) 3.1 to 12.5), total alcohols calculated as geraniol (%) minimum 90 and solubility soluble in 2.0 volumes of 70% alcohol.

Virmani et al. (1977) were of opinion that the characteristic features of oil of palmarosa were its sweet odour, solubility in 70 per cent alcohol. Solubility of oil in 2.2 to 4.2 volumes of the alcohol indicating a higher percentage of free geraniol. They reported that palmarosa oil contained 75 to 95 per cent of alcohols, calculated as geraniol, a small but varying amount of esters of the same alcohol, principally acetic and caproic acids.

Gupta et al. (1978) observed a higher percentage of free alcohol calculated as geraniol (72.0 to 79.9 per cent) in the oil of leaves as compared to oil of exclusively flower crop and composite flower and leaf crop. They observed a higher content of ester in the oil of leaves of May harvest. The oil of leaves was stated to possess the best odour with good fruity smell and least terpenic note while the oil of flower contained terpenic note due to higher

ester content in the oil and was given a lower rank for perfumery purpose. The physico-chemical properties reported by the above workers for oil of leaves were specific gravity 0.87592 to 0.87907, refractive index 1.47254 to 1.47294, optical rotation +0.40° to +0.68°, geranyl acetate 19.9 to 36.2, free alcohol 53.6 to 71.9 and total alcohol 83.3 to 87.6. For the oil of flower they observed a specific gravity 0.87852, refractive index 1.47094 optical rotation +0.58°, geranyl acetate 23.3 to 38.3, free alcohol 53.6 to 71.9 and total alcohol 80.3 to 85.9.

Gupta and Jain (1978) noticed that palmarosa oil of commerce contained about 80 to 90 per cent geraniol.

Analysis of essential oil of palmarosa from different tracts in Maharashtra and Madhya Pradesh was carried out by Gupta et al. (1980). They found that the oil showed much variability with regard to their geraniol and geranyl acetate contents. They observed that the tract having a cooler climate at harvest time produced superior quality of oil. They were of the opinion that the cooler climate induces the plant to synthesise more of geraniol. They concluded that palmarosa grass yielding more herbage with higher oil content of superior quality occur in the forest ranges where soil is comparatively medium in texture, rich in nutrients and climate is cool at the harvest time.

Also, they found that the oil from these tracts showed much variability with regard to their physical as well as chemical properties. The range observed in the physico-chemical properties were: specific gravity 0.8702 to 0.9174, refractive index 1.4712 to 1.4787, optical rotation -0.05° to -0.75°, linalool 1.0 to 4.6, geranyl acetate 2.0 to 24.5 and geraniol 59.6 to 93.4.

Pareek et al. (1980) conducted evaluation of ten elite clones selected from wild growing population of palmarosa in Madhya Pradesh and Maharashtra. They observed that the clones varied widely with regard to their physico-chemical properties - specific gravity (27°C) 0.8616-0.9182, refractive index (27°C) 1.4690-1.4899, acid number 0.08-17.9, ester value 8.0-76.0, geranyl esters (%) 2.5-26.6, geraniol (%) 65.2-92.8 and total alcohols calculated as geraniol (%) 67.5-96.5.

5. GAS CHROMATOGRAPHIC ANALYSIS

Gas chromatography is the technique of separating the individual components contained in a mixture, in which the separation takes place in the vapour phase. By proper monitoring of the column effluent, information is obtained which can be related to the amounts of individual components present as well as to their identification (Ettre, 1973). Gas Chromatographic analysis has been used

for the identification of components of essential oils and also for conforming the results obtained by quantitative methods. In the present review a brief account of the gas chromatographic analysis of essential oils is presented.

Nigam and Handa (1964) examined the essential oil of Piper nigrum by gas chromatographic analysis under Burrell Kromotog K-2 and found to contain α-pinene, camphene, β-pinene, sabinene, myrocene, limonene, γ-terpinene, p-cymene, α-bergamotene, caryophyllene, α-humulene and α-selinene.

Chemotaxonomic studies on the genus Cymbopogon were conducted by Nigam and Datta (1973) and the essential oil from the two strains of Cymbopogon martini (motia and sofia) were examined by gas chromatography. The investigation revealed that motia strain commonly known as palmarosa contains largely geraniol (80-90%). The palmarosa oil produced under Lucknow conditions on gas chromatographic analysis revealed the presence of geraniol (88.9%), limonene (0.4%), Methyl heptenone (0.9%), geranyl acetate (1.1%) and farnesol (6.7%).

Sinha et al. (1974) employed gas liquid chromatography for the identification of constituents of essential oil of Anaphalis contoria, an unworked species so far. Conditions mentioned were column carbowax -1540 (20 m), oven temperature -17°C, sensitivity -10, carrier gas-nitrogen, chart

speed -20 mm/hr, detector-flame ionisation detector and quantity of sample-3 ul. Using GLC different constituents were identified by injection method. When a standard sample of any constituent was injected along with the oil an enhanced peak of that constituent was obtained. This process was repeated successfully for each constituent under uniform conditions. The percentage of each constituent was calculated by assessing the peak area by triangle method.

The chemical composition of the essential oil of Bergamot mint was investigated by gas liquid chromatography on a Beckman GC-2A gas chromatograph with a thermal conductivity detector and the output was recorded with a bristol dynamaster recorder. Investigations by Bhagat et al. (1975) revealed the presence of 18 constituents, of which the two major ones were linalool and linalyl acetate. The constituents were assigned by comparing their retention times with that of the authentic samples on various columns under identical conditions.

Bradu et al. (1977) investigated the chemical composition of essential oil of Mentha citrata by gas liquid chromatography in a Perkin Elmer Model-881 and they found that ester content was highest in the third harvest.

In view of the conflicting reports about the chemical constituents of Coriandrum sativum, the essential oil was re-examined by gas liquid chromatography as reported by Gupta et al. (1977). GLC of the oil was done on Perkin Elmer-881 fitted with stainless steel 6 ft column packed with SE-30 and FID detector. Fifteen constituents have been detected and the compounds were identified by comparing their retention times with those of reference samples.

Chandra (1978) observed a high percentage of geraniol (90%) on gas chromatographic analysis of essential oil of palmarosa grown at pH conditions ranging from 8-10.

Hazarika et al. (1978) while investigating the effect of NPK fertilizers on the yield and quality of oil of palmarosa estimated the geraniol in each sample by GLC method. Analysis was conducted in a Beckman GC-2 A gas chromatograph with Bristol dynamaster 1 mV recorder.

The re-investigation of the essential oil of Prangos pabularia by GLC method led Koul and Thakur (1978) to the identification of 19 compounds. The GLC of the oil was done on AIMIL having SE-3 M long and nitrogen as the carrier gas. The compounds were identified by comparison of their retention times with those of authentic samples run under similar conditions.

Cymbopogon martini var. sofia was conducted by Thappa et al. (1978) in Perkin Elmer F-7 Chromatograph using 42 SR-400 column, nitrogen as carrier gas and flame ionisation detector. Confirmation of the identified compounds was done by comparing their retention times with those of the reference samples.

Materials and Methods

MATERIALS AND METHODS

The present investigations were carried out at the Lemongrass Research Station, Odakkali during 1979-80. The station is situated at an elevation of 66 m from mean sea level and the average rainfall is 2900 mm with 160 rainy days per annum. The soil of the experimental site is lateritic loam.

The study was conducted on palmarosa crop of uniform growth, during its second year from which period onwards optimum oil yield is obtained for the crop. The entire area for the experiment was planted with ODP-2 which gives a high oil yield with good quality compared to the existing variety ODP-1. This was a transplanted crop and well managed as per the Package of Practices recommendations of the Kerala Agricultural University.

Five random samples were selected for each treatment during each harvest.

The treatments were

1. Flower top of the plant
2. 2/3rd portion of the plant after removal of flower top (representing leafy portion)
3. Remaining 1/3rd portion of the plant (representing mostly stalk portion)
4. Whole plant (control)

The crop was harvested when the maximum number of plants were in full bloom. All the plants were cut from the field at 10 cm height as it was the practice adopted. Then the cut plants were separated into flower top (panicle with the boot leaf) and the remaining part into 2/3rd and 1/3rd portions depending on length. To serve as control the cut whole plants were kept as it was. The quantity of flower top for distillation was limited to two kg as it was difficult to collect more quantity. Ten kg each of other treatments were taken for distillation. In all the treatments, the herbage were allowed to wilt in shade for 24 hours.

The essential oil content was assayed on fresh weight basis by steam distillation method suggested by Guenther (1948). The distillation was conducted treatment-wise in small stills installed for experimental purpose. The oil obtained after distillation was further clarified to make it free of sediments and water drops before the quantity was measured.

Six harvests were taken during the year under study of which the first three harvests were conducted in the monsoon season and the latter three in the post-monsoon season.

OBSERVATIONS RECORDED

1. WEATHER DATA

Rainfall, maximum and minimum temperature and relative humidity were recorded daily from April 1979 to April 1980.

2. BIOMETRIC CHARACTERS

Observations on growth characters namely plant height, length of panicle and tiller number were recorded before each harvest. Herbage yield per plant was also recorded. Twentyfive plants were randomly selected to record the biometric characters from each sample.

2.1. Plant height

Height of the plant from the ground level to the tip of the longest tiller was measured.

2.2. Length of panicle

The length of the panicle was measured from the point of sheath union of boot leaf to the tip of the panicle.

2.3. Flowered tillers

The number of tillers that had flowered per clump at the time of harvest was recorded.

2.4. Non-flowered tillers

The number of tillers of the same clump which did not flower was also recorded.

2.5. Total tillers

The total number of tillers of the selected plants were worked out.

2.6. Herbage yield per plant

Weight of herbage of the selected plants were recorded as and when they were harvested.

3. HERBAGE YIELD PER HECTARE

The herbage yield for the different treatments from unit area was recorded during each harvest and the yield per hectare worked out from it.

4. ESSENTIAL OIL RECOVERY

The quantity of oil obtained from each treatment was used for working out the percentage of oil recovery on fresh weight basis of the herbage.

