PHYSIOLOGICAL BASIS OF YIELD VARIATIONS IN *MENTHA ARVENSIS* L DUE TO NITROGEN FERTILIZATION AND THEIR AGRONOMIC APPRAISAL.

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CERTIFICATE

This is to certify that the thesis entitled, "Physiological basis of yield variations in *Mentha arvensis* L. due to nitrogen fertilization and their agronomic appraisal" submitted by Shri Muni Ram for the award of the degree of Doctor of Philosophy in Agronomy, is a record of bonafide research carried out under our guidance and supervision and no part of the thesis has been submitted for any other degree or distinction.

The assistance and help received during the course of this investigation and source of literature have been duly acknowledged.

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ABSTRACT

Field experiments were conducted during 1983 and 1984 at the Central Institute of Medicinal and Aromatic Plants, Lucknow to study the effect of N-carriers, prilled urea (PU), urea super granules (USG), lac coated urea (LCU) and neem cake coated urea (NCU) at three timings of application (full basal, 1/3 at planting + 1/3, 45 days after planting + 1/3 after first harvest, and 1/2, 45 days after planting + 1/2 after first harvest) on yield and quality of oil derived from *Mentha arvensis* L., nitrogen losses under different treatments were also studied.

Application of nitrogen as NCU, USG and LCU proved significantly superior to PU to promote plant height, number of leaves/plant, size of leaves, leaf/stem ratio, dry matter production and leaf area index. Application of NCU and USG increased the herbage yield by 23 and 18% higher over PU, respectively.

The per cent increase in oil yield due to the applications of NCU and USG were 31 and 27, respectively. Application of 120 kg N/ha caused significantly more (87%)

oil yield than those obtained in the control plot (no nitrogen) or in plot receiving 60 kg N/ha (11%). Split applications (two and three) gave better results than those recorded when dose of nitrogen was applied at the time of planting in case of prilled urea. But this was not the case when nitrogen was applied as NCU or USG; the effect of LCU was inferior and inconsistent in this regard. Nitrogen reduced the oil content in herbage. Amongst different N-carriers, the lowest oil content (0.61%) was recorded in the crop fertilized with PU followed by those (0.62%) fertilized with LCU, USG and NCU at the first harvest. At the time of second harvest it followed similar trend of variations. With increasing rate of nitrogen level (upto 120 kg N/ha), the menthol content in oil increased. The increase in menthol content in oil during the period between 60 and 120 days after planting were 33.6, 26.4 and 20%, due to the applications in the form of USG, NCU and PU, respectively. The difference between LCU and PU was, however, not wide. Maximum production of menthol was observed in plots fertilized with NCU followed by USG. Menthol yield was improved by 49 and 45% due to the application of NCU and USG over PU in in 1983, respectively. The magnitude of menthol yield, however, declined in 1984, where NCU and USG caused 40 and 30% better yield than PU, respectively. Biological efficiency of nitrogen application (BENA) was higher through NCU, USG and LCU than PU. Higher BENA was observed at lower rate of nitrogen application i.e. 60 kg N/ha. Considering the BENA during entire growth period of Mentha arvensis L., two split applications of prilled urea have an edge over other timings of nitrogen application, but this was not conspicuous in other cases.

There was inverse relationship between nitrogen and oil content in plants. But LAI and menthol content were positively correlated. The relationship between oil concentration and menthol content was close and positive.

Use of PU as a source of nitrogen fertilizer caused higher losses of nitrogen through leaching and ammonia volatilization in Mentha arvensis L. Leaching losses could be minimised from 29.7% recorded with PU to 10.7% observed with NCU and 12.8% with USG. Ammonia volatilization losses were reduced from 9% in case of PU to 2.5% in NCU and 3% in USG. These losses could be prevented by the application of nitrogen in the form of NCU and USG. Hence, NCU and USG were most efficient than PU as a source of fertilizer for the fertilization of <u>*Mentha arvensis*</u> L. Application of nitrogen in the form of NCU and USG showed better benefit: cost ratio than that was recorded with LCU or PU. At 60 and 120 kg N applied in the form of NCU its efficiency in oil production was equivalent to 80 and 150 kg of nitrogen in the form of prilled urea. Basal application of nitrogen as NCU or USG showed better effect than the application of prilled urea applied in split doses. The effect of LCU was inconsistent.

1. INTRODUCTION

Perfumes and perfumery materials have attracted attention since the dawn of human civilization and these materials have sacrosantly been used in temples, religious functions and also for personal sophistication. The best reference to such materials are found in Vedas where sandal wood, camphor and saffron etc., have been frequently mentioned in connection with certain rites. Though at one time, perfumes were considered as a sign of luxury, but this is not so in modern times as many daily requirements of life, such as soaps, detergents, tooth pastes, tooth powders, boot polishes deodorants, etc. can not be manufactured or will not find market acceptance without the aid of perfumery materials. Moreover, the closely related flavouring materials, now a days find extensive use in food products.

India has climatic conditions varying from tropical plains and temperate hill valleys to moist and dry regions supported with abundant supply of water. Thus, almost all important exotic plant species which predominantly figure in the list of raw materials for pharmaceutical, phytochemical perfumery and food flavouring could be produced in the country.

More than two decades ago Japanese mint (*Mentha arvensis* L.) was introduced in India from Japan. In the year 1954, four suckers were obtained from Japan by Sir Col. R.N. Chopra, Director, DRL, Jammu through the courtsey of UNESCO. However, the possibility of its commercial cultivation in Tarai region of Uttar Pradesh was established only in 1964 when CIMAP Regional Centre, Pantnagar developed suitable agrotechnology for this crop. As a result of transfer of technology carried out by CIMAP (C.S.I.R.), its cultivation has now been extended in Moradabad, Rampur, Bareilly, Badaun, Pilibhit, Barabanki, Nainital districts of Uttar Pradesh. It has also recently been introduced in Punjab, Madhya Pradesh, Maharashtra, Bihar and Orissa state of India as a cash crop.

Japanese mint is a potential source of natural menthol which is widely used in pharmaceutical and cosmetic preparations, such as vicks inhalor, cough syrups, tooth pastes, mouth washes and is also used as a flavour in confectionery, tobacco and pan masala industries.

Now-a-days Japanese mint is one of the most important essential oil bearing crops occupying a place of pride in the national economy. Its volatile oil is obtained from steam distillation containing 70-80% menthol as a principal constituent of its essential oil. The present production of Japanese mint oil in the country is about 600 tonnes per annum. It was previously being imported in India to meet the internal requirement of essential oil industries.

Among the various agronomic practices for higher production of herbage and oil per unit area, adequate application of nitrogenous fertilizers deserves top most priority. The simple reason is that mint, being a leafy crop, favourably responds to nitrogen application. This has a marked effect on the oil yield too.

Under intensive cultivation of Mentha arvensis L., herb and oil yields increase by heavy nitrogen application. Recent oil crisis has made nitrogen a precious commodity in agriculture where increasing cost has prompted the search for more efficient system of using it on crop plant. Several methods, like use of slow release nitrogen fertilizers and nitrification inhibitors have been suggested and investigated. The use of these fertilizers has not been investigated in relation to Mentha arvensis L.

Since the nitrogen utilization efficiency of Mentha arvensis L., even under best agronomical management practices, is less than 40%; this needs to be improved if one wishes to conserve nitrogen fertilizer to reduce the cost of cultivation. This study, therefore, has aimed to find out ways and means by which the nitrogen utilization efficiency of *Mentha arvensis* L. can be increased. An attempt will be made to analyse the physiological causes influencing the menthol content due to heavy nitrogen application. More precisely, the study intends to achieve the following objectives :

1. The effect of different sources of nitrogen fertilizers on herb and oil yield of *Mentha arvensis* L.
2. The effect of different rates of nitrogen fertilizers (applied by different forms) on menthol content in essential oil of *Mentha arvensis* L.
3. The effect of different nitrogen sources on nitrogen leaching in soil.
4. The effect of different nitrogen sources on volatilization of nitrogen from the soil.
5. The scope of economising nitrogen application to *Mentha arvensis* L. by reducing leaching and volatilization losses.

2. REVIEW OF LITERATURE

Mentha arvensis L. popularly known as Japanese mint is one of the most important essential oil bearing crop and a potential source of natural menthol. Among the various agronomical practices used for higher production of herbage and oil, adequate application of nitrogen plays an important role. The response of Japanese mint to different levels and sources of nitrogen fertilizers differ markedly because of the differential availability and nutrient absorption efficiency of the crop. In this chapter an attempt has been made to review the aspects of nitrogen fertilization in Japanese mint. Some literature on slow release N fertilizers have also been compiled and reviewed.

2.1. Effect of nitrogen on growth of plants

2.1.1 Plant height

Samra *et al*., (1975) observed significant increase in plant height upto an application of 150 kg N/ha at Ludhiana. Ghosh and Chatterjee (1976) reported that nitrogen, phosphorus and potassium were beneficial to increase plant height of *Mentha* species at Burdwan. Thus, nitrogen deficiency caused reduced plant height of Japanese mint (Rai *et al*., 1977). While an application of 160 kg N/ha increased the height of *Mentha spicata* significantly over control (Jha and Singh, 1979), Singh and Duhan (1979), however, reported that 40 kg N/ha as an optimum dose to increase plant height. Nitrogen beyond this dose remained ineffective at Pantnagar. Similarly Singh and Singh (1979) found increased height of <u>Mentha</u> with nitrogen application. At Varanasi plant height increased only upto the application of 60 kg N/ha (Singh, 1983). Chandra <u>et al</u>., (1983) reported that plant height of Japanese mint increased upto 160 kg N/ha .

2.1.2 Number of leaves per plant

At Ludhiana, number of leaves per plant increased significantly upto 150 kg N/ha (Samra et al., 1975). Application of nitrogen beyond 150 kg N/ha did not influence the number of leaves. Singh and Garg (1976) found less leaves per plant in winter crop compared to summer season crop. Rai <u>et al</u>., (1977) studied that nitrogen deficiency reduced the number of leaves per plant. Jha and Singh (1979) reported significantly more leaves per plant at 160 kg N/ha than control. Singh and Singh (1979) observed that nitrogen application affected the number of leaves per plant positively in different mint species.

2.1.3 Leaf area index

Verma (1970) and Singh (1983) observed that application of nitrogen increased leaf area index significantly in Japanese mint. Rai <u>et al</u>., (1977) observed reduced leaf area due to nitrogen deficiency. Leaf area index was positively corelated with nitrogen levels in the studies of Samra <u>et.al</u>., (1975), Singh et al., (1979), Yadav and Mohan (1982), Yadav et al., (1981) observed highest leaf area index and leaf area duration at 120 kg N/ha. Singh (1983) observed consistence increase in leaf area index due to increase in nitrogen levels. Application of 120 kg N/ha increased leaf area index significantly over control and at 60 kg N/ha. Fertilization beyond 120 kg N/ha did not influence the leaf area index.

2.1.4 Dry matter accumulation

Samra et al., (1975) reported that nitrogen application upto 150 kg N/ha increased the dry matter accumulation significantly. Nitrogen beyond 150 kg N/ha did not influence dry matter accumulation at Ludhiana. Ghosh and Chatterjee (1976) at Burdwan (West Bengal) observed higher dry matter accumulation with increasing rates of nitrogen. Rai et al., (1977) reported that nitrogen deficiency reduced dry weight of plants. Jha and Singh (1979) reported that *Mentha spicata* accumulated significantly higher dry matter at 160 kg N/ha than control. Singh and Duhan (1979) observed successive increase in dry matter with increased application of nitrogen at the rates of 0,80,160 to 200 kg/ha. Singh and Singh (1979) reported that dry matter accumulation was affected positively by nitrogen application at Pantnagar. Singh et al.,(1979) studied the effect of different doses of nitrogen (0,40,80 and 120 kg N/ha) on *Mentha citrata* and reported that application of 120 kg N/ha produced maximum dry matter at Pantnagar. At Varanasi, however, Singh (1983) observed higher dry matter accumulation at 180 kg N/ha as compared to 0, 60 and 120 kg N/ha. At Lucknow Yadav et al., (1983) reported a little lesser dose of nitrogen (i.e. 160 kg N/ha) for higher dry matter production. Chandra et al., (1983) observed higher dry matter accumulation at 160 kg N/ha as compared to 0,40, 80 and 120 kg N/ha at Pantnagar.

2.1.5. Leaf stem ratio

Jha and Singh .(1979) reported significantly higher leaf stem ratio at each successive increment of nitrogen from 0 to 160 kg N/ha. Singh and Duhan (1979) did not observe significant differences in leaf stem ratio by the application of nitrogen upto 200 kg N/ha. Singh et al., (1979) observed higher leaf shoot ratio with increased nitrogen supply from 0 to 120 kg N/ha . Singh (1983) reported that fertilizing the crop with 180 kg N/ha increased the leaf to stem ratio over 0,60 and 120 kg doses of N/ha while Chandra et al., (1983) observed increased leaf stem ratio upto 160 kg N/ha.

2.2. Yield and quality

2.2.1. Fresh herbage yield

Nitrogen fertilization increased the herbage production of peppermint in the studies of Baird (1957). The applications of 100 and 200 kg N/ha produced 40.77 and 50.65 q /ha herbage, respectively; control plots, however, yielded 12.4 quintals/ha. Davis et al., (1957) reported that at Michigan

Mentha piperita L. and *Mentha spicata* L. showed positive response to 25 and 50 kg N/ha in comparison to control. In Jammu conditions of India Dutta and Chatterjee (1961) obtained 171 q/ha herbage of *Mentha arvensis* L. by application of 57 kg N/ha which was about 45 q higher than the control plots. Singh (1969) recommended 80 kg N and 60 kg P_2O_5 /ha for Jammu conditions. Gupta and Gulati (1970) recommended 120 kg N/ha with 60 kg P_2O_5/ha to obtain highest herbage at Pantnagar. Increase in fresh herbage yield due to nitrogen application has been reported by Baslas (1970) at Nainital. Dutta (1971) found nitrogen to be the main source to increase oil yield per unit area because nitrogen increased the fresh herbage yield. In this experiment 0, 30, 60, 90 and 120 kg N/ha was applied in three equal splits. Highest (317.69 q/ha) herbage yield was obtained with 90 kg N/ha while control produced 188 q/ha. The herbage yield (289.0 q/ha) decreased at 120 kg N/ha . Similarly, Gulati and Duhan (1971) recommended 90 kg N/ha for maximum yield of Japanese mint in comparison to 0,30 and 60 kg N/ha. Chandra (1971) observed favourable response of Japanese mint to fertilizer application. Nelson *et al.*,(1971) at Washington state University U.S.A. reported an increase in herbage yield by nitrogen fertilization upto 200 kg N/ha. Onwards a declining trend was observed in peppermint. The experiment conducted at Hakkaido (Japan) indicated that fresh herbage yield increased from 162 at control to 261 q/ha at 113 kg N/ha (Anonymous,1971). Singh (1972) suggested 220 kg N and 125 kg P_2O_5/ha for optimum herbage yield of Japanese mint. Singh et al., (1973) observed significant increase in herbage yield at 60 and 120 kg N/ha over control at Jammu Tawi. The differences between lower (60 kg) and higher (120 kg N/ha) doses were highly significant. The percent increase in yield over control due to 60 kg N/ha was 18.4 and 32.3 due to 120 kg N/ha. Significant increase in yield due to application of nitrogen in Japanese mint was reported by Duhan et al., (1975). Singh and Balyan (1975) studied the response of peppermint var. vulvaris to 0, 25, 50, 75, 100 and 125 kg N/ha in silty loam soil of Jammu Tawi. They observed significantly higher herbage yield at 125 kg N/ha. However, application of 100 kg N/ha brought maximum benefit for each kilogram of nitrogen applied. Ghosh and Chatterjee (1976) at Burdwan (West Bengal) recommended 200 kg N, 100 kg P_2O_5 and 50 kg K_2O /ha for maximum yield of Mentha species (i.e. Mentha piperita, Mentha spicata and Mentha citrata). Panda (1977) at Pantnagar reported highest herbage yield (227.89 q /ha) of Mentha piperita at 150 kg N/ha; yield obtained at 100 kg N/ha (224.5 q /ha) was also at par. Increase in herbage yield of Japanese mint due to nitrogen application was observed by Duhan et al., (1977) in the agro-climatic conditions of Uttar Pradesh Tarai. Maximum dose of nitrogen application (120 kg N/ha) increased 23.44% herbage yield over 60 kg N/ha. Although total herbage yield differed significantly at 0, 30 and 60 kg N/ha but herbage yield at 90 kg N/ha could not differ significantly from 60 kg N/ha. Japanese mint showed linear response upto 150 kg N/ha at Patnagar (Singh et al., 1977). Saha et al., (1978) studied the performance of peppermint at Imphal (Manipur). Six levels of nitrogen (0, 20, 40, 60, 80 and 100 kg N/ha) in conjunction with uniform level of 60 kg P_2O_5 and 70 kg K_2O/ha were tried. Compost was added @ 20 tonnes/ha to facilitate the growth of the crop. It was found that increasing levels of nitrogen upto 80 kg N/ha increased the herbage yield significantly. Nitrogen application beyond this dose reduced the yields. The highest herbage yield of 13.82 tonnes/ha was harvested by applying 80 kg N/ha. Application of 100 kg N/ha produced 13.02 tonnes/ha. Shelke and Morey (1978) recommended 40 kg N/ha for highest yield in Japanese mint. Bharadwaj et al., (1979) reported maximum herbage yield in Mentha piperita and Mentha spicata at 225 kg N/ha. The different levels of nitrogen, however, had no specific effect on the essential oil content. Duhan (1979) reported significantly higher herbage yield of Mentha piperita with increased nitrogen application upto 80 kg/ha. This dose could produce 25.9 and 58.9% higher herbage in 1975 and 31.4 and 76.5% in 1976 than 40 kg N/ha during first and second cuttings, respectively. Singh et al., (1979) reported that nitrogen application at the rate of 120 kg/ha increased the herbage yield significantly over lower doses. The increased rate due to an application of 120 kg N/ha was 282.6, 86.2 and 29.9% over 0, 40, and 80 kg N/ha, respectively. Studying the response of spearmint (Mentha spicata) to nitrogen application in tarai region of U.P., Singh and Duhan (1979) reported that herbage yield increased with increasing levels of nitrogen. Bharadwaj et al., (1980) observed that nitrogen fertilization upto 160 kg/ha in peppermint produced significantly higher yield at Solan. However, 120 kg N/ha was calculated to be an optimum and economical dose for herbage production. An increase (37%) in herbage yield with 150 kg/ha application of each of N, P & K was reported by Dechera et al., (1980). Sharma and Singh (1980) calculated 199.1 kg N/ha as an optimum dose for Japanese mint at Lucknow. Application of 100 and 200 kg N/ha returned Rs. 9.73 and Rs. 6.89 for each Rupee invested on nitrogen fertilization, respectively. Singh and Duhan (1981) indicated that nitrogen application upto 120 kg/ha increased the fresh herb yield significantly while Singh and Kewlanand (1981) at Pantnagar reported significant increase in fresh herb yield of Mentha citrata due to application of 160 kg N/ha over control. Visuttipitakul et al., (1982) and Chandra et al., (1983) reported that herbage yield of *Mentha arvensis* L. increased significantly by nitrogen application. Harvesting at 130 days after planting produced higher yields as compared to delayed or early harvestings (Chandra et al., 1983). Singh (1983) reported consistent increase in herbage yield with increase in nitrogen dose. Higher herbage yield was obtained at 180 kg N/ha. The difference in yield at 160 and 120 kg N/ha were significant but increasing the dose beyond 120 kg N/ha did not influence the herbage yield significantly. Singh et al., (1983) at Pantnagar found maximum herbage production of *Mentha citrata* at 100 kg N and 60 kg P_2O_5 / ha as compared to 0, 50, 150 and 200 kg N/ha. Rao et al., (1983) observed 66.8 and 100% increase in herbage yield of *Mentha* citrata due to the application of 50 and 100 kg N/ha. Verma et al., (1983) reported that nitrogen application upto 200 kg/ha increased the herbage yield in four Mentha species at Dehradun. The highest yield of 25 tonnes/ha in Mentha arvensis was recorded by the application of 300 kg N/ha. Yadav et al., (1983) observed highest yield of Japanese mint by an application of 160 kg N/ha at Lucknow. Randhawa et al., (1984) at Ludhiana observed significant increase in herbage yield of Mentha citrata with increase in nitrogen dose upto 125 kg/ha as compared to control. In peppermint application of 160 kg N/ha produced 21% more herbage than 80 kg N/ha (Yadav et al., 1985).

Samra et al., (1978) observed significant increase in herbage yield of Mentha arvensis in second cutting when nitro- was applied in two splits (½ at planting + ½ at first cut) over whole of nitrogen applied at sowing. Bharadwaj et al., (1980) advocated the use of 120 kg N/ha in Mentha piperita in three equal splits for higher herbage yield. Bharadwaj et al., (1983) reported that 120 and 160 kg N/ha increased the herbage yield significantly over control at Solan. Nitrogen application in three splits (1/3 planting + 1/3, 60 days after planting + 1/3 after first cutting) proved beneficial as compared to two, four and five splits. Rao et al., (1984) observed highest herbage production as well as oil yield at 75 kg N/ha applied in two equal splits (½ at planting and ½ after first harvest).

2.2.2 Oil yield

Baslas (1970), Chandra (1971), Dutta (1971) and Clark and Menary (1980) have emphasized the importance of nitrogen for increasing oil yield. Baird (1957) observed marked increase in oil yield of _Mentha piperita_ due to nitrogen application. Application of 100 and 200 kg N/ha produced 49.3 and 62.9 kg oil/ha, respectively which was significantly higher than the oil yield of 9 kg/ha obtained in control plots. Gulati and Duhan (1971) found 12.91, 49.25 and 70.61% increases in oil yield due to the applications of 30, 60 and 90 kg N/ha, respectively over control. At Washington in U.S.A. oil yield increased by nitrogen application upto 200 kg N/ha and declined thereafter (Nelson _et al_., 1971). But at Jammu Tawi in India oil yield increased significantly only upto 125 kg N/ha (Singh and Balyan, 1975). At Pantnagar, however, Panda (1977) observed increased oil yield upto 100 kg N/ha. Nitrogen application beyond this dose reduced the oil yield. Duhan _et al_., (1977) observed 15.71% increase in oil yield due to application of 120 kg N/ha over 60 kg N/ha in tarai conditions of Uttar Pradesh. Shalke and Morey (1978) recommended 40 kg N/ha for highest oil yield of Japanese mint. Bharadwaj _et al_., (1979) has recommended 225 kg N/ha for _Mentha spicata_ and 300 kg N/ha for _Mentha citrata_ in Solan conditions of Himachal Pradesh. Singh _et al_., (1979) obtained highest oil yield (91.1 kg/ha) of _Mentha arvensis_ at 120 kg N/ha. This dose of N application increased the oil yield by 325.7, 93 and 25.1%

over 0, 40 and 80 kg N/ha, respectively. Singh and Duhan (1979) observed increase in oil yield of Mentha spicata with increase in nitrogen dose upto 120 kg N/ha at Pantnagar. Singh and Kewlanand (1981) at Pantnagar observed an increase in oil yield of Mentha citrata by application of 160 kg N/ha. Singh (1983) and Bharadwaj et al., (1983), however, recorded higher oil yields at 60 and 120 kg N/ha in comparison to control. Rao et al., (1983) observed 50 and 100 kg N/ha to produce higher oil yields of Mentha citrata over control. The increase being 68.4% at 50 kg and 108.9% at 100 kg N/ha over control. The oil yield increased with increasing rates of nitrogen upto 160 kg N/ha at Pantnagar (Chandra et al., 1983). For Mentha citrata, Singh et al., (1983) recommended 100 kg N and 60 kg P_2O_5/ha to obtain higher oil yields in comparison to 0, 50, 150, 200 kg N/ha. Yadav et al., (1983) at Lucknow, reported that oil yield of Mentha arvensis increased with increasing rates of nitrogen and maximum oil yield was obtained at 160 kg N/ha. Randhawa et al., (1984) however, reported that oil yield increased significantly with an increase in nitrogen levels upto 125 kg N/ha as compared to control. In Mentha piperita application of 160 kg N/ha produced 9.8% more oil in 1980 and 18.4% more oil in 1981 than application of 80 kg N/ha in the study of Yadav et al., (1985).

2.2.3 Oil content

Large number of experiments have indicated that nitrogen fertilization increased the oil content in Mentha species.

Henn (1943) found that moderate nitrogen application during initial period of growth with supplimentary dose of nitrogen during budding stage, helped to increase oil content in mint leaves. Increase in oil content due to nitrogen application has also been reported by Baslas (1970). Franz (1972) reported that application of 3 g N/pot (3.5 kg of soil) brought 39% improvement in oil content of Mentha piperita leaves over control. Oil content (on dry weight basis) was 3.91% at 3 g N/pot and 2.81% at control. Upadhyay et al., (1974) also observed significant increase in oil content of Mentha piperita by 120 kg N/ha over control. Ghosh and Chatterjee (1976) noticed increased oil formation with advancement in cropage but the oil content dropped again at reproductive stage. Ammonical nitrogen produced, leaves having higher percentage (2.7 %) of essential oil (Singh and Singh, 1978) than with nitrate nitrogen. However, on single plant basis the essential oil was higher (0.4 ml/plant) in plants receiving nitrate nitrogen because of higher foliage production. Saha et al., (1978) studied the effect of six levels of nitrogen (0, 20, 40, 60 80 and 100 kg N/ha) on oil content of Mentha and observed highest oil percentage at 60 and 80 kg N/ha. lower than 60 and higher than 80 kg N/ha reduced the oil content significantly. But Shelke and Morey (1978) recorded highest percentage of oil at 40 kg N/ha. Chandra et al., (1983) observed increase in oil content of Mentha arvensis L. by 160 kg N/ha over 0, 40, 80 and 120 kg N/ha.

There are few studies which has indicated that nitrogen did not have significant influence on oil content in leaves of *Mentha* species. Singh and Balyan (1975) studied the effect of different doses of nitrogen on essential oil content of *Mentha piperita* and found that different levels of nitrogen did not influence oil concentration in leaves. The experiment of Singh *et al*., (1978) indicated that there was no effect of nitrogen levels 10, 25, 50, 75, 100 and 125 kg N/ha) on volatile oil content of *Mentha piperita*. Similarly, Bharadwaj *et al*., (1979, 1983) found that different levels of nitrogen had no specific effect on the essential oil content. Singh *et al*., (1983) observed slightly decrease in oil content of *Mentha citrata* with the application of nitrogen. Yadav and Ram (1983) observed that oil content of *Mentha arvensis* did not differ significantly by nitrogen rates (0, 40, 80 and 120 kg N/ha). Rao *et al*., (1984) observed that oil concentration of *Mentha citrata* was not affected by nitrogen rates.

2.3 Quality of oil

The effect of nitrogen on the contents of menthol, menthone, menthyl acetate etc., in the essential oil of Japanese mint, have been studied by many workers. Gulati and Duhan (1971) found reduction in menthol content from 81.11 to 78.42 per cent with increasing levels of nitrogen from 30 to 90 kg/ha. Similarly Franz (1972) observed decrease in menthol content from 51 to 42% by nitrogen fertilization.

Menthone content, however, increased with the application of nitrogen. He explained that nitrogen did not influence menthol content directly. But it has altered the growth of plant which in turn affected the oil quality. Duhan et al., (1975, 1977) also observed decreased menthol with increasing rate of nitrogen application. In the essential oil of *Mentha arvensis*, menthol and menthyl acetate increased with increasing doses of nitrogen upto 150 kg/ha, while menthone increased upto 250 kg/ha (Shelke and Morey, 1978). Yadav et al., (1981) reported that nitrogen fertilization (90-120 kg/ha) increased the menthol yield and prolonged the time of its accumulation in *Mentha arvensis*. The rate of menthol accumulation was 251-264 g/ha/day in nitrogen fertilized plants against 215 g/ha/day in control plants. At 120 kg N/ha, actual menthol accumulation continued for 66 days where as in control plants it was for 38 days. However, the lag period was 6 days at 120 kg N/ha and only 1 day for control.

However, Baslas (1970); Singh et al., (1978) and Clark and Menary (1980) have not observed consistent effect of nitrogen on the quality of essential oil.

Yadav and Mohan (1982) reported that menthol decreased and menthone and menthyl acetate increased in the oil of *Mentha arvensis* at higher doses of nitrogen. Farooqui et al., (1983) reported that menthol accumulation reached to its peak at flowering stage of plants, thereafter, it started declining.

2.4 Nitrogen concentration and uptake

Baird (1957) mentioned that fertilizing *Mentha piperita* with 200 kg N/ha increased the leaf nitrogen concentration from 3.05 (control) to 3.53% and that of petiole 0.98 to 1.24%. Samra *et al*., (1976) noted an increase in nitrogen concentration of plants with the increase in nitrogen fertilization. The nitrogen concentration in fertilized plants was 1.40% against 1.28% in unfertilized plants. They further mentioned that second harvest had more (1.46%) nitrogen concentration than in the first one (1.28%). Total nitrogen uptake also increased with increasing doses of nitrogen. A dose of 150 and 225 kg N/ha increased the total uptake of nitrogen by 93.0 and 145.4% over control, respectively. Rai *et al*., (1977) reported that nitrogen deficiency decreased the concentration of nitrogen in plants. The phosphorus and potassium concentration, however, increased with nitrogen deficiency. The nitrogen concentration of plants decreased with advancing age and reached the lowest at harvest (Singh *et al*., 1979), whereas uptake of nitrogen increased with age and reached highest at harvest. Significantly higher nitrogen concentration was observed at 250 kg N/ha. The control treatment showed lowest uptake. Yadav and Mohan (1982) observed highest nitrogen utilization efficiency at 20 kg N/ha, where as the uptake of nitrogen was highest at 40 kg N/ha during first harvest of *Mentha arvensis* in Lucknow conditions. Singh (1983) observed highest nitrogen uptake at 180 kg N/ha at Varanasi. The uptake and utilization efficiency of nitrogen by the crop increased with efficient weed control methods. Application of terbacil @ 2 kg/ha checked the weeds vis-a-vis the uptake of N by them. This finally resulted into highest uptake of N by the crop plants. The uptake of N in hand weeded plots, however, was greater than the uptake in plots of any other chemical weed controlled plots.

2.5 Slow release fertilizers

Various slow release nitrogenous fertilizers like neem cake coated urea, sulphur coated urea, lac coated urea, oxamides, isobutylidene diurea (1BDU), guanylurea (GU), Urea-acetaldihyde and N-enriched coal are available for use in crop plants (Prasad *et al.*, 1971). Because of their low dissolution rate in water, nitrogen release is slow from these fertilizers. Nitrogen released slowly is utilized fully by the growing plants. Thereby chances of wasteful nitrogen losses are minimised by using these fertilizers (Prasad; 1966 and Prasad *et al.*, 1971).

Nitrogen inhibitors like N-serve, neem cake and coaltar extract, Sulfa drugs, Karanja seed extract, Nitrapyrin, Malathion and Parathion are also used to slow down the rate of nitrogen mineralization (Prasad, 1966; Reddy and Prasad, 1975; Prasad and Reddy, 1977; Owens, 1981; Sahrawat, 1981; Sahrawat; 1980). The function of nitrogen inhibitors is to knock down the activity of nitrosomonas bacteria which then slow down the conversion of ammonium nitrogen to nitrite nitrogen. The release of nitrate thus become slow and plants use it efficiently.

In India, several indigenous materials, like neem cake and lac, have been utilized for coating the urea to make it slow release fertilizer (Prasad *et al.*, 1971). Though, sulphur coated urea have proven ability to release nitrogen slowly (Allen, 1968 C.F. Prasad *et al.*, 1971), its practical use in India is limited as no firm makes sulphur coated urea at present in the country.

Nitrification is the biological oxidation of ammonium into nitrate via nitrite. It is mediated by nitrosomonas and nitrobactor species of nitrifying bacteria. Usea is the most important nitrogen fertilizer and its use is steadily increasing to boost up the agricultural production. This trend is very likely to continue as hunger still prevails in the world. It is also a fact that the transformation of urea into ammonium and its utilization efficiency could be controlled by inhibiting the action of nitrifying bacteria on it.

In Japanese mint (*Mentha arvensis* L.) slow release fertilizers have not yet been tried. However, these have shown beneficial effect in certain other field crops. Therefore, the review in this section is based on crops other than *Mentha arvensis* L.

2.5.1 Rate of nitrogen mineralization

Reddy and Prasad (1975) reported nitrification inhibitory properties in neem cake. Khandelwal et al., (1977) observed that urea coated by 0.5, 1 and 2 ppm of neem cake extract mineralized within 4 weeks of incubation while in coated urea got mineralized in one week of incubation. The low rate of mineralization by neem cake extract was due to its inhibitory action on the population of nitrosomonas and nitrobactor. Sahrawat (1981) reported nitrification inhibitory properties in Karanja (Pomengia glabra) seed cake and bark also. In another study, Sahrawat (1982) treated urea with alcohol extract of Karanja and neem seed and also with Karanjin. The extract retarded mineralization process for 45 days while Karanjin prolonged its for 60 days. Thomas and Prasad (1983) revealed that coating of urea by neem cake imparted both slow release and nitrification inhibiting properties. They reported that inhibition of nitrification by neem cake was gratest at the end of first week in the alkaline soils and at the end of second week in other soils included in the study.