5. OIL YIELD PER HECTARE

The yield of oil per hectare was calculated by multiplying the yield of fresh herbage per hectare with the

percentage recovery of the oil for the respective treatments. This was then multiplied by the specific gravity in order to express this in kg.

6. PHYSICO-CHEMICAL PROPERTIES OF OIL

Oil samples were drawn from each treatment replicationwise and the physical and chemical properties determined as per the method prescribed by the Indian Standards Institution (1952).

6.1. Specific gravity

Specific gravity was determined at room temperature using a specific gravity bottle.

6.2. Optical rotation

The optical activity was recorded in degrees of rotation using a polarimeter.

6.3. Refractive index

Refractive index was determined using an 'Abbe' refractometer.

6.4. Solubility

One ml of the oil was taken in a test tube and 70 per cent alcohol was added from a burette, shaking the

contents, till a clear solution was obtained. The volume of alcohol added gave the solubility of oil in volumes of 70 per cent alcohol.

6.5. Acid value

2.5 g of the oil were weighed accurately and dissolved in 20 ml of ethyl alcohol previously neutralised with approximately 0.1 N potassium hydroxide. Ten drops of phenolphthalein indicator were added to it and titrated against 0.1 N potassium hydroxide. From the titre value the acid value was calculated.

6.6. Saponification value of unacetylised oil

Transferred two g of oil into a round bottom flask and added 25 ml of 0.5 N alcoholic potassium hydroxide. The contents were refluxed for one hour. After cooling it was titrated against 0.5 N hydrochloric acid using phenolphthalein as the indicator. A blank value was determined following the same procedure. The saponification value of the unacetylised oil was then calculated.

6.7. Ester value

Ester value was computed by working out the difference between the saponification value of the unacetylised oil and acid value.

6.8. Ester content

Ester content was determined from the ester value using the formulae $\frac{E \times M}{561}$

Where

E is the ester value

M is the molecular weight of the ester

6.9. Saponification value after acetylation

The oil was acetylated first. Then it was hydrolysed and the weight of potassium hydroxide required to neutralise the acid liberated was calculated.

6.9.1. Acetylation

Ten ml of the oil was mixed with ten ml of acetic anhydride and two g of sodium acetate and boiled for two hours. Allowed the contents to cool, added 50 ml of water and boiled for 15 minutes. Then the acetylated oil was made neutral and made free of water with two g of sodium sulphate and filtered.

6.9.2. Hydrolysis

Twentyfive ml of ethanolic potassium hydroxide were added to one g of the acetylated oil. The content was boiled

for one hour, cooled, and diluted with 20 ml of water. Titrated the excess alkali against 0.5 N hydrochloric acid using phenophthalein as the indicator.

6.10. Free alcohol as geraniol

Free alcohol was computed using the formula $\frac{S-E \times M}{1356-S \times 0.42}$ and expressed as percentage

Where,

S - the saponification value after acetylation

E - the ester value

M - the molecular weight of the alcohol.

6.11. Combined alcohol

The percentage of alcohol combined as esters in the oil was calculated using the formula $\frac{E \times A}{561}$ and expressed as percentage.

Where,

E - the ester value

M - the molecular weight of the alcohol

6.12. Total alcohol as geraniol

Total alcohol was computed by adding free alcohol and combined alcohol and expressed as geraniol per cent.

6.13. Geraniol yield per hectare

This was arrived at by multiplying the geraniol percentage with the oil yield of the respective treatment.

7. GAS CHROMATOGRAPHIC ANALYSIS

The percentage composition of the aromatic isolates were further verified by gas liquid chromatography. One sample from each treatment for the six harvests was drawn for GLC analysis.

GLC of the oil was done on AC gas chromatograph model No.S 17410 of Chromatography and Instruments Co., Baroda. The oil (0.2 µl) was injected into the gas chromatograph fitted with SE-30 3 m long column, flame ionisation detector and potentiometric strip chart recorder. Nitrogen was used as the carrier gas. The operating conditions were: Oven temperature 160°C, attenuation 526, hydrogen 1 kg/cm^2 and chart speed 1 cm/minute.

The compounds were identified by comparing their retention times with those of authentic reference samples. Under the operating conditions given above the retention time of geraniol and geranyl acetate were between 9 to 10 minutes and 15 to 16 minutes, respectively. The percentage of each constituent was calculated by assessing the peak area by triangle method.

8. STATISTICAL ANALYSIS

The data collected on yield and quality attributes were analysed by applying the two-way classification model-1 suggested by Li (1964). Since this was a fixed model the various effects were tested against error mean square.

Results

R E S U L T S

The results of the different aspects of investigations are presented under the following sections. The analysis of variance tables for the different characters are given in Appendices I to VII.

1. WEATHER

The details of the meteorological observations for the cropping period are given in Appendix I.

The maximum rainfall was received during the month of July, 1979 (780.5 mm) with the minimum during April, 1979 (1.4 mm). The number of rainy days varied from 3 in December to 30 days in July. The rain was fairly well distributed with only two months without showers. The daily maximum temperature during the cropping period ranged from 26.5°C to 34.5°C and the minimum temperature from 18.6°C to 24.2°C. The range of relative humidity was 84.0 to 91.2 per cent, the maximum being recorded during the month of November.

2. BIOMETRIC CHARACTERS

Data presented in Table 1 represent the biometric characters during each harvest.

It may be seen that the plant height varied from

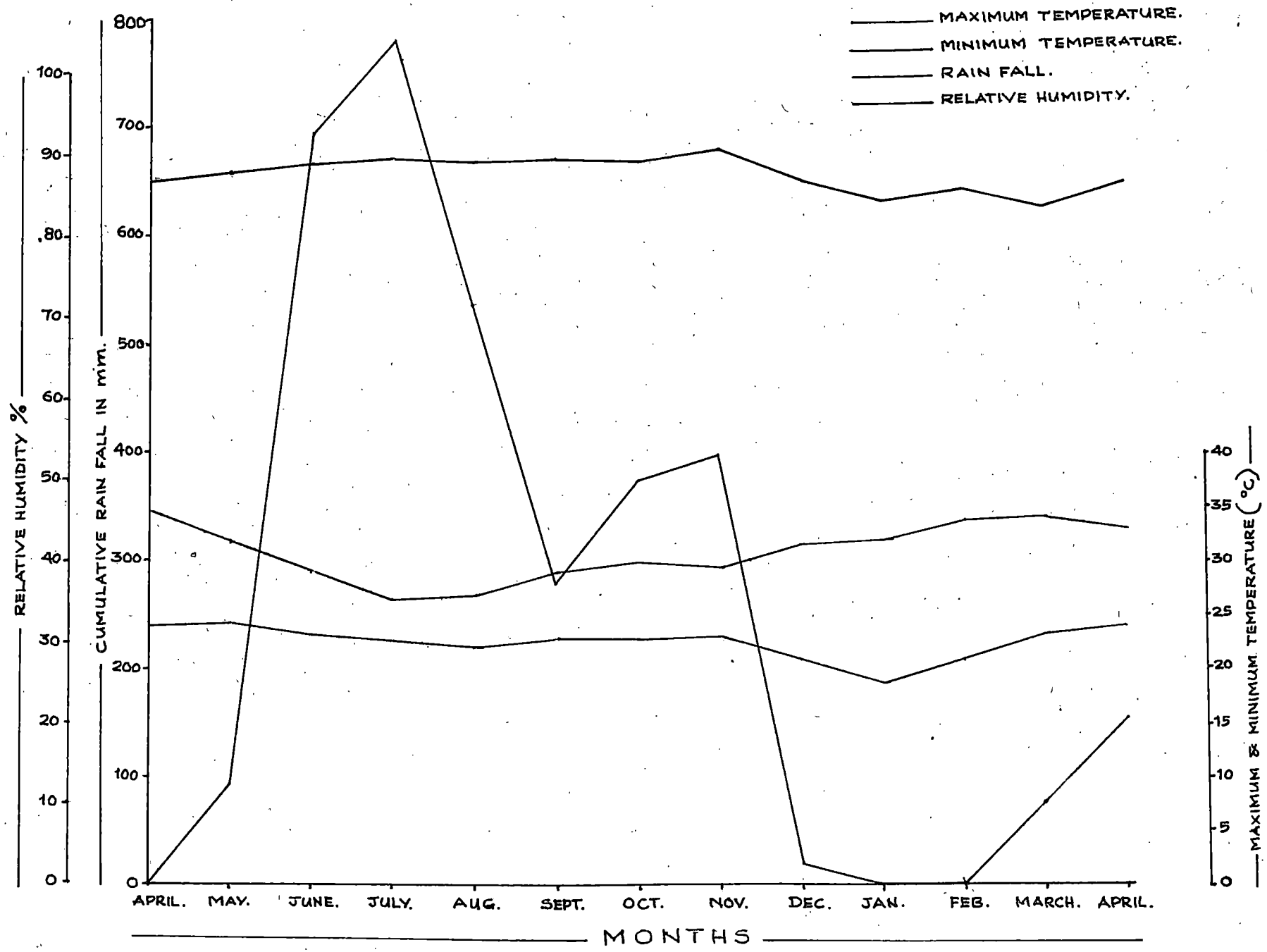
Table 1. Biometric characters during each harvest viz., plant height, panicle length, flowered tillers, non-flowered tillers, total tillers and weight of herbage per plant

Harvests	Plant height (cm)	Panicle length (cm)	Flowered tillers	Non-flowered tillers	Total tillers	Weight of herbage/ plant (g)
1st	160.6	42.9	13.9 (63)	8.2 (37)	22.1	128.54
2nd	186.2	47.8	14.8 (79)	3.9 (21)	18.7	76.56
3rd	165.9	40.7	16.9 (78)	4.9 (22)	21.8	53.75
4th	160.9	39.7	20.9 (84)	4.1 (16)	25.0	56.25
5th	77.5	19.3	4.7 (28)	12.2 (72)	16.9	8.94
6th	121.3	31.9	11.6 (61)	7.4 (39)	19.0	29.44

Values in parenthesis indicate the percentage of flowered and non-flowered tillers

(The percentage has been rounded to the nearest whole number)

FIG. 1 - METEOROLOGICAL DATA FOR THE PERIOD FROM APRIL 1979 TO APRIL 1980.



77.5 cm to 186.2 cm, the maximum being recorded in the second harvest. The range in the length of the inflorescence was 19.3 cm to 47.8 cm. The inflorescence showed an increase in length with increase in height of the plant.

Maximum number of flowered tillers (20.9) and the minimum number of nonflowered tillers (4.1) were observed during the fourth harvest. Tillers bearing flowering shoots made a major contribution towards total tillers in all the harvests except in fifth harvest where tillers not bearing flowering shoots contributed the maximum (72%).

The weight of herbage per plant varied from 8.94 g to 128.54 g and the maximum weight was recorded in the first harvest and the minimum weight in the fifth harvest.

3. YIELD OF HERBAGE

Data on the herbage yield from different portions of the plant from each harvest are furnished in Table 2a.

A perusal of the data indicated that the 2/3rd portion made the maximum contribution (46%) towards total herbage yield, followed by the 1/3rd portion (42%) and the flower top (12%). The contribution of different portions towards total yield in different harvests also showed high variation. Maximum contribution was made by the first harvest.

Table 2a. Yield of herbage (kg/hectare) from different portions of the plant in different harvests

Treatments	Yield of herbage (kg/ha)						Total yield per hectare per year
	Harvests						
	1st	2nd	3rd	4th	5th	6th	
1	852.9 (9)	677.6 (12)	396.2 (10)	746.2 (18)	85.7 (13)	338.1 (14)	3096.7 (12)
2	4740.0 (50)	2427.1 (43)	1783.3 (45)	1741.9 (42)	276.7 (42)	1062.4 (44)	12031.4 (46)
3	3886.2 (41)	2540.0 (45)	1783.3 (45)	1659.1 (40)	296.2 (45)	1013.8 (42)	11178.5 (42)
4	9479.0	5644.8	3962.9	4147.1	658.6	2414.9	26307.3

Values in parenthesis indicate the percentage contribution of different portions of the plant towards total yield

(The percentage has been rounded to the nearest whole number)

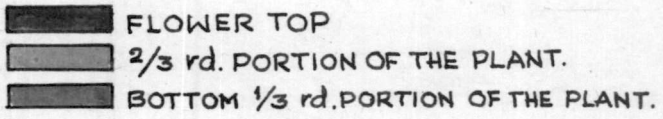
Table 2b. Yield of herbage (kg/hectare) from different portions of the plant during monsoon and post-monsoon season

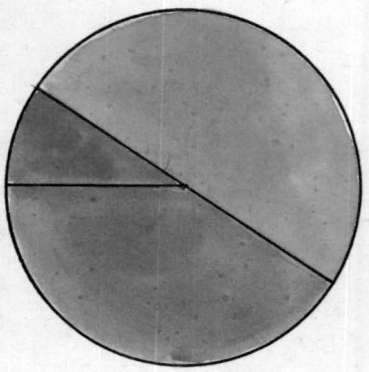
Treatments	Yield of herbage (kg/ha)	
	Monsoon season	Post-monsoon season
1	1926.7 (10)	1170.0 (16)
2	8950.4 (46)	3081.0 (43)
3	8209.4 (43)	2969.1 (41)
4	19086.7	7220.6

Values in parentheses indicate the percentage contribution of the different portion of the plant towards total yield during the monsoon and post-monsoon season.
(The percentage has been rounded to the nearest whole number)

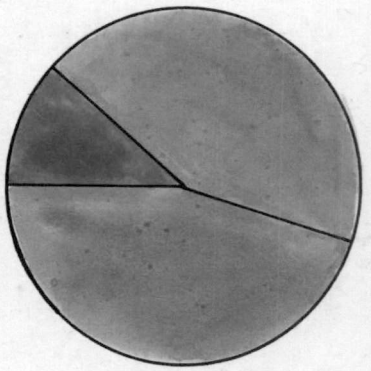
FIG-2

CONTRIBUTION OF DIFFERENT PORTIONS OF THE PLANT TOWARDS THE HERBAGE YIELD IN EACH HARVEST.

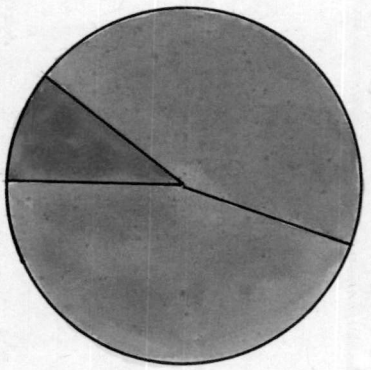




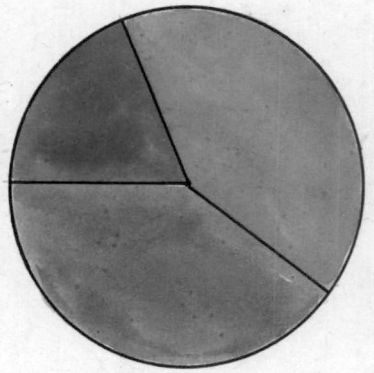
1 st. HARVEST.



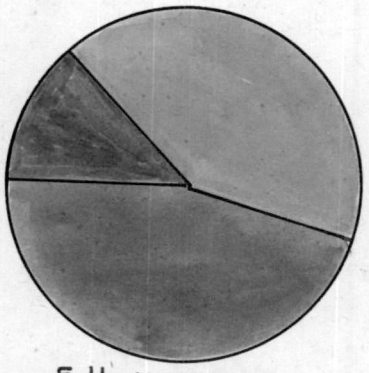
2 nd. HARVEST.



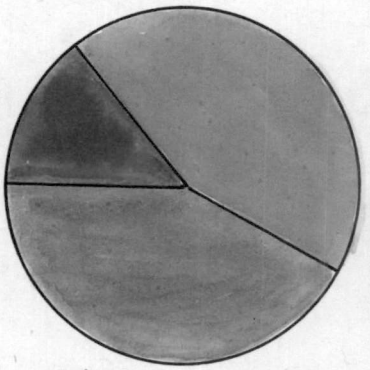
3 rd. HARVEST.



4 th. HARVEST.



5 th. HARVEST.



6 th. HARVEST.

Data presented in Table 2b indicated that the highest herbage yield was obtained from the harvests during the monsoon season with regard to all the plant portions. It accounted for nearly 3/4th of the total herbage yield. It may be noted that flowertop made an increased contribution towards total herbage yield during the post-monsoon harvests when compared with that in the monsoon season.

4. RECOVERY OF OIL

Data presented in Table 3a represent the percentage recovery of oil from the different portions of the plant. Highly significant differences were noticed between the treatments in respect of the percentage of oil recovery. Highest recovery was recorded by the flowertop (0.87%) followed by the 2/3rd portion (0.34%) and the least in the 1/3rd portion (0.18%). Statistically, oil recovery recorded by the whole plant and the 2/3rd portion were on par.

The yield of oil in the different harvests also differed significantly. The fifth harvest which recorded the maximum oil content (0.58%) was significantly superior to all others. The third and fourth harvests were on par while the first harvest was inferior to all.

Interaction between the effects of the treatments and harvests was found to be significant. In all the harvests

Table 3a. Recovery of oil (%) as influenced by the treatments and harvests

Treatments	Recovery of oil (%) mean values						Mean
	Harvests						
	1st	2nd	3rd	4th	5th	6th	
1	0.68	0.92	0.87	0.87	1.03	0.85	0.87
2	0.34	0.30	0.27	0.25	0.50	0.39	0.34
3	0.11	0.11	0.11	0.10	0.31	0.32	0.18
4	0.28	0.29	0.28	0.30	0.49	0.44	0.35
Mean	0.35	0.41	0.38	0.38	0.58	0.50	

C.D.(0.05) for comparing treatments - 0.02
C.D.(0.05) for comparing harvests - 0.03
C.D.(0.05) for comparing treatments within the same harvest - 0.05

Table 3b. Recovery of oil (%) from different treatments during monsoon and post-monsoon season

Treatments	Recovery of oil (%) mean values	
	Monsoon season	Post-monsoon season
1	0.82	0.92
2	0.30	0.38
3	0.11	0.24
4	0.28	0.41

the flower top recorded a higher recovery and it was significantly superior to all other treatments. In the harvests first, second and fifth, the 2/3rd portion was found to be significantly superior to the whole plant but in third, fourth and fifth harvests, it was not statistically different. The 1/3rd portion was significantly inferior to all other treatments in all the six harvests.

Post-monsoon harvests recorded the highest oil recovery in all the four treatments; the recovery being 0.92 per cent, 0.38 per cent, 0.24 per cent and 0.41 per cent for the flower top, the 2/3rd portion, the 1/3rd portion and the whole plant plant respectively. During the monsoon season, it was slightly lower, being 0.82 per cent, 0.30 per cent, 0.11 per cent and 0.28 per cent for the respective treatments (Table 3b). It may be noted that treatment 4 recorded a high recovery compared to treatment 2 during the post-monsoon season while the trend was vice-versa during the monsoon season.

5. OIL YIELD

Data relating to the oil yield from different treatments during each harvest are presented in Table 4a.

Whole plant recorded a total oil yield of 69.63 kg per hectare per year out of which the maximum contribution

Table 4a. Oil yield (kg/hectare) from different portions of the plant in different harvests

Treatments	Oil yield, kg/ha (mean values)						Mean
	Harvests						
	1st	2nd	3rd	4th	5th	6th	
1	5.107 (22)	5.517 (38)	3.073 (34)	5.752 (52)	0.784 (28)	2.555 (28)	3.798 (33)
2	14.295 (62)	6.450 (45)	4.194 (47)	3.779 (34)	1.225 (44)	3.669 (40)	5.602 (48)
3	3.776 (16)	2.467 (17)	1.661 (19)	1.471 (13)	0.801 (28)	2.877 (32)	2.175 (19)
4	23.485	14.498	9.674	11.027	2.865	9.434	11.830
Mean	11.665	7.233	4.650	5.507	1.418	4.633	

C.D. (0.05) for comparing treatments - 0.33

C.D. (0.05) for comparing harvests - 0.41

C.D. (0.05) for comparing treatments within the same harvest -0.81

Values in parenthesis indicate the percentage contribution of different portions of the plant towards oil yield.