In sulphur coated urea, coating of sulphur is made on urea prills. Therefore, nitrogen released from coated urea is controlled. The dissolution rate of sulphur coated urea is also low. Rind et al., (1968) /C.F. Prasad et al., 1971 / reported that the dissolution rate of urea in water was 1 and 0.3% when 9 and 15% sulphur coating was made over it, respectively.

Sulphur as a coated material reduced into sulphide and ferrous sulphide is also formed around urea granule. This effectively incircle the urea and prevent the contact of granule with urease. Thus urea hydrolysis is inhibited.

In rice fields, oxygen availability from rice roots, oxidise the ferrous sulphide present around urea granule. This makes the release of nitrogen from urea easy. However, sulphur coated urea mineralize slowly in water logged than the arable field conditions (Rajale and Prasad, 1970). Under high temperature, the dissolution rate of sulphur coated urea is enhanced and thus nitrogen release is faster. This, however, could be controlled by increasing thickness of coated material and placing the fertilizer below root zone.

Lac coating on urea also make it slow release fertilizer because lac have low dissolution rate in water. Patro et al., (1975) observed that an application of lac coated urea at the rate of 100 kg N/ha was superior to 150 kg N/ha applied as prilled urea.

Prasad et al., (1970) reported that nitrogen losses through leaching, ammonia volatilization and denitrification could be minimised by increasing the size of nitrogen fertilizer granule. Chakravorty (1979) emphasized the importance of slow release nitrogenous fertilizers to minimise nitrogen losses through leaching, ammonia volatilization and denitrification. Coating of urea with nitrification retarding chemicals and materials viz. sulphur, neem cake and lac make the urea to release nitrogen slowly. Urea Super granule (USG), a new fertilizer product of Indian farmers fertilizers cooperative Ltd. (IFFCO), India has shown high nitrogen utilization efficiency in rice crop (Thomas and Prasad, 1982). Losses of nitrogen leaching, volatilization, denitrification and runoff were minimised when USG was used. In urea Super granule, the granule of urea were increased to 1-2 gm size. The pH of the soil in the vicinity of USG increased upto 9, while enzyme could function only upto an optimum pH of 8. Thus, urease activity is reduced which ultimately affected the hydrolysis process adversely.

Moreover, the upward diffusion of ammonium released from hydrolysis process of USG is low. Thus, the ammonia found in the soil where USG is placed come out in the atmosphere slowly and hence volatilization losses are reduced.

The low concentration of nitrate formed by nitrification also lead to minimum possibilities of nitrogen loss through leaching and denitrification in the an aerobic layer. In light textured soil with a high percolation rate nitrogen in urea super granule is subjected to extreme leaching losses. Thomas and Prasad (1982) reported that hydrolysis of USG was slower than the prilled urea. This has resulted into a longer persistence of ammonical nitrogen and lower concentration of nitrate nitrogen in the soil.

Nitrogen recovery by deep placed USG in wet land has been shown to be greater than that of its split application

(Savant *et al.*, 1983). Chen and Zhv (1982) observed enhanced uptake of nitrogen by crops and reduced losses by USG than powdered urea. Rao *et al.*, (1985) reported 38-51% nitrogen recovery by the use of USG, 32-44% by prilled urea and 20% by splits application in intermediate deep water conditions of rice crop. Split application or foliar spray of urea did not prove effective in intermediate deep water conditions. Eriksen *et al.*, (1985) also reported higher nitrogen recovery in rice with 5, 10 and 15 cm deep placement of USG than surface applied urea and USG. Reddy and Mitra (1985) observed higher nitrogen uptake by SCU and USG than prilled urea.

Prasad and Reddy (1977) reported that sulfa drugs (Sulfa thiozole, sulfa nilamide and sulfa pyridine) have nitrification inhibitory properties. Sulfa thiozole applied @ 2 ppm inhibited nitrification most effectively than sulfa nilamide and sulfa pyridine. About 14% of nitrogen from applied urea have accumulated in form of NO_2-N with in first week of incubation. Sulfa drugs when applied with urea reduced this NO_2 accumulation. Sahrawat (1980) suggested the use of Malathione, Parathione and nitrapyrine to inhibit the activities of urease. Prasad (1982) on the basis of several field trials have concluded that nitrification inhibitors and slow release nitrogenous fertilizers are effective in rice cultivation as they check leaching and volatilization losses which occur in submerged conditions.

Singh and Ram (1976) studied mineralization rate of slow release nitrogenous fertilizers under water logged conditions at Azamgarh district of Uttar Pradesh. They showed that ammonical nitrogen increase during the first 4 weeks of submergence. Thereafter it tended to decrease. The magnitude of nitrogen release from various N-carriers was in the order of Ammonium sulphate > urea > LCU > SCU. Maximum nitrogen was released from ammonium sulphate and urea in comparison to sulphur coated urea. Savant and De Datta (1979) studied the pattern of nitrogen release from deep placement site of prilled urea (PU), USG, SCU and urea in Mud ball (MBU). Nitrogen release from PU and USG was rapid during first day after placement and decreased thereafter in comparison to SCU and MBU. Nair and Sharma (1979) showed that urea and Isobutylidene diurea (IBDU) hydrolised rapidly and have left no traces after two weeks while SCU mineralised slowly and retained nitrogen upto 4 weeks after incubation. The rate of nitrogen release from NCU was intermediatory in between the above mentioned two N-carriers. Thomas and Prasad (1982) studied the rate of nitrogen mineralization from NCU, SCU and N-serve treated urea (NSU) in sandy clay loam. After three weeks of incubation inhibition of nitrification was 63, 46, 29 and 12% with NSU, NCU (Alachemie 15%), NCU (IARI 20%) and Neem mixed urea (NMU) IARI 20%) respectively. Neem cake coating of urea slowed down the release of mineral nitrogen from urea as well as inhibited the nitrification of released ammonium nitrogen.

2.5.2 Volatilization and leaching losses of nitrogen

The recoveries of applied fertilizer nitrogen hardly exceed 40% (Allison, 1966; Prasad, 1971; Engelstad and Russel, 1975; Sanchez, 1976 and Sahrawat, 1979 ,1980) it usually ranges between 20-30%. Apart from the immobilization and fixation of ammonical nitrogen in clay lattice (which is very minor), the low recoveries are due to losses of nitrogen through leaching and volatilization. Pande and Adak (1971) recorded 45 to 60% leaching of basal applied nitrogen. The leaching was minimised to 11-33% by split application of nitrogen. N^{15} studies of Daftardar (1973), however, indicated only 4-25.6% leaching of applied nitrogen through ammonium nitrate. Leaching occurred in form of nitrate nitrogen. Ammonical nitrogen did not leach much. Smith and Chalk (1978) reported that in alkaline pH nitrogen losses in form of ammonical fertilizers were N_2, N_2O, No and NO_2. Milkkelsen <u>et al</u>., (1978) reported as high as 20% losses through ammonia volatilization by broad casted urea in neutral flooded soil. In acidic soils volatilization losses were less than 1%. Placement of nitrogen fertilizers at the depth of 10-12 cm reduced ammonia volatilization to less than 1%.

Terman (1979) observed maximum volatilization from soils having pH values from 8-9. Vilek and Craswell (1979) found that soon after hydrolysis, volatilization proceeded to a maximum of 50%, within 2-3 weeks. The volatilization losses from ammonium sulphate reached to 15% within three weeks while volatilization from urea remained negligible. Rao and Prasad (1980) found 20% leaching of nitrogen from all the N-carriers except of sodium nitrate. Leaching however, was reduced by blending the urea with nitrification inhibitors N-serve, neem cake, sulphur and by using urea super granule. Bauder and Montgomery (1980) suggested timely application of ammonium fertilizers and low volume of irrigations to minimise leaching of nitrate nitrogen below root zone of wheat crop. Arora and Juo (1982) compared nitrogen leaching from bare and cropped coarse textured Kaolinite ultisol under high rainfall conditions. One to three split applications reduced nitrogen leaching from 53 to 28%. In maize, the leaching of applied nitrogen was 22, 35 and 41% from one, two and three splits, respectively. In rice, the respective values changed to 31, 39 and 61% for one, two and three splits, applications. Romanin (1982) observed that, ammonia volatilization was higher from ammonium sulphate in comparison to urea within 24 hours of application. However, after 7-9 days volatilization increased in urea in comparison to ammonium sulphate. Sinde *et al*., (1982) reported that out of total nitrogen leaching (6.37%), 1.25 was ammonical and 4.88% was nitrate. Rao and Bhat (1984) compared ammonia volatilization from different N-carriers in Java citronella, a aromatic crop grown largely in eastern and southern parts of the country. Surface application of nitrogen resulted substantial losses of ammonia as gas (PU 19.8%, USG 29.3% and SCU 9.8%) and placement of nitrogen at 5 cm depth eliminated the losses (PU 69%, USG 1.4% and SCU 1.1%). USG could be advantageously used in upland crop situations to minimise ammonia volatilization. Eriksen _et al_., (1985) found 24% nitrogen losses from surface applied urea through ammonia volatilization. The losses could, however, be checked effectively by deep placement of USG.

2.5.3 Crop response

Prasad (1966) showed that ammonium sulphate treated with N-serve increased 8 q/ha yields of rice over prilled urea. Both N-serve and ammonium.sulphate found to be effectiv Benefits due to nitrification inhibitors, however, more in dwarf than in tall rice varieties (Lakhdive and Prasad, 1970, 1971). Prasad _et al_., (1971) opined that slow release nitrogenous fertilizers and nitrification inhibitors increased crop yields by minimising leaching and volatilization losses of applied nitrogen. Nelson _et al_., (1976) reported 12-25% increase in corn yield and 13-20% in wheat yields by applying nitrogen with nitrapyrin terrazole, a nitrification inhibitor. Sharma (1976) at Pantnagar reported that Isobutylidene diurea (IBDU) and sulphur coated urea (SCU) significantly higher wheat grain yields than urea. Knop _et al_., (1976) studied the effect of slow acting fertilizers in spring wheat and barley. Application of slow acting urea blended with neem cake, coaltar and Kerosene produced 5.2 t/ha yields. Nitrogen concentration in plants also increased with the same proportion. Split application of coaltar kerosene oil coated urea as 25, 50 and 25%p at sowing, tillering and penicle initiation stages, respectively, produced maximum rice yields (Rajan and Subramaniyan, 1981). Eriksen and Nilsen (1982) observed 85% increase in grain yield with an application of two levels of USG and prilled urea (2 gm and 4 gm urea/0.1 m^2) applied at the surface of submerged clay soil. The differences in yield between prilled urea applied in three split doses and one application of USG was not significant. Deep placement of USG at 5 cm depth increased the grain yield by 20% over surface application. The yield differences of 60 kg N/ha applied equally in three splits i.e. transplanting, tillering and penicle initiation stages and 40 kg N/ha applied in form of urea at the time of transplanting with 20 kg N applied at penicle initiation stage were not significant. The yield obtained at 60 kg N/ha through lac coated urea as basal dose was also at par (Laskar and Dadhwal, 1982). Lal <u>et al</u>., (1982) suggested the use of seed cake (neem) with coaltar and kerosene oil (1:2) to blend the urea. Basal application of this fertilizer at 50 kg N/ha produced 5.3 t/ha rice grain which was higher than the split application (5.1 t/ha) of urea. Sannigrahi and Mandal (1984) showed that lac coated urea and urea were equally efficient in rice grain production, but were significantly superior to urea form (40% N), IBDU (31.2% N) and crotonylidene diurea (CDU),(31% N). Uptake of nitrogen by straw under different N-carriers was in the order of lac coated urea, urea form Isobutylidene diurea, crotonylidene diurea. Deep placement of USG in continuous or intermettent flooding produced significantly higher rice yields in comparison to surface application of prilled urea or urea super granule (Eriksen et al.,1985). Reddy and Mitra (1985) reported that under intermediate flooding of 15-35 cm deep water during entire growth period sulphur coated urea and urea super granule placement was superior to prilled urea in increasing the grain yield of rice.

2.6. Scope of utilising slow release nitrogenous fertilizers in Mentha arvensis

Mentha arvensis is a crop where frequent irrigations are required to sustain higher growth. The crop passes through rainy season and takes about 9 months for its maturity. Broadcast application of urea, the main fertilizer source available to the farmers, is utilized inefficiently by the crop because most of the nitrogen is lost through leaching, denitrification and ammonia volatilization. The nitrogen recovery by the crop is almost 35% which is very low. The excess concentration of fertilizer in the root zone which is likely to be lost through the process as mentioned above can be reduced by split application of fertilizer, incorporation of fertilizer, deep placement of fertilizer in soil and the use of slow release fertilizers at higher rates proved beneficial to increase spring wheat yields. Khandelwal *et al.*, (1977) reported that an application of 60 kg N/ha through urea coated with neem extract at 0.5, 1.0 and 2.0 kg increased the grain and straw yields of wheat in comparison to control. Prasad (1979) observed higher fertilizer use efficiency in rice, maize, sugarcane etc. by the use of nitrification inhibitors, urea briquetts, urea super granule (USG) and urea mixed and coated with neem cake over prill urea. Similarly, Seshadri and Prasad (1979) reported significantly higher seed yields ef cotton with the application of SCU and N-serve urea than prilled urea. Sharma and Prasad (1980) observed higher dry matter production and nitrogen uptake in rice crop at an application of 150 kg N/ha in comparison to control. Chaing and Yang (1980) reported that SCU increased the grain yields of early rice. The increase rate was 17% in comparison to basal dressing and three side dressings of urea. Milenko *et al.*, (1981) reported that N-serve treated urea increased the yields of winter wheat and sugarbeet without affecting their quality. Milenko and Milan (1981) applied 125 and 80 kg N/ha through urea mixed with N-serve and found that 125 kg N/ha increased 6-10% grain yield of wheat in comparison to 80 kg N/ha. Rabindra and Rajappa (1981) observed that grain yield of rice increased from 2.6 t/ha in control to 4.2 t/ha at 100 kg N/ha applied in three splits of urea. Application of 80 kg N/ha through neem cake blended urea in two splits produced 4.7 t/ha yields while the same dose applied through nitrogenous fertilizers. Split application and deep placement involve extra cost of application. Slow release fertilizers which can be applied at planting may not require more labour for its application at later stages. The slow release concept relies on delaying the availability of soluble nitrogen to the crop plant until the plant has a strong root system which can compete with the loss mechanism and biological immobilization for fertilizer nitrogen. If the release rate can be matched to the needs of the crop plant, no doubt, the yield of the crop will increase in a most efficient way. No work in this respect has been done on Mentha species. There is much scope to do experiments on slow release nitrogenous fertilizers with Mentha arvensis L. crop for increasing the efficiency in nitrogenous fertilizer use in Mentha crop.

3. MATERIALS AND METHODS

The present investigation on "Physiological basis of yield variations in <u>Mentha arvensis</u> L. due to nitrogen fertilization and their agronomic appraisal" was conducted at Agricultural Research Farm of the Central Institute of Medicinal and Aromatic Plants, Lucknow during 1983 and 1984. The details of materials used and methods employed during the course of this investigation have been elaborated in this chapter.

3.1 Experimental site and climate

The agricultural farm of the Central Institute of Medicinal and Aromatic Plants, Lucknow is situated at 26.5° N latitude 80.5° E longitude and at 120 m altitude. Climatologically, Lucknow is classified in semi-arid sub-tropical zone with severe hot summers and fairly cool winters. In this region, monsoon normally onsets from last week of June and continues till end of September. About 88% of the monsoon rains are received during July and August. Winter also experiences some rains due to cyclonic disturbances in Arabian sea.

3.2 Weather conditions during the course of investigation

The details of weather conditions that prevailed during the course of this investigation have been depicted in

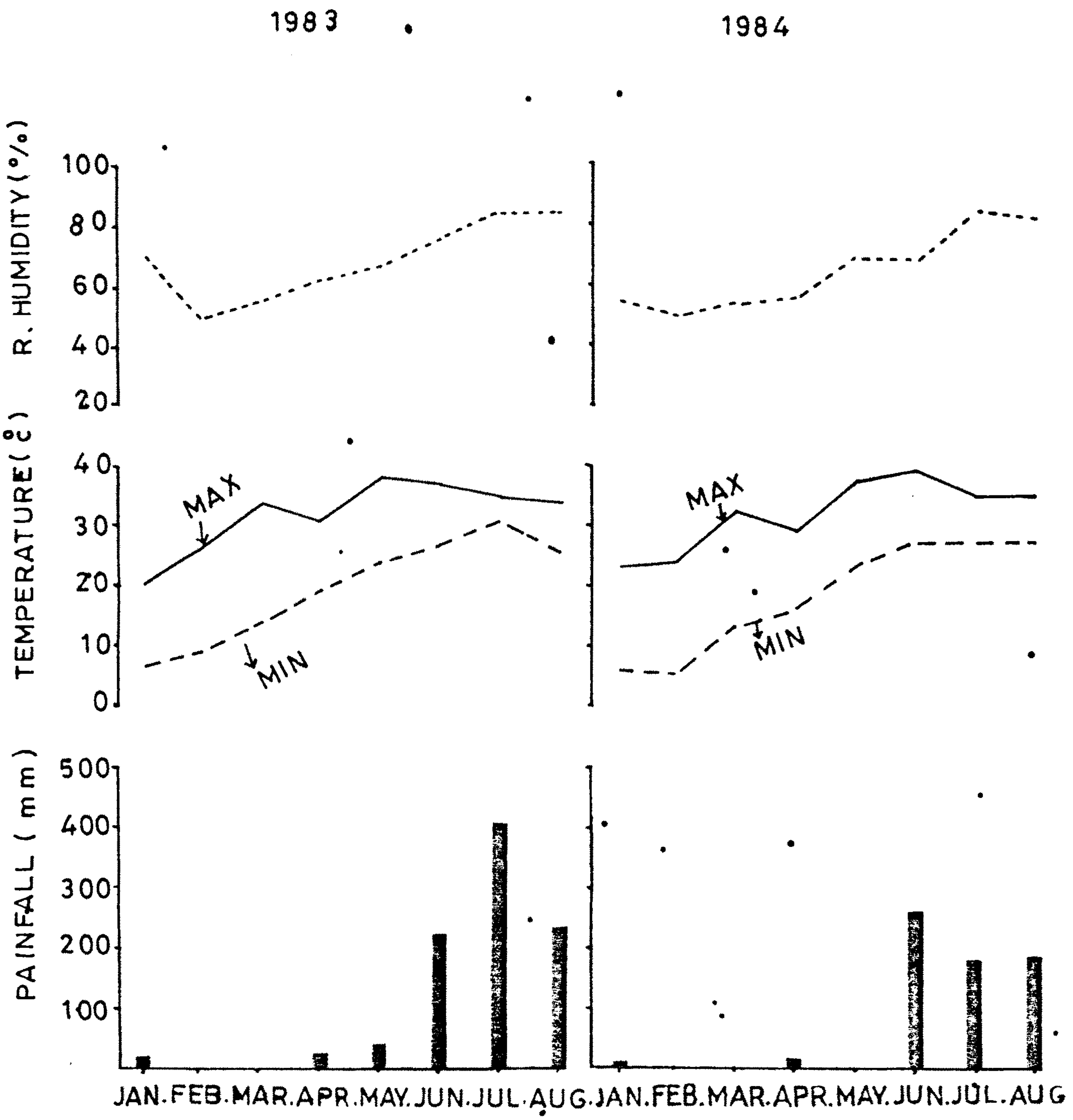


FIG. 1. WEATHER CONDITIONS OF CROP GROWTH SEASONS.

Fig. 1 and presented in Appendix 1. The minimum and maximum temperatures fluctuated between 4.6°C and 29.5°C and 15.4°C and 42.3°C, respectively through out the crop life cycle. The lowest minimum temperature (4.6°C) was recorded in third week of January in 1983, and in the last week of January in 1984. After this, minimum temperature increased and attained peak (29.5°C) in second week of June . Maximum temperatures were also low in January. In 1983, lowest maximum temperature of 15.4°C was recorded in first week of January, while in 1984, the lowest value of 23°C was observed in third week of January. The relative humidity varied from 57.3 to 94.0% in 1983 and 58.7 to 96.5% in 1984. The experimental crop received 942.9 mm rainfall during entire life cycle in 1983. Maximum rainfall of 404.3 mm, however was received in July. In 1984 season, the crop experienced 653.6 mm rainfall, of which maximum (267.8 mm) was received in June.

3.3 Soil characteristics

Soil of the experimental area was sandy loam in texture and alkaline in reaction (pH 8.5). The physico-chemical properties of the soil indicated that soil was deficient in nitrogen and medium in phosphorus and low in potasium (Table 1). The particle density of the soil was 2.22 g/cc.

Table 1: Physico-chemical characteristics of the experimental soil

Particulars		Value 1983	Value 1984	Methods employed
1. Physical characteristics				
(a)	Sand %	66.2	66.2	Hydrometric Method, Buoyoucos, 1962
(b)	Salt %	24.0	24.1	
(c)	Clay %	9.8	9.8	
(d)	Particle density gm/cc	2.22	2.23	
2. Chemical characteristics				
(a)	Available nitrogen (kg/ha)	141.1	150.0	Alkaline permagnate method, Subbiah & Asija, 1973
(b)	Available P (kg/ha)	9.6	12.0	Olsen's $NaHCO_3$ method, Jackson, 1967
(c)	Exchangeable K (kg/ha)	50.4	55.0	Ammonium acetate Flame Photometer
(d)	pH	8.5	8.6	Digital pH meter model LI-120

3.4 Gropping history

The agricultural research farm of the Central Institute of Medicinal and Aromatic Plants, Kukrail was the undulated barren forest land acquired from the forest department of Uttar Pradesh government in 1976. To make it cultivable, heavy levelling was done. Therefore, whole soil profile was disturbed. To stabilise soil profile, aromatic grasses like citronella and palmarosa were grown in initial years of its development. The crops which were grown on the experimental plots after 1978-79 crop season, have been shown in table 2.

Table 2. Previous cropping history.of the experimental field

Year	Season	Crop grown	Remarks
1978-79	Rabi	Mustard	-
1979-80	Rabi, Kharif	Japanese mint	Entomological experiment
1980-81	Kharif, Rabi	<u>Costus</u> species	Agronomical experiment
1981-82	Kharif, Rabi	<u>Costus</u> species	Agronomical experiment
1982-83	Rabi, Kharif	Japanese mint	Present experiment
1983-84	Rabi, Kharif	Japanese mint	Present experiment

3.5 Experimental details

To achieve the objectives, diliented in the introduction, a field experiment was laid out with following treatments during 1983 and 1984.

3.5.1 Treatments

1. Nitrogen carriers

(i)	Prilled urea	(PU) - S_1
(ii)	Urea super granule	(USG) - S_2
(iii)	Lac coated urea	(LCU) - S_3
(iv)	Neem cake coated urea	(NCU) - S_4

2. Nitrogen levels (kg/ha)

(i)	0	(Control)
(ii)	60	(N_1)
(iii)	120	(N_2)

3. Time of nitrogen application

(i)	Full basal	(T_1)
(ii)	1/3 basal + 1/3, 45 days after planting + 1/3 after first harvest	(T_2)
(iii)	1/2, 45 days after planting + 1/2 after first harvest	(T_3)

3.5.1.1 Details about nitrogen carriers

(i) Urea : Urea of Indian Farmers Fertilizer Cooperative Ltd. containing 46% N was used. This was in the form of prills of 3.4 mg size.

(ii) Urea super granule (USG): Urea super granule was obtained from Indian Farmers Fertilizer Cooperative Ltd. The weight per granule was 1 gm having 46% N.

(iii) Lac coated urea (LCU): Lac coated urea was made by shallac coating on the prill urea. Shallac resin was dissolved in absolute alcohol (1:2 ratio). A mixture of linseed oil, soap and coaltar was also prepared. These two mixtures were, then mixed and poured in a drum where urea was placed. The drum was rotated with 600 r.p.m. This caused a thin coating of mixture on urea prills. The final urea formed, thus, contained (33.9%) N on weight basis. The compositions of all the materials in final product was urea 73.9%, Resin shallac 16.2%, boiled linseed oil 3.3%, soap stone (conditioner) 2.9%, wax 3.6% and coaltar 0.3%.

(iv) Neem cake coated urea (NCU): A simple technique for coating urea with neem cake was developed at IARI, New Delhi. The same was used here. One kilogram coaltar was dissolved in two litres of kerosene, oil through shaking and the required quantity of solution (2 ml/100 gm urea) was added to urea kept in a polythene bag and the content were thoroughly mixed. This gave a simple coating of coaltar on urea prills. Fine powdered neem cake (20 gm/100 gm urea) was then added and the content of the bag were thoroughly mixed. The neem cake contained 5.4% N and thus the neem cake coated urea contained 38% N.

3.5.2 Layout plan

(i)	Design	Randomised Block Design
(ii)	Replication	Three
(iii)	No. of plots in one replication	25
(iv)	Total No. of plots	75
(v)	Gross plot size	18 m^2
(vi)	Net plot size	6.75 m^2
(vii)	Sampling area	11.25 m^2
(viii)	One control per replication was taken	

3.5.3 Crop culture

3.5.3.1 Field preparation

About a month before planting the field was deep ploughed with soil turning plough. This was followed by a

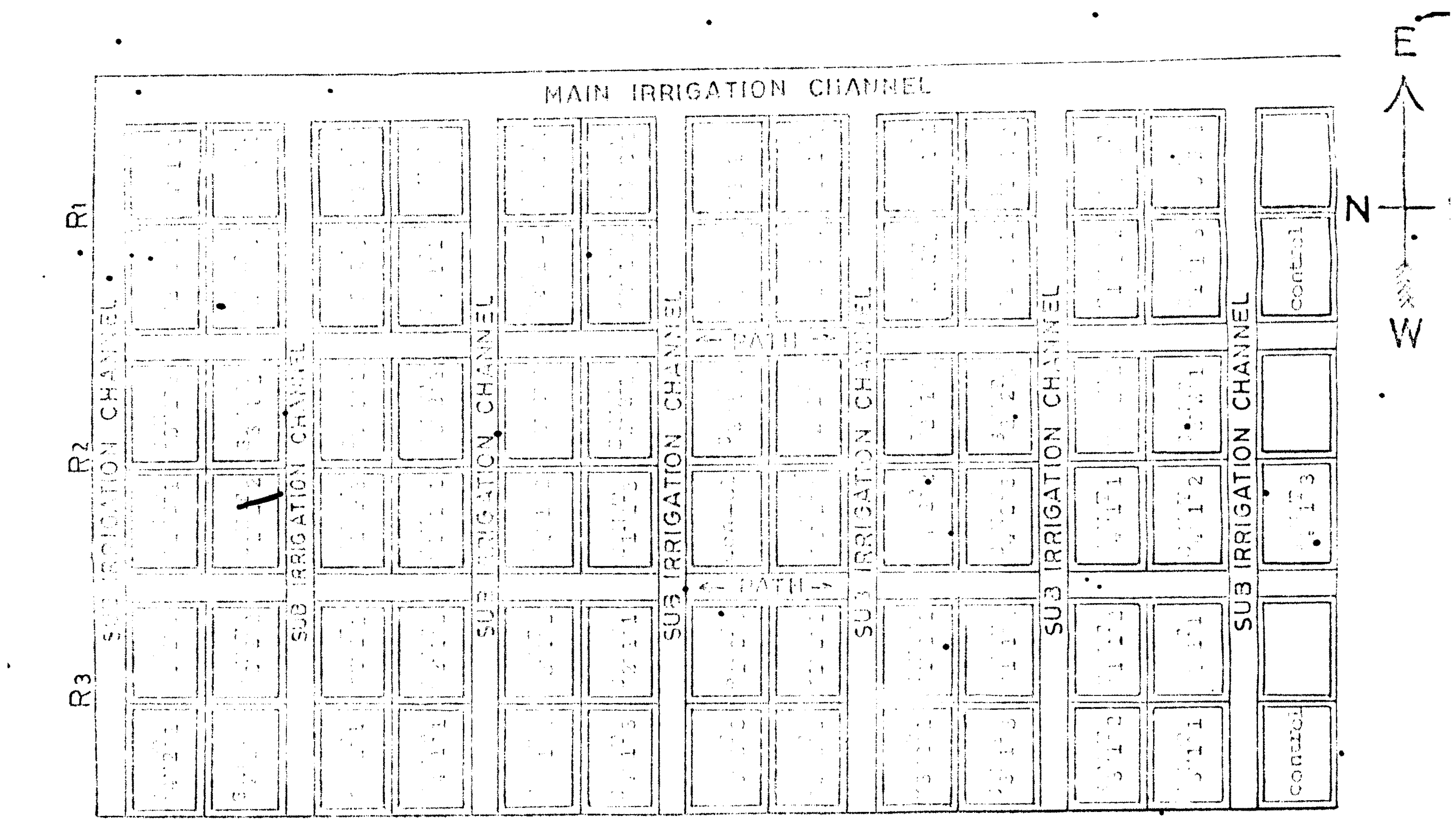


FIG. 2. LAY OUT PLAN

harrowing, then one pre-sown irrigation was given when the field came in condition, final beds were prepared by three cross harrowing and planking.

3.5.3.2 Planting dates and seed rate

The crop was planted in rows 45 cm apart using 5 q of suckers/ha on January 22 in both the years. For planting, suckers were placed end to end in 5 cm deep furrows opened by hand hoe and covered with 2.5 cm soil. A light irrigation was given just after planting to ensure good sprouting of suckers.

3.5.3.3 Fertilizer application

Phosphorus and potassium fertilizers were applied at the rate of 60 kg P_2O_5 or K_2O/ha each using single super phosphate (16% P_2O_5) and murate of potash (60% K_2O), respectively. The exact quantity of these fertilizers per plot was mixed thoroughly, broadcasted and incorporated uniformly before planting. Nitrogen was applied as per treatments. However, the basal application of nitrogen was given in the furrow below the suckers but USG was placed 5 cm deep in between two rows of Japanese mint.

3.5.3.4 Weeding

To keep the field free from weeds, seven mannual weedings were done on the dates given in table 3. Weeds were removed by scrapping the soil with the help of khurpi.

Table 3. Calender of field operations

Operations	Dates 1983	1984
1. Preparatory tillage presowing irrigation cross harrowing followed by planking	December, 28	25
2. Lay out of field experiment	January, 19	16
3. Planting	January, 22	22
4. Application of fertilizer		
(a) Basal dose	January, 21	21
(b) Top dressing and incorporation of fertilizer into the soil	March,3 and May, 25	March 7 and May, 28
5. Irrigation	January, 22 February, 8, 28 March,6,16 & 28 April,7,17 & 27 May, 12, 24 June,2, 15 July	22 10, 21, 9,17, 26 8,19,30 14,25 4,16 12
6. Weeding	March,8,30 April,9;20 & 29 May, 27 June, 9	11,30 10,21 1,29 11
7. Harvesting		
First harvest Second harvest	May, 22 August,5	21 4

3.5.3.5 Irrigation

The crop was irrigated at an interval of 15 days during January-February. The interval of irrigation was reduced to 10 days during March-June. During rainy season, crop was not irrigated. Thus, in total 13 irrigations were given during 1983 and 14 in 1984.

3.5.3.6 Harvesting

The crop was harvested twice each year. First harvest was done at 120 days after planting(DAP), while second harvest of regenerated growth was done 75 days after first harvest. Harvesting was done with the help of sickles close to the ground level. The produce was weighed immediately after harvest.

3.6 Observations

Following observations were recorded as per techniques mentioned below :

3.6.1 Growth

Growth observations were recorded on plants from 25 cm running row length which were cut close to the ground level at 15 days interval from 60 days after planting.

3.6.1.1 Plant height

Five plants from the whole harvested lot were selected and their height was recorded. The average height of these five plants was considered height at that stage.

3.6.1.2 Number of leaves

Green leaves of the harvested plant samples were counted and expressed as number of leaves per 25 cm row length.

3.6.1.3 Leaf area

The separated leaves were divided into three groups; small, medium and large. Five leaves of each group were taken for measuring leaf area. The leaf area was measured by portable leaf area meter Model LICOR-3000.

3.6.1.4 Leaf: stem ratio

The leaves and stem of plant sample from 25 cm row length were separated and weighed separately. Leaf: stem ratio was calculated by dividing the weight of leaves to that of stem, in fresh weight basis.

3.6.1.5 Dry matter accumulation

The observations on dry matter accumulation were made on a separate sample harvested from 50 cm row length each time. The sample was dried at 70°C - 80°C for 48 hours. The dry matter have been expressed on hectare basis.

3.6.2 Growth analytical observations

The data on leaf area and dry matter accumulation were subjected to following growth studies. Growth analysis formulae given by Radford (1967) were utilized.

3.6.2.1 Leaf area index

Total leaf area of 25 cm row length was divided by the ground area i.e. 45 cm x 25 cm.

3.6.2.2 Crop growth rate (C.G.R.)

The formula for mean crop growth rate ($\overline{CGR}$) was as follows :

$$\overline{CGR} = (W_2 - W_1) / (t_2 - t_1)$$

3.6.2.3 Relative growth rate (R.G.R.)

Relative growth rate ($\overline{RGR}$) of the crop was calculated by the following formula

$$(\overline{RGR}) = (\log_e^{W_2} - \log_e^{W_1} / (t_2 - t_1)$$

where W_2 and W_1 were the values of dry weight of the plant at t_2 and t_1 time intervals.