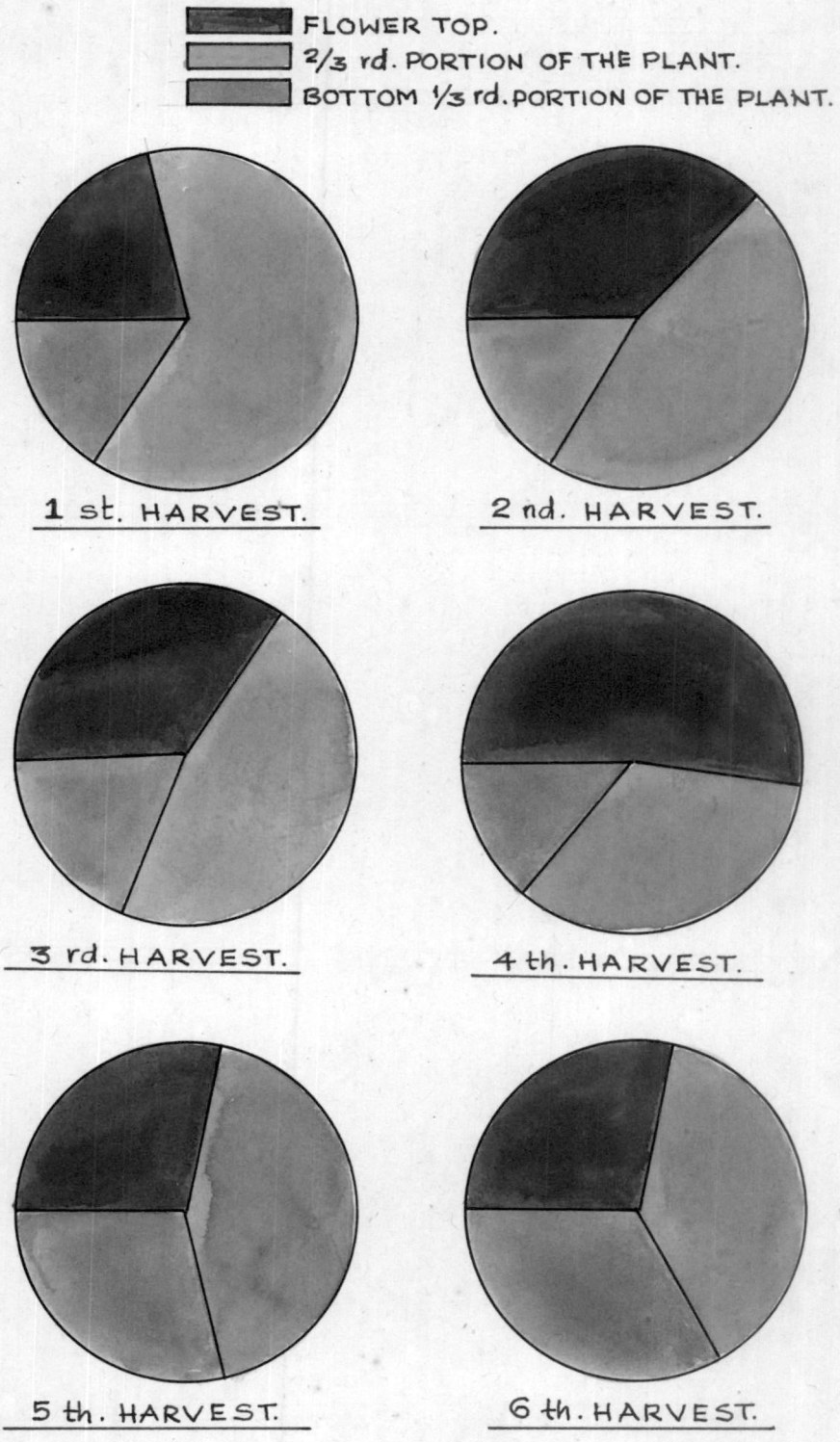
(The percentage has been rounded to the nearest whole number)

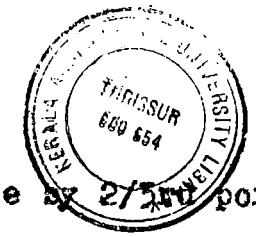
Table 4b. Oil yield (kg/hectare) from the different portions of the plant during the monsoon and post-monsoon season

Treatments	Oil yield (kg/ha)		Total oil yield kg/ha/year
	Monsoon season	Post-monsoon season	
1	13.697	9.091	22.788
2	24.939	8.673	33.612
3	7.904	5.149	13.053
4	47.657	21.973	69.630

FIG.-3.

CONTRIBUTION OF DIFFERENT PORTIONS OF THE PLANTS TOWARDS THE OIL YIELD IN EACH HARVEST.





was made by 2/3rd portion (48%) followed by flower top (33%); the lowest (19%) being contributed by 1/3rd portion.

Different harvests also showed significant differences in oil yield. First harvest recorded the maximum oil yield (11.665 kg) followed by harvests 2 (7.233 kg), 4 (5.507 kg), 3 (4.650 kg), 6 (4.633 kg) and 5 (1.416 kg) in that order.

Considering the effect of treatments within the same harvest, the percentage contribution of 2/3rd portion towards total yield decreased progressively except in third harvest. The 2/3rd portion of the plant made the maximum contribution towards oil yield in all the harvests except the fourth one, in which the maximum contribution was made by the flower top (52%). The 1/3rd portion had the lowest contribution in all the harvests except the sixth.

Harvests during the monsoon season registered the maximum oil yield for all the treatments. It may be noted that during the monsoon season, more than half of the total oil yield was contributed by the 2/3rd portion, while the yield of oil from the flower top exceeded that of the 2/3rd portion during the post-monsoon harvests.

6. PHYSICO-CHEMICAL PROPERTIES OF THE OIL

6.1. Specific gravity

Data presented in Table 5 showed that treatment 1 had

Table 5. Specific gravity of the oil as influenced by the treatments and harvests

Treatments	Specific gravity of the oil (mean values)						Mean
	Harvests						
	1st	2nd	3rd	4th	5th	6th	
1	0.8871	0.8869	0.8876	0.8881	0.8878	0.8881	0.8876
2	0.8871	0.8858	0.8877	0.8857	0.8862	0.8857	0.8864
3	0.8834	0.8830	0.8869	0.8869	0.8869	0.8869	0.8857
4	0.8849	0.8857	0.8878	0.8865	0.8880	0.8881	0.8868
Mean	0.8856	0.8854	0.8875	0.8868	0.8872	0.8872	

C.D. (0.05) for comparing treatments - 0.0005
C.D. (0.05) for comparing harvests - 0.0006
C.D. (0.05) for comparing treatments within the same harvest - 0.0011

the highest specific gravity and it was statistically significant. Treatments 2 and 4 were on par while treatment 3 showed the lowest value.

Highest specific gravity was recorded for the oil obtained in third harvest. Harvests 5 and 6 were statistically on par. Second harvest recorded the lowest specific gravity and the differences were statistically significant.

6.2. Optical rotation

The optical rotation of the oil was + 0.3^{o} irrespective of the treatments and harvests tried in the study.

6.3. Refractive index

Data relating to the refractive index of the oil are furnished in Table 6. It may be seen that the refractive index of oil from treatment 3 was statistically on par with treatment 2. The lowest value was recorded by treatment 1 and it was not statistically different from that of treatment 4.

The oil obtained in different harvests also differed significantly, the maximum value being recorded in the fourth harvest (1.4709) and the minimum in the fifth harvest (1.470). There was significant interaction between the effects of treatments and harvests. In the first two harvests the

Table 6. Refractive index of the oil as influenced by the treatments and harvests

Treatments	Refractive index of the oil (mean values)						Mean
	Harvests						
	1st	2nd	3rd	4th	5th	6th	
1	1.4700	1.4702	1.4700	1.4706	1.4700	1.4700	1.4701
2	1.4704	1.4700	1.4698	1.4718	1.4698	1.4704	1.4704
3	1.4704	1.4702	1.4706	1.4710	1.4702	1.4706	1.4705
4	1.4700	1.4700	1.4710	1.4700	1.4700	1.4702	1.4702
Mean	1.4702	1.4701	1.4704	1.4709	1.4700	1.4703	

C.D. (0.05) for comparing treatments - 0.0002
C.D. (0.05) for comparing harvests - 0.0003
C.D. (0.05) for comparing treatments within the same harvest - 0.0005

treatments showed no significant difference while the treatments varied significantly in the rest of the harvests.

6.4. Solubility of the oil

The data furnished in Table 7 revealed that there was significant variation among the treatments as regards the solubility of the oil. Treatment 2 had the highest solubility (1.64) followed by treatment 3 (1.62), 4 (1.52) and 1 (1.51). There was no significant difference between treatments 2 and 3 but treatment 2 differ significantly from treatment 1 and 4.

Different harvests did not show significant difference with regard to the solubility of the oil. But there was significant interaction between the effects of treatments and harvests.

6.5. Acid value

Data on the acid value of the oil for different treatments during each harvest are furnished in Table 8.

As evident from the data, the lowest acid value was recorded by the whole plant and it was on par with that of the 1/3rd portion. Treatments 1 and 2 were on par and they varied significantly from treatments 3 and 4. Highest acid value was recorded by treatment 1 (3.40).

Table 7. Solubility of the oil as influenced by the treatments and harvests

Treatments	Solubility of the oil (mean values)						Mean
	Harvests						
	1st	2nd	3rd	4th	5th	6th	
1	1.51	1.50	1.51	1.51	1.52	1.51	1.51
2	1.61	1.66	1.68	1.62	1.62	1.63	1.64
3	1.60	1.62	1.62	1.62	1.61	1.62	1.62
4	1.50	1.52	1.52	1.51	1.52	1.55	1.52
Mean	1.56	1.58	1.58	1.57	1.57	1.58	

C.D. (0.05) for comparing treatments - 0.04

C.D. (0.05) for comparing harvests - 0.05

C.D. (0.05) for comparing treatments within the same harvest - 0.11

Table 8. Acid value of the oil as influenced by the treatments and harvests

Treatments	Acid value of the oil (mean values)						Mean
	Harvests						
	1st	2nd	3rd	4th	5th	6th	
1	3.42	3.44	2.91	4.22	3.13	3.27	3.40
2	3.37	2.31	3.56	4.09	3.13	3.24	3.28
3	2.36	2.51	1.97	3.51	3.22	3.64	2.87
4	1.92	2.33	3.02	3.20	2.84	3.22	2.76
Mean	2.77	2.65	2.87	3.76	3.08	3.34	

C.D. (0.05) for comparing treatments - 0.13

C.D. (0.05) for comparing harvests - 0.16

C.D. (0.05) for comparing treatments within the same harvest - 0.32

The oil obtained for the second harvest recorded the lowest acid value and it varied significantly from other harvests except the first one which was on par. The maximum value was observed for the fourth harvest (3.76).

6.6. Saponification value of unacetylised oil

Data presented in Table 9 revealed that the lowest value for saponification of unacetylised oil was recorded by treatment 3 and it varied significantly from the rest of the treatments. Treatments 1 and 4 were on par.

It was observed that the saponification value in the different harvests showed high statistical significance. The lowest value (43.71) was recorded by first harvest and the highest value (71.58) by third harvest.

The effects of treatments within the same harvest showed significant variation. Treatments 1 and 4 were on par for all the harvests except harvest 3 and 5 where it showed significant difference. The treatments in general, showed a tendency to increase in saponification value of unacetylised oil upto the third harvest and gradually decline thereafter.

6.7. Ester value

The data on the ester value of the oil for different

Table 9. Saponification value of the unacetylised oil as influenced by the treatments and harvests

Treatments	Saponification value of unacetylised oil (mean values)						Mean
	Harvests						
	1st	2nd	3rd	4th	5th	6th	
1	45.60	70.46	81.97	69.44	60.06	60.45	64.66
2	41.22	61.92	66.80	54.60	58.68	45.98	54.87
3	41.50	54.61	60.44	59.34	57.25	48.56	53.62
4	46.50	68.64	77.12	68.30	63.14	59.32	63.84
Mean	43.71	63.91	71.58	62.92	59.78	53.58	

C.D. (0.05) for comparing treatments - 0.98
C.D. (0.05) for comparing harvests - 1.20
C.D. (0.05) for comparing treatments within the same harvest - 2.36

Table 10. Ester value of the oil as influenced by the treatments and harvests

Treatments	Ester value of the oil (mean values)						Mean
	Harvests						
	1st	2nd	3rd	4th	5th	6th	
1	42.18	67.02	79.06	65.22	56.93	57.18	61.27
2	37.85	59.61	63.24	50.50	55.54	42.74	51.58
3	39.14	52.11	58.47	55.83	54.23	44.92	50.78
4	44.18	66.31	74.11	65.12	60.30	56.10	61.02
Mean	40.84	61.26	68.72	59.17	56.75	50.24	

C.D. (0.05) for comparing treatments - 0.98

C.D. (0.05) for comparing harvests - 1.20

C.D. (0.05) for comparing treatments within the same harvest - 2.40

treatments and harvests are furnished in Table 10.

From the data it is evident that ester value followed the same trend as that of the saponification value of un-acetylised oil except that the treatments 2 and 3 were on par.

6.8. Ester content

Data furnished in Table 11 represented the ester content for the treatments during different harvests.

The data indicated that the treatments varied significantly with regard to the ester content except treatments 1 and 4 which were on par. The lowest value was recorded by treatment 3 (17.78%) followed by treatments 2 (18.06%), 4 (21.36%) and 1 (21.44%).

Harvests differed significantly with regard to the ester content. The lowest value was obtained for the first harvest and the maximum for the third harvest.

6.9. Saponification value after acetylation

Data on the saponification value after acetylation of oil are presented in Table 12.

As regards the saponification value after acetylation of oil there was significant variation among treatments.

Table 11. Ester content of the oil (per cent) as influenced by the treatments and harvests

Treatments	Ester content of the oil (per cent) (mean values)						Mean
	Harvests						
	1st	2nd	3rd	4th	5th	6th	
1	14.76	23.45	27.67	22.83	19.93	20.01	21.44
2	13.25	20.86	22.14	17.68	19.44	14.96	18.06
3	13.70	18.24	20.47	19.54	18.98	15.72	17.78
4	15.46	23.21	25.94	22.79	21.11	19.63	21.36
Mean	14.29	21.44	24.06	20.71	19.87	17.58	

C.D. (0.05) for comparing treatments - 0.34

C.D. (0.05) for comparing harvests - 0.42

C.D. (0.05) for comparing treatments within the same harvest - 0.84

Table 12. Saponification value of the acetylised oil as influenced by the treatments and harvests

Treatments	Saponification value of the acetylised oil (mean values)						Mean
	Harvests						
	1st	2nd	3rd	4th	5th	6th	
1	264.95	267.23	259.25	265.26	267.44	263.61	264.62
2	275.76	279.57	277.49	264.37	271.65	272.91	273.63
3	275.46	273.63	267.80	264.56	267.52	270.97	269.99
4	275.16	273.07	275.34	270.88	266.44	268.63	271.59
Mean	272.83	273.38	269.97	266.27	268.26	269.03	

C.D. (0.05) for comparing treatments - 1.10

C.D. (0.05) for comparing harvests - 1.34

C.D. (0.05) for comparing treatments within the same harvest - 2.67

Treatment 2 recorded the highest value (273.63) followed by treatments 4 (271.59), 3 (269.99) and 1 (264.22).

The above factor also showed variation in different harvests, highest value being recorded by the second harvest and the fourth harvest being inferior to all others. There was significant interaction between treatments and harvests. The maximum values were recorded by the oil of the 2/3rd portion in all the harvests except the fourth one.

6.10. Free alcohol

The data on the free alcohol content for different treatments during each harvest are given in Table 13.

The results showed that the treatments differed significantly with regard to the free alcohol of the oil. The 2/3rd portion ranked first, with a value of 76.79 followed by 1/3rd portion (75.56%), whole plant (72.69%) and flower top (69.74%).

Significant difference was observed between harvests with regard to the free alcohol content of the oil. Maximum value was obtained for the first harvest (80.18%) and the lowest for the third harvest (69.39%). Interaction effect was found to be significant. Treatments 2 and 3 recorded higher values in all the harvests, compared to treatments 1 and 4.

Table 13. Free alcohol (per cent) of the oil as influenced by the treatments and harvests

Treatments	Free alcohol (per cent) (mean values) Harvests						Mean
	1st	2nd	3rd	4th	5th	6th	
1	76.41	68.81	61.49	68.64	72.38	70.72	69.74
2	82.44	76.50	74.36	73.32	74.60	79.54	76.79
3	81.87	76.61	72.00	71.57	73.34	77.98	75.56
4	79.99	71.47	69.70	70.97	70.81	73.19	72.69
Mean	80.18	73.35	69.39	71.13	72.78	75.36	

C.D. (0.05) for comparing treatments - 0.59
C.D. (0.05) for comparing harvests - 0.73
C.D. (0.05) for comparing treatments within the same harvest - 1.46

6.11. Combined alcohol (per cent)

Data on combined alcohol are presented in Table 14.

It was observed that treatment 1 topped the list with a value of 16.85 closely followed by treatment 4 (16.79). Though treatments 1 and 4 were on par, they varied significantly from other treatments.

With regard to combined alcohol, harvests differed significantly and it followed the same pattern as that of ester value. The highest per cent of combined alcohol was recorded by the 3rd harvest (18.91) and lowest value by the first harvest (11.23).

6.12. Geraniol content

Data furnished in Table 15 give the geraniol content in the oil from different treatments during each harvest.

Treatments showed statistical difference with regard to geraniol content. The highest percentage was recorded by treatment 2 (90.98) and lowest by treatment 1 (86.60). Treatments 3 and 4 were on par.

There was significant variation between harvests with regard to geraniol content. First harvest recorded the highest percentage (91.41) and it was statistically superior to other harvests. Second harvest recorded the lowest

Table 14. Combined alcohol (per cent) of the oil as influenced by the treatments and harvests

Treatments	Combined alcohol of the oil (per cent) (mean values) Harvests						Mean
	1st	2nd	3rd	4th	5th	6th	
1	11.60	18.44	21.75	17.94	15.66	15.73	16.85
2	10.41	16.40	17.40	13.89	15.28	11.76	14.19
3	10.77	14.34	16.09	15.36	14.92	12.36	13.97
4	12.15	18.24	20.39	17.92	16.59	15.43	16.79
Mean	11.23	16.86	18.91	16.28	15.61	13.82	

C.D. (0.05) for comparing treatments - 0.27

C.D. (0.05) for comparing harvests - 0.33

C.D. (0.05) for comparing treatments within the same harvest - 0.66

Table 15. Geraniol (per cent) of the oil as influenced by the treatments and harvests

Treatments	Geraniol content of the oil (per cent) (mean values)						Mean
	Harvests						
	1st	2nd	3rd	4th	5th	6th	
1	88.02	87.24	83.24	86.58	88.04	86.45	86.60
2	92.85	92.89	91.76	87.21	89.88	91.30	90.98
3	92.63	90.94	88.08	86.93	88.26	90.34	89.53
4	92.14	89.71	90.09	88.89	87.40	88.62	89.48
Mean	91.41	90.20	88.29	87.40	88.40	89.18	

C.D. (0.05) for comparing treatments - 0.46

C.D. (0.05) for comparing harvests - 0.57

C.D. (0.05) for comparing treatments within the same harvest - 1.13

value (87.4%). Interaction between effects of treatments and harvests was found to be significant. A high geraniol content was recorded by treatment 2 as compared to other treatments in all the harvests except the fourth. Also it was found that treatment 1 recorded the lowest value in all the harvests except fifth harvest.