3.6.3 Herbage yield

There were 8 rows of 5 m length in each plot as shown in Fig. 3. Sample for growth was done in rows 1,2,3, 7 & 8. Three central rows (i.e. 4,5 & 6) were harvested for herbage yield at first harvest. Sampling of regenerated growth was done in 4 and 5th rows. Second harvest was taken from two central (i.e. 5 and 6) rows. The total of first and second harvest in a plot was considered as herbage

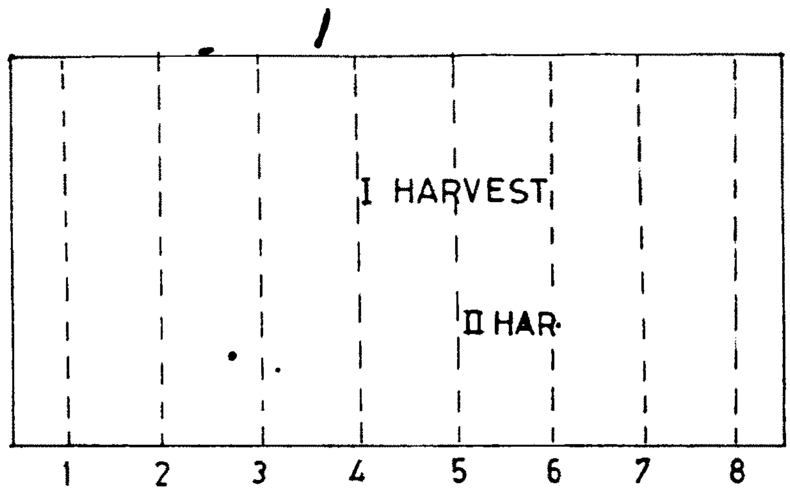


FIG. 3 SAMPLING PLOT OF MENTHA ARVENSIS L.

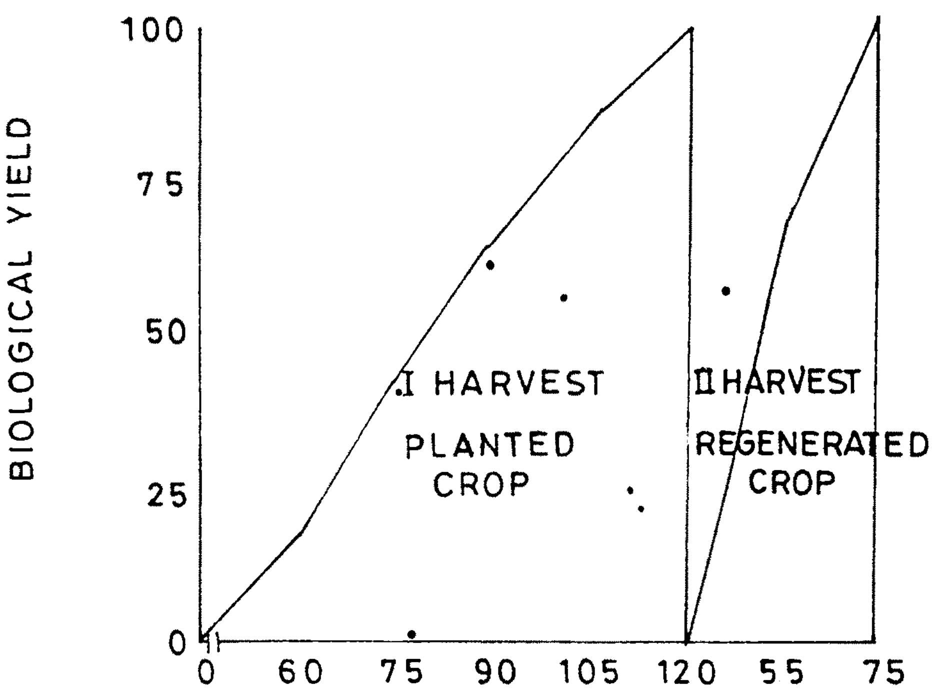


FIG 4 BUILD UP OF BIOLOGICAL YIELD IN FIRST AND SECOND HARVEST OF MENTHA ARVENSIS L

production of that plot, which then was converted into q/ha for treatment comparisons. The build up of biological yield at first harvest (planted crop) and second harvest (regenerated crop) have been shown in Fig. 4.

3.6.4 Oil content

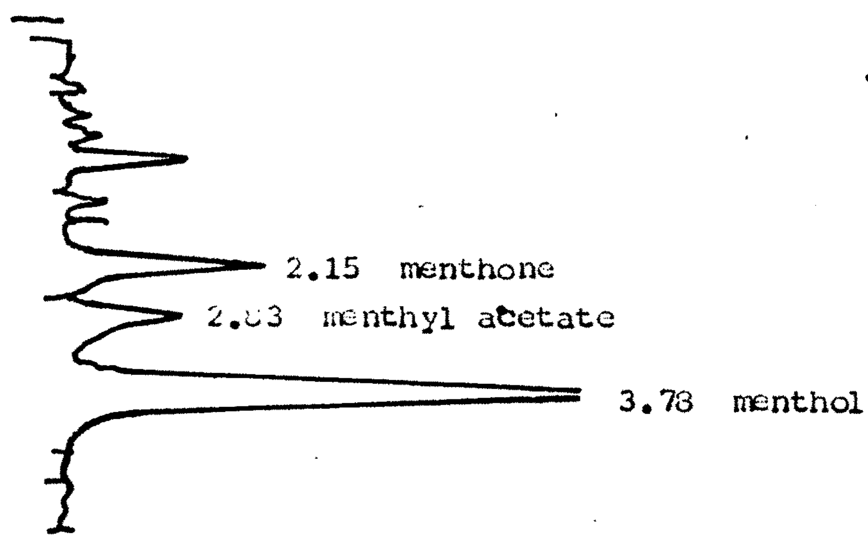
Oil content was determined in 100 gm plant sample by hydrodistillation method using Clavenger's apparatus. Plants were chopped and filled in boiling flask of Clavenger's apparatus. The flasks were placed on heating mentle and the distillation was done on a constant heat.

3.6.5 Oil yield

Oil yield was calculated by multiply the fresh herbage yield with that of oil content in respective plant samples.

3.6.6 Oil quality

Oil quality in terms of menthol, menthone and menthyl acetate content was determined by gas liquid chromatography on Perkin Elmer 3920 chromatograph using 20% replex - 400 on chromosorb WN AW".1/4" x 6 ft column and TCD as detector with hydrogen as carrier gas. Peaks of menthol, menthone and menthyl acetate on G.L.C. graphs have been shown in Fig. 5.



RUN 40

AREA%

RT	AREA	TYPE	AR/HT	AREA%
0.24	122	PP	0.088	0.026
0.38	275	PB	0.031	0.058
0.59	876	PV	0.043	0.184
0.72	3760	VV	0.062	0.791
0.86	15375	VB	0.070	3.232
1.17	178	BP	0.072	0.037
1.36	5060	PB	0.106	1.064
2.15	68020	PB	0.202	14.300
2.83	51305	PP	0.267	10.786
3.78	324260	PB	0.268	68.171
5.90	6425	BP	0.422	1.351

TOTAL AREA = 475660
MUL FACTOR = 1.0000E+00

Fig. 5. Gas Liquid Chromatography of *Mentha arvensis* oil

3.6.7 Biological efficiency of nitrogen application

This was calculated by the following formula

$$\text{BENA} = \frac{\text{(Dry matter yield in fertilized plots)} - \text{(Dry matter yield in control)}}{\text{Amount of fertilizer applied}} \times 100$$

3.6.8 Studies on nitrogen losses

3.6.8.1 Nitrate nitrogen leaching losses

The contents of nitrate-N in different soil horizones i.e. 0-15, 15-30, 30-45, 45-60, 60-75 and 75-90 cm depth, were determined before planting and at 30 and 120 days after planting in five plots of different N-carriers at 120 kg/ha basal nitrogen application. Soil samples from different depths were taken out by auger (Fig. 6) and collected in moisture box. Half of the sample was kept for moisture determination and in remaining half nitrate N was estimated using phenol 2-4 disulphonic acid method (Black, 1965).

3.6.8.2 Ammonia volatilization

Ammonia volatilization of various N-carriers at 120 kg/ha basal N application was also determined. The determination of ammonia volatilization was continued till 35 days after planting. The technique used for ammonia

Fig.6: Sampling procedure for nitrate nitrogen leaching

Fig.7: Equipment showing collection of volatilized ammonia in field conditions.

Fig.8: Cross Section of metal drum used for the collection of volatilized ammonia

volatilization was that of Nommik (1973). In this technique, the metal cylinders of 28 cm diameter and 50 cm height were fixed in the soil in between two rows of the crop to a depth of 5 cm (Fig. 7). Foam disc with 28 cm diameter and 2.5 cm thickness were taken. The two discs in each system were placed, at the top of the cylinders and supported by wood sticks as shown in Fig. 8. the upper disc helped to avoid contamination of the lower disc from the atmospheric ammonia. Before placing in metal cylinders the lower disc was leached out with 1 M KOH and 1 M H_3PO_4 solutions and finally with distilled water. Soon after rinsing it, the lower disc was soaked in a solution containing 100 ml of concentrated H_3PO_4 and 40 ml glycerol per litre. The foam disc was sequeezed for removing excess of the solution. Foam disc was replaced at weekly intervals. Ammonia absorbed in the disc was leached by successive washing with 500 ml distilled water. Ammonia content in the leachate was determined by steam distillation.

3.7. Statistical analysis of the data

F test was used for treatment comparisons. Critical differences of two means were calculated using the procedure of Randomised Block Design. However, for comparing control with rest of the treatments, critical differences were calculated using following formula

$$\sqrt{(EMSS/3 + EMSS/72)} \times t$$

For interaction effect, sum of squares, combination of the three treatments (S x N x T) was calculated from the table, from which sum of square of individual treatment S, N and T, respectively were deducted to get the interaction sum of square S x N x T. These were compared by the CD values calculated as given below

$$\sqrt{2 EMSS/ r} \times t$$

The relationship of menthol with leaf area index, nitrogen concentration and oil content and nitrogen concentration with oil content was studied by correlation techniques described by Panse and Sukhatme (1967). The variation caused in above characters by N-carriers, their dose and time of application at different growth stages over a period of two years was taken into consideration to work out correlation values.

4. RESULTS

The results of this investigation on "Physiological basis of yield variations in <u>Mentha arvensis</u> L. due to nitrogen fertilization and their agronomic appraisal" obtained during the course of experimentation are presented in this chapter.

4.1 Growth

4.1.1 Plant height

4.1.1.1 Effect of nitrogen carriers

The general trend of variations in plant height due to nitrogen carriers was almost the same in both the years. However, plant attained greater height in 1983 crop season than 1984 (Table 4 and Fig. 9). In general USG, LCU and NCU produced taller plants than those plots receiving PU. The differences in plant height from plots treated with PU and other nitrogen carriers were significant althrough except at 60 days after planting, where plants from NCU treated plots were significantly taller than those from plots fertilized with urea. Finally at the first harvest (120 days after planting), plants fertilized with NCU, USG, LCU and PU attained heights of 53.3, 49.1, 43.4 and 40.7 cm in 1983 and 48.4, 43.9, 43.0 and 41.9 cm in 1984, respectively. In regenerated growth, the respective N-carriers produced plants with 57.9, 57.2, 54.5 and 47.5 cm

Table 4. Plant height (cm) of *Mentha arvensis* L. as influenced by N-carriers, their rates and time of application

Treatments	1983							1984						
	Days after planting					Days after I harvest		Days after planting					Days after I harvest	
	60	75	90	105	120	55	75	60	75	90	105	120	55	75
Nitrogen carriers														
PU	7.83	15.6	22.2	34.8	40.7	37.2	47.5	6.00	11.2	21.8	32.6	41.9	29.9	36.9
USG	8.34	20.8	27.9	40.8	49.1	40.7	57.2	6.58	12.0	24.2	35.9	43.9	34.3	43.4
LCU	8.45	16.2	26.5	37.00	43.4	37.9	54.5	6.44	11.5	23.3	34.1	43.0	32.6	40.2
NCU	9.74	23.2	30.0	40.8	53.3	41.1	57.9	7.56	12.7	26.6	36.9	48.4	36.0	43.8
SEm ±	0.36	0.19	0.3	0.50	0.4	0.7	0.55	0.15	0.34	0.31	0.25	0.20	0.40	0.35
C D 5%	0.98	0.52	0.70	1.40	1.10	1.93	1.53	0.43	0.94	0.87	0.70	0.55	1.11	0.97
N-rates (kg/ha)														
60	7.87	17.8	25.4	36.5	45.4	37.6	53.4	5.89	11.5	23.1	33.5	42.9	32.2	40.1
120	9.11	20.1	27.1	40.3	48.9	40.9	55.2	7.39	12.2	24.9	33.2	45.8	34.2	42.1
SEm ±	0.25	0.13	0.2	0.4	0.3	0.49	0.39	0.11	0.24	0.22	0.18	0.14	0.29	0.25
C D 5%	0.69	0.37	0.5	1.0	0.8	1.36	1.08	0.30	0.66	0.61	0.49	0.39	0.79	0.69
Time of application														
T_1 (Basal)	9.16	21.1	29.8	40.4	48.9	35.1	49.0	7.50	12.9	26.9	36.6	46.0	29.3	36.9
T_2 (3 splits)	8.44	19.2	27.0	39.0	47.4	38.6	53.6	6.60	11.9	24.1	35.3	45.1	33.0	41.2
T_3 (2 splits)	7.88	16.4	23.2	35.7	43.6	44.0	60.1	5.92	10.8	20.8	32.7	41.9	37.4	45.2
SEm ±	0.31	0.16	0.20	0.04	0.40	0.60	0.48	0.13	0.29	0.27	0.22	0.17	0.35	0.31
C D 5%	0.85	0.45	0.60	1.20	1.00	0.67	0.32	0.36	0.80	0.75	0.60	0.47	0.97	0.84
Control	7.13	9.50	20.1	31.3	35.4	34.0	40.0	5.03	9.67	19.0	25.3	40.0	21.0	31.0
C D 5% (control vs. rest)	1.74	0.92	1.30	3.75	1.98	3.42	2.71	0.76	1.65	1.54	1.23	0.97	1.98	1.74

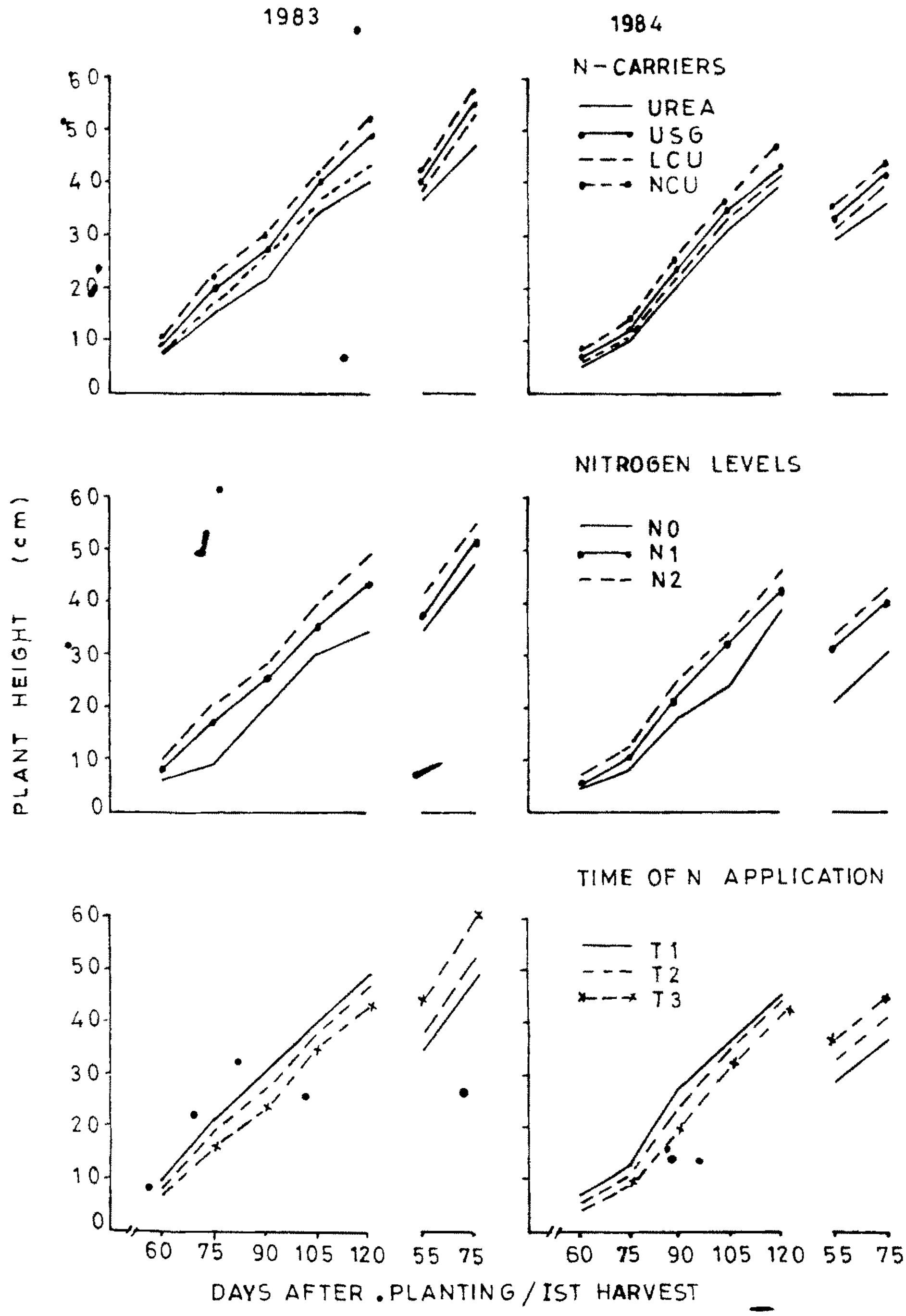


FIG.9 PLANT HEIGHT (cm) AT DIFFERENT GROWTH STAGES A INFLUENCED BY N-CARRIERS THEIR RATES AND TIME OF NITROGEN APPLICATION

tall in 1983 and 43.8, 43.4, 40.2 and 36.9 cm tall in 1984 at 75 days after first harvest.

4.1.1.2 Effect of nitrogen levels

At 60 days after planting, during 1983, the differences of plant height between control and those receiving 60 kg N/ha, were not significant. Application of 120 kg N/ha produced significantly taller plants than those in control plots and those receiving 60 kg N/ha. With advancement in age, plant height increased significantly with successive increase in the nitrogen doses from 0 to 120 kg N/ha. In 1984, at 60 days after planting, increasing doses of nitrogen increased the plant height significantly.

The height of regenerated growth, recorded at 55 days after first harvesting (36.7 cm) was almost same to that recorded 105 days after planting (36.0 cm). This showed that the growth of regenerated crop was faster than the planted crop.

Increasing levels of nitrogen exhibited beneficial effect on the height of Japanese mint during regenerated growth. At 55 and 75 days after first harvest the heights of regenerated growth in control plots were significantly lower than the fertilized plots; the maximum height was recorded at 120 kg N/ha.

4.1.1.3 Effect of time of nitrogen application

Under full basal application of nitrogen, plants emerged quickly and attained significantly greater height than those getting nitrogen in split doses. The differences in plant height in plots receiving nitrogen at full basal, three and two split applications of nitrogen were significant, during both the years, at all the growth stages except 60 days after planting in 1983. At 120 days after planting, plant attained 48.9, 47.4 and 43.6 cm height in 1983 and 46.0, 45.1 and 41.9 cm height in 1984 in plots supplied with nitrogen as full basal, in three and two split applications, respectively. In regenerated crop, the above trend reversed. The heights of plants recorded finally at second harvest were 49.0, 53.6 and 60.1 cm in 1983 and 36.9, 41.2 and 45.2 cm in 1984 in plots getting nitrogen as full basal in three and two split applications, respectively.

4.1.1.4 Interaction of N-carriers, their rates and time of nitrogen application

The plant height was significantly influenced by the interaction of N-carriers x N-rates x time of nitrogen application at all the growth stages during both the years. However, the effect of interaction at the final stages i.e. at first (120 days after first harvest) harvest is summarized in table 5. The application of 120 kg N/ha at the time of

Table 5. Plant height (cm) during first harvest of *Mentha arvensis* L. as influenced by the interaction of N-carriers, their rates and time of application

Treatments	PU	USG	LCU	NCU
		1983		
60 kg N/ha				
T_1	37.0	50.4	44.3	55.0
T_2	41.0	47.0	39.3	51.2
T_3	40.5	44.2	38.0	45.2
120 kg N/ha				
T_1	37.9	57.0	49.0	60.5
T_2	44.7	50.0	46.7	59.3
T_3	43.3	46.0	43.0	49.0
C D 5%				4.74
		1984		
60 kg N/ha				
T_1	40.0	45.3	44.0	47.7
T_2	43.7	42.0	42.7	47.0
T_3	37.0	39.0	41.0	45.0
120 kg N/ha				
T_1	43.7	48.7	45.0	53.7
T_2	44.7	46.0	43.7	51.3
T_3	42.7	42.7	41.7	46.0
C D 5%				2.31

Table 6. Plant height (cm) during second harvest of *Mentha arvensis* L. as influenced by the interaction of N-carriers, their rates and time of application

Treatments	PU	USG	LCU	NCU
		1983		
60 kg N/ha				
T_1	42.7	50.0	46.7	52.7
T_2	46.0	54.7	54.3	56.0
T_3	54.0	62.0	57.7	64.0
120 kg N/ha				
T_1	41.0	53.7	53.0	52.0
T_2	46.7	58.3	56.0	57.0
T_3	54.7	64.7	59.0	65.7
C D 5%				6.49
		1984		
60 kg N/ha				
T_1	30.7	38.3	35.7	37.0
T_2	36.0	42.0	39.3	44.0
T_3	41.0	47.0	44.0	46.0
120 kg N/ha				
T_1	34.7	40.3	38.0	40.3
T_2	38.3	45.0	38.0	47.0
T_3	40.7	48.0	46.3	48.7
C D 5%				4.14

planting through NCU produced significantly taller plants than those recorded from other treatment combinations except the same dose through USG and three split applications of NCU during 1983. Split applications of urea increased the plant height significantly than its basal application. Plant heights, however, decreased when NCU, USG and LCU were applied in splits. Split application of urea under lower nitrogen doses favoured plant height increase than basal application of higher doses. Two split applications of 60 and 120 kg N/ha through all the N-carriers produced plants of almost similar height. The height attained with two split doses was significantly more than those recorded under basal application of 60 and 120 kg N/ha through all N-carriers. Greater height of regenerated plants (Table 6) at basal application of both the nitrogen doses through NCU, USG and LCU than PU indicated that NCU, USG and LCU had larger residual effect than PU.

4.1.2 Number of leaves

4.1.2.1 Effect of nitrogen carriers

The initiation of leaves was very slow till 60 days of planting. After 60 days, leaf initiation increased at a greater rate till 105 days (Table 7) in 1983 that of in 1984. Thereafter it got reduced during 1983. While in 1984, leaf initiation continued to increase till final harvest.

Table 7. Number of leaves per 25 cm row length of <u>Mentha arvensis</u> L. as influenced by N-carriers, their rates and time of application

Treatments	1983							1984						
	Days after after planting					Days after I harvest		Days after planting					Days after I harvest	
	60	75	90	105	120	55	75	60	75	90	105	120	55	75
Nitrogen carriers														
PU	42.0	125	274	543	591	568	605	37.0	91	192	376	426	537	574
USG	43.0	212	341	684	687	675	708	39.0	103	232	428	553	644	679
LCU	42.0	147	318	653	666	601	657	39.0	99	221	390	491	571	624
NCU	46.0	256	384	721	739	686	748	44.0	103	253	457	635	655	719
SEm ±	0.21	6	8	10	12	9	10	0.41	2.4	8	8	8	9	10
C D 5%	0.58	15	23	26	34	25	26	1.12	7.2	22	21	23	25	28
N-rates (kg/ha)														
60	42.0	165	305	619	650	603	646	38.0	95	212	393	501	573	615
120	44.0	205	353	682	692	661	713	42.0	103	237	432	551	631	683
SEm ±	0.15	4	6	7	9	7	7	0.29	1.9	6	5	6	7	7
C D 5%	0.41	11	16	19	24	18	19	0.80	5.2	15	15	16	18	20
Time of application														
T_1 (Basal)	46.0	216	388	709	733	565	601	45.0	107	248	440	577	534	571
T_2 (3 splits)	43.0	189	358	670	691	637	684	40.0	99	228	417	524	606	653
T_3 (2 splits)	40.0	150	240	572	588	696	754	34.0	91	198	382	478	666	723
SEm ±	0.18	5	7	8	11	8	8	0.35	2.3	7	7	7	8	9
C D 5%	0.50	13	20	23	29	22	23	0.97	6.3	19	18	20	22	24
Control	32.0	63	180	352	389	284	323	22.0	57	177	211	372	252	327
C D 5% (Control vs. rest)	1.04	27	41	47	60	45	47	1.99	13	38	38	40	45	49

The environmental condition during the period 90 to 105 days after planting favoured leaf production appreciably.

At all the growth stages, NCU, USG, LCU and PU increased the number of leaves significantly over control. The number of leaves per unit area attained in plants due to the application of USG was significantly higher than those attained due to the application of LCU and PU. LCU and PU produced almost equal number of leaves at 60 days during 1983 and 105 days during 1984 in planted crop. In 1984, at 75 and 90 days after planting, NCU and USG resulted into same number of leaves. Similarly, both the N-carriers caused non-significant differences in leaf number at 55 days after first harvest during both the years. At 120 days after planting, USG caused 16% in 1983 and 30% in 1984, more leaves than in plots receiving PU. The per cent increases in leaf number due to the application of nitrogen through LCU over PU was 13 in 1983 and 15 in 1984. Similarly, NCU caused 25% increase in 1983 and 49% in 1984 leaves over PU.

At the final stage of second harvest, NCU caused significantly higher number of leaves per unit area than those recorded in plots receiving other N-carriers. The production of leaves in regenerated growth through USG, though was significantly lower than NCU, but significantly higher than those receiving PU and LCU. PU caused production of leaves significantly lower than those recorded under other forms of N-carriers.

4.1.2.2 Effect of nitrogen levels

Nitrogen application at all the levels increased the number of leaves significantly than control during both the years. The differences in leaf number due to the application of 60 and 120 kg N/ha were also significant. At the final stage of first harvest, application of 120 kg N/ha caused 78% and 48% greater leaf number over control in 1983 and 1984, respectively. The magnitude of increase in leaf number due to the application of 60 kg N/ha over control was 67% in 1983 and 35% in 1984. The differences in leaf number due to the application of 60 and 120 kg N/ha were 7% in 1983 and 10% in 1984.

In regenerated crop, leaf number differed significantly between the plots receiving 60 and 120 kg N/ha. At the final stage of second harvest, application of 120 kg N/ha caused 120% and 109% increases in leaf number in 1983 and in 1984, respectively than control. The magnitude of increase in leaf number due to 60 kg N/ha over control was 100% and 88% in 1983 and in 1984, respectively. Application of 60 and 120 kg N/ha caused 10% and 11% differences in leaf number over control during 1983 and 1984, respectively.

4.1.2.3 Effect of time of nitrogen application

Full basal application of nitrogen produced significantly higher number of leaves than two and three split applications at all the growth stages, upto 120 days after planting. The differences between two and three split applications of nitrogen in leaf production was also significant. In 1983, the per cent increases in number of leaves due to basal application of nitrogen were 6% and 25% over two split applications; in 1984, the respective values were 10% and 21%.

In second harvest (75 days after first harvest), two split applications caused significantly greater number of leaves than those recorded due to basal and three split applications of nitrogen. Leaves increased by 26% over basal and 10% over three split applications in 1983. In 1984, two split applications caused 27% and 11% higher number of leaves than those recorded under basal and three split applications, respectively. Basal application of nitrogen in second harvest (regenerated growth) caused production of significantly lower number of leaves than two or three split applications.

4.1.2.4 Interaction amongst N-carriers, their rates and time of nitrogen application

The production of leaves per unit area was influenced significantly due to the interaction of N-carriers x rates of nitrogen application x time of application at all the growth stages. The effect of interaction at the final stage of first (120 days after planting) and second (75 days after first harvest) harvests have been presented in table 8 and 9. Application of 120 kg N/ha at the time of planting through NCU, USG and LCU caused production of significantly higher number of leaves than other treatment combinations during 1983. In 1984, however, only NCU at 120 kg N/ha basal application caused production of significantly higher number of leaves followed by USG at the same rate and time of application than other treatment combinations.

Split application of 120 kg N/ha through PU caused higher leaf number than basal application of urea at the same dose. The split applications of USG, NCU and LCU reduced the leaf number significantly than those recorded when applied as a basal dose. The differences between two and three splits of 60 and 120 kg N/ha applied through urea were not significant.

The effect of interaction in regenerated crop was not significant during 1984 while in 1983, it was significant. In regenerated crop two split application of NCU, USG and LCU produced higher number of leaves than those recorded with PU.

Table 8. Number of leaves/25 cm row length during first harvest of *Mentha arvensis* L. as influenced by the interaction of N-carriers, their rates and time of application

Treatments	PU	USG	LCU	NCU
		1983		
60 kg N/ha				
T_1	520.3	803.3	709.0	829.0
T_2	587.7	672.7	655.7	731.0
T_3	603.7	567.3	520.0	596.3
120 kg N/ha				
T_1	525.7	799.7	778.7	900.7
T_2	694.3	709.0	732.7	746.7
T_3	616.3	572.3	600.0	629.7
C D 5%				143.2
		1984		
60 kg N/ha				
T_1	400.3	605.3	539.7	641.0
T_2	408.0	527.7	462.0	590.7
T_3	441.0	441.7	388.0	568.3
120 kg N/ha				
T_1	416.7	663.7	563.0	784.3
T_2	439.3	587.7	539.0	641.0
T_3	451.0	493.7	455.0	583.0
C D 5%				96.77

Table·9. Number of leaves/25 cm row length during second harvest of *Mentha arvensis* L. as influenced by the interaction of N-carriers, their rates and time of application

Treatments	PU	USG	LCU	NCU
		1983		
60 kg N/ha				
T_1	500.0	615.0	550.0	650.0
T_2	534.3	688.0	645.0	728.0
T_3	625.0	732.3	708.3	774.7
120 kg N/ha				
T_1	571.7	640.7	601.7	675.3
T_2	660.7	740.0	697.0	776.0
T_3	737.3	832.0	639.7	885.0
C D 5%				111.99

4.1.3. Size of leaves

4.1.3.1 Effect of nitrogen carriers

The general trend of variations in leaf size at different N-carriers was similar during both the years. However, 1983 crop season produced bigger leaves than those recorded in 1984 crop season (Table 10). At all the growth stages, nitrogen applied through NCU, USG and LCU caused production of bigger sized leaves than those fertilized with PU. In 1983, at 120 days after planting, NCU caused 20% increase in size than those recorded with PU. Leaves obtained from plots fertilized with USG were 13% larger than those recorded in PU treated plots. LCU caused 12% improvement in leaf size over PU. In 1984, the magnitude of improvement in leaf size, due to NCU, USG and LCU over PU was very small. NCU and USG caused 7% increase in leaf size than those due to PU. The differences due to the use of LCU and PU were marginal.

In regenerated growth, NCU caused production of largest leaves followed by USG and LCU. The leaf size obtained due to the fertilization through PU was the lowest.

4.1.3.2 Effect of nitrogen levels

The leaf size increased progressively with increase in doses of nitrogen from 0 to 120 kg/ha. In 1983, at 120 days after planting, 120 kg N/ha caused 25 and 2% increases in leaf size over control and 60 kg N/ha, respectively; the corresponding improvements were only 13 and 1%.

Table 10. Size of leaves (cm^2) of <u>Mentha arvensis</u> L. as influenced by N-carriers, their rates and time of application

Treatments	1983							1984						
	Days after planting					Days after I harvest		Days after planting					Days after I harvest	
	60	75	90	105	120	55	75	60	75	90	105	120	55	75
Nitrogen carriers														
PU	5.33	5.88	6.39	6.65	6.80	6.41	7.14	5.58	6.14	6.26	6.71	6.63	4.28	5.19
USG	6.11	6.48	7.05	7.53	7.67	7.00	7.94	6.09	6.62	6.76	6.97	7.06	5.04	6.68
LCU	5.91	6.31	6.82	7.30	7.60	6.63	7.40	5.85	6.33	6.42	6.54	6.64	5.06	6.47
NCU	6.19	6.49	7.14	7.56	8.15	7.18	8.07	6.43	6.68	6.74	6.97	7.06	5.22	6.94
N-rates (kg/ha)														
60	5.75	6.23	6.71	7.16	7.47	6.63	7.41	5.84	6.41	6.49	6.75	6.84	4.80	6.17
120	6.01	6.35	6.99	7.36	7.63	6.98	7.86	6.13	6.47	6.60	6.84	6.90	5.01	6.47
Time of application														
T_1 (Basal)	6.36	6.77	7.19	7.71	8.02	6.26	7.02	6.49	7.22	7.34	7.58	7.63	4.58	5.85
T_2 (3 splits)	5.89	6.42	6.98	7.29	7.56	6.73	7.56	5.86	6.33	6.44	6.70	6.76	4.96	6.27
T_3 (2 splits)	5.40	5.69	6.38	6.79	7.07	7.43	8.33	5.61	5.77	5.86	6.11	6.23	5.16	6.84
Control	4.00	4.25	5.07	5.66	6.10	5.40	6.27	4.56	5.29	5.67	5.98	6.02	3.10	4.27

At the final harvest of regenerated crop, the mean size of leaves in control plot was 6.27 cm^2 in 1983 and 4.27 cm^2 in 1984. Leaf area increased to 6.63 cm^2 in 1983 and 6.17 cm^2 in 1984 at an application of 60 kg N/ha. Additional nitrogen at the rate of 120 kg/ha caused formation of bigger leaves (7.86 cm^2) in 1983 and (6.47 cm^2) in 1984, than those recorded in the control (6.27 cm^2 in 1983 and 4.27 cm^2 in 1984) plot.