6.13. Geraniol yield per hectare

The data on the yield of geraniol from different portions of the plant during each harvest are furnished in Table 16.

Treatments showed highly significant variation with regard to geraniol yield. Compared between the different portions of the plant, it was the highest in the 2/3rd portion (5.15 kg/ha) followed by the flower top and the 1/3rd portion.

It was observed that harvests differed significantly with regard to geraniol yield except third and sixth harvests which were on par. First harvest was significantly superior to all other harvests. There was also significant interaction between effects of the treatments and harvests. Considering each harvest, it was found that treatment 3 was inferior to all treatments in all the harvests except fifth and sixth in which it was on par with treatment 1.

Table 16. Geraniol yield (kg/ha) as influenced by the treatments and harvests

Treatments	Geraniol yield (kg/ha) (mean values) Harvests						Mean
	1st	2nd	3rd	4th	5th	6th	
1	4.49	4.81	2.56	4.98	0.70	2.21	3.29
2	13.28	6.00	3.85	3.30	1.10	3.35	5.15
3	3.50	2.20	1.44	1.28	0.71	2.60	1.96
4	21.64	13.02	8.72	9.80	2.50	8.36	10.67
Mean	10.73	6.51	4.14	4.84	1.25	4.13	

C.D. (0.05) for comparing treatments - 0.32

C.D. (0.05) for comparing harvests - 0.39

C.D. (0.05) for comparing treatments within the same harvest - 0.78

7. GLC ANALYSIS

Data on the geraniol and geranyl acetate per cent determined by GLC analysis are presented in Table 17 and 18 respectively.

The data revealed that the values obtained for geraniol (free alcohol) and geranyl acetate (ester content) by GLC analysis are in conformity with the values by quantitative method. However, a small difference was noticed, GLC analysis recorded a slighter low value with regard to geraniol and geranyl acetate. This may perhaps be due to the hydrolysis of esters taking place during the estimation of free alcohol content (expressed as geraniol) using chemical methods. High values for free alcohol (expressed as geraniol) and ester content (expressed as geranyl acetate) can be expected due to the presence of alcohol other than geraniol and esters other than geranyl acetate in the palmarosa oil.

8. ECONOMICS OF HARVESTING AND DISTILLATION OF DIFFERENT PORTIONS OF THE PLANT AS COMPARED TO WHOLE PLANT

Economics of harvesting and distillation of the various treatments were worked out and the same are furnished in Table 18.

The expenditure for harvest and distillation was taken as the input factor since all other factors were assumed to

Table 17. Content of free alcohol (as geraniol) in different portions of palmarosa plant in in different harvestsdetermined by Gas Liquid Chromatographic analysis (Per cent)

Harvests	Free alcohol content of the oil (per cent)			
	Treatments			
	1	2	3	4
1st	75.65	81.20	78.76	79.10
2nd	66.75	75.64	74.27	69.44
3rd	60.62	73.45	69.80	65.83
4th	66.89	72.13	70.13	69.26
5th	71.10	73.85	72.54	69.28
6th	69.94	78.15	76.23	73.19

Table 18. Content of geranyl acetate (per cent) in different portions of palmarosa plant in different harvests determined by Gas Liquid Chromatographic analysis

Harvests	Geranyl acetate content of the oil (per cent)			
	Treatments			
	1	2	3	4
1st	13.23	11.55	12.63	13.33
2nd	19.79	16.87	16.35	22.10
3rd	26.88	19.10	18.81	23.40
4th	20.27	15.40	17.10	20.85
5th	16.86	17.31	16.85	19.76
6th	18.58	12.81	13.32	18.20

be uniform for the treatments. Harvesting of the flower top and the 1/3rd portion involved and additional cutting and that of the 2/3rd portion involved two cuttings additionally, the expenditure for which is also added. The oil yield was considered as the output factor.

The data furnished in Table 19 revealed that distilling the whole plant is economical. It has recorded a profit of Rs.6682.77 per hectare per year. Harvesting and separating the plant into different portions for distillation is not at all economical and distilling only the 1/3rd portion has even resulted in a loss. It was also evident that distilling after removing the bottom 1/3rd portion i.e. flower top + the 2/3rd portion had resulted in lower profit than distilling the whole plant.

Table 19. Economics of harvesting and distillation of the different portions of the plant as compared to whole plant

Treatments	Oil yield (kg)	Income @ Rs.175/kg	Expenditure for harvesting and distillation (Rs)	Profit (Rs)
Flower top	22.788	3987.90	3310.40	677.50
2/3rd portion	33.616	5882.10	5270.50	611.60
1/3rd portion	13.053	2284.28	4354.38	-2070.10
Whole plant	69.630	12185.24	5502.47	6682.77
Flower top + 2/3rd portion	56.404	9870.00	4864.43	5005.57

Discussion

D I S C U S S I O N

The present investigation has thrown light on the distribution of the oil in different portions of palmarosa plant and also on the variations in quantity and quality of the oil obtained during different harvests. The results obtained are discussed hereunder:

Herbage yield

The herbage yield was 26307.3 kg per hectare from six harvests made during the year out of which the maximum contribution (12031.4 kg) was made by the 2/3rd portion, followed by the 1/3rd portion (11178.5 kg). Flowertop had only a meagre share of 3096.7 kg towards herbage yield. Pareek et al. (1980) while evaluating palmarosa accessions found that the fresh herbage varied from 6.6 to 55.0 tonnes per hectare and the herbage yield recorded in the present study was within the above range. Nair et al. (1980) reported a herbage yield of 10.41 tonnes under Kerala conditions. This low herbage yield was due to the number of harvests being limited to three as the study was conducted during the 1st year of the crop. Other reports with regard to the herbage yield are not in agreement with the results obtained in the present study (Rao et al., 1948; Singh, 1961; Gupta, 1976 and Ghosh and Chatterjee, 1976).

The number of harvests was found to vary depending on the climatic conditions. Also the herbage yield recorded for the different treatments varied during each harvest. Herbage yield for whole plant varied from 9479.1 kg for the first harvest to 658.6 kg for the fifth harvest. Six harvests were obtained in the present study and this is inclusive of the last two harvests which fell during the dry months. Nair and Mariam (1978) obtained three to four harvests in an year with variety Amaravathi a late flowering one, which in turn reduced the number of harvests. The number of harvests was found to be a reason for the increased herbage yield obtained in the present study against a low yield reported by Singh (1958) and Gupta (1976). Contrary to the results obtained in the present study, one to three harvests were reported by Burger (1958), Singh (1958), Ghosh and Chatterjee (1976) and Virmani et al. (1977).

Oil yield

Considering the oil yield also, whole plant registered the maximum oil yield of 69.63 kg per hectare per year in which 2/3rd portion contributed 48 per cent of the total oil yield. Unlike that of herbage yield, flowertop contributed 33 per cent of the total oil yield while 1/3rd portion had only a meagre share (19 per cent). This low yield from the 1/3rd portion can be attributed to the low oil recovery.

The total oil yield obtained in this study is in conformity with the findings of Rao et al. (1948), Burger (1958), Virmani et al. (1977) and Nair and Mariam (1978), but disagrees with yield reported by Singh (1958), Ghosh and Chatterjee (1976) and Nair et al. (1980). Maximum oil yield under report by Ghosh and Chatterjee (1976) can be attributed to the fertilizer response. Similar to grass yield, the report of Nair et al. (1980) for oil yield was for the first year of study. It can also be seen that the oil yield recorded in the present study was within the range of 41.67 to 163.6 litres per hectare reported by Pareek et al. (1980).

Harvests also showed much variation with regard to oil yield and they differed significantly. Maximum oil yield was obtained in the first harvest (11.665 kg) and the lowest (1.418 kg) in the fifth harvest. This may be mainly due to the herbage yield recorded for these harvests. The report of Singh (1958) with regard to oil yield, though not in conformity with the oil yield recorded in the present study, agrees to the fact that oil yield varies between harvest. It may be noticed that the 2/3rd portion made a major contribution towards total oil yield in all the harvests except fourth harvest where the flowertop had recorded a higher oil yield.

Rai et al. (1977) observed that total production of mint oil per plant was highest in rainy season and they related this to the largest production of leaves in this season. In the present study also highest oil production with regard to all the treatments was observed during the monsoon season which may be associated with the largest production of herbage in this season.

Essential oil recovery

The treatments showed highly significant difference in essential oil recovery. The flowertop recorded the highest essential oil content (0.87%) followed by the whole plant (0.35%), the 2/3rd portion (0.34%) and the 1/3rd portion (0.18%). Statistically the whole plant and the 2/3rd portion were on par with regard to oil recovery. Oil content recorded by whole plant is in close agreement with the findings of Nair and Mariam (1978) who reported an oil recovery of 0.35 to 0.40 per cent from the wilted herbage. Other reports with regard to theessential oil recovery (Hall, 1935; Narian and Das Gupta, 1948; Burger, 1958; Virmani et al., 1967 and Anon, 1978) varied widely and are not in agreement with the results obtained in the present study. This variation in oil recovery can be attributed to the variation in agro-climatic conditions of the place of cultivation, the height of harvesting the grass and the proportion of flower, leaf and stalk in the herbage.

There are conflicting reports about the height at which the plants are harvested for distillation. A range of 5 to 30 cm from ground level in the harvesting height have been reported by Burger (1958), Virmani et al. (1977) and Gupta et al. (1978). The harvesting height adopted for the present study (10 cm) was within the range reported above. Kashyapa and Jain (1977) observed that the upper two-third portion of the plant was harvested and used for extraction of oil. Gupta et al. (1980) reported that the plants were cut at a height of 0.6 to 0.8 m from the bottom. They also noticed that the average length of these flowering tops cut for distillation were around 50 cm and had 4 to 5 floral leaves only. This variation in harvesting height may also be a reason for the wide differences in the recovery of oil reported.