4.1.3.3. Effect of time of nitrogen application

At all the growth stages till the final stage of first harvest, basal application of nitrogen caused production of bigger sized leaves than those recorded under split applications. However, in regenerated growth, split application showed bigger leaves than those recorded under basal application. At the beginning basal nitrogen produced leaves of 6.36 cm^2 in 1983 and 6.49 cm^2 in 1984. At this stage, three split applications reduced the leaf size to 5.89 cm^2 in 1983 and 5.86 cm^2 in 1984. The area was further reduced by two split applications. Similar trend of variation continued till 120 days after planting.

In regenerated growth, two split applications caused production of large sized leaves followed by three splits and than basal nitrogen application. The mean sizes of leaves in two split applications were 8.33 cm^2 in 1983 and 6.84 cm^2 in 1984, respectively as compared to 7.02 cm^2 in 1983 and 5.85 cm^2 in 1984 at basal application of nitrogen.

4.1.4 Leaf: stem ratio

4.1.4.1 Effect of nitrogen carriers

Initially *Mentha arvensis* L. had higher leaf to stem ratio. It narrowed with the advancement in crop age (Table 11).

In 1983, at 60, 75 and 90 days after planting, use of NCU, USG and LCU resulted into significantly greater leaf: stem ratio than those recorded with PU. At 105 days, the difference between NCU and PU was not significant. At the final stage of first harvest (120 days after planting), NCU, USG and LCU caused significant increase leaf: stem ratio than those due to PU. However, the difference between USG and LCU was not significant. In 1984, at 75, 105 and 120 days after planting, differences due to the applications of NCU, USG and LCU did not differ significantly among themselves.

In regenerated crop, NCU significantly increased leaf: stem ratio over other N-carriers. In 1984, at 55 days after first harvest, NCU and USG did not cause significant differences among themselves, but had significantly greater leaf: stem ratio than LCU and PU. At 75 days after first harvest, NCU, USG and LCU significantly increased leaf: stem ratio over those recorded with PU. The differences between USG and NCU and between NCU and LCU were, however, not

Table 11. Leaf: stem ratio of *Mentha arvensis* as influenced by N-carriers, their rates and time of application

Treatments	1983							1984						
	Days after planting					Days after I harvest		Days after planting					Days after I harvest	
	60	75	90	105	120	55	75	60	75	90	105	120	55	75
Nitrogen carriers														
PU	1.75	1.69	1.54	1.01	0.92	1.09	0.92	1.72	1.69	1.02	0.97	0.90	1.22	0.96
USG	2.10	1.98	1.70	1.21	0.96	1.20	0.97	1.90	1.83	1.06	1.05	1.03	1.32	1.00
LCU	1.84	1.77	1.60	1.12	0.95	1.16	1.02	1.74	1.63	1.02	1.00	0.93	1.22	0.98
NCU	2.20	2.06	1.77	1.07	1.00	1.19	1.00	1.95	1.88	1.11	1.06	1.00	1.33	1.03
SEm ±	0.02	0.03	0.01	0.03	0.01	0.01	0.01	0.02	0.02	0.01	0.01	0.01	0.01	0.01
C D 5%	0.07	0.09	0.02	0.09	0.02	0.03	0.02	0.06	0.07	0.03	0.03	0.03	0.02	0.02
N-rates (kg/ha)														
60	1.80	1.79	1.59	1.06	0.95	1.12	0.94	1.79	1.72	1.01	1.02	0.95	1.24	0.97
120	2.10	1.96	1.71	1.14	0.97	1.19	0.97	1.85	1.79	1.10	1.03	0.97	1.30	1.01
SEm ±	0.01	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01
C D 5%	0.04	0.07	0.01	0.07	0.01	0.02	0.01	0.04	0.05	0.02	0.02	0.02	0.01	0.01
Time of application														
T_1 (Basal)	2.30	2.20	1.86	1.17	1.00	1.06	0.92	2.00	1.91	1.17	1.11	1.02	1.13	0.95
T_2 (3 splits)	1.90	1.76	1.64	1.11	0.96	1.17	0.96	1.84	1.77	1.06	1.02	0.96	1.20	0.00
T_3 (2 splits)	1.75	1.66	1.47	1.03	0.92	1.24	0.99	1.71	1.59	0.94	0.93	0.91	1.48	1.02
SEm ±	0.02	0.03	0.01	0.03	0.01	0.01	0.01	0.02	0.02	0.01	0.01	0.01	0.01	0.01
C D 5%	0.06	0.08	0.02	0.08	0.02	0.03	0.02	0.05	0.06	0.03	0.03	0.03	0.02	0.02
Control	1.07	1.50	1.25	1.10	0.93	1.05	0.92	1.50	1.29	1.20	1.00	0.90	1.00	0.95
C D 5% (control vs. rest)	0.05	0.16	0.04	0.04	0.04	0.05	0.04	0.06	0.05	0.05	0.05	0.05	0.04	0.04

significant. But LCU produced wider leaf: stem ratio than USG. In 1984, 55 days after first harvest, USG and NCU caused significantly wider ratio than those recorded with LCU and PU. However, the differences between LCU and PU and between USG and NCU were not significant. At 75 days after first harvest, USG and NCU produced significantly higher ratio than those recorded with other N-carriers. The effect of LCU did not differ significantly with USG.

4.1.4.2 Effect of nitrogen levels

Application of nitrogen at 60 and 120 kg/ha increased the leaf: stem ratio significantly when compared with control. The ratio of leaf to stem at 120 kg N/ha was significantly greater than those recorded at 60 kg N/ha.

In regenerated crop, the ratio also differed significantly at 60 and 120 kg N/ha, however, at 120 kg N/ha the ratio was higher than those at 60 kg N/ha. At 55 and 75 days of regenerated growth, leaf: stem ratio in control treatment was significantly lower than those recorded at 60 and 120 kg N/ha.

4.1.4.3 Time of nitrogen application

Full basal application of nitrogen gave significantly higher ratio than two and three split applications at all the growth stages upto 120 days after

Table 12. Leaf: stem ratio during first harvest of *Mentha arvensis* L. as influenced by the interaction of N-carriers, their rates and time of application

Treatments	PU	USG	LCU	NCU
		1983		
60 kg N/ha				
T_1	0.99	1.00	1.06	1.00
T_2	0.92	0.99	0.95	0.98
T_3	0.87	0.95	0.88	1.00
120 kg N/ha				
T_1	0.98	0.99	1.00	1.00
T_2	0.91	0.96	0.95	0.99
T_3	0.86	0.89	0.87	1.02
C D 5%				0.09
		1984		
60 kg N/ha				
T_1	0.96	1.13	1.00	1.00
T_2	0.91	1.04	0.93	0.99
T_3	0.86	0.99	0.91	0.97
120 kg N/ha				
T_1	0.98	1.10	0.97	1.00
T_2	0.87	1.00	0.98	0.98
T_3	0.79	0.91	0.80	1.03
C D 5%				0.09

Table 13. Leaf: stem ratio during second harvest of *Mentha arvensis* L. as influenced by the interaction of N-carriers, their rates and time of application

Treatments	PU	USG	LCU	NCU
		1983		
60 kg N/ha				
T_1	0.92	0.98	0.95	1.03
T_2	0.98	1.03	1.00	1.03
T_3	0.99	1.08	1.07	1.07
120 kg N/ha				
T_1	0.88	0.92	0.90	0.99
T_2	0.98	0.99	0.99	1.03
T_3	0.98	1.00	1.00	1.00
C D 5%				0.09
		1984		
60 kg N/ha				
T_1	0.92	0.95	0.92	0.98
T_2	0.96	0.99	0.94	1.00
T_3	0.98	1.00	0.96	1.04
120 kg N/ha				
T_1	0.80	0.93	0.85	0.98
T_2	0.87	0.98	0.93	1.00
T_3	0.97	0.99	0.95	1.00
C D 5%				0.09

planting except at 105 days in 1983 where differences of full basal and three split applications were not significant. The difference between two and three split application was also not significant.

In regenerated crop, the above trend reversed. Two split applications of nitrogen increased the ratio significantly over basal and three split applications. In 1984, however, the difference between two and three split applications was not significant.

4.1.4.4. Effect of interaction amongst N-carriers, their rates and time of nitrogen application

Interaction of N-carriers x N-rates x time of nitrogen application was significant at all the growth stages. The interaction at final stages at first and second harvests have been presented in table 12 and 13. The use of nitrogen through any carrier and at all the rates, at the time of planting produced maximum leaf: stem ratio of first harvest. At second harvest maximum ratio was observed due to two split applications either of 60 or 120 kg N/ha.

4.1.5 Dry matter accumulation pattern

4.1.5.1 Effect of nitrogen carriers

In general; dry matter accumulation was very slow till 60 days. Thereafter, dry matter accumulation increased at a faster rate and attained peak at 120 days after planting. In regenerated growth, dry matter accumulation continued to increase upto 75 days when the final harvest was taken (Table 14 and Fig. 10). At 60 and 75 days after planting, NCU, USG and LCU caused production of significantly higher dry matter than PU. However, in 1983, the dry matter accumulation on 90th day through LCU and PU did not differ significantly. The differences between NCU and USG at 90 and 105 days after planting were also not significant. In 1984, the differences due to NCU and USG was not significant at 120 days after planting but both showed significantly higher dry matter accumulation than LCU and PU. At this stage, NCU produced 36% and 23% higher dry matter than PU, in 1983 and 1984, respectively. The per cent increases in dry matter due to USG over PU was 32% and 22% in 1983 and 1984, respectively. Similarly, LCU produced 24% and 8% higher dry matter in 1983 and 1984, respectively over PU. At the final stage of second harvest NCU, USG and LCU caused production of dry matter significantly more than PU. However, the differences amongst NCU, USG and LCU were not significant during 1983, while in 1984, these differences were significant.

4.1.5.2 Effect of nitrogen levels

All the levels of nitrogen increased the dry matter accumulation significantly over control during both the years. The differences in dry matter accumulation at

Table 14. Dry matter yield (q/ha) of *Mentha arvensis* L. as influenced by different N-carriers, their rates and time of application

Treatments	1983							1984						
	Days after planting					Days after I harvest		Days after planting					Days after I harvest	
	60	75	90	105	120	55	75	60	75	90	105	120	55	75
Nitrogen carriers														
PU	0.48	2.84	11.2	15.3	26.2	20.7	33.0	0.66	2.63	10.2	15.1	25.5	12.7	25.4
USG	0.70	5.24	15.3	21.1	34.5	27.0	37.4	0.57	4.30	14.0	19.1	31.1	14.5	31.0
LCU	0.61	5.24	11.3	18.3	32.5	24.2	36.0	0.59	3.35	12.8	17.3	27.4	13.5	29.0
NCU	0.72	6.69	15.3	22.6	35.7	28.3	38.8	0.70	5.14	14.6	23.4	31.3	14.9	30.9
SEm ±	0.03	0.11	0.43	0.54	0.72	0.42	1.35	0.01	0.06	0.17	0.29	0.47	0.20	0.29
C D 5%	0.09	0.31	1.19	1.50	1.99	1.16	3.73	0.02	0.17	0.48	0.80	1.30	0.54	0.80
N-rates (kg/ha)														
60	0.58	4.68	12.5	18.1	29.2	23.5	34.5	0.61	3.72	12.1	17.9	27.6	12.8	28.6
120	0.68	5.32	14.1	20.5	35.2	26.5	38.1	0.65	3.99	13.7	19.5	30.1	14.9	29.5
SEm ±	0.62	0.08	0.31	0.38	0.51	0.30	0.95	0.01	0.04	0.12	0.20	0.33	0.14	0.20
C D 5%	0.07	0.22	0.84	1.06	1.41	0.82	2.64	0.01	0.12	0.34	0.57	0.92	0.38	0.57
Time of application														
T_1 (Basal)	0.81	6.57	15.3	23.0	35.6	20.7	32.1	0.78	4.57	17.3	21.9	30.3	11.1	24.7
T_2 (3 splits)	0.67	5.16	13.8	19.4	31.6	26.1	36.8	0.64	3.92	15.1	17.8	29.8	13.5	29.6
T_3 (2 splits)	0.40	3.27	10.7	15.7	29.3	28.2	40.0	0.48	3.08	13.4	16.4	26.3	17.0	32.9
SEm ±	0.03	0.10	0.37	0.47	0.62	0.36	1.17	0.01	0.05	0.15	0.25	0.41	0.17	0.25
C D 5%	0.08	0.26	1.03	1.30	1.73	1.00	3.23	0.02	0.15	0.41	0.69	1.12	0.47	0.69
Control	0.42	2.25	4.78	8.40	19.7	12.1	20.0	0.38	2.23	7.77	11.3	17.3	7.91	16.9
C D 5% (Control vs. rest)	0.15	0.52	2.12	2.66	3.53	2.05	6.60	0.04	0.28	0.85	1.42	2.30	0.96	1.42

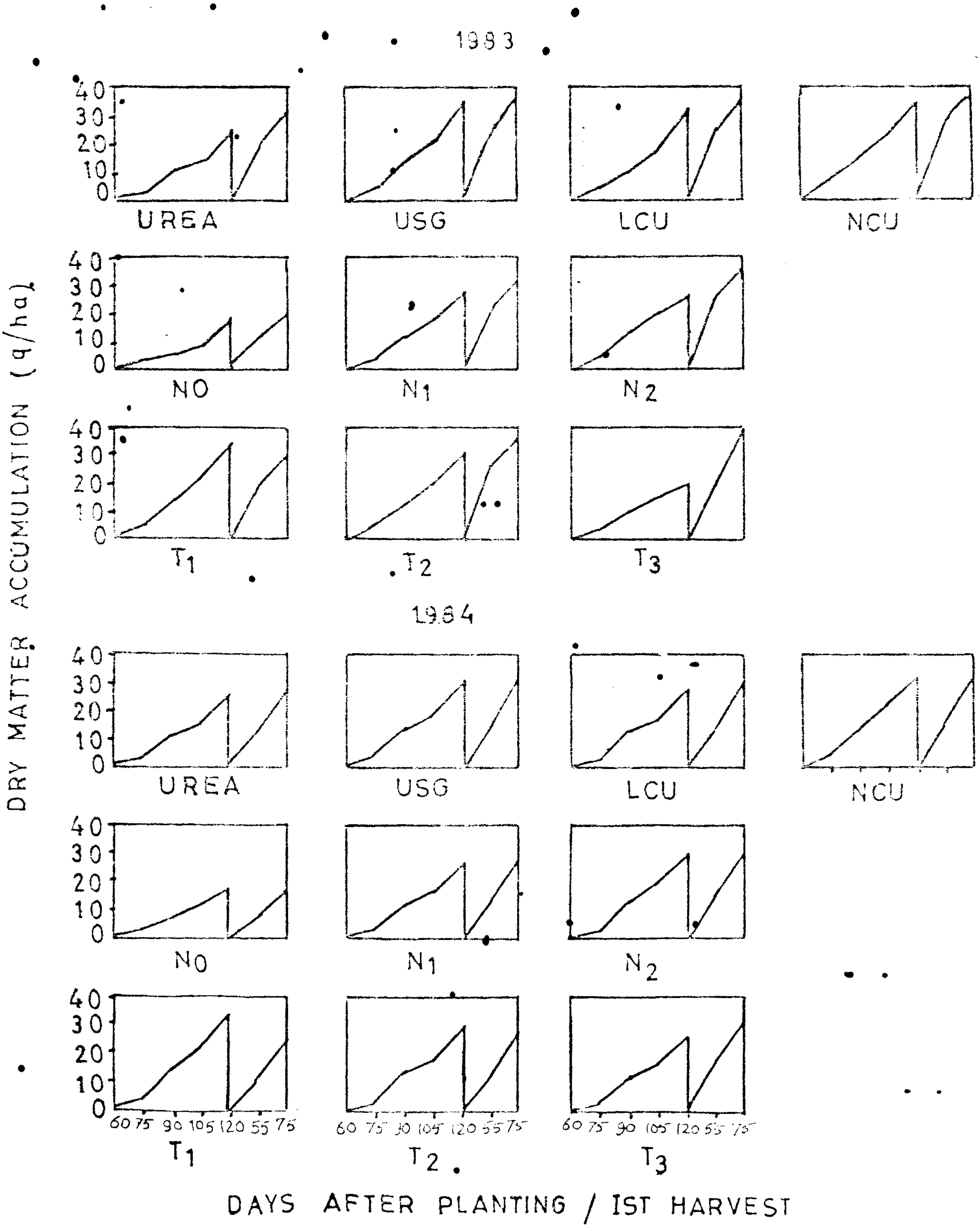


FIG.10 DRY MATTER ACCUMULATION AT DIFFERENT GROWTH STAGES AS INFLUENCED BY N-CARRIERS THEIR RATES AND TIME OF NITROGEN APPLICATION.

60 and 120 kg N/ha were also significant. At 120 days after planting application of 120 kg N/ha resulted in about 76% more of dry matter accumulation than in control. The per cent increase in dry matter accumulation due to 60 kg N/ha over control was nearly 53%. Nitrogen application at 120 kg/ha caused 20% increase in dry matter accumulation over 60 kg N/ha.

In regenerated crop also nitrogen levels caused significant variation in dry matter accumulation. At the final stage of second harvest, application of 120 kg N/ha on an average caused production of 82% higher dry matter than control. The magnitude of increase in dry matter yield due to 60 kg N/ha over control was 71%. On an average of both the years of experiments nitrogen doses at 60 and 120 kg/ha caused 7% difference in dry matter accumulation.

4.5.1.3 Effect of time of nitrogen application

Full basal application of nitrogen produced significantly higher dry matter accumulation than two or three split applications at all the growth stages upto 120 days after planting. The difference between two and three splits was also significant. At final stage of harvest, the per cent increase in dry matter with basal application of nitrogen was 13 and 22 over three and two split, respectively in 1983; in 1984, the respective values were 1.7% and 15.2%.

In second harvest (75 days after first harvest), two split applications produced significantly higher dry matter than basal and three split applications of nitrogen.

4.5.1.4 Interaction amongst N-carriers, their rates o and time of nitrogen application

Interaction of N-carriers x nitrogen levels x time of nitrogen application affected the dry matter accumulation significantly at all the growth stages. However, the interaction effect at the final stages of first (120 days after planting) and second (75 days after first harvest) harvests are presented in table 15 and 16. Application of whole quantity of 120 kg N/ha at the time of planting through USG and NCU caused production of significantly more dry matter in 1983 than split applications. However, the dry matter production due to 60 and 120 kg N/ha through USG, LCU and NCU at the time of planting and 120 kg N/ha through NCU and USG in two or three splits was also at par. In 1984, applications of USG and LCU at the rate of 120 kg N/ha, whole at the time of planting resulted into maximum dry matter production. However, basal application of 60 kg N/ha through USG, LCU and NCU and 120 kg N/ha through NCU, three split applications of 60 kg N/ha through USG and NCU and of 120 kg N/ha through NCU were all at par. In 1983, basal application of NCU, USG and LCU proved better or as good as split application at both the levels of nitrogen application.

Table 15. Dry matter yield (q/ha) during first harvest of *Mentha arvensis* L. as influenced by the interaction of N-carriers, their rates and time of application

Treatments	PU	USG	LCU	NCU
		1983		
60 kg N/ha				
T_1	20.0	37.2	38.1	37.0
T_2	27.0	27.1	27.6	32.8
T_3	22.2	21.5	27.9	32.3
120 kg N/ha				
T_1	27.6	43.1	40.7	41.1
T_2	31.8	41.2	29.3	35.9
T_3	32.1	37.2	31.5	34.7
C D 5%				8.46
		1984		
60 kg N/ha				
T_1	23.0	31.9	29.0	32.2
T_2	27.4	33.7	21.7	30.7
T_3	24.9	26.8	22.0	27.9
120 kg N/ha				
T_1	24.2	33.8	33.8	34.6
T_2	28.2	32.5	31.1	33.1
T_3	25.9	27.9	26.7	29.3
C D 5%				5.15

Table 16. Dry matter yield (q/ha) during second harvest of *Mentha arvensis* L. as influenced by the interaction of N-carriers, their rates and time of application

Treatments	PU	USG	LCU	NCU
		1984		
60 kg N/ha				
T_1	18.4	26.8	25.5	32.6
T_2	25.8	31.1	28.2	30.4
T_3	31.1	33.5	31.9	34.1
120 kg N/ha				
T_1	20.2	26.9	25.8	27.3
T_2	26.1	33.2	30.3	31.7
T_3	31.0	34.4	32.3	35.3
C D 5%				3.40

On the other hand when nitrogen was applied in PU form, split applications proved superior to basal application. NCU,. USG and LCU caused better dry matter production in the first harvest than nitrogen was applied as PU.

The effect of interaction in regenerated crop, was not significant in 1983, while in 1984, it was significant where basal application of 60 and 120 kg N/ha through PU produced significantly lower dry matter than other treatment combinations. Basal application of nitrogen through any carrier at both the rates produced less dry matter.accumulation in regenerated growth than through split applications of nitrogen. However, two splits of 120 kg N/ha through NCU resulted into highest dry matter of regenerated crop (Table 16). The dry matter production due to basal and split applications of 60 kg N/ha through NCU in two and three splits through USG and only two splits through LCU and in two and three splitting of 120 kg nitrogen through USG, LCU and NCU were also at par. In the regenerated crop, the herbage production in second harvest through basal applications of USG, NCU and LCU was as good as their split applications in 1983. In 1984 only at high level of nitrogen application, split applications of nitrogen in all the cases showed some advantages over basal application, more particularly when nitrogen was applied as PU.

4.2 Growth analysis

4.2.1 Leaf area index

4.2.1.1 Effect of nitrogen carriers

In general, LAI increased at a slow rate in early stages of crop growth during both the years (Table 17, Fig. 11). The LAI developed with a faster rate as the crop age advanced and attained the peak at 120 days after planting. In regenerated crop, the peak, however, was attained at 75 days after first harvest. Applications of nitrogen through NCU, USG and LCU resulted into significantly higher LAI in comparison to the application of PU at all the growth stages during both the years except at 60 days after planting in 1984, where applications of LCU and PU did not cause significant differences. In 1983 applications of both NCU and USG increased the LAI over LCU and PU from 60 to 120 days after planting. However, at 120 days the difference between LCU and USG was not significant but the differences between NCU and LCU were significant. In 1984 at 60 and 90 days, the difference in the effects of USG and LCU was not significant. The effect of USG also did not differ significantly from NCU at 75 and 90 days after planting. At 105 and 120 days, the LAI obtained due to the application of LCU and USG differed significantly. The difference due to the effects of USG and NCU was significant.

Table 17. Leaf area index of *Mentha arvensis* L. as influenced by N-carriers, their rates and time of application

Treatments	1983							1984						
	Days after planting					Days after I harvest		Days after planting					Days after I harvest	
	60	75	90	105	120	55	75	60	75	90	105	120	55	75
Nitrogen carriers														
PU	0.20	0.65	1.56	3.22	3.52	3.26	3.87	0.19	0.50	1.07	2.25	2.55	2.06	2.71
USG	0.23	1.24	2.16	4.62	4.73	4.23	5.04	0.21	0.61	1.41	2.67	3.51	2.90	4.07
LCU	0.22	0.83	1.95	4.27	4.51	3.59	4.34	0.20	0.56	1.28	2.28	2.91	2.58	3.62
NCU	0.26	1.50	2.48	4.89	5.40	4.40	5.42	0.25	0.62	1.53	2.85	4.02	3.05	4.46
SEm ±	0.001	0.03	0.05	0.06	0.08	0.06	0.07	0.002	0.01	0.05	0.05	0.05	0.04	0.06
C D 5%	0.003	0.09	0.15	0.17	0.23	0.17	0.18	0.01	0.04	0.13	0.13	0.15	0.11	0.17
N-rates(kg/ha)														
60	0.22	0.03	1.84	3.99	4.36	3.60	4.29	0.20	0.54	1.23	2.37	3.08	2.47	3.43
120	0.24	1.18	2.23	4.51	4.75	4.14	5.04	0.23	0.60	1.41	2.65	3.42	2.82	3.98
SEm ±	0.001	0.02	0.04	0.04	0.06	0.04	0.05	0.002	0.01	0.03	0.03	0.04	0.03	0.04
C D 5%	0.002	0.07	0.10	0.12	0.17	0.12	0.13	0.01	0.03	0.09	0.09	0.10	0.08	0.12
Time of application														
T_1 (Basal)	0.26	1.32	2.51	4.95	5.32	3.15	3.76	0.26	0.69	1.63	2.97	3.89	2.19	3.00
T_2 (3 splits)	0.23	1.09	2.23	4.35	4.66	3.84	4.62	0.21	0.56	1.31	2.49	3.22	2.69	3.68
T_3 (2 splits)	0.19	0.76	1.37	3.45	3.68	4.62	5.62	0.17	0.47	1.03	2.07	2.64	3.06	4.44
SEm ±	0.001	0.03	0.05	0.05	0.07	0.05	0.06	0.002	0.01	0.04	0.04	0.05	0.04	0.05
C D 5%	0.003	0.08	0.13	0.15	0.20	0.15	0.16	0.01	0.04	0.11	0.11	0.18	0.10	0.15
Control	0.11	0.24	0.81	1.77	2.08	1.36	1.80	0.09	0.27	0.89	1.12	1.99	0.69	1.25
C D 5%(Control vs. rest)	0.01	0.15	0.26	0.28	0.45	0.28	0.33	0.01	0.07	0.23	0.23	0.26	0.20	1.20

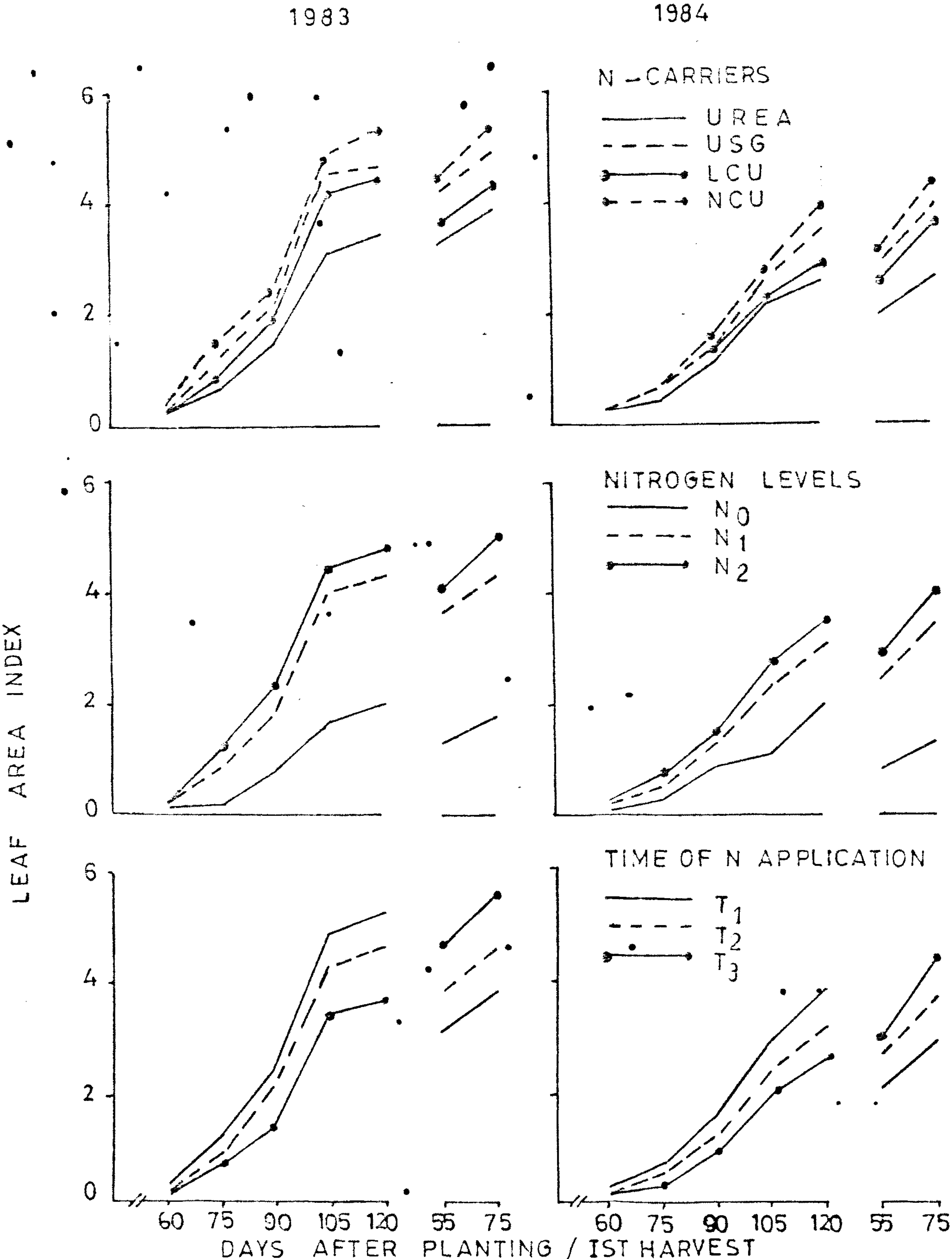


FIG.11 LEAF AREA INDEX (LAI) AT DIFFERENT GROWTH STAGES AS INFLUENCED BY N-CARRIERS, THEIR RATES AND TIME OF NITROGEN APPLICATION

In regenerated crop, application of nitrogen through USG, NCU and LCU caused significant increase in LAI in comparison to PU. The application of nitrogen through PU and LCU produced significantly lower LAI than NCU and USG.

4.2.1.2 Effect of nitrogen levels

Nitrogen application at the rates of 60 and 120 kg/ha increased the LAI significantly in plant as well as in regenerated crop. The LAI obtained through 120 kg N/ha was also significantly higher than that obtained at the control treatment and at 60 kg N/ha.

4.2.1.3 Effect of time of nitrogen application

Full basal application of nitrogen gave significantly higher LAI than applications in two and three splits at all the growth stages. In split application, three splits proved conducive for plant crop and two splits were beneficial for regenerated crop.

4.2.1.4 Effect of interaction amongst N-carriers, their rates and time of nitrogen application

The interaction of N-carriers x N-rates x time of nitrogen application influenced the LAI significantly at all the growth stages. However, the effect of

Table 18. Leaf area index during first harvest of *Mentha arvensis* L. as influenced by the interaction of N-carriers, their rates and time of application

Treatments	PU	USG	LCU	NCU
		1983		
60 kg N/ha				
T_1	3.13	5.89	4.95	6.47
T_2	3.60	4.52	4.31	5.14
T_3	3.54	3.54	3.23	3.94
120 kg N/ha				
T_1	3.17	6.11	5.66	7.21
T_2	4.31	4.75	5.17	5.46
T_3	3.67	3.58	3.73	4.21
C D 5%				1.07
		1984		
60 kg N/ha				
T_1	2.45	4.20	3.39	4.49
T_2	2.45	3.26	2.67	3.71
T_3	2.41	2.49	2.20	3.19
120 kg N/ha				
T_1	2.46	4.67	3.74	5.69
T_2	3.05	3.62	3.06	3.92
T_2	2.51	2.80	2.42	3.13
C D 5%				0.62

Table 19. Leaf area index during second harvest of *Mentha arvensis* L. as influenced by the interaction of N-carriers, their rates and time of application

Treatments	PU	USG	LCU	NCU
		1983		
60 kg N/ha				
T_1	2.89	3.84	3.34	4.11
T_2	3.28	4.56	4.17	4.79
T_3	4.14	5.74	4.88	5.72
120 kg N/ha				
T_1	3.44	4.24	3.76	4.44
T_2	4.22	5.18	4.64	6.06
T_3	5.22	6.65	5.25	7.39
C D 5%				0.78
		1984		
60 kg N/ha				
T_1	2.02	3.04	2.76	3.51
T_2	2.27	3.85	3.37	4.21
T_3	2.76	4.54	4.06	4.76
120 kg N/ha				
T_1	2.37	3.39	3.14	3.76
T_2	2.97	4.21	3.87	4.67
T_3	3.62	5.41	4.50	5.87
C D 5%				0.78

interaction at final stage of plant crop (120 days after planting) and regenerated crop (75 days after first harvest) have been presented in table 18. Application of the extra amount of 120 kg N/ha through NCU gave significantly higher LAI followed by the same dose through USG. Two split applications of 120 kg N/ha supplied through NCU, USG and LCU decreased the LAI significantly as compared to their basal and three split applications.

PU when applied in three splits increased the LAI as compared to its application in two splits and basal.

In regenerated crop, two split applications of 120 kg N/ha through USG and NCU produced significantly higher LAI as compared to other treatment combinations during both the years (Table 19).

4.2.2 Crop growth rate

4.2.2.1 Effect of nitrogen carriers

The mean crop growth rate ($\overline{CGR}$) in different growth intervals is presented in table 20 (a and b) and Fig. 12. The crop growth rate was low initially but increased with the advancement in crop age and reached maximum in about 106 to 120 days. The period preceeding to this maximum growth rate i.e. 91 to 105 days, however,

Table 20 a. Mean crop growth rate (q/day/ha) of *Mentha arvensis* L. as influenced by N-carriers, their rates and time of application

Treatments	1983				
	Days interval after planting				Days interval after I harvest
	61-75	76-90	91-105	106-120	56-75
Nitrogen carriers					
PU	0.16	0.50	0.27	0.73	0.62
USG	0.30	0.67	0.39	0.89	0.52
LCU	0.31	0.40	0.47	0.95	0.59
NCU	0.41	0.57	0.49	0.87	0.53
N-rates (kg/ha)					
60	0.27	0.52	0.37	0.74	0.55
120	0.31	0.59	0.43	0.98	0.58
Time of application					
T_1 (Basal)	0.38	0.58	0.51	0.84	0.57
T_2 (3 splits)	0.30	0.58	0.37	0.81	0.54
T_3 (2 splits)	0.19	0.50	0.33	0.91	0.59
Control	0.12	0.17	0.24	0.75	0.40

Table 20 b. Mean crop growth rate (q/day/ha) of *Mentha arvensis* L. as influenced by N-carriers, their rates and time of application

Treatments	1984				
	Days interval after planting				Days interval after I harvest
	61-75	76-90	91-105	106-120	56-75
Nitrogen carriers					
PU	0.13	0.50	0.33	0.69	0.64
USG	0.25	0.65	0.34	0.80	0.83
LCU	0.18	0.63	0.30	0.67	0.78
NCU	0.30	0.63	0.59	0.53	0.80
N-rates (kg/ha)					
60	0.21	0.56	0.39	0.65	0.79
120	0.22	0.65	0.39	0.71	0.73
Time of application					
T_1 (Basal)	0.25	0.85	0.31	0.56	0.68
T_2 (3 splits)	0.22	0.75	0.18	0.80	0.81
T_3 (2 splits)	0.17	0.69	0.20	0.66	0.80
Control	0.12	0.37	0.23	0.40	0.45

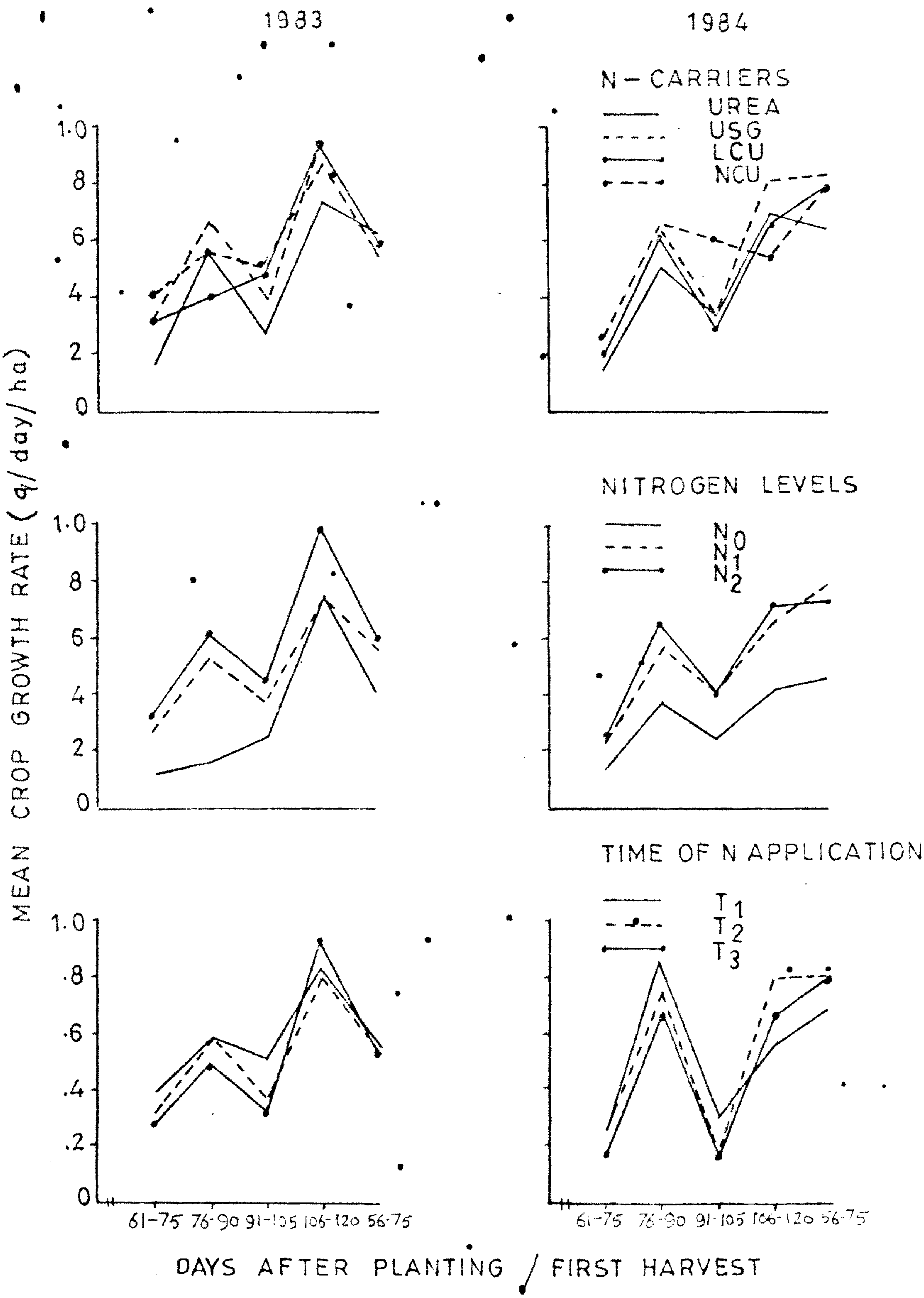


FIG.12 MEAN CROP GROWTH RATE (q/ day / ha) AT DIFFERENT GROWTH PERIODS AS INFLUENCED BY N - CARRIERS, THEIR RATES AND TIME OF NITROGEN APPLICATION

experienced the slackness in crop growth during both the years.

In 1983, nitrogen application through NCU resulted into higher CGR in comparison to other N-carriers between 61 and 75 days. Thereafter USG superseded rest other carriers. But again between 91 and 105 days growth period NCU took the lead. Finally, LCU proved superior to others, although the differences with USG and NCU were very marginal. In regenerated growth PU caused better growth than all other carriers. In 1984, between 61 and 75 days the NCU caused 0.30 q/day/ha growth rate and it excelled all other carriers. But between 76 and 90 days growth period, USG superseded by enhancing the growth rate to 0.65 q/day/ha between 91 and 105 days growth period, NCU increased the crop growth rate to 0.59 q/day/ha which was higher than other carriers. Finally USG increased the crop growth rate to 0.80 q/day/ha which was better than all other N-carriers.

4.2.2.2 Effect of nitrogen levels

Increasing doses of nitrogen increased the CGR at all the growth stages during both the years. Highest CGR of 0.98 q/day/ha in 1983 and 0.71 q/day/ha in 1984 were recorded between 106 and 120 days growth period through the application of 120 kg N/ha. The control had lowest the CGR of 0.75 q/day/ha in 1983 and 0.40 q/day/ha in 1984.

4.2.2.3 Effect of time of nitrogen application

Full basal application of nitrogen enhanced the growth rate in comparison to three and two split applications upto 105 days after planting. Thereafter two split applications took the lead and maintained the same in regenerated growth. In 1984, the trend of variation observed remained to be the same except that during last stages of plant and in regenerated crop. Three splits caused better growth than two splits of N-application.

4.2.3 Relative growth rate

4.2.3.1 Effect of nitrogen carriers

The mean relative growth rates ($\overline{RGR}$) were high in initial growth stage. It decreased with the advancement in crop age. Minimum RGR was recorded in the period between 91 and 105 days (Table 21 (a and b) and Fig. 13). In the period between 106 and 120 days, RGR improved slightly during both the years. In 1983, initially between (61 and 75 days), NCU caused higher RGR (0.149 g/g of dry weight/day) than others. It decreased to 0.026 g/g of dry weight/day between 91 and 105 days. Finally between 106 and 120 days stage, low RGR was recorded with NCU followed by USG among all the N-carriers. In 1984, USG caused higher RGR

Table 21 a. Mean relative growth rate (g/g of dry weight/day) of *Mentha arvensis* L. as influenced by N-carriers, their rates and time of application

Treatments	1983				
	Days interval after planting				Days interval after I harvest
	61-75	76-90	91-105	106-120	56-75
Nitrogen carriers					
PU	0.119	0.096	0.021	0.036	0.023
USG	0.134	0.071	0.021	0.033	0.016
LCU	0.143	0.051	0.032	0.038	0.020
NCU	0.149	0.055	0.026	0.031	0.016
N-rates (kg/ha)					
60	0.139	0.066	0.025	0.031	0.019
120	0.137	0.065	0.025	0.036	0.018
Time of application					
T_1 (Basal)	0.140	0.056	0.027	0.029	0.022
T_2 (3 splits)	0.136	0.066	0.023	0.033	0.017
T_3 (2 splits)	0.140	0.079	0.026	0.042	0.018
Control	0.112	0.050	0.037	0.057	0.025

Table 21 b. Mean relative growth rate (g/g of dry weight/day) of *Mentha arvensis* L. as influenced by N-carriers, their rates and time of application

Treatments	1984				
	Days interval after planting				Days interval after I harvest
	61-75	76-90	91-105	106-120	56-75
Nitrogen carriers					
PU	0.092	0.090	0.026	0.035	0.035
USG	0.135	0.079	0.021	0.033	0.038
LCU	0.116	0.089	0.020	0.031	0.038
NCU	0.133	0.070	0.031	0.019	0.037
N-rates (kg/ha)					
60	0.121	0.079	0.026	0.029	0.040
120	0.121	0.082	0.024	0.029	0.034
Time of application					
T_1 (Basal)	0.118	0.089	0.016	0.022	0.040
T_2 (3 splits)	0.121	0.090	0.011	0.034	0.039
T_3 (2 splits)	0.124	0.098	0.014	0.032	0.033
Control	0.118	0.084	0.024	0.029	0.050

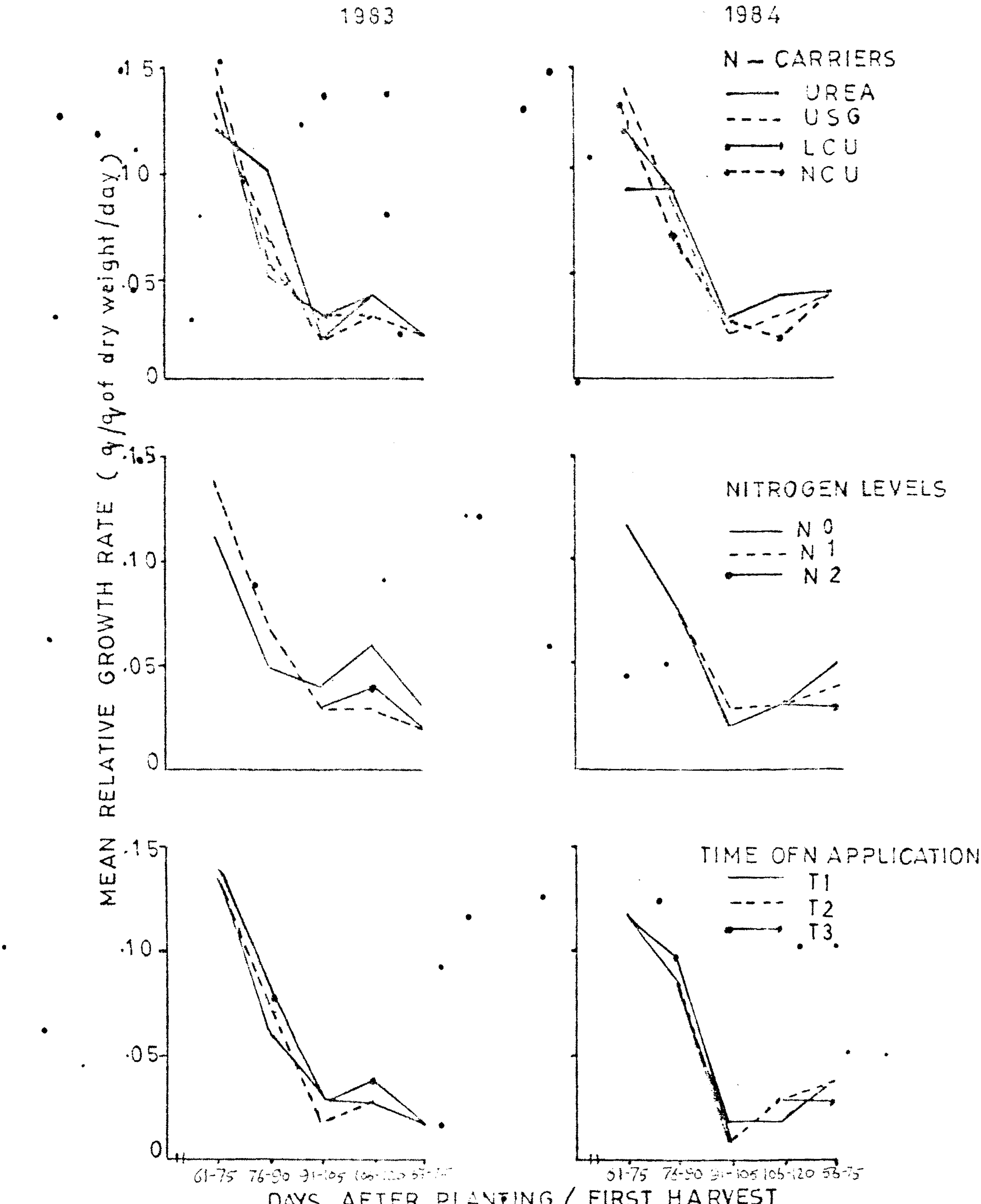


FIG.13 MEAN RELATIVE GROWTH RATE (g/g of dry weight/day) AT DIFFERENT GROWTH PERIODS AS INFLUENCED BY N – CARRIERS THEIR RATES AND TIME OF NITROGEN APPLICATION.

(0.135 g/g of dry weight/day) between the period 61 and 75 days followed by those caused by NCU. At the stage between 106 and 120 days NCU and LCU had low RGR. PU exhibited maximum RGR during both the years.

4.2.3.2 Effect of nitrogen levels

Nitrogen application improved the RGR of *Mentha arvensis* L. However, difference due to the application of both the nitrogen doses was very low. The dose of 60 kg N/ha showed better results in initial stages of 1983, while in 1984 both the doses remained at par throughout the crop season.

4.2.3.3 Effect of time of nitrogen application

Time of nitrogen application did not influence the RGR in a definite pattern except that RGR at full basal application of nitrogen remained low than those recorded under split application.

4.3 Productivity

4.3.1 Fresh herbage yield

4.3.1.1 Effect of nitrogen carriers

(a) First harvest (Planted crop)

Application of nitrogen through NCU, USG and LCU caused significantly higher herbage yield as compared to PU.

Among the former three N-carriers, LCU caused significantly lower herbage yield than NCU and USG. The effects of NCU and USG on the productivity of herbage, however, did not differ significantly among themselves (Table 22 and Fig.14). NCU, USG and LCU caused 34%, 29% and 22% higher herbage production than PU in 1983, respectively. All the carriers influenced the herbage yield almost in the similar fashion during 1984 except that the magnitude of differences in herbage yield due to various N-carriers changed slightly. NCU, USG and LCU caused 25%, 17% and 8% higher herbage production than PU, respectively.

(b) Second harvest (Regenerated crop)

In regenerated crop, all the slow release nitrogen fertilizers increased herbage productivity over PU. The increase in yield due to NCU in second harvest was 13% more than PU, USG and LCU produced 12% and 7% higher yield, respectively than PU. Among various slow release nitrogen fertilizers, the differences of NCU and USG were not significant in 1983. But in 1984, NCU proved significantly superior to USG; the difference was, however, of only 3%.

(c) Total herbage yield

When the combined yield of first and second harvests was compared, slow release fertilizers showed their significant superiority over PU. NCU improved herbage

Table 22. Herbage yield (q/ha) of *Mentha arvensis* L. as influenced by N-carriers, their rates and time of application

Treatments	1983			1984		
	I harvest (Planted crop)	II harvest (Regenerated crop)	Total herbage yield	I harvest (Planted crop)	II harvest (Regenerated crop)	Total herbage yield
Nitrogen carriers						
PU	102.8	129.4	232.2	97.4	93.9	119.3
USG	132.3	145.5	277.8	113.9	111.2	225.1
LCU	125.0	138.7	263.7	105.5	102.9	208.4
NCU	137.6	146.1	283.7	121.6	115.0	236.6
SEm ±	2.7	2.5	5.9	1.9	1.1	2.2
C D 5%	7.4	7.0	16.2	5.2	2.9	6.0
N-rates (kg/ha)						
60	111.7	134.7	246.4	103.0	102.9	205.9
120	136.7	145.1	281.1	115.9	108.6	224.5
SEm ±	1.9	1.8	4.1	1.3	0.7	1.5
C D 5%	5.2	4.9	11.4	3.7	2.0	4.3
Time of application						
T_1 (Basal)	141.4	121.5	262.9	118.7	87.4	206.1
T_2 (3 splits)	122.0	142.2	264.2	113.9	107.8	221.7
T_3 (2 splits)	109.4	156.2	265.6	96.2	122.0	218.2
SEm ±	2.3	2.2	5.1	1.6	0.9	1.9
C D 5%	6.4	6.1	14.0	4.5	2.5	5.2
Control	65.0	69.6	134.7	56.7	57.2	115.4
C D 5% (Control vs. rest)	13.1	10.7	28.7	9.3	5.1	10.7

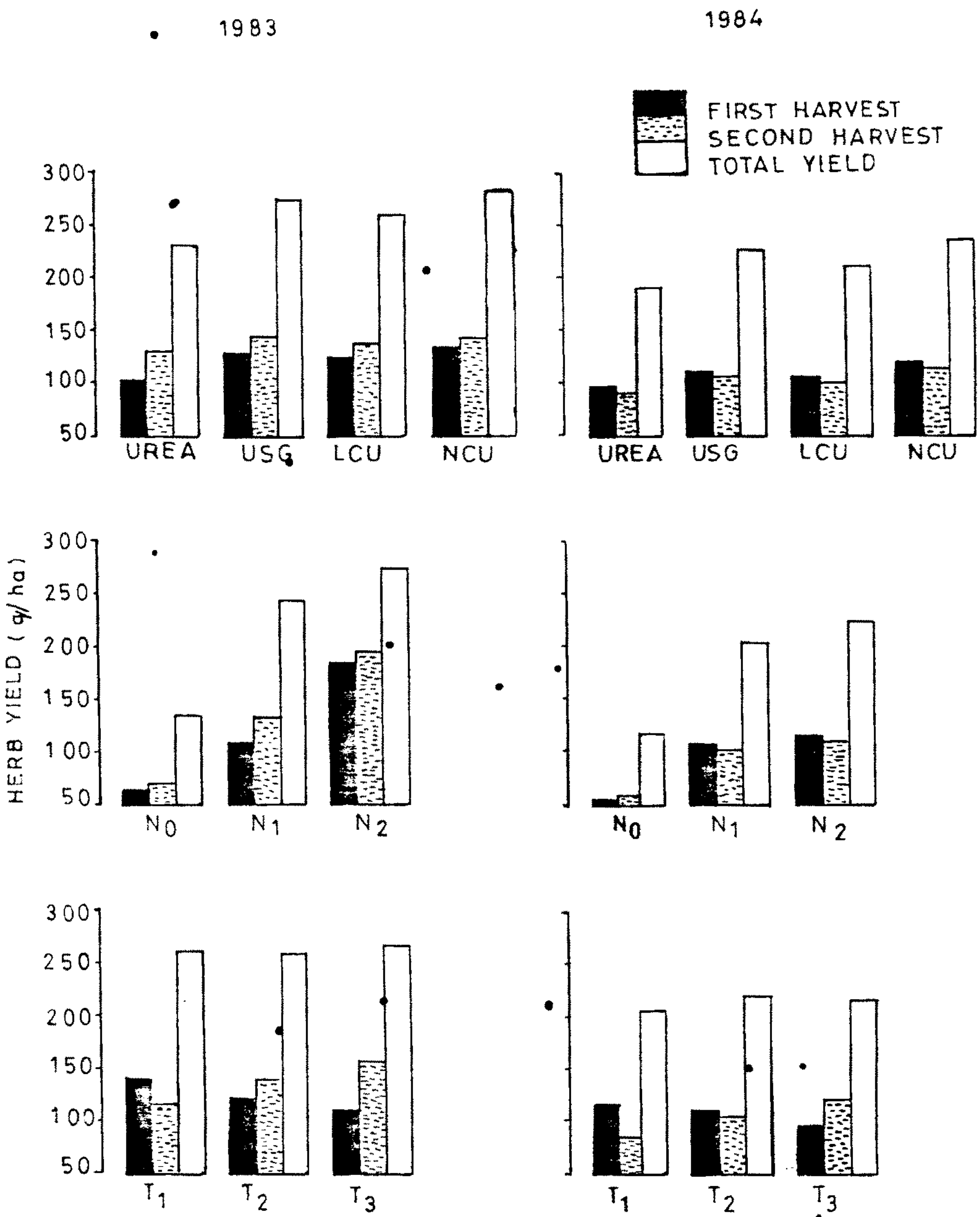


FIG.14 HERB YIELD (q/ha) OF FIRST HARVEST SECOND HARVEST AND TOTAL OF BOTH AS INFLUENCED BY N – CARRIERS THEIR RATES AND TIME OF NITROGEN APPLICATION

production with 23% over PU. USG and LCU improved the herbage production by 19% and 14%, respectively over PU in 1983, in 1984 the corresponding values were 24, 18 and 9%. NCU increased herbage yields over USG to the extent of 3% and 5% in 1983 and 1984, respectively. On the other hand NCU had an edge over LCU to the tune of 8 and 14% ~~over LCU~~ in 1983 and 1984 seasons. USG caused increase in herbage yield over LCU to the extent of 4 and 8% in 1983 and 1984, respectively.

4.3.1.2 Effect of nitrogen levels

(a) First harvest (Planted crop)

Nitrogen application increased the herbage yield significantly over control. Application of 120 kg N/ha almost doubled the production as compared to control. Nitrogen application at the rate of 60 kg/ha enhanced the herbage production by 75% over control. The difference between 60 and 120 kg N/ha was also significant. Nitrogen application at the rate of 120 kg N/ha on an average produced nearly 17% (22% in 1983 and 13% in 1984) higher yield over 60 kg N/ha.

(b) Second harvest (Regenerated crop)

The herbage yield of regenerated crop increased significantly due to increase in nitrogen doses. Application of 120 kg N/ha produced 108 and 90% higher herbage yield in 1983 and 1984, respectively over control. Magnitude of increase in herbage yield due to 60 kg N/ha over control was 94 and 80% in 1983 and 1984, respectively. The difference between 120 and 60 kg N/ha was on an average of 7% (8 and 6% in 1983 and 1984, respectively).

(c) Total herbage yield

The total yield of both the harvests was significantly higher at 120 kg N/ha as compared to control and 60 kg N/ha. Nitrogen application at the rate of 60 kg/ha also produced significantly higher herbage yield than that of control. The difference between 60 and 120 kg N/ha was also significant. The per cent increase in herbage production due to 120 kg N/ha over control was 109 and 94 in 1983 and 1984, respectively. Application of 60 kg N/ha caused into 82 and 79% increase in productivity in 1983 and 1984, respectively over control.

4.3.1.3 Effect of time of nitrogen application

(a) First harvest (Planted crop)

Basal application of nitrogen increased the herbage yield significantly over two and three split applications. Among split applications, three splits were better than two splits. The per cent increase in herbage yield due to basal application was 16 over three and 29 over two splits in 1983. In 1984, the magnitude of increase dropped to 4.2% due to three and 24% due to two split applications over basal.

(b) Second harvest (Regenerated crop)

In regenerated growth, two split applications proved significantly superior to basal and three split applications. The per cent increase in herbage yield due to two and three splits were 26 and 10 over basal application in 1983, in 1984 this corresponding increases upto 40 and 13%, respectively.

(c) Total herbage yield

The time of nitrogen application did not influence the total herbage production significantly in 1983. However, in 1984, split applications proved significantly superior to basal application in increasing herbage yields.

4.3.1.4 Interaction amongst N-carriers, their rates and time of nitrogen application

(a) First harvest (Planted crop)

Basal application of nitrogen at the rate of 120 kg N/ha through USG produced highest herbage during first harvest (Table 23). However, yields recorded due to basal application of NCU and LCU and three split application of USG were also at par. Lowest yield was obtained at 60 kg N/ha applied at the time of planting as PU. During 1984, the highest yield was obtained by basal application of 120 kg N/ha through NCU. The yields obtained through basal application of 120 kg N/ha through USG and LCU, three split

Table 23. Herbage yield (q/ha) during first harvest of *Mentha arvensis* L. as influenced by the interaction of N-carriers, their rates and time of application

Treatments	PU	USG	LCU	NCU
		1983		
60 kg N/ha				
T_1	77.4	144.2	152.9	145.3
T_2	105.9	103.7	105.9	124.4
T_3	85.2	78.5	99.2	118.2
120 kg N/ha				
T_1	107.5	170.4	162.9	170.3
T_2	125.9	158.5	112.6	138.7
T_3	110.5	138.7	116.1	128.7
C D 5%				31.3
		1984		
60 kg N/ha				
T_1	86.0	124.0	112.6	129.8
T_2	106.6	114.0	84.9	114.8
T_3	92.4	93.2	86.2	95.1
120 kg N/ha				
T_1	93.1	130.0	129.6	144.1
T_2	110.4	122.6	122.6	135.2
T_3	95.9	99.4	96.8	110.4
C D 5%				22.2

application of USG, LCU and NCU and the basal application of 60 kg N/ha through USG and NCU were significantly superior to rest of the treatment combinations.

(b) Second harvest (Regenerated crop)

In 1983, the interaction was not significant, while in 1984 it turned out to be significant for which the data are presented in table 24. Highest herbage yield was obtained by two split applications of 60 kg N/ha through NCU. Two split applications of NCU and USG at 120 kg N/ha also produced significantly higher yield than remaining treatment combinations.

(c) Total herbage yield

Highest total herbage yield was observed at three splits of 120 kg N/ha through USG (Table 25). The yields obtained by basal application of 120 kg N/ha through USG, LCU, NCU and two split applications of same dose through USG and NCU were statistically at par. Significantly lowest yield was obtained at 60 kg N/ha through PU applied as basal, as compared to other treatment combinations in 1983. During 1984, the statistical significance remained the same but 120 kg N/ha through NCU surpassed the production than other treatments. It is interesting to note that in case of USG, NCU and LCU basal application of fertilizer at

Table 24. Herbage yield (q/ha) during second harvest of *Mentha arvensis* L. as influenced by the interaction of N-carriers, their rates and time of application

Treatments	PU	USG	LCU	NCU
		1984		
60 kg N/ha				
T_1	67.4	92.1	86.2	95.0
T_2	95.9	110.8	100.5	112.0
T_3	111.0	122.0	112.4	129.5
120 kg N/ha				
T_1	74.9	95.2	89.2	99.3
T_2	98.6	117.2	110.1	117.2
T_3	115.4	130.0	119.3	136.8
C D 5%				12.26

Table 25. Total herbage yield (q/ha) of *Mentha arvensis* L. as influenced by the interaction of N-carriers, their rates and time of application

Treatments	PU	USG	LCU	NCU
		1983		
60 kg N/ha				
T_1	181	259	271	267
T_2	237	237	240	276
T_3	231	231	249	275
120 kg N/ha				
T_1	218	314	288	304
T_2	261	316	261	285
T_3	266	303	273	296
C D 5%				39.6
		1984		
60 kg N/ha				
T_1	153	216	199	225
T_2	201	225	185	227
T_3	203	215	199	225
120 kg N/ha				
T_1	168	225	219	243
T_2	209	240	233	252
T_3	211	229	216	247
C D 5%				14.7

both the levels produced as much as herbage which was obtained through the split applications except in the case of USG in 1984. On the other hand split application of nitrogen as PU always produced significantly more herbage than their basal application at both the levels.

4.3.2 Oil production

4.3.2.1 Oil concentration at different growth stages

4.3.2.1.1 Effect of nitrogen carriers

In general, oil content in the plants of Mentha arvensis L. increased with the advancement in crop age (Table 26) and the highest oil concentration was observed at 120 days after planting and 75 days after first harvest. The oil concentration in the plants at the time of final harvest of regenerated crop was higher than the final harvest of planted crop.

On an average, the oil concentration increased from 0.31% in 1983 and 0.41% in 1984 at 60 days after planting to about 0.6% in 1983 and 0.63% in 1984 at 120 days after planting. Nitrogen reduced oil content in herbage. Amongst different N-carriers the lowest oil content (0.59%) in the crop fertilized with PU followed by LCU (0.60%), USG and NCU (0.61%). In the regenerated crop similar trend of variations was observed ; the regenerated crop showed higher oil content than the planted crop.

Table 26. Oil content of *Mentha arvensis* L. as influenced by N-carriers, their rates and time of application

Treatments	1983							1984						
	Days after planting					Days after I harvest		Days after planting					Days after I harvest	
	60	75	90	105	120	55	75	60	75	90	105	120	55	75
Nitrogen carriers														
PU	0.27	0.42	0.45	0.55	0.59	0.57	0.60	0.38	0.49	0.56	0.59	0.64	0.62	0.67
USG	0.32	0.42	0.48	0.56	0.61	0.61	0.71	0.43	0.49	0.56	0.59	0.62	0.60	0.72
LCU	0.32	0.44	0.47	0.54	0.60	0.62	0.67	0.41	0.54	0.59	0.60	0.63	0.60	0.70
NCU	0.33	0.44	0.49	0.57	0.61	0.63	0.72	0.43	0.52	0.58	0.58	0.62	0.62	0.73
N-rates (kg/ha)														
60	0.31	0.43	0.48	0.56	0.61	0.60	0.68	0.42	0.51	0.57	0.59	0.64	0.61	0.71
120	0.31	0.43	0.47	0.55	0.60	0.60	0.67	0.41	0.50	0.57	0.59	0.63	0.61	0.71
Time of application														
T_1 (Basal)	0.29	0.40	0.46	0.54	0.59	0.61	0.69	0.38	0.48	0.55	0.58	0.63	0.62	0.73
T_2 (3 splits)	0.31	0.44	0.47	0.56	0.60	0.61	0.67	0.43	0.52	0.58	0.59	0.63	0.62	0.71
T_3 (2 splits)	0.32	0.45	0.49	0.57	0.61	0.60	0.66	0.43	0.53	0.59	0.59	0.64	0.59	0.69
Control	0.40	0.51	0.54	0.62	0.65	0.65	0.75	0.50	0.58	0.60	0.63	0.67	0.69	0.75

4.3.2.1.2 Effect of nitrogen levels

In general, application of nitrogen reduced the oil concentration in *Mentha arvensis* L. The rate of decrease in oil concentration was maximum from control to 60 kg N/ha. At 120 kg N/ha although there was further reduction in the oil concentration but the extent of reduction was lesser than the those recorded between 0 and 60 kg N/ha.

4.3.2.1.3 Effect of time of nitrogen application

Split applications of nitrogen reduced the short fall of oil concentration in *Mentha arvensis* L. due to nitrogen applications, in the planted crop. But in the regenerated crop oil concentration was slightly more than the crops growth with split applications of nitrogen.

4.3.2.2 Oil accumulation pattern

4.3.2.2.1 Effect of nitrogen carriers

In general, oil accumulation increased with the advancement in crop age and reached to maximum at 120 days after planting (Table 27). In regenerated crop, maximum oil accumulation was recorded at 75 days after first harvest.