The trend in the variation in oil content from different portions of palmarosa plant, highest oil recovery from the flowertop followed by the 2/3rd portion and 1/3rd portion recorded in the present study is in agreement with the findings of Rakshit and Dutt (1947), Rao et al. (1951), Deshmukh et al. (1976), Dutta and Paul (1976), Virmani et al. (1977), Anon. (1977-78), Chandra (1978) and Gupta et al. (1978). But it should be pointed out that the values reported varied greatly compared to the results of the present study.

Of the different harvests examined, essential oil recovery was at its maximum during the fifth harvest (0.58 per cent). It may be noted that the fifth harvest fell in the summer season and this may account for the increased oil concentration in plants during summer season. This is in agreement with the findings of Kulkarni (1959) who observed an increased oil recovery during the summer season. El-Din et al. (1976) in Eucalyptus canaldulensis and Rai et al. (1977) in mint reported an increased essential oil concentration in summer season. In the present investigation also all the treatments recorded a high oil recovery percentage during the post-monsoon season compared to the monsoon season.

PHYSICO-CHEMICAL PROPERTIES OF THE OIL

Specific gravity

As per the ISI specification, the specific gravity of palmarosa oil should be within the range of 0.8740 to 0.8860 at 30°C. The specific gravity recorded by the different treatments was found to vary from 0.8857 to 0.8876, the maximum being recorded by the oil of the flowertop. Geraniol has a low specific gravity (0.8894) compared to geranyl acetate (0.9174) (Anon., 1976). A high specific gravity recorded for the oil of the flowertop may be explained by the high content of esters in the oil of the flowertop and

the lowest specific gravity recorded by the oil of the 1/3rd portion may be due to the low content of esters. There was significant difference between harvests with regard to the specific gravity of the oil. When the different harvests were compared with regard to the mean specific gravity, the lowest (0.8854) was recorded by the second harvest and the highest by the third harvest (0.8875). Also it may be noted that the oil obtained from third harvest which recorded the highest specific gravity had the highest content of esters also. The specific gravity reported by all the workers have been found to be high compared with the ISI specification (Narian and Das Gupta, 1948; Guenther, 1950; Burger, 1958; Gupta et al., 1980 and Pareek et al., 1980).

Optical rotation

The optical rotation of the oil did not vary with the portion of the plant selected for the extraction of the oil or with the number of harvests indicating that these factors have no influence on the constituents of the oil imparting optical activity. Pure geraniol, geranylacetate and the allied substances cannot have any optical activity because of the absence of asymmetric centre. Hence the slight activity observed may be due to some minor components present in the oil which are optically active.

Refractive index

The refractive index of the oil from different portions of the plant was found to vary from 1.4701 to 1.4705, the maximum being recorded by the 1/3rd portion (1.4705). The highest refractive index recorded by the oil of the 1/3rd portion may be due to the low content of esters present in the oil. Geranyl acetate has a low refractive index (1.4628) compared to geraniol (1.4766), (Anon., 1976).

Harvests also showed variation with regard to the refractive index of the oil and the maximum was obtained for the 4th harvest (1.4709). It may be noted that the refractive index of the oil from the different portions of the plant during each harvest confirm to the ISI specification for the refractive index of palmarosa oil.

The refractive index of oil of the flowertop (1.4701) and the 2/3rd portion (1.4704) recorded in the present study is in conformity with the findings of Gupta et al. (1980). High value for the refractive index of the oil reported by Narian and Das Gupta (1948), Guenther (1950), Burger (1958), Gupta et al (1980) and Pareek et al. (1980) was not obtained in this study.

Solubility (in 70 per cent ethyl alcohol)

Among the treatments, the highest solubility was recorded by the oil of the 2/3rd portion (1.64) and the lowest value by the oil of the flowertop (1.51). A high solubility recorded by the oil of the 2/3rd portion and the low solubility for the oil of the flowertop may be explained by the geraniol content in the oil. Geraniol is more polar compared to geranyl acetate and hence geraniol will dissolve more in the polar solvent (alcohol). With regard to the solubility of the oil in 70 per cent alcohol, there was no significant variation among harvests. The solubility recorded by the treatments in different harvests confirm to the ISI standards which specify a solubility of two volumes in 70 per cent ethyl alcohol. This observation is in agreement with the findings of Burger (1958). A high solubility reported by Narian and Das Gupta (1948), Guenther (1950) and Virmani et al. (1977) for the oil of palmarosa was not obtained in the present study.

Acid value

High acid values were obtained for the oil of flowertop (3.40) and the 2/3rd portion (3.28). The lowest acid value was recorded by the oil of the whole plant (2.76). High acid value recorded by the oil of flowertop may be due to the increased partial conversion of the geraniol to geranic acid.

The first three harvests which were taken during the monsoon season recorded low values as compared to harvests in the post-monsoon season. The acid value recorded by the oil of the 1/3rd portion and the whole plant in the first three harvests was below 3.0 and satisfied the ISI requirement. Narian and Das Gupta (1948), Guenther (1950) and Burger (1958) also recorded oils with acid values conforming to ISI standards. However, Pareek et al. (1980) reported a range of 0.08 to 17.90 for acid number. The acid values recorded in the present studies for the different treatments during each harvest (1.92 to 4.22) fell within the above range.

Saponification value of unacetylised oil, ester value and ester content

The saponification value and ester value are indicative of the ester content of the oil. The lowest values with regard to the above three parameters were recorded by the 1/3rd portion, the highest value being obtained for the oil of the flowertop. It may be assumed that in the oil of flowertop stabilization of alcohol (by forming their esters) is more. It should be pointed out that the acid value of the oil of flowertop was also relatively high. This can be explained assuming conversion of geraniol to geranic acid and geranyl acetate taking place in the oil of the flowertop simultaneously.

There was also significant difference between harvests with regard to the above parameters. First harvest recorded the lowest value, the highest being recorded by the third harvest.

A high ester content in the oil of palmarosa is not a desirable character and such oils are given a lower rank for perfumery purpose. ISI requirement for the ester content of palmarosa oil is within the range of 3.1 to 12.5. The lowest ester content (17.78) was recorded by the oil of the 1/3rd portion and the highest (21.44) by the oil of the flower top.

The ISI specifies a value within the range of 9 to 36 for ester value. The lowest value recorded for the treatments was 50.78 in the oil of the 1/3rd portion and for the harvest, 40.84 in the oil from the first harvest. A very high ester value of 76 was recorded by Pareek et al. (1980). Narian and Das Gupta (1948), Guenther (1950) and Burger (1958) also reported fairly high ester values for palmarosa oil which did not satisfy the ISI requirements.

A high ester content in the oil of May harvest was observed by Gupta et al. (1978). On the contrary, in the present study, a low ester content was recorded for the first harvest which fell during May-June. Gupta et al. (1980)

observed that tracts having a cooler climate produced superior quality oil with high geraniol per cent. The warm climatic conditions of Kerala may be a reason for the increased ester content of the oil recorded in this study.

Saponification value after acetylation

Saponification value after acetylation can be taken as an indirect measure of total alcohols (as geraniol) present in the oil. Treatments differed significantly with regard to the saponification value after acetylation of the oil. The highest mean value with regard to this parameter (273.63) was recorded by the 2/3rd portion and the lowest (264.62) by the flowertop. This may be due to the relatively higher content of geraniol in the oil of the 2/3rd portion of the plant. This observation is further corroborated by the low specific gravity and high refractive index of this plant portion obtained in the present study. Among the harvests, the highest value was recorded for the 2nd harvest.

The saponification value after acetylation for the different treatments during each harvest recorded in the present study ranged from 259.25 to 279.57. These figures are comparable with the ISI requirements for this character which

specifies a range of 266 to 280. Guenther (1950) reported a range of 226 to 274 where as Burger (1956) reported a value of 268.8 for the saponification value after acetylation of the oil.

Free alcohol

Free alcohol was found to be at its maximum (76.79%) in the oil of the 2/3rd portion and the lowest (69.74%) in the oil of the flowertop. A similar trend, a higher percentage of free alcohol (53.6 to 71.9%) in the oil of leaves as compared to the oil of flowertop (50 to 62.8%) was observed by Gupta et al. (1978). The highest free alcohol recorded by the oil of the 2/3rd portion and loweet in the oil flowertop may be explained by the fact that stabilization of alcohol by forming esters and conversion to acid is more in the oil of flowertop than in the oil of the 2/3rd portion, as indicated by the ester content and acid value of the oil.

The highest free alcohol was recorded for the oil obtained for the first harvest and the lowest for the third harvest. It may be noted that the lowest ester value was recorded for the first harvest where as the ester value of the third harvest was high. It may be noted that when the free alcohol increased the ester content decreased.

Combined alcohol

The percentage of alcohol which occurs in oil in combined form as esters is referred as the combined alcohol. Oil of the flowertop recorded the highest percentage of combined alcohol (16.85%) followed by that of whole plant (16.79%). The lowest value with regard to combined alcohol was observed for the oil of the 1/3rd portion. Harvests also differed significantly for the combined alcohol, the maximum being recorded for the third harvest and the minimum for the first harvest. It may be noted that the combined alcohol recorded by the various treatments in different harvests followed the same trend as that of the ester content. Combined alcohol is indicative of the ester content of the oil.

Geraniol content

The geraniol content recorded for the treatments varied from 86.60 to 90.98. The oil of the 2/3rd portion met the ISI requirement of minimum 90 per cent geraniol. The oil of the 1/3rd portion and of the whole plant were very close to it. A low geraniol per cent in the oil of the flowertop was observed in the present study. It may be noted that the geraniol content in different portions of the plant showed variation and this may be because of the variation in the extent of biosynthesis in different parts. It is also likely

that stabilization of alcohol by forming esters and conversion of the alcohol to the corresponding acids vary in different parts of the plant.