In 1983, 60 days after planting, plants accumulated 2.24% of the total oil when PU was used as N-carrier. USG, NCU and LCU caused 2.77, 2.79 and 2.87% of

Table 27. Oil accumulation pattern (kg/ha) of *Mentha arvensis* L. as influenced by N-carriers, their rates and time of application

Treatments	1983							1984						
	Days after planting					Days after I harvest		Days after planting					Days after I harvest	
	60	75	90	105	120	55	75	60	75	90	105	120	55	75
Nitrogen carriers														
PU	1.35	7.42	22.2	33.9	60.3	55.4	77.7	2.1	7.27	26.7	37.9	62.5	36.8	63.0
USG	2.24	13.2	35.2	47.3	80.8	71.6	103.5	3.4	10.7	36.8	51.7	71.7	44.5	79.8
LCU	2.08	12.4	27.0	41.0	74.5	64.3	92.6	2.9	10.6	35.8	45.6	66.7	39.7	72.2
NCU	2.40	15.6	38.6	52.2	83.7	76.4	104.4	3.5	14.8	42.9	60.7	75.2	48.3	83.2
SEm ±	0.08	0.24	0.90	1.37	1.58	0.85	3.54	0.08	0.19	0.48	0.76	1.11	0.58	0.74
C D 5%	0.23	0.66	2.48	3.79	4.35	2.34	9.80	0.22	0.51	1.30	2.10	3.08	1.59	2.06
N-rates (kg/ha)														
60	1.87	11.2	29.0	40.8	67.6	61.9	91.8	2.85	10.4	33.2	47.0	65.5	39.2	72.6
120	2.17	13.2	32.5	46.4	82.0	71.9	97.4	3.10	11.2	37.9	51.0	72.6	45.5	76.5
SEm ±	0.06	0.17	0.6	0.97	1.11	0.69	2.51	0.06	0.13	0.33	0.54	0.79	0.41	0.53
C D 5%	0.16	0.47	1.75	2.67	3.08	1.65	6.93	0.15	0.36	0.92	1.48	2.18	1.13	1.46
Time of application														
T_1 (Basal)	2.50	15.5	36.5	52.0	83.9	53.1	84.0	3.60	12.4	47.0	57.8	73.9	32.9	63.6
T_2 (3 splits)	2.24	13.1	31.1	43.7	73.4	70.9	95.9	3.19	11.3	31.4	47.4	72.2	42.4	76.3
T_3 (2 splits)	1.32	8.03	24.6	35.1	67.1	76.8	103.7	2.13	8.8	28.2	41.8	61.0	51.7	83.7
SEm ±	0.07	0.21	0.78	1.18	1.36	0.73	3.07	0.07	0.16	0.41	0.66	0.96	0.50	0.60
C D 5%	0.20	0.58	2.15	3.23	3.76	2.03	8.48	0.19	0.44	1.13	1.81	2.67	1.38	1.78
Control	1.61	5.61	12.4	19.7	42.2	30.5	52.0	2.15	6.6	19.7	26.6	38.0	24.9	43.1
C D 5% (control vs. rest)	0.40	1.18	4.42	6.73	7.65	4.16	17.4	0.38	0.91	2.32	3.73	5.48	2.84	3.65

total oil accumulation, respectively, at this stage. The rate of accumulation remained low thereafter upto 75 days irrespective of N-carriers. At 90 days, after planting PU caused 36.82% accumulation of total oil. USG, LCU and NCU caused 43.56, 36.24 and 46.12% accumulation of total oil, respectively, at this stage. Up to 105 days, the crop accumulated 56.22, 58.54, 55.03 and 62.37% of total oil production at first harvest due to the application of nitrogen through PU, USG, LCU and NCU, respectively. The trend of variation remained almost the same in 1984.

In regenerated crop, PU caused 71.31% oil accumulation upto 55 days after first harvest. At this stage, USG and LCU caused nearly 69% accumulation of total oil production of second harvest. NCU accumulated 73.18% of oil at this stage.

4.3.2.2.2 Effect of nitrogen levels

At 60 days after planting, plants in control plots accumulated more oil than in both the doses of nitrogen because plants in control plots accumulated 3.81% of total oil of first harvest, while at 60 and 120 kg N/ha only 2.77 and 2.65% accumulation of total oil, respectively were recorded at this stage. The superiority of control over nitrogen fertilization vanished at 75 days after planting. Plants getting 60 kg N/ha showed higher oil accumulation than at 120 kg N/ha. This trend continued till 105 days. The accumulation pattern of oil due to 60 kg N/ha was 16.57, 42.0 and 60.36% of total at 75, 90 and 105 days after planting, respectively. Application of 120 kg N/ha caused 16.10, 39.63 and 56.59% of total oil accumulation at 75, 90 and 105 days after planting, respective. The season of 1984, exhibited almost similar trend of variation.

In regenerated crop, increases in the doses of nitrogen increased oil accumulation. In control plot 58.69% oil out of total oil (recorded at 75 days after planting) accumulated at 55 days. The accumulation percentage increased to 67.43 at 60 kg N/ha and 73.82 at 120 kg N/ha.

4.3.2.2.3 Effect of time of nitrogen application

In the planted crop basal application of nitrogen caused 2.98, 18.47, 43.5 and 61.98% accumulation of total oil at 60, 75, 90 and 105 days, respectively in 1983. In 1984, the oil accumulation pattern changed to 4.87, 16.78 63.6 and 78.2% of total oil at 60, 75, 90 and 105 days, respectively. Three split applications resulted to the accumulation of 3.05, 17.85, 42.37 and 59.54% of oil in 1983 at 60, 75, 90 and 105 days, respectively. In 1984, three splits helped to accumulate 4.42, 15.65, 43.49 and 65.65% of total oil at 60, 75, 90 and 105 days, respectively.

The accumulation of oil by two splits was 1.97, 11.97, 36.66 and 52.31% of the total in 1983 and 3.49, 14.42, 46.20 and 68.48% in 1984 at 60, 75, 90 and 105 days, respectively.

In regenerated crop, the oil accumulation by basal application was 63.13% in 1983 and 51.73% in 1984 at 55 days after first harvest, while three splits helped to accumulate 73.93% oil in 1983 and 55.57% in 1984 at this stage. Two splits caused 74.06% accumulation of total oil in 1983 and 61.77% in 1984, at this stage.

4.3.2.3 Oil yield

4.3.2.3.1 Effect of nitrogen carriers

(a) First harvest (Planted crop)

During 1983 crop season NCU, USG and LCU produced significantly higher oil than PU. However, the differences in oil yield due to the applications of NCU and USG were not significant. But the effects of both the N-carriers in augmenting oil yield was superior to LCU (Table 28 and Fig. 15). In 1984, NCU produced significantly higher oil than other N-carriers. The production of oil through the application of USG, LCU and PU was in descending order. NCU produced 20 and 39% higher oil yield in 1983 and 1984, respectively than PU. USG caused 35 and 14% higher oil,

Table 28. Oil yield (kg/ha) of *Mentha arvensis* L. as influenced by N-carriers, their rates and time of application

Treatments	1983			1984		
	I harvest (Planted crop)	II harvest (Regenerated crop)	Total oil yield	I harvest (Planted crop)	II harvest (Regenerated crop)	Total oil yield
Nitrogen carriers						
PU	60.3	77.7	138.0	62.5	63.0	125.5
USG	80.8	103.5	184.3	71.7	79.8	151.5
LCU	74.5	92.6	167.1	66.7	72.2	138.9
NCU	83.7	104.4	188.1	75.2	83.2	158.4
SEm ±	1.6	3.5	3.9	1.1	0.7	1.4
C D 5%	4.4	9.8	10.9	3.1	2.1	3.9
N-rates (kg/ha)						
60	67.6	91.8	159.4	65.5	72.6	138.1
120	82.0	97.4	179.4	72.6	76.5	149.1
SEm ±	1.1	2.5	2.8	0.8	0.5	1.0
C D 5%	3.1	6.9	7.7	2.2	1.5	2.7
Time of application						
T_1 (Basal)	83.9	84.0	167.9	73.9	63.6	137.5
T_2 (3 splits)	73.4	95.9	169.3	72.2	76.3	148.5
T_3 (2 splits)	67.1	103.7	170.8	61.0	83.7	144.7
SEm ±	1.4	3.1	3.4	1.0	0.6	1.2
C D 5%	3.8	8.5	9.4	2.7	1.8	3.3
Control	42.2	52.0	94.3	38.0	43.1	81.1
C D 5% (Control vs. rest)	7.8	17.4	19.3	5.5	3.7	6.9

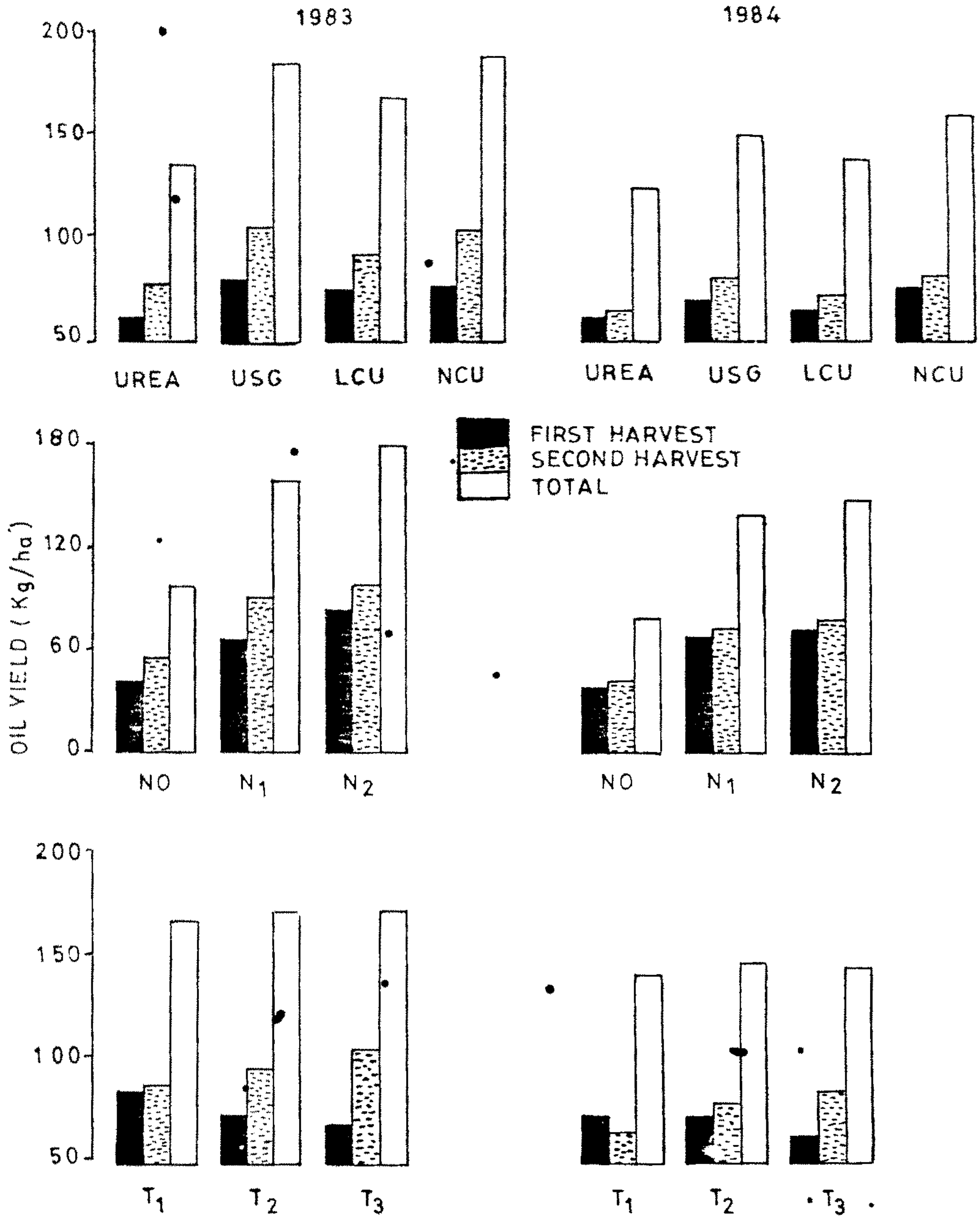


FIG.15 OIL YIELD (Kg/ha) OF FIRST HARVEST SECOND HARVEST AND TOTAL OF BOTH AS INFLUENCED BY N-CARRIERS, THEIR RATES AND TIME OF NITROGEN APPLICATION.

respectively than PU. In oil production LCU excelled PU by 24 and 8% in 1983 and in 1984, respectively.

(b) Second harvest (Regenerated crop)

The oil production of regenerated crop in 1983 was significantly higher than nitrogen was applied through NCU, USG and LCU as compared to those obtained through the application of PU. The treatment difference between NCU and USG did not differ significantly, but oil production through NCU was more than that was recorded through USG. In 1984 difference was significant. NCU caused nearly 33% increase in oil yield of regenerated crop over PU. The increase in oil yield of second harvest through USG over PU was 33 and 27% in 1983 and in 1984, respectively. Similarly LCU improved oil production by 19 and 15% in 1983 and in 1984 over PU.

(c) Total oil yield

NCU, USG and LCU caused significantly higher total oil yield than PU during 1983. The difference between NCU and LCU, however, were not significant. But in 1984, these differences remained significant. Total oil production increased by 36 and 26% in 1983 and in 1984 due to the application of nitrogen through NCU over PU. USG excelled PU by 34 and 21% in 1983 and in 1984, respectively.

LCU improved oil production over PU by 21 and 11% in 1983 and in 1984, respectively.

4.3.2.3.2 Effect of nitrogen levels

(a) First harvest (Planted crop)

Application of nitrogen at both the rates (i.e. 60 and 120 kg N/ha) increased the oil yield significantly over control. Nitrogen at the rate of 120 kg/ha increased the oil yield significantly over 60 kg N/ha. The benefits of 120 kg N/ha over control in terms of oil yield were 94 and 91% in 1983 and in 1984, respectively. At 60 kg N/ha the oil production increased by 60 and 72% in 1983 and in 1984, respectively over control. The difference in oil yield between 60 and 120 kg N/ha were 21 and 11% in 1983 and 1984, respectively.

(b) Second harvest (Regenerated crop)

In regenerated crop, the differences in oil yield due to the application of 0, 60 and 120 kg N/ha were significant except that in 1983, difference between 60 and 120 kg N/ha was not significant. However, in this season too maximum oil yield was obtained at 120 kg N/ha.

(c) Total oil yield

Application of 120 kg N/ha produced significantly higher oil as compared to those recorded in control treatment and at 60 kg N/ha. Application of 60 kg N/ha also exhibited significant improvement in oil yield over control treatment. The per cent increase in oil due to 120 kg N/ha over control was 90 and 84 in 1983 and in 1984, respectively. Application of 60 kg N/ha increased the oil yield by 69 and 70% in 1983 and in 1984, respectively over control. The improvements in oil yield due to the application of 120 kg N/ha over 60 kg N/ha were 13 and 8% in 1983 and in 1984, respectively.

4.3.2.3.3 Time of nitrogen application

(a) First harvest (Planted crop)

Full basal application of nitrogen caused significantly higher oil yield than application of nitrogen in three and two splits. However, the difference in oil production due to basal and application of nitrogen in three splits was not significant in 1984. Basal application increased the yield by 25 and 14% over two and three splits, respectively in 1983, in 1984, the corresponding figures were 21 and 3% .

(b) Second harvest (Regenerated crop).

In regenerated crop, two split applications of nitrogen caused significantly more oil yield over basal and three split applications of nitrogen. However, the difference between two and three split applications in 1983 was not significant. Application of nitrogen in two splits, however, produced maximum oil yield.

(c) Total oil yield

In 1983, the differences in oil yield due to basal, two and three split applications were not significant. But in 1984, application of nitrogen in three splits significantly increased oil yield over basal and two split applications.

4.3.2.3.4 Effect of interaction amongst N-carriers, their rates and time of nitrogen application

(a) First harvest (Planted crop)

The interaction of N-carriers x N-rates x time of nitrogen application has been summarized in Table 29. Basal application of 60 and 120 kg N/ha through USG, NCU and LCU, three split application of 120 kg N/ha through NCU and USG and two split application of USG produced significantly higher oil yield than other treatment combinations in 1983. In 1984, the basal application of 60 kg N/ha through NCU and USG, basal application of 120 kg N/ha through NCU, USG, LCU and three split applications of these N-carriers resulted into significantly higher yield than other treatment combinations.

(b) Second harvest (Regenerated crop)

During 1983 crop season, the interaction effect was not significant (Table 30). But in 1984, significantly higher oil yield was obtained by split applications of 120 kg N/ha through NCU and USG in two and three splits. Application

Table 29. Oil yield (kg/ha) during first harvest of *Mentha arvensis* L. as influenced by the interaction of N-carriers, their rates and time of application

Treatments	PU	USG	LCU	NCU
		1983		
60 kg N/ha				
T_1	46.3	87.5	89.2	87.2
T_2	62.1	63.6	64.3	76.7
T_3	50.2	49.4	61.2	74.1
120 kg N/ha				
T_1	64.8	101.1	94.5	100.5
T_2	72.9	96.2	67.5	84.1
T_3	65.2	86.9	70.5	79.4
C D 5%				18.47
		1984		
60 kg N/ha				
T_1	56.1	77.7	71.7	78.7
T_2	67.8	72.2	54.6	72.8
T_3	59.7	59.7	55.2	59.6
120 kg N/ha				
T_1	60.2	80.1	80.4	86.0
T_2	69.9	78.0	77.2	84.7
T_3	61.1	62.6	61.3	69.2
C D 5%				13.06

Table 30. Oil yield (kg/ha) during second harvest of *Mentha arvensis* L. as influenced by the interaction of N-carriers, their rates and time of application

Treatments	PU	USG	LCU	NCU
		1984		
60 kg N/ha				
T_1	46.9	69.0	61.7	70.9
T_2	62.3	78.3	71.0	81.8
T_3	72.1	85.5	79.0	91.9
120 kg N/ha				
T_1	52.4	70.5	62.5	75.1
T_2	69.0	84.4	76.7	86.7
T_3	75.0	91.0	82.3	92.5
C D 5%				8.73

of 60 kg N/ha through NCU and USG only, two splits increased oil yield as compared to other treatment combinations.

(c) Total oil yield

In 1983, application of nitrogen at 120 kg N/ha as basal in two or three splits through NCU and USG produced significantly higher oil than other treatment combinations (Table 31). Two and three splits of 60 kg N/ha through NCU also produced significantly higher oil yield than rest of the treatments. In 1984, three splits of 120 kg N/ha through NCU produced highest oil which was closely followed by USG at the same rate and method of application, application of 120 kg N/ha in two splits through NCU was also at par. Basal application of 60 and 120 kg N/ha through PU gave significantly the lowest oil.

An interesting thing to note was that basal application of NCU, USG and LCU caused as much yield increase as was observed through split application; the difference was, however, just the reverse in case of PU. In 1984, the trend of variation remained similar at 60 kg N/ha. At 120 kg N/ha, however, split application of NCU, USG and LCU showed significantly more oil production than the basal application of fertilizers; this effect was similar to those observed in case of PU.

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Table 31. Total oil yield (kg/ha) of <u>Mentha</u> <u>arvensis</u> L. as influenced by the interaction of N-carriers, their rates and time of application

Treatments	PU	USG	LCU	NCU
		1983		
60 kg N/ha				
T_1	109	174	169	177
T_2	139	164	157	185
T_3	138	156	161	184
120 kg N/ha				
T_1	133	206	179	182
T_2	152	206	164	188
T_3	158	200	173	199
C D 5%				26.69
		1984		
60 kg N/ha				
T_1	103	147	133	150
T_2	130	151	126	155
T_3	132	145	134	152
120 kg N/ha				
T_1	113	151	143	161
T_2	139	166	154	171
T_3	136	154	144	162
C D 5%				9.46

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4.4 Oil quality

4.4.1 Menthol content

4.4.1.1 Effect of nitrogen carriers

In general, menthol the essential constituent in the oil of Mentha arvensis L. increased with the advancement in crop age and reached to its maximum at 120 days after planting in plant crop and 75 days after first harvest in regenerated crop (Table 32 and Fig. 16 a and b) .

In 1983, at 60 days after planting, maximum menthol was observed when nitrogen was applied to the crop through NCU. At this stage lowest menthol was recorded in the treatment where crop was fertilized with USG. Thereafter, till harvesting of the plant crop, crop fertilized with USG maintained maximum menthol in the essential oil. However, at harvesting, LCU also had the similar menthol content at all the stages, PU applied plants contained lowest menthol in the oil. In 1984, at 75 days and onwards, application of nitrogen through NCU produced maximum menthol in the oil. Fertilized plots with PU contained lowest menthol at all the growth stages in 1984 too, except 60 days after planting.

During both the years, in regenerated crop, NCU caused maximum menthol content in the oil. Fertilization through PU caused lowest content of menthol in the regenerated crop.

Table 32. Menthol content (%) in essential oil of *Mentha arvensis* L. as influenced by N-carriers, their rates and time of application

Treatments	1983							1984						
	Days after planting					Days after I harvest		Days after planting					Days after I harvest	
	60	75	90	105	120	55	75	60	75	90	105	120	55	75
Nitrogen carriers														
PU	50.3	55.0	56.9	57.0	59.2	54.1	59.7	53.4	53.5	58.5	62.1	65.3	62.4	64.6
USG	49.8	59.6	62.0	62.0	63.5	63.7	65.8	50.7	60.4	64.6	68.7	70.2	67.0	69.6
LCU	51.0	58.6	58.6	61.2	63.5	60.7	61.2	51.6	60.1	59.3	68.0	70.1	66.6	68.5
NCU	52.6	59.4	60.9	61.5	63.0	66.1	66.3	53.3	61.2	66.2	69.4	71.5	69.5	72.2
N-rates (kg/ha)														
60	51.2	56.4	58.9	58.9	61.1	63.1	62.1	51.7	59.2	62.3	66.7	69.1	65.3	68.0
120	50.6	60.3	60.0	62.0	63.4	59.2	63.8	51.7	58.3	62.0	67.4	69.4	67.5	69.5
Time of application														
T_1 (Basal)	51.1	57.2	57.4	59.5	62.9	61.7	57.5	51.1	58.1	60.4	67.8	69.3	65.5	68.9
T_2 (3 splits)	51.1	53.2	60.8	60.6	61.6	62.5	68.8	51.8	60.6	64.4	67.0	69.4	67.1	69.1
T_3 (2 splits)	50.7	59.1	60.1	61.2	62.4	59.3	62.5	52.3	57.6	61.7	66.4	69.0	66.5	67.4
Control	55.0	58.2	58.4	59.0	59.0	59.0	62.3	56.0	60.7	61.0	63.3	65.3	64.2	66.2

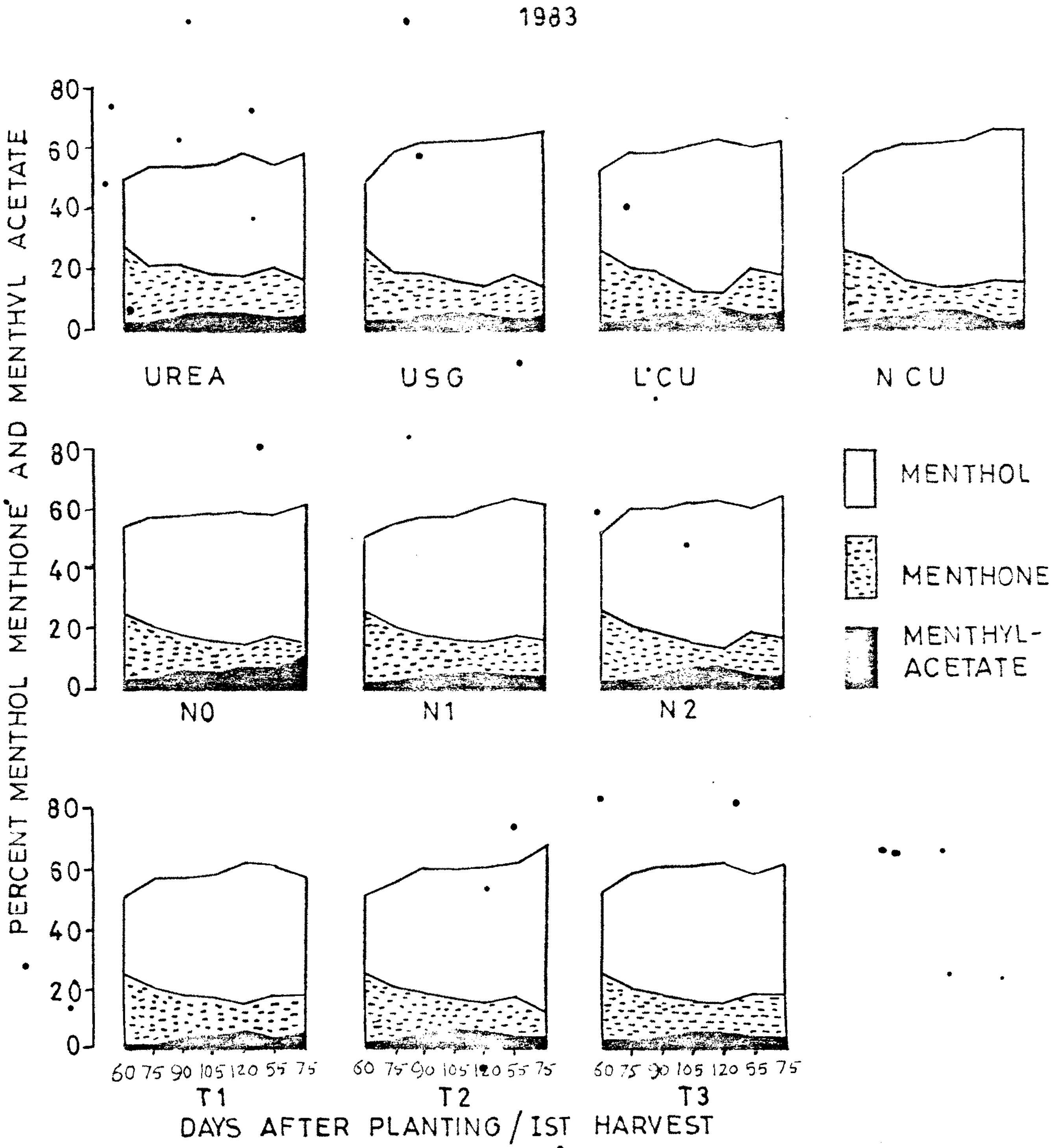

FIG.16a MENTHOL, MENTHONE AND MENTHYL ACETATE CONTENT AT DIFFERENT GROWTH STAGES AS INFLUENCED BY N-CARRIERS, THEIR RATES AND TIME OF NITROGEN APPLICATION

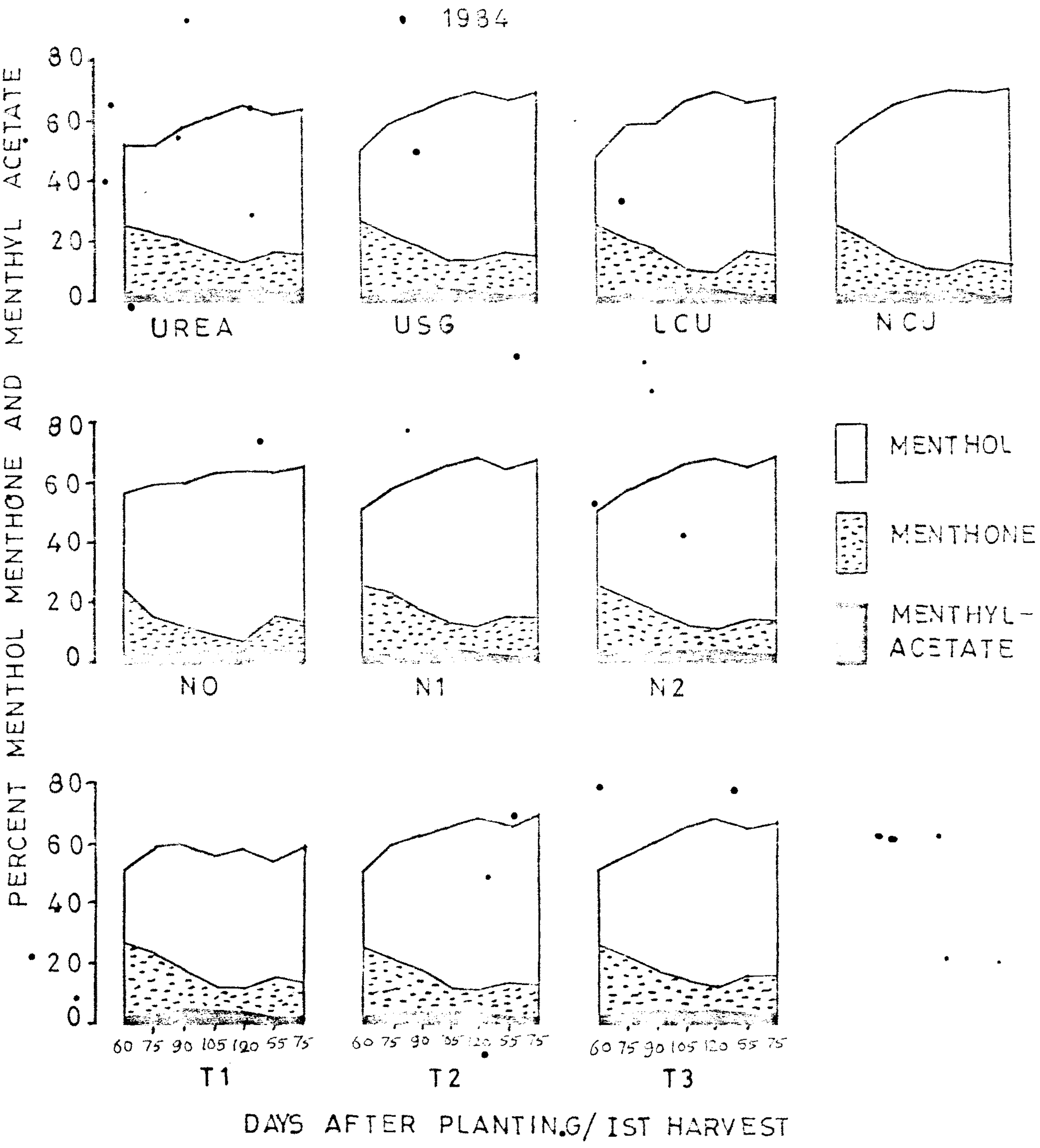

FIG.16b MENTHOL, MENTHONE AND MENTHYL ACETATE CONTENT AT DIFFERENT GROWTH STAGES AS INFLUENCED BY N-CARRIERS, THEIR RATES AND TIME OF NITROGEN APPLICATION.

4.4.1.2 Effect of nitrogen levels

Up to 60 days after planting, the unfertilized crop recorded the highest menthol content in oil. Menthol content in oil decreased when the rate of N-fertilization increased. At 75 days after planting, however, in the treatment receiving 120 kg N/ha plants had the maximum content of menthol in oil followed by control. Thereafter, successive increase in the dose of nitrogen increased the menthol content in oil. At final harvesting of plant crop during 1984, oil content in plants due to the application of two doses of nitrogen (60 and 120 kg N/ha), however, did not differ much.

In regenerated crop also, application of 120 kg N/ha resulted into maximum contents of menthol in its essential oil.

4.4.1.3 Effect of time of nitrogen application

Though a definite trend of variation in menthol content in essential oil of <u>Mentha arvensis</u> L. was not observed due to time of nitrogen application, yet it can be inferred from the data presented in table 32 that split application had edge over basal upto 105 days after planting.

4.4.2 Menthone content

4.4.2.1 Effect of nitrogen carriers

In general, the menthone content decreased with the advancement in crop age and reached the lowest at 120 days after planting in plant crop and 75 days after first harvest in regenerated crop (Table 33 and Fig. 16 a and b).

In 1983, at 60 days after planting, plants fertilized with NCU and LCU had lower menthone content than USG and PU. However, at 75 days after planting, menthone content decreased faster when nitrogen was applied through USG and LCU than that plants fertilized with PU and NCU. At 90 and 105 days after planting, plants fertilized with NCU and LCU had lower menthone content than that due to PU and USG. At 120 days fertilization with PU produced essential oil with highest content, due to LCU plants contained the lowest amount of menthone in oil. Similarly in 1984, plants fertilized with PU recorded the maximum and LCU minimum menthone in the essential oil at the time of harvesting plant crop.

4.4.2.2 Effect of nitrogen levels

In initial stages, nitrogen application increased the menthone content in oil as compared to control. At 75 days after planting and onwards, the differences in various nitrogen doses with regards to menthone content in oil narrowed down.

Table 33. Menthone content (%) in essential oil of *Mentha arvensis* L. as influenced by N-carriers, their rates and time of application

Treatments	1983							1984						
	Days after planting					Days after I harvest		Days after planting					Days after I harvest	
	60	75	90	105	120	55	75	60	75	90	105	120	55	75
Nitrogen carriers														
PU	28.1	20.5	20.0	19.8	17.0	20.1	15.1	26.9	24.2	20.0	16.6	13.8	16.9	16.0
USG	28.2	19.5	19.0	16.0	15.5	19.4	15.0	26.9	22.3	18.0	14.7	13.6	16.8	16.0
LCU	27.5	20.0	19.1	15.3	13.9	20.3	18.0	26.8	22.3	18.7	12.5	11.8	17.0	16.1
NCU	26.0	23.0	16.6	15.5	15.9	16.8	15.0	26.2	22.6	15.2	13.2	12.1	15.0	14.1
N-rates (kg/ha)														
60	27.0	21.2	19.4	17.4	16.3	18.0	16.0	26.5	24.0	18.2	14.5	13.5	16.8	15.0
120	27.9	20.2	18.7	15.8	14.8	20.3	17.5	26.9	23.2	17.8	14.0	13.2	16.0	15.6
Time of application														
T_1 (Basal)	27.5	20.3	18.7	17.4	15.6	19.5	19.0	26.7	24.0	18.5	13.6	13.7	16.2	14.7
T_2 (3 splits)	27.3	20.7	19.5	16.3	15.7	18.5	13.5	27.0	22.9	17.5	13.2	12.5	15.3	13.9
T_3 (2 splits)	27.5	21.1	19.0	16.1	15.4	19.5	17.9	26.3	24.0	18.0	15.9	13.9	17.8	18.1
Control	24.5	20.9	19.1	17.7	14.6	19.7	14.5	24.0	16.3	13.3	11.0	9.0	17.0	14.1

4.4.2.3 Effect of time of nitrogen application

Time of nitrogen application did not affect the contents of menthone in essential oil appreciably.

4.4.3 Menthyl acetate content

4.4.3.1 Effect of nitrogen carriers

Menthyl acetate content of essential oil was less initially and increased afterwards with the advancement in crop age (Table 34 and Fig. 16 a and b). With the application of PU menthyl acetate content increased from 2.77% at 60 days after planting to 6.80% at 120 days during 1983. In 1984, the values changed from 2.51 to 5.33 . Fertilization with USG almost doubled the menthyl acetate content in the oil during 60 to 120 days. Application of LCU increased the menthyl acetate of oil from 2.60 to 7.34% in 1983 and 2.56 to 5.58% in 1984 from 60 to 120 days after planting. The increases of menthyl acetate during this period due to NCU were from 2.70 to 7.72% in 1983 and from 2.63 to 5.83% in 1984.

4.4.3.2 Effect of nitrogen levels

Unfertilized crop had maximum menthyl acetate content in essential oil at 90 days and onwards. The differences in menthyl acetate content between plants from control and in the plants fertilized with 120 kg N/ha, however,

Table 34. Menthyl acetate content (%) in essential oil of *Mentha arvensis* L. as influenced by N-cafriers, their rates and time of application

Treatments	1983							1984							
	Days after planting					Days after I harvest		Days after planting						Days after I harvest	
	60	75	90	105	120	55	75	60	75	90	105	120		55	75
Nitrogen carriers															
PU	2.77	2.53	5.46	6.42	6.80	4.43	5.89	2.51	3.96	4.50	5.03	5.33		3.74	4.14
USG	2.51	2.75	5.49	5.62	5.62	3.33	4.48	2.63	3.54	4.77	4.76	5.73		2.95	3.21
LCU	2.60	2.69	5.28	6.97	7.34	4.50	5.45	2.56	3.01	5.46	5.54	5.58		3.41	3.64
NCU	2.70	2.96	4.21	7.09	7.72	3.00	3.68	2.63	3.58	5.50	5.51	5.83		2.92	3.09
N-rates (kg/ha)															
60	2.64	2.55	4.98	5.89	5.69	4.75	4.97	2.60	3.51	4.99	4.86	5.53		3.15	3.46
120	2.65	2.92	5.07	7.15	7.15	4.80	4.84	2.56	3.53	5.12	5.16	5.70		3.36	3.58
Time of application															
T_1 (Ba.sal)	2.82	2.42	5.12	5.78	6.24	4.44	5.62	2.70	3.60	4.80	4.83	5.78		3.11	3.49
T_2 (3 splits)	2.62	2.79	5.35	7.13	6.98	4.92	4.96	2.50	3.46	4.80	5.10	5.19		3.00	3.25
T_3 (2 splits)	2.50	2.99	4.86	6.60	6.64	4.93	4.75	2.55	3.51	4.92	5.00	5.89		3.66	3.83
Control	2.50	2.80	5.60	6.00	7.20	8.90	10.9	2.40	3.00	4.00	4.50	5.25		3.80	3.90

were very marginal. Application of 60 kg N/ha resulted into lowest production of menthyl acetate in the essential oil. Similar trend of variation was recorded in regenerated crop as well.

4.4.3.3 Effect of time of nitrogen application

At 60 days after planting, the menthyl acetate content in the essential oil was higher when entire dose of nitrogen was applied at the time of planting. But thereafter split application of nitrogen caused higher production of menthyl acetate except at the final harvest of regenerated crop during 1983 where menthyl acetate content was high due to basal application of fertilizers.

4.4.4 Menthol yield

4.4.4.1 Effect of nitrogen carriers

(a) First harvest (Planted crop)

Highest menthol yield was obtained with the application of NCU which was closely followed by USG, LCU and then PU (Table 35). The per cent increase in menthol yield due to NCU over PU was 48 and 32 in 1983 and in 1984, respectively. Application through USG resulted into 42 and 23% increase in yield in 1983 and in 1984, respectively over PU. Application through LCU caused only 33 and 15% higher menthol yield over PU in 1983 and in 1984, respectively.

Table 35. Menthol yield (kg/ha) of <u>Mentha arvensis</u> L. as influenced by N-carriers, their rates and time of application

Treatments	1983			1984		
	I harvest (Planted crop)	II harvest (Regenerated crop)	Total menthol yield	I harvest (Planted crop)	II harvest (Regenerated crop)	Total menthol yield
Nitrogen carriers						
PU	35.7	46.4	82.1	40.8	40.7	81.5
USG	51.3	68.1	119.4	50.3	55.5	105.8
LCU	47.3	56.7	104.0	46.8	49.5	96.3
NCU	52.7	69.2	121.9	53.8	60.1	113.9
N-rates (kg/ha)						
60	41.3	57.0	98.3	45.3	49.4	94.7
120	52.0	62.1	114.1	50.4	53.2	103.6
Time of application						
T_1 (Basal)	52.8	48.3	101.1	51.2	43.8	95.0
T_2 (3 splits)	45.2	66.0	111.2	50.1	53.3	103.4
T_3 (2 splits)	41.9	64.8	106.7	42.1	56.4	98.5
Control	24.9	32.4	57.3	24.8	28.5	53.3

(b) Second harvest (Regenerated crop)

Nitrogen carriers influenced the menthol yield of regenerated growth in the similar manner to that of plant crop.

(c) Total menthol yield

The variation in total menthol yield were the same as that of first and second harvests at various N-carriers. Menthol yield was improved by 49, 45 and 27% due to the applications of NCU, USG and LCU over PU in 1983. The magnitude of improvement, however, declined in 1984 where applications of NCU, USG and LCU caused 40, 30 and 18% better yield than PU, respectively.

4.4.4.2 Effect of nitrogen levels

(a) First harvest (Planted crop)

Menthol yield of <u>Mentha</u> <u>arvensis</u> L. increase progressively with an increasing application of nitrogen.

(b) Second harvest (Regenerated crop)

In regenerated crop also nitrogen application improved the menthol yield. The improvement due to 120 kg N/ha over control was 92 and 86% in 1983 and 1984, respectively.

(c) Total menthol yield

Total menthol yield increased successively with increase application of nitrogen doses. A dose of 120 kg N/ha almost doubled the menthol production as compared to control.

4.4.4.3 Effect of time of nitrogen application

(a) First harvest (Planted crop)

Basal application of nitrogen produced the highest menthol yield. The yield improvement due to basal application over two and three splits was 26 and 17% in 1983 and 22 and 2% in 1984, respectively.

(b) Second harvest (Regenerated crop)

The menthol yield of regenerated crop increased appreciably due to split application of nitrogen as compared to basal doses.

(c) Total menthol yield

Three split applications of nitrogen proved best to produce menthol in *Mentha arvensis* L. Menthol production was the lowest when nitrogen was applied only at the time of planting.

4.5. Biological efficiency (BE) of nitrogen application and losses when applied in different forms, methods and doses

4.5.1 Pattern of biological efficiency of nitrogen application

4.5.1.1 Effect of nitrogen carriers

In general, the biological efficiency of nitrogen application increased with the crop age during both the years (Table 36). In 1983 at 60 days after planting, USG, LCU and NCU increased the biological efficiency of nitrogen application significantly over PU. At 75 days after planting NCU increased the BE of nitrogen application significantly over USG, LCU and PU. However, at 90 and 105 days BE of NCU and USG did not differ significantly. But at 120 days both the N-carriers differed the BE of the carriers significantly among themselves where NCU recorded higher biological efficiency of nitrogen application. The BE of LCU and USG did not differ significantly. In 1984 at 60 days after planting NCU showed significantly higher biological efficiency than LCU, USG and PU. But nitrogen application through PU was showed better BE than LCU and USG at the same stage. At 75 days fertilizer aapplication through NCU, USG and LCU showed significantly better BE than PU. But at 90 days, the difference between NCU and USG was not significant. But these differences turned out significant at 105 days after planting where NCU showed higher efficiency. Finally, at 120 days after planting

Table 36. Pattern of biological efficiency of nitrogen application as influenced by N carriers, their rates and time of nitrogen application

Treatments	1983							1984						
	Days after planting					Days after I harvest		Days after planting					Days after I harvest	
	60	75	90	105	120	55	75	60	75	90	105	120	55	75
Nitrogen carriers														
PU	0.04	0.61	7.73	7.78	6.89	10.2	15.8	0.35	0.56	3.01	4.07	9.97	5.44	10.7
USG	0.33	3.63	12.4	15.5	16.2	17.8	20.6	0.24	2.46	7.47	9.59	16.2	6.97	16.6
LCU	0.23	3.62	8.03	11.9	15.4	14.5	19.2	0.25	1.19	5.66	7.38	11.2	6.40	15.0
NCU	0.35	5.44	12.9	17.5	19.7	19.7	22.8	0.39	3.68	7.99	15.0	17.1	8.14	16.5
SEm ±	0.05	0.16	0.53	0.78	0.98	0.51	2.07	0.01	0.08	0.21	0.42	0.69	0.28	0.40
C D 5%	0.13	0.45	1.52	2.22	2.78	1.46	5.88	0.02	0.23	0.58	1.20	1.95	0.79	1.12
N-rates (kg/ha)														
60	0.25	4.09	12.8	16.3	16.1	19.1	24.2	0.39	2.45	7.16	11.1	17.1	8.17	19.6
120	0.22	2.56	7.68	10.1	12.9	11.9	15.1	0.22	1.49	4.91	6.91	10.2	5.31	9.77
SEm ±	0.03	0.11	0.38	0.55	0.69	0.36	1.46	0.01	0.06	0.15	0.30	0.49	0.20	0.28
C D 5%	0.09	0.32	1.07	1.57	1.97	1.03	4.16	0.01	0.16	0.41	0.85	1.38	0.56	0.80
Time of application														
T_1 (Basal)	0.46	5.20	12.6	17.5	18.9	9.94	14.3	0.47	2.84	11.6	12.8	15.7	3.48	8.43
T_2 (3 splits)	0.29	3.50	10.9	13.4	13.7	16.9	20.3	0.32	2.01	3.88	7.74	15.0	6.46	15.7
T_3 (2 splits)	0.04	1.27	7.2	8.61	11.0	19.8	24.3	0.12	1.09	2.64	6.45	10.1	10.3	20.0
SEm ±	0.04	0.14	0.46	0.68	0.85	0.44	1.79	0.01	0.07	0.18	0.37	0.59	0.24	0.34
C D 5%	0.11	0.39	1.31	1.93	2.41	1.26	5.09	0.02	0.20	0.50	1.04	1.69	0.68	0.97

application of nitrogen fertilizer through NCU, USG and LCU showed better BE than PU; the difference between NCU and USG was not significant.

In regenerated crop, fertilization with NCU,USG and LCU showed significantly better BE than PU during both the years. However, in the regenerated crop the BE of NCU and USG did not differ significantly.

4.5.1.2 Effect of nitrogen levels

Higher biological efficiency of nitrogen application at 60 kg N/ha was observed than those recorded at 120 kg N/ha at all the growth stages. Finally at 120 days after planting (first harvest), biological efficiency was 16.12 and 12.93% at 60 and 120 kg N/ha in 1983 and 17.06 and 10.19% at 60 and 120 kg N/ha in 1984, respectively.

In regenerated crop similar was the trend of variation. High biological efficiency of nitrogen application was recorded at low rate of nitrogen application i.e. at 60 kg N/ha.

4.5.1.3 Time of nitrogen application

Basal application of nitrogen increased the biological efficiency of nitrogen application than in split applications of nitrogen upto 120 days after planting during both the years. Finally at first harvest, the biological efficiencies were 18.88, 13.68 and 11.02% in 1983 and 15.73, 15.01 and 10.07% in 1984 due to basal, three and two split applications of nitrogen.

In regenerated crop two split application showed significantly higher biological efficiency of nitrogen application than basal and three split applications of nitrogen in 1984. In 1983, the differences between two and three split applications of nitrogen were not significant. However, two split application showed higher efficiency than three split applications.

4.5.2 Biological efficiency of nitrogen application at harvest

4.5.2.1 Effect of nitrogen carriers

(a) First harvest (Planted crop)

Application of nitrogen through NCU, USG, LCU increased the biological efficiency of nitrogen application significantly over PU. Application of nitrogen through NCU showed higher biological efficiency than other N-carriers during both the years (Table 37).

(b) Second harvest (Regenerated crop)

Application of nitrogen through NCU, LCU, and USG also showed higher BE over PU. The difference in BE between USG and NCU was not significant.

Table 37. Total biological efficiency of nitrogen application as influenced by N-carriers, their rates and time of nitrogen application

Treatments	1983			1984		
	First harvest (Planted crop)	Second harvest (Regenerated crop)	Total	First harvest (Planted crop)	Second harvest (Regenerated crop)	Total
Nitrogen carriers						
PU	6.89	15.84	22.37	9.97	10.65	20.45
USG	16.20	20.55	36.66	16.19	16.60	34.44
LCU	15.44	19.23	34.75	11.19	15.03	26.44
NCU	19.66	22.78	40.99	17.06	16.50	34.39
SEm ±	0.98	2.07	2.40	0.69	0.40	0.84
C D 5%	2.78	5.88	6.81	1.95	1.12	2.39
N-rates (kg/ha)						
60	16.12	24.15	40.11	17.06	19.61	36.59
120	12.93	15.05	27.45	10.19	9.77	21.27
SEm ±	0.69	1.46	1.69	0.49	0.28	0.59
C D 5%	1.97	4.16	4.81	1.38	0.80	1.69
Time of application						
T_1 (Basal)	18.88	14.25	32.75	15.73	8.43	25.31
T_2 (3 splits)	13.68	20.26	33.51	15.01	15.66	30.65
T_3 (2 splits)	11.02	24.29	35.11	10.07	19.99	30.82
SEm ±	0.85	1.79	2.08	0.59	0.34	0.73
C D 5%	2.41	5.09	5.90	1.69	0.97	2.07

(c) Total biological efficiency

The superiority of biological efficiency due to applications of NCU, LCU and USG over PU was recorded when first and second harvests were combined. NCU showed higher biological efficiency of nitrogen application in 1983 than other N-carriers. In 1984 USG maintained higher BE than NCU; the differences was, however, not significant.

4.5.2.2. Effect of nitrogen level

(a) First harvest (Planted crop)

The higher biological efficiency of fertilizers were observed at lower rates of nitrogen. The biological efficiency decreased with the increasing rates of nitrogen.

(b) Second harvest (Regenerated crop)

Similar trend of variation in biological efficiency of nitrogen application at different levels of nitrogen was observed as it was in first harvest. Application of nitrogen at 60 kg N/ha increased the biological efficiency of nitrogen application significantly over 120 kg N/ha.

(c) Total biological efficiency

When first and second harvests were combined together the superiority of biological efficiency of nitrogen application was observed to be more at 60 kg N/ha than 120 kg N/ha.

4.5.2.3 Effect of time of nitrogen application

(a) First harvest (Planted crop)

Basal application of nitrogen caused greater increase in biological efficiency of nitrogen application than three and two split applications of nitrogen. Two split application of nitrogen showed significantly lower biological efficiency than application of nitrogen in three splits and basal application of nitrogen.

(b) Second harvest (Regenerated crop)

Biological efficiency of two split applications of nitrogen was significantly better than basal application of nitrogen.

(c) Total biological efficiency

When the BE of first and second harvests were combined, the biological efficiencies of nitrogen application did not show significant difference in 1983. However, in 1984 applications of nitrogen through two and three split applications increased the biological efficiency of nitrogen application.

4.5.2.4 Effect of interaction amongst N-carriers, their rates and time of nitrogen application

(a) First harvest (Planted crop)

Higher biological efficiency of nitrogen application was observed by basal application of 60 kg N/ha

Table 38. Biological efficiency of nitrogen application during first harvest of <u>Mentha</u> <u>arvensis</u> L. as influenced by the interaction of N-carriers, their rates and time of application

Treatments	PU	USG	LCU	NCU
		1983		
60 kg N/ha				
T_1	0.61	29.25	30.65	29.00
T_2	12.16	12.35	13.30	21.96
T_3	4.30	3.01	13.77	23.11
120 kg N/ha				
T_1	6.62	19.54	17.57	17.87
T_2	10.08	17.97	3.04	13.55
T_3	7.56	14.59	9.33	12.49
C D 5%				6.81
		1984		
60 kg N/ha				
T_1	9.49	24.35	19.51	24.84
T_2	16.31	27.23	7.33	22.35
T_3	11.53	15.78	7.30	17.64
120 kg N/ha				
T_1	5.77	13.76	13.72	14.43
T_2	9.04	12.66	11.49	13.13
T_3	7.15	3.36	7.78	9.95
C D 5%				4.78

Table 39. Biological efficiency of nitrogen application during second harvest of *Mentha arvensis* L. as influenced by the interaction of N-carriers, their rates and time of application

Treatments	PU	USG	LCU	NCU
		1983		
60 kg N/ha				
T_1	11.49	16.51	18.38	20.72
T_2	21.25	25.23	23.47	30.32
T_3	27.40	31.04	29.31	34.37
120 kg N/ha				
T_1	7.14	15.57	10.86	13.32
T_2	11.10	17.42	15.96	17.34
T_3	16.64	17.61	17.38	20.22
C D 5%				14.40
		1984		
60 kg N/ha				
T_1	2.63	16.51	14.46	16.21
T_2	15.01	23.72	18.93	22.65
T_3	23.72	27.71	25.12	28.68
120 kg N/ha				
T_1	3.05	3.34	7.55	3.68
T_2	7.73	13.63	11.20	12.39
T_3	11.78	14.66	12.89	15.36
C D 5%				2.75

through LCU. (Table 38) than others. Basal application of USG and NCU at the same rate increased significantly the biological efficiency over other treatments in 1983. In 1984 basal application of 60 kg N/ha through USG and NCU and application of nitrogen in three splits through USG resulted into significantly higher biological efficiency than other treatments. Three split applications of 60 kg N/ha through PU increased the biological efficiency significantly over basal application of 60 kg N/ha through urea.

(b) Second harvest (Regenerated crop)

Two split applications of 60 kg N/ha through NCU, USG, LCU, PU and three split applications of PU, NCU, USG, LCU and basal application of NCU resulted into significantly higher biological efficiency of nitrogen application than other treatments in 1983. In 1984, two split applications of USG and NCU also showed significantly higher biological efficiency than in other treatments (Table 39).

(c) Total biological efficiency

The total biological efficiency of nitrogen application as influenced by interaction of N-carriers x N-rates x time of nitrogen application is presented in Table 40 and shown in Fig. 17. Higher biological efficiency was observed with basal application of 60 kg N/ha through NCU, USG and LCU. However, two split applications of NCU also

Table 40. Total biological efficiency of nitrogen application as influenced by the interaction of N-carriers, their rates and time of application

Treatments	PU	USG	LCU	NCU
		1983		
60 kg N/ha				
T_1	12.10	45.76	49.03	49.72
T_2	33.41	37.58	36.77	52.27
T_3	31.70	34.05	43.07	55.84
120 kg N/ha				
T_1	13.77	35.11	28.42	27.85
T_2	21.18	35.33	23.99	27.56
T_3	24.20	32.13	27.20	32.71
C D 5%				16.67
		1984		
60 kg N/ha				
T_1	12.12	40.36	33.97	41.05
T_2	31.32	50.95	26.31	45.00
T_3	35.30	43.49	32.93	46.32
120 kg N/ha				
T_1	8.57	22.10	21.22	23.11
T_2	16.32	26.24	23.52	25.57
T_3	19.06	23.52	20.67	25.30
C D 5%				5.84

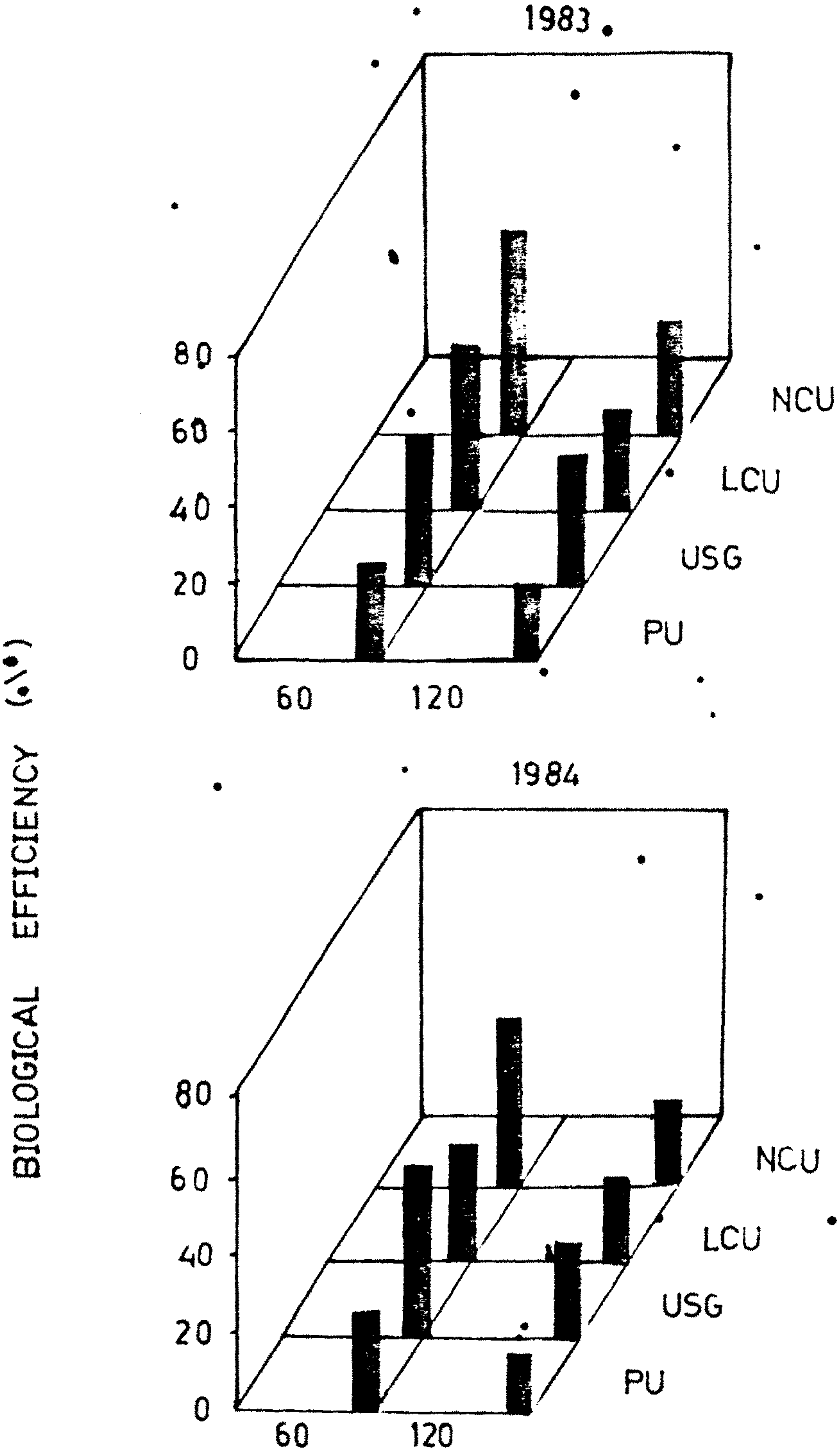

FIG 17 EFFECT OF N-CARRIERS AND RATES OF NITROGEN ON BIOLOGICAL EFFICIENCY IN MENTHA ARVENSIS L.

showed higher biological efficiency at 60 kg N/ha. Two split applications of LCU, three split applications of NCU and basal application of 60 kg N/ha through USG, LCU and NCU showed significantly higher biological efficiency than other treatment combinations in 1983. In 1984, three split applications of USG and two split applications of NCU resulted into significantly higher biological efficiency at 60 kg N/ha than other treatments. Three and two split applications of 60 kg N/ha through PU showed significantly higher BE than its basal application of nitrogen. In 1984, the superiority of three and two split applications of nitrogen through PU was also observed at 120 kg N/ha over others.

4.5.3 Leaching losses of nitrate-nitrogen

Use of PU as a source of nitrogen caused maximum losses of nitrogen in nitrate form through leaching (Table 41 and Fig. 18). The leaching of nitrate was minimised when nitrogen was applied through NCU, USG was the second best fertilizer to prevent leaching losses of nitrate nitrogen.

4.5.4 Volatilization losses of ammonia-nitrogen

Losses of nitrogen through ammonia volatilization were high when urea was used as N-carrier (Table 41 and Fig. 19). In terms of percentage, these losses were 8 and 10% in 1983 and in 1984, respectively. Use of NCU as a N-carrier

Table 41. Per cent nitrogen losses from different N-carriers as fertilizer source

Nitrogen carriers	1983		1984	
	NH_3 volatilized	NO_3 leached	NH_3 volatilized	NO_3 leached
PU.	8.38	27.27	9.89	32.30
USG	3.27	12.00	2.83	13.70
LCU	4.71	16.80	3.85	20.60
NCU	2.69	9.87	1.71	11.50

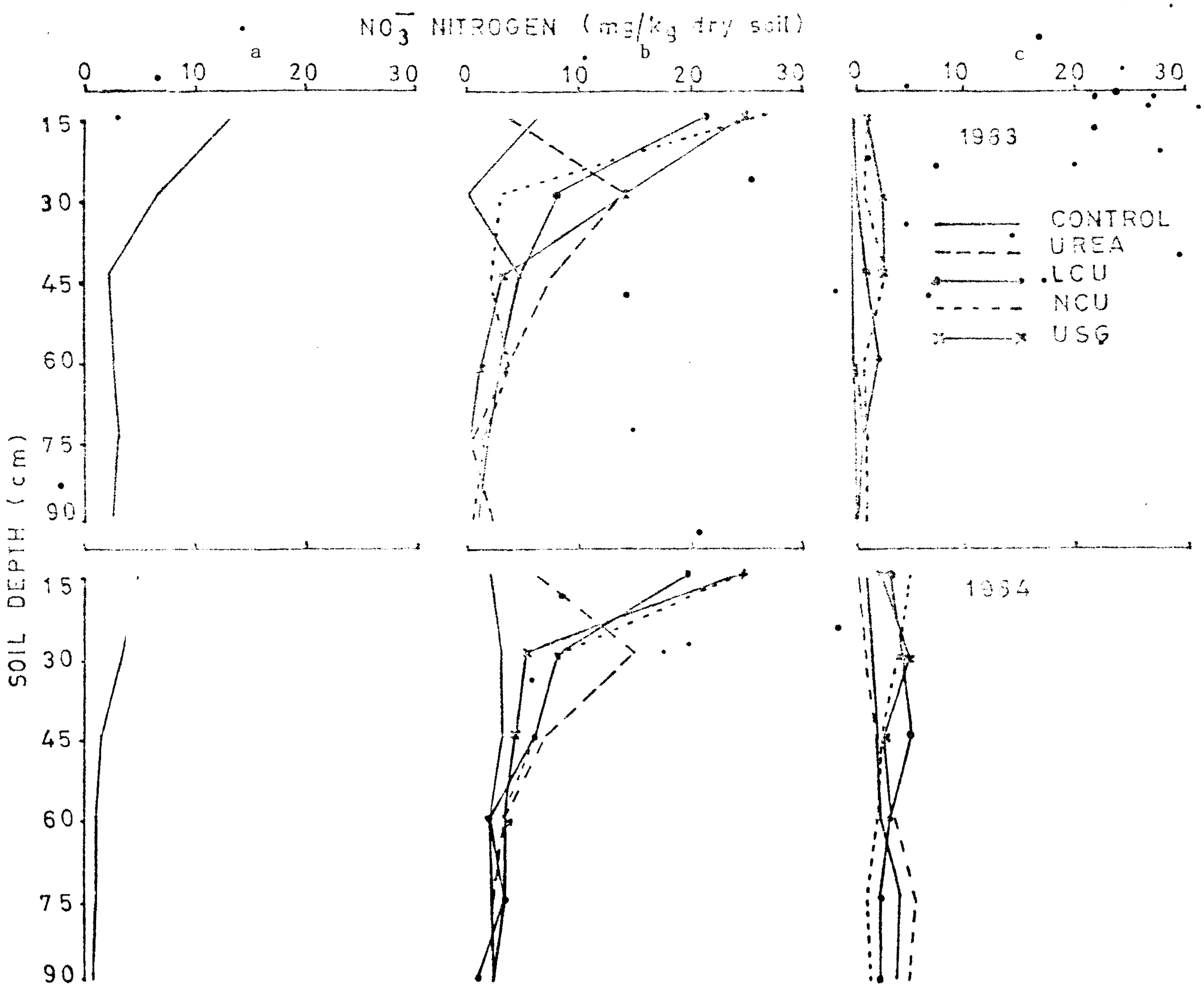

FIG .18 NITRATE NITROGEN LEACHING FROM DIFFERENT FERTILIZER SOURCES UPTO 90 cm DEPTH IN SOIL
(a) BEFORE PLANTING (b) ONE MONTH AFTER PLANTING (c) AFTER 1st HARVEST

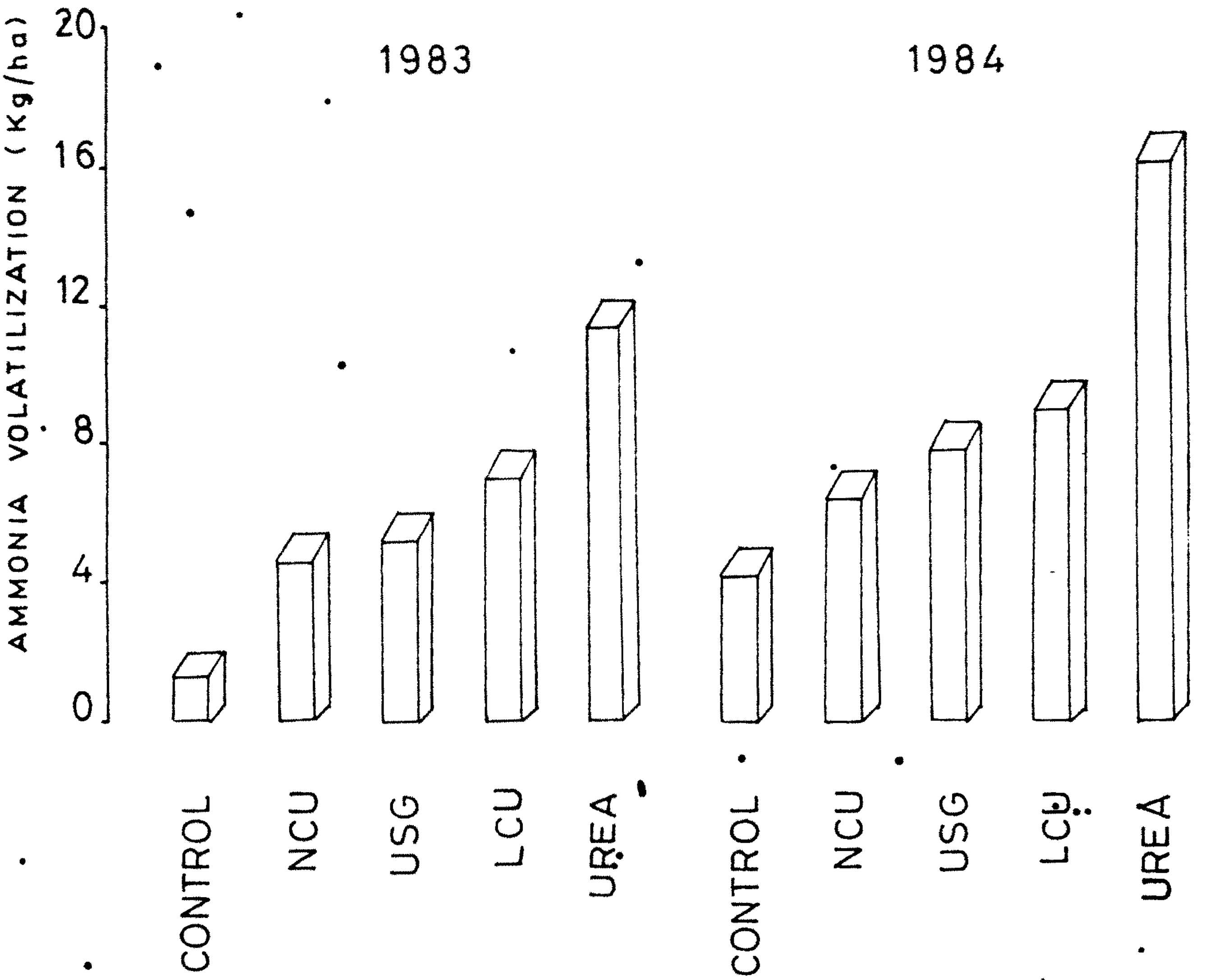

FIG. 19 AMMONIA VOLATILIZATION (Kg/ha) FROM DIFFERENT N- CARRIERS AS FERTILIZER SOURCE

reduced ammonia volatilization to 3 and 2% in 1983 and in 1984, respectively, when nitrogen was applied through USG, the loss of nitrogen in the form of ammonia gas was 3.3 and 2.8% in 1983 and in 1984, respectively.

4.6 Relationship between different growth attributes

4.6.1 Relationship of LAI with menthol content

The relationship between the LAI of crop with menthol content in oil was very close (r = 0.4693). The relationship was further worked out through regression equation (Table 42 and Fig. 20).