Gupta et al. (1978) reported a low geraniol percentage of 80.3 to 85.9 in the oil of the flowertop. Though the geraniol percentage of the 2/3rd portion recorded in the present investigation was higher than the figures reported by the above worker, it agrees to the fact that geraniol percentage was high in the oil of the leafy portion (83.3 to 87.6%) as compared to that of the flowertop. A high geraniol content of 93 per cent was observed by Burger (1958) for a crop of palmarosa raised in Africa. Geraniol contents below and above the ISI requirements were recorded by Narian and Das Gupta (1948), Guenther (1950), Virmani et al. (1977), Gupta and Jain (1978), Gupta et al. (1980) and Pareek et al. (1980).

Harvests also showed significant variation, the highest geraniol per cent being recorded for the 1st harvest and lowest during the 4th harvest. A similar increase of active principle in the rainy months was observed by El-Din et al. (1976) in Eucalyptus camaldulensis, a high cineole content in May-June and a low content in January-February.

Geraniol yield

Whole plant yielded the highest quantity of geraniol though the percentage of geraniol was highest in the oil of the 2/3rd portion of the plant. It may be due to the high oil yield from the whole plant as compared to the portions of the plant. The geraniol yield of the whole plant was 10.67 kg, the 2/3rd portion 5.15 kg, the flower top 3.29 kg and the 1/3rd portion 1.96 kg. It is interesting to note that flower top which recorded the lowest geraniol per cent ranked third with regard to geraniol yield due to the fairly high oil yield. Geraniol yield was highest for the first harvest (10.73 kg) and least for the fifth harvest (1.25 kg). High geraniol yield (7.13 kg) was recorded during the monsoon season while post-monsoon season recorded only 3.41 kg. This clearly indicated that geraniol yield was more dependent on oil yield than on geraniol content.

Summary

the first. Post-monsoon harvests registered maximum recovery of essential oil in all the four treatments. Interaction between effects of treatments and harvests was also found to be significant. Flower top recorded a high oil recovery in all the harvests while the 1/3rd portion of the plant yielded the minimum quantity.

3. Oil yield recorded for the different treatments during each harvest differed significantly. Whole plant recorded an oil yield of 69.63 kg per hectare per year out of which the relative contributions were 33 per cent by the flower top, 48 per cent by the 2/3rd portion and 19 per cent by the 1/3rd portion of the plant. Highest oil yield was obtained from the first harvest and the least from the fifth harvest. The effect of treatments within the same harvest was also significant. The contribution of the 2/3rd portion of the plant towards the total yield decreased progressively with successive harvests except in the third harvest.

4. The economics of harvesting and distillation when worked out showed that the maximum profit was obtained by distilling the whole plant.

5. Optical rotation of the oil showed no difference with the treatments and harvests included in the study.

With regard to all other physico-chemical properties of the oil, the treatments and harvests showed significant differences except for solubility of the oil in which case the harvests did not differ significantly. Interaction between the effects of treatments and harvests was also found to be significant. Maximum values with regard to the specific gravity, acid value, saponification value of unacetylised oil, ester value, ester content and combined alcohol of the oil were recorded by the oil of the flower top and the minimum values for the above parameters by the oil of the 1/3rd portion. Maximum values with regard to acid value of the oil were recorded for the oil of the fourth harvest and specific gravity, saponification value of unacetylised oil, ester value, ester content and combined alcohol for the oil of the third harvest.

Refractive index was maximum in the oil of the 1/3rd portion. When the different harvests were compared the maximum value was recorded for the fourth harvest.

The oil of the 2/3rd portion recorded maximum solubility, free alcohol and geraniol content. Free alcohol and geraniol content were maximum during the first harvest when the ester content was the minimum.

6. Maximum yield of geraniol was obtained from the whole plant indicating that geraniol yield is more dependent on oil yield than geraniol content. The first harvest which recorded maximum oil yield had also yielded the maximum geraniol.

References

S U M M A R Y

The investigations reported in the Thesis were conducted at the Lemongrass Research Station, Odakkali during 1979-80 to study the oil yield and quality of oil from different portions of palmarosa plant during each harvest. The salient results obtained are summarised below:

1. Herbage yield recorded by the treatments in different harvests varied widely. Out of the 26307.3 kg of herbage per hectare obtained from whole plant, the relative proportion of the flowertop, the 2/3rd portion and the 1/3rd portion of the plant were 12 per cent, 46 per cent and 42 per cent respectively. Maximum herbage yield was recorded in the first harvest and the lowest in the fifth. Harvests during the monsoon season accounted for 73 per cent of the total herbage yield while post-monsoon harvests yielded only 27 per cent of the total.

2. Essential oil recovery recorded for the treatments showed highly significant differences. Highest recovery of oil was obtained from the flowertop and the lowest from the 1/3rd portion. Harvests also varied significantly with regard to essential oil recovery the maximum being recorded from the fifth harvest and the minimum from

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Appendices

APPENDIX I

Weather data (monthly average) for the period from April 1979 to April 1980

Month	Temperature °C		Relative humidity (%)	Total rainfall (mm)	Number of rainy days
	Maximum	Minimum			
1979					
April	34.5	24.0	87.0	1.4	4
May	31.9	24.2	87.8	95.0	9
June	29.2	23.4	88.8	695.9	26
July	26.5	22.5	90.0	780.5	30
August	27.2	22.1	89.6	537.9	18
September	29.3	23.1	90.0	280.0	20
October	30.0	22.7	89.8	373.6	15
November	29.5	22.8	91.2	398.8	21
December	31.8	21.0	86.9	19.2	3
1980					
January	32.4	18.6	85.3	Nil	Nil
February	33.8	21.4	86.0	Nil	Nil
March	34.3	23.4	84.0	78.2	5
April	33.3	24.2	87.0	157.3	19

APPENDIX II

Analysis of variance for the oil recovery and the oil yield as influenced by the treatments and harvests

Source	df	Mean squares	
		Oil recovery (%)	Oil yield (kg/ha)
Harvests	5	0.1593**	233.60**
Treatments	3	2.7319**	535.59**
Interaction	15	0.0174**	43.56**
Error	96	0.0017	0.42

** Significant at 1% level

APPENDIX III

Analysis of variance for the specific gravity, refractive and solubility of the oil as influenced by the treatments and harvests

Source	df	Mean squares		
		Specific gravity	Refractive index	Solubility
Harvests	5	0.0000160**	0.00000178**	0.00197
Treatments	3	0.0000190**	0.00000082**	0.12569**
Interaction	15	0.0000050**	0.00000086**	0.00124
Error	96	0.0000008	0.00000017	

** Significant at 1% level

APPENDIX IV

Analysis of variance for the saponification value of unacetylised oil, the ester value and the ester content of the oil as influenced by the treatments and harvests

Source	df	Mean squares		
		Saponification value of unacetylised oil	Ester value	Ester content (%)
Harvests	5	1858.10**	1852.16**	226.96**
Treatments	3	1006.94**	995.72**	121.90**
Interaction	15	64.37**	63.13**	7.74**
Error	96	3.63	3.63	0.44

** Significant at 1% level

APPENDIX V

Analysis of variance for the acid value and the saponification value after acetylation of the oil as influenced by the treatments and harvests

Source	df	Mean squares	
		Acid value	Saponification value of acetylised oil
Harvests	5	3.43**	149.19**
Treatments	3	2.96**	445.61**
Interaction	15	0.99**	63.35**
Error	96	0.64	4.52

** Significant at 1% level

APPENDIX VI

Analysis of variance for the free alcohol and the combined alcohol content of the oil as influenced by the treatments and harvests

Source	df	Mean squares	
		Free alcohol (%)	Combined alcohol (%)
Harvests	5	283.60**	140.21**
Treatments	3	297.29**	75.29**
Interaction	15	17.35**	4.78**
Error	96	1.34	2.75

** Significant at 1% level

APPENDIX VII

Analysis of variance for the geraniol content and geraniol yield of the oil as influenced by the treatments and harvests

Source	df	Mean squares	
		Geraniol content (%)	Geraniol yield (kg/ha)
Harvests	5	42.31**	201.02**
Treatments	3	101.47**	440.67**
Interaction	15	10.84**	37.74**
Error	96	0.81	0.38

** Significant at 1% level

STUDIES ON THE VARIATION IN THE QUANTITY AND QUALITY OF OIL IN DIFFERENT PARTS OF PALMAROSA *(Cymbopogon martini Stapf. var. motia)* IN DIFFERENT SEASONS

BY

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ABSTRACT OF THE THESIS

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A B S T R A C T

Investigations were carried out at the Lemongrass Research Station, Odakkali, with the objective of assessing the yield and quality of oil, obtained from the different portions of the palmarosa plant as compared to the whole plant and from the different harvests taken in an year. It was also aimed at finding out the economics of harvesting and distilling of the different portions of the plant.

The results of the study revealed the quantity of grass and oil obtained from the whole plant and the relative contribution of the flower top, the 2/3rd portion and the 1/3rd portion of the plant towards total yield. The whole plant yielded 26307.3 kg of herbage/ha/year, out of which the maximum was contributed by the 2/3rd portion of the plant (46%) followed by the 1/3rd portion of the plant (42%) and the flower top (12%). The flower top recorded the maximum oil recovery and the percentage contribution of the flower top towards total yield was notable (33%) eventhough the maximum contribution was given by the 2/3rd portion of the plant (48%). Both herbage and oil yield were maximum from the monsoon harvests (1st, 2nd and 3rd) which recorded 73 per cent of total herbage and 68 per cent of total oil yield.

Economics of harvesting and distillation of the different portions of the plant when compared to the whole plant indicated that maximum profit was obtained by distilling the whole plant. Distillation of the flower top + the 2/3rd portion of the plant ie., after removing the bottom 1/3rd portion had resulted in a much lower income. This study has proved beyond doubt that distilling the whole plant is economical and more profitable than utilising a portion of it.

The quality of the oil from different portions of the plant in different harvests showed wide variation. The geraniol content of the plant portions and the whole plant was within acceptable limits except the flower top, which was low in geraniol. In general, the ester content of the oil was found to be high which might have contributed to the high specific gravity. The high content of esters in palmarosa oil lowers its perfumery value. Hence, further investigations to probe the possible reasons for the increased content of esters are necessary.