4.6.2 Relationship of nitrogen concentration with menthol content

The menthol concentration in oil of Mentha arvensis decreased with an increasing nitrogen content in plants (r = -0.4388).

4.6.3 Relationship of nitrogen concentration with oil content

The essential oil content of Mentha arvensis was also negatively influenced by nitrogen content in the plant. This has been shown by negative correlation values between oil content and nitrogen concentration. The contribution of nitrogen concentration in influencing oil yield was worked out to be 33.6% .

Table 42. Relationship of different growth attributes

Character (Y)	Correlated with (X)	r value	Regression equation Y=	R^2
Menthol content	Leaf area index	0.4693	56.3489 + 2.0764 X	0.22
Menthol content	Nitrogen content	-0.4388	73.4605 - 4.6876 X	0.19
Oil content	Nitrogen content	-0.7625	0.8571 - 0.1188 X	0.58
Oil content	Menthol content	0.6297	-0.0128 + 0.0092 X	0.40

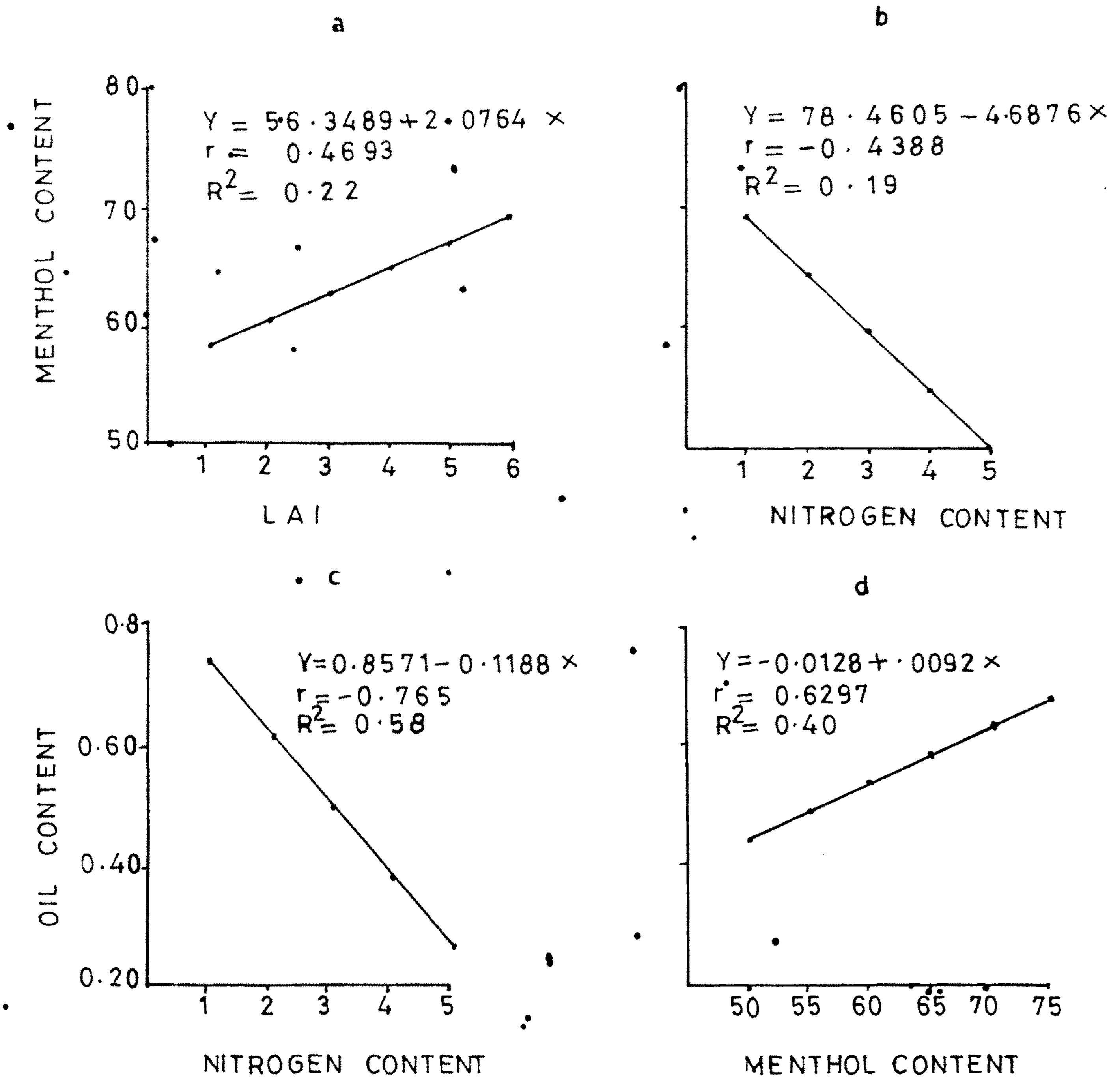

FIG. 20 RELATIONSHIP BITWEEN DIFFERENT GROWTH ATTRIBUTES (a) LAI AND MENTHOL CONTENT (b) NITROGEN CONTENT AND MENTHOL CONTENT (c) NITROGEN CONTENT AND OIL CONTENT (d) MENTHOL CONTENTAND OIL CONTENT

4.6.4 Relationship of menthol content with oil content

The relationship between oil and menthol content in the plant was close (r = 0.6297). The coefficient of determination showed that increasing or decreasing menthol content in the oil had only 16% influence on the essential oil concentration.

4.7 Economics of various nitrogen carriers

The economic evaluation of different N-carriers have revealed that under sub-optimal conditions of nitrogen use in Mentha arvensis i.e. at 60 kg N/ha, the use of NCU is most profitable (Table 43). However, when optimum nitrogen is used, application of USG turned out to be most economical. Application of nitrogen through PU gave the lowest profit at both the rates of nitrogen. At 60 kg N/ha, use of NCU increased the profit by about Rs. 19,506/- . At 120 kg N/ha nitrogen through USG showed high advantage (Rs. 22,583/-).

Table 43. Economics of various nitrogen carriers

Nitrogen carriers	Total oil produced (kg/ha)		Total oil produced in control (kg/ha)	Net gain in oil due to N-application		Cost of nitrogen (Added cost)		Added advantage		Net profit only at fertilizer cost excluding cost of cultivation		Benefit: cost ratio	
	60 kg N/ha	120 kg N/ha		60 kg N/ha	120 kg N/ha	60 kg N/ha	120 kg N/ha	60 kg N/ha	120 kg N/ha	60 kg N/ha	120 kg N/ha	60 kg N/ha	120 kg N/ha
PU	125.1	138.4	87.7	37.4	50.7	293.4	586.8	9345	12668	9152	12081	32	22
USG	156.0	180.4	87.7	68.3	92.7	293.4	586.8	17080	23170	16787	22583	58	40
LCU	146.8	162.6	87.7	59.2	74.9	435.6	851.2	14790	18725	14354	17874	34	22
NCU	167.0	179.4	87.7	79.3	91.7	325.7	651.3	19833	22920	19507	22269	61	35

While calculating the economics, the price of oil was taken Rs. 250 per kg of oil and price of nitrogen was Rs. 4.89, Rs. 4.89, Rs. 7.26 and Rs. 5.43 per kg of nitrogen applied through PU, USG, LCU and NCU, respectively.

5. DISCUSSION

At present *Mentha arvensis* L. is grown in more than 6,000 hectares in India. The production of menthol is about 300 tonnes per annum. This is sufficient for internal consumption. If the present rate of menthol consumption continues, it is estimated that in 2,000 AD, India would require about 600 tonnes of menthol. To produce such an huge quantity of menthol, *Mentha arvensis* L. cultivation has to be done in a larger area, in about 12,000 hectares. Since the possibility of extending more area under *Mentha* cultivation is limited as most of the arable land was already been exploited for food grain production, hence yield per unit area has to be increased. The yield of a crop is a result of the extent of successful completion of growth and the developmental activities in the individual plant, which in turn would depend upon the heredity potential of the agro-type and the environmental conditions to which it is exposed during the course of its life cycle. Several agronomical manipulations are possible to change the local environmental conditions to such an extent that the yielding potentiality of the agro-type could be exploited to its maximum. In order to get the maximum yield potential under a set of agro-climatic conditions, it is very essential that the local plant environment is maintained at optimum level. Indian soils are known to be deficient in nitrogen (Jenny and Raychaudhuri, 1967). Therefore, addition of nitrogen from external sources may result into variation into edaphic environment.

To get optimum yields of *Mentha arvensis* L. in Punjab, 150 kg N/ha has been recommended by Samra *et al*., (1975). For Lucknow conditions, Yadav *et al*., (1983) suggested an optimum dose, 160 kg N/ha. While for Burdwan (West Bengal) Ghosh and Chatterjee (1976) worked out 200 kg N/ha to be an optimum dose.

Mentha arvensis L. is a long duration crop and its growth phase passes through the summer months where frequent irrigations are required to sustain the growth. Under such condition chances of nitrogen loss through leaching are more. Leaching losses may increase further with the on set of monsoon. Yadav and Mohan (1982) reported only 20% nitrogen use efficiency when used as PU, of *Mentha arvensis* L. in light soils of Lucknow. To increase the nitrogen use efficiency of rice in India, Prasad (1966), Prasad *et al*., (1971) and Chatterjee et al., (1975) suggested the use of nitrogen inhibitors and slow release nitrogen fertilizers. In wheat Sharma (1967), Knop *et al*., (1976), Khandelwal *et al*., (1977) and Milenko and Milan (1981) reported the beneficial effect of slow release nitrogen fertilizers and nitrogen inhibitors. Similarly, in Maize Nelson et al., (1976) obtained higher yields due to the use of slow release nitrogen fertilizers and nitrogen inhibitors. Seshadri and Prasad (1979) reported significantly higher seed yields of cotton with the application of sulphur coated urea and N-serve urea than prilled urea.

Since nitrogen fertilization is one of the most important problem and is an item of considerable cost, it is necessary to analyse the effect of nitrogen obtained from different sources, which has hitherto not been worked out. In this study, the slow release nitrogen fertilizers have been tried to reduce the nitrogen losses by leaching and ammonia volatilization vis-a-vis increasing yields.

5.1 Growth

The general trend in growth (plant height, dry matter accumulation and leaf area index) during the life cycle of crop, followed sigmoid path which is characteristics of any growth as described by Galston (1968). It is consisted of atleast four distinct components viz., (a) initial 'lag' period during which internal changes occur that are preparatory to growth (b) a phase of ever increasing rate of growth frequently referred to as a 'log period' (since logarithms of growth rate when plotted against time yields a straight line during this period (c) a phase in which growth rate gradually diminishes and (d) steady rate, a point at which the plant approaches maturity and growth ceases.

In general, the height of Mentha arvensis L. in this experiment increased with a slow rate i.e. 1.26 mm/day upto 60 days. Thereafter upto 75 days, the rate of growth increased to 5.22 mm/day. In 75 to 90 days period, the height increased at the rate of 6.66 mm/day. The maximum rate of increase in height i.e. 7.05 mm/day was observed during 90 to 105 days. Thereafter, the rate of increase declined to 6.45 mm/day upto 120 days. These observations inferred that Mentha arvensis L. has 'lag period' of growth upto 60 days. Its growth enters into a 'log'phase thereafter, which continues upto 105 days. The period of 105 to 120 days may be considered a phase of declining growth. The last phase of steady state of growth was not observed in Mentha arvensis L. because being a vegetative crop, harvesting was done when maximum growth was achieved. With the application of neem cake coated urea, even the state growth was not recorded as the height continued to increase with a greater rate till the harvesting done, at 120 days. This shows that nitrogen availability to the crop remained with the same index when neem cake coated urea was used because neem cake coated urea releases the nitrogen slowly. Slow availability of nitrogen throughout the crop growth period with the application of neem cake coated urea have been reported by several workers in other crops (Prasad _et al._, 1971; Reddy and Prasad, 1975; Prasad, 1979; Sahrawat, 1981; Sahrawat, 1982; and Thomas and Prasad, 1983).

The higher nitrogen dose exhibited greater influence on the height of the plant. Nitrogen brought an increase in plant height because of its emmense effect on cell multiplication and enlargement. Positive correlations between plant height and nitrogen levels has also been reported by Samra _et al._, (1975); Rai _et al._, (1977) and Singh (1983).

On an average the dry matter accumulation pattern of the crop remained slow from sprouting to 60 days. During this period, the crop accumulated one kg dry matter/ha/day. From 60th day onwards upto 75 days, the crop started accumulating dry matter at the rate of 29 kg/ha/day. Thereafter upto 90 days, the rate of accumulation increased to 55.5 kg/ha/day. After this upto 105 days, the rate of increase declined to 39 kg/ha/day. The crop growth rate increased appreciably again between 105 and 120 days when 86 kg of dry matter was accumulated in a day from one hectare of land. The possible reasons of slackness in the growth, during 90 to 105 days and acceleration again are that after attaining maximum leaf area index, due to higher canopy coverage, lower leaves operated under shade. Thus they started senescing and hence total dry matter decreased at 105 days. After that, when increased rate of height of plants declined, photosynthates were used for lateral spread. Thereby branching increased. This fortified the accelerated growth rate between 105 and 120 days. Singh (1983) also reported linear increase in dry matter production at successive stages of the crop growth. In his studies, dry matter increased at a faster rate after March which coincided with 60 days in the present study.. He, however, has observed the highest dry matter accumulation during July-August. This was due to well developed vegetative frame work of the plant at this stage, more active leaves, high humidity, high temperature and long day conditions which are favourable for the growth of _Mentha arvensis_ L. The findings are also similar to those obtained by Rai _et al._, (1977) who reported vigorous growth of mint during rainy season followed by summer and winter. Singh and Singh (1979) also expressed similar opinion. Yadav and Mohan (1982) too have reported sigmoid pattern of dry matter accumulation in _Mentha arvensis_ L.

Urea super granule and neem cake coated urea have shown higher rates of accumulation of dry matter from the very beginning of the crop growth, indicating thereby that these fertilizers are efficient source of nitrogen for *Mentha arvensis* L. For other crops as well, their superiority over other sources have been tested (Khandelwal *et al.*, 1977; Sharma and Prasad, 1980; Eriksen and Nilsen, 1982; Reddy and Mitra, 1985; Eriksen *et al.*, 1985).

Increasing nitrogen levels consistently increased the dry matter accumulation. Phenomenal response of *Mentha arvensis* L. to nitrogen application is understandable because nitrogen is known to promote luxurious vegetative growth by increasing rate of photosynthesis and subsequently converting the photosynthates to protein and causing production of more vegetative tissues. Increasing rates of nitrogen have also increased the rate of dry matter accumulation at all the growth stages of *Mentha arvensis* L. in a study of Yadav and Mohan (1982).

Basal application of nitrogen caused higher rate of dry matter accumulation in case of NCU, USG and LCU but not in case of PU in both the years during first harvest, thereafter in second harvest two split applications showed their superiority over basal and over three split applications in case of LCU and PU only. The reasons are well known that availability of nitrogen through basal application at different growth stages upto first harvest quite matches to the need of the plant only in cases where nitrogen has been supplied as NCU, USG and LCU. But where PU was used, application of nitrogen before first harvest (i.e. 1/3 at planting and 1/3 at 45 days after planting) in two lots (out of three splits) showed a significant advantage over basal application of fertilizer. In second harvest, however, two split applications caused significant increase in dry matter indicating thereby that for regeneration direct application of nitrogen was very helpful for *Mentha*.

There was an improvement in leaf to stem ratio with the increased application of nitrogen. Fertilization with 120 kg N/ha was found to be more conducive in increasing leaf to stem ratio over control and application at 60 kg N/ha. The possible reasons for improved leaf to stem ratio upto the maximum dose of nitrogen applied may be because of increase in plant height did not increase in the same proportion as that could be obtained at lower doses. Hence additional supply of nitrogen led to production of more foliage which resulted higher leaf to stem ratio. Singh *et al*., (1979) and Singh (1983) also noted higher leaf to stem ratio with increased supply of nitrogen. The declining trend of leaf to stem ratio with advancement in crop age indicated the reduced proportion of leaves in total herbage production. Previous observation of increased dry matter due to branching support this finding that with more branching leaf: stem ratio declines.

The leaf area index is an important factor related to oil production in Mentha arvensis L. In general, in 1983 the crop maintained higher leaf area index than 1984 crop sseason. It is because of the high humidity and high temperature which boosted up the crop growth and led to higher leaf area index in 1983. NCU proved superior to USG in increasing leaf area index. It was because NCU prevented leaching and volatilization losses of nitrogen better than any other sources and regulated the availability of nitrogen to plants to match their demand for growth. With the availability of nitrogen to plants in well regulated quantity, leaf area index increased where NCU was applied. Prilled urea (PU) showed lower leaf area index in comparison to other N-carriers because of greater amount of nitrogen was lost through leaching and ammonia volatilization. Where PU was used less nitrogen was available for plant utilization.

In general, leaf area index increased with increasing application of nitrogen upto 120 kg N/ha. Higher leaf area index with higher nitrogen application was attributed to the production of more vegetative tissues. The results are in accordance with those reported by Samra et al., (1975), Yadav and Mohan (1982) and Singh (1983).

Basal application of nitrogen increased the leaf area index during first harvest of both the years. But in second harvest two split applications proved superior to basal and three split applications. The nitrogen applied at the time of planting remained available to the crop only at first harvest. After that, with the on set of monsoon that nitrogen might have lost in leaching in addition to those utilized by the plant. Therefore, the additional nitrogen application after first harvest in split treatments, increased the availability of nitrogen to the crop of second harvest thereby its leaf area index increased.

On an average CGR increased upto 90 days of planting. Thereafter, with a slow growth rate upto 105 days, CGR again increased and attained a peak between 106 and 120 days after planting. Thus, two clear peaks were observed in CGR of Mentha arvensis L. As mentioned earlier, the dry matter accumulation and leaf area index continued to increase upto 90 days. Thereafter, because of mutual shading, the lower leaf start senescing and hence might have declined the CGR but once the flowering started initiating, the increased height due to flower bud initiation might have added to little dry matter yield.

The differences in CGR between USG and NCU were marginal. Some times USG proved little better than NCU or at times the effects were equal. While at one instance NCU was better than USG but both remained always superior to PU and LCU. Reasons are obvious, NCU and USG might have supplied nitrogen to the crop more effectively as has been reported by several workers (Prasad, 1979; Thomas.and Prasad, 1982; Savant et al., 1983).

Contrary to CGR, RGR decreased with advancement in age. However, like CGR it has also shown two peaks. The decreasing rate of RGR with advancement in crop age showed that efficiency of plants to produce dry matter over its original weight decreases. Whenever the increase in weight diminishes a little, RGR shows increase .

The decrease in RGR with advancement in crop age can be explained on the basis of work done by Friend et al., (1965) who observed that the increase in LAR during early growth and later on the decrease was primarily because of an initial increase in the growth of leaves relative to stem and roots and later rapid increase in stem growth associated with flowering. They further reported that increasing the temperature from 10 to 25°C increased the LAR, but further increase in temperature to 30°C lowered the LAR because of an increased proportion of stem and thicker leaves.

5.2 Yield

On an average 1983 crop season was most favourable to produce luxuriant herbage than 1984 season. High rainfall, high humidity, high temperature all together interacted to produce luxuriant growth in 1983 crop season. On an average Mentha arvensis L. yielded 23% higher in 1983 crop season than those recorded in 1983 season. First harvest yielded 13% higher and second harvest 32% higher yields in 1983 as compared to 1984 crop season. In 1983, at first harvest, NCU caused slightly better production than USG, while in second harvest the effects due to USG and NCU did not differ much. But in 1984, NCU was found to be better than USG to produce more herbage yield. NCU also caused better production than those obtained through USG, LCU and PU applications. On an average of both the crop seasons, NCU maintained the lead to produce only 4% higher herbage than USG, but both these sources were many times better than that was recorded due to the applications of LCU and PU. Prasad et al., (1971), Nelson et al., (1976), Sharma (1976), Knop et al., (1976), Khandelwal et al., (1977), Seshadri and Prasad (1979), Chang and Yang, (1980); Milenko et al., (1981), Milenko and Milan, (1981), Eriksen et al., (1985), and Reddy and Mitra (1985) also showed the superiority of NCU and USG applications over PU in other crops. NCU might have released nitrogen slowly as per the requirement of crop at different growth stages. Therefore, the crop never suffered for the deficiency of nitrogen. Nitrogen losses through leaching and ammonia volatilization were also less when NCU and USG were used.

Herbage production increased consistently with increases in nitrogen levels, similar to those reported by Baird (1957), Dutta and Chatterjee (1961), Gupta and Gulati (1970), Dutta (1971), Nelson et al., (1971), Sharma and Singh (1980), Singh (1983), Verma et al., (1983), Yadav et al., (1983) and Randhawa et al., (1984).

Basal application of nitrogen in the form of NCU, USG and LCU resulted into higher production of Mentha arvensis L. during first harvest. But while PU was used, split applications proved to be more conducive for herbage production than basal application. It was noted that basal application of nitrogen in the form of USG, NCU and

LCU proved to be better than split (two) applications of nitrogen as PU only in total herbage yield. Split applications of nitrogen through NCU, USG and LCU was not as good as basal application of the entire dose.

The production of oil is a net result of herbage production and its oil concentration. Higher herbage yield led to higher oil yield. NCU was found superior to increase total oil yield during both the years followed by USG than others.

Increasing levels of nitrogen also resulted into higher production of oil. A number of research workers noted increase in oil yield due to nitrogen fertilization. (Baslas 1970; Chandra 1971; Dutta 1971; Panda 1977; Duhan et al., 1977; Singh et al., 1979; Clark and Menary, 1980; Singh and Kewlanand 1981; Chandra et al., 1983; Yadav et al., 1983 and Randhawa et al., 1984).

Different sources on nitrogen did not influence oil content of *Mentha arvensis* L. very much. Oil concentration in plants of second harvest was more than that of first harvest because regenerated growth had more leaf area where oil glands are situated. High humidity prevailed during entire period of regenerated growth might have helped in more leaf initiation and leaf area index which ultimately favoured oil production in leaves.

5.3. Oil quality

In general, the pattern of menthol accumulation with time indicated that at 60 days of planting, menthol, menthone and menthyl acetate contents were 51.3, 27.3 and 2.6%, respectively. With the advancement in crop age menthone content was reduced and menthol content increased, menthyl acetate content increased slightly between 60 and 120 days after planting, during this period menthol content improved by 28% while menthone decreased to the extent of 46%. The increase in menthol content during this period was only 20% where PU was applied. Highest increase 33.6% was observed in case of USG. NCU caused only 26.4% improvement in menthol content during this period.

In unfertilized plot menthol content increased from 55 to 60% between 60 and 120 days i.e. about 10% increase. Application of nitrogen at the rate of 60 kg N/ha caused 28% improvement in menthol content. Further increase in nitrogen rates to 120 kg/Ha brought about almost 30% improvement which is only 2% higher than that was observed at 60 kg N/ha. While studying the rate and duration of menthol accumulation in <u>Mentha arvensis</u> L. at different rates of fertilization Yadav <u>et al.</u>, (1981) reported 251-264 g/ha/day menthol accumulation in nitrogen fertilized plants as against 215 g/ha/day in control plants.

At 120 kg N/ha, menthol accumulation continued to increase upto 66 days where as in control plants, it continued to increase upto 38 days. Gulati and Duhan (1971), Franz (1972), Duhan et. al., (1975 and 1977) and Yadav and Mohan (1982) reported decrease in menthol content with increase in N-rates under field conditions. But in this study this was not observed rather with the increase in nitrogen levels, the menthol content slightly improved. Amongst the different sources of nitrogen fertilizers it was observed that application of NCU, USG and LCU improved menthol content better than PU, quite possible slowly available nitrogen helped better menthol content in plants. With advancement in crop age menthone was reduced to menthol. Thus, menthol increased and attained a peak at 120 days. After 125 days menthol content decreased again due to its esterification into menthyl acetate. The reduction of menthol in oil at higher N-rates and at later harvesting dates was also due to decrease in the proportion of leaves in total herbage yields. Menthol synthesis in plants takes place towards the region of photosynthetic activity, where carbon dioxide is reduced and carbohydrates are synthesized (Guenther, 1960). Loomis (1967) described the menthol synthesis pattern as indicated in.Fig. 21. Tyagi et al., (1983) also confirmed it. Farooqi et al., (1983) also reported higher menthol in oil at the time of flowering which occured 120 days after planting.

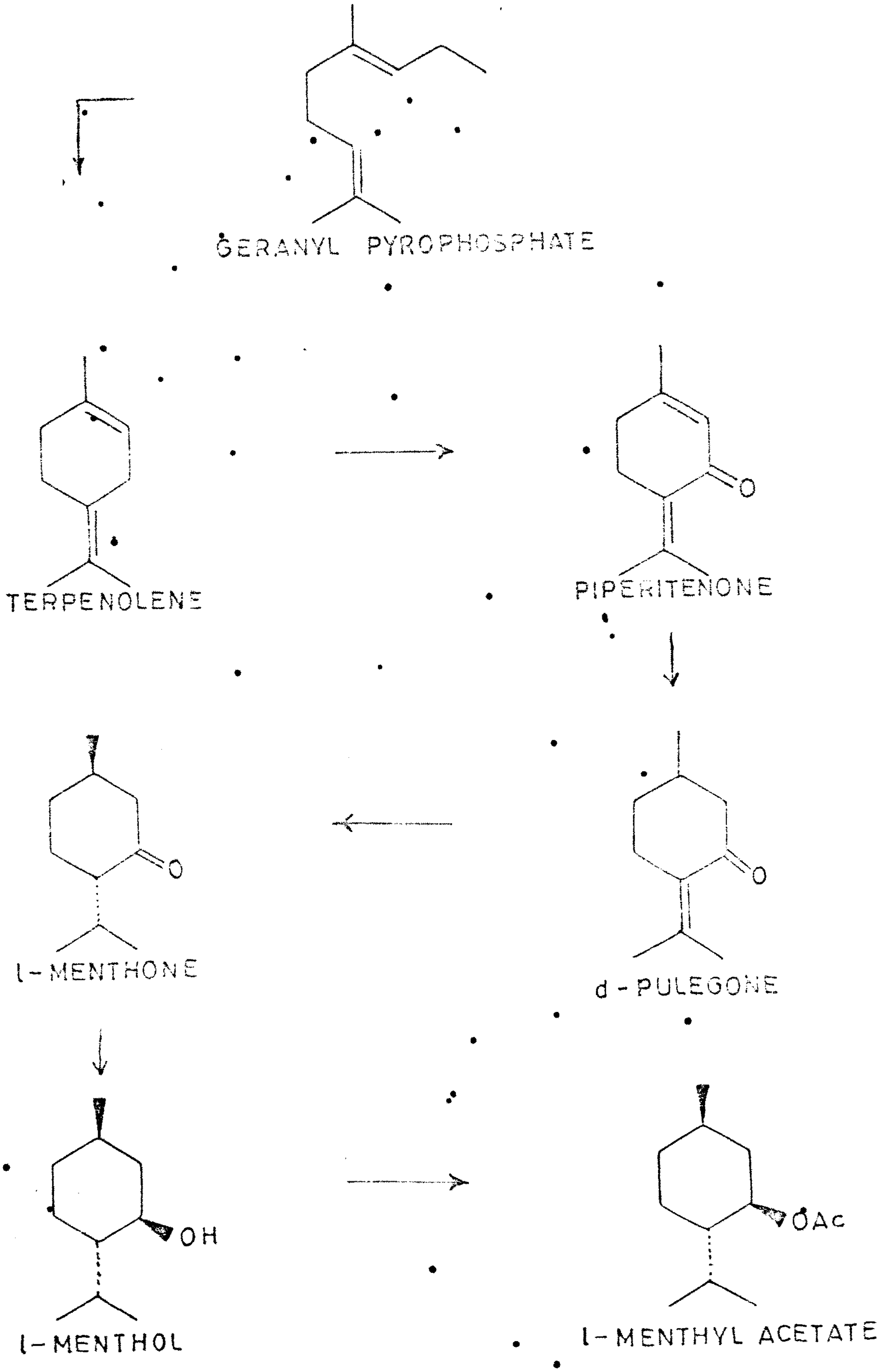

FIG.21 . BIOSYNTHETIC PATH WAY OF MENTHOL IN MENTHA ARVENSIS L.

5.4 Efficiency of nitrogen application and its losses

Efficiency of nitrogen utilization as indicated by biological efficiency of nitrogen increased with advancement in crop age. Root proliferation increased with the advancement of crop age and thus efficiency of nitrogen utilization also increased. At harvesting biological efficiency was higher when nitrogen was applied through NCU, USG was also at par. With the application of USG and NCU losses of nitrate leaching and ammonia volatilization were less as compared to that in PU. Neem cake possesses nitrification inhibitory properties which slow down the action of nitrosomonas and nitrobactor bacteria in the soil. Coating of neem cake with coaltar on urea prills check the process of hydrolysis as well as nitrification. This reduced formation of ammonium ions and the conversion of ammonium ions to nitrate ions is also inhibited. As a result of this nitrogen might have been available to the plants at a slow rate. This helped to minimise nitrogen losses and better utilization of nitrogen. Application of nitrogen through USG also minimise the losses of nitrogen. The pH of the soil in the vicinity of USG increased upto 9, while enzyme could function only upto an optimum pH of 8. Thus, urease enzyme activity is reduced which ultimately affected the hydrolysis process adversely. Moreover, the upward diffusion of ammonium released from hydrolysis process of USG is low. Thus, the ammonia formed in the soil, where USG is placed, come out in the atmosphere slowly and hence volatilization loss is appreciably reduced. The low concentration of nitrate formed by nitrification also lead to minimum loss of nitrogen through leaching and dinitrification in the an aerobic layer. The another possible reason of reduced leaching and volatilization losses of nitrogen is that application of USG resulted into longer persistence of ammonical nitrogen and lower concentration of nitrate nitrogen in the soil. Reddy and Prasad (1975), Khandelwal et al., (1977), Rao et al., (1980), Sahrawat (1981), Thomas and Prasad (1982), Chen and Zhv (1982), Sahrawat (1982), Savant et al., (1983), Thomas and Prasad (1983), Rao et al., (1985), Eriksen et al., (1985), Reddy and Mitra (1985) also showed the superiority of these fertilizers over PU in most of the arable lands. The biological efficiency of nitrogen application was higher at low rates of nitrogen application. Biological efficiency of nitrogen application at first harvest was higher due to basal application, while two splits increased the biological efficiency at second harvest. Considering the biological efficiency of nitrogen application during entire growth period of *Mentha arvensis* L., two splits have an edge over other timings of nitrogen application with particular reference to the use of PU.

However, this effect was not observed in case of NCU and USG considering the SEm of the experiment.

It is thus apparent that basal application of neem cake coated urea as well as USG increased herbage production, improved more of menthol in the oil, oil yield than when urea applied in two or three splits. To boost up production after first harvest there appeared to be great need of nitrogen. It may be interesting to find out the effect of split application of PU after first harvest, in the plots which receive nitrogen in the form of NCU or USG as a basal dose. Effect of LCU, however, was inferior to NCU and USG and needs further verification. Effect of NCU and USG were good in 1983 when the crop yield was more and rainfall receipt was high but this effect was not so distinctly observed in the year 1984 which received less rain.

6. SUMMARY AND CONCLUSION

Japanese mint (*Mentha arvensis* L.) has turned out to be an important crop in India. For its high commercial value farmers are using very heavy doses of nitrogen alongwith large number of supplementary irrigations. It has been estimated that hardly 20-40% of applied urea is utilized for crop production. In order to find out the scope of utilizing, some of the slow release nitrogenous fertilizers for improving the biological efficiency of applied nitrogen, an investigation was carried out at the research farm of the Central Institute of Medicinal and Aromatic Plants, Lucknow for two successive years 1983 and 1984. The N-carriers used were prilled urea (PU), urea super granules (USG), lac coated urea (LCU) and neem cake coated urea (NCU). Two levels of nitrogen 60 and 120 kg/ha and three timings of application (full basal, 1/3 at planting + 1/3, 45 days after planting + 1/3 after first harvest and 1/2, 45 days after planting + 1/2 after first harvest) were tried. The treatments were laid out in Randomised Block Design with separate control plot in three replicates. The salient features of the experimental results from the present investigation are summarized below:

1. Application of NCU, USG and LCU fertilizers produced taller plants than PU. Application of nitrogen at 120 kg N/ha

caused maximum plant height. Application of the whole of nitrogen at planting through NCU, USG and LCU caused greater increase in plant height than its split applications during first harvest. Split application increased plant height more than that was recorded through basal application during second harvest of the crop.

2. At all the growth stages application of NCU, USG and LCU increased the number of leaves; the respective N-carriers caused 25 to 49, 16 to 30 and 13 to 15% increase in leaf number per 25 cm long rows in both the years. Whole nitrogen applied through NCU, USG and LCU produced greater number of leaves at first harvest of the crop than its split applications. Two split applications of USG, NCU, LCU and PU produced significantly greater number of leaves than its basal application of nitrogen in regenerated crop.

3. The size of leaves increased by the application of N-carriers more than those increased through PU. Through NCU and USG, the enlargement of leaf was more than that was recorded by the application of LCU. Similar trend of variation was observed in regenerated crop as well.

4. Initially dry matter accumulation was slow. Thereafter it increased with a faster rate and attained a peak at 120 days after planting and 75 days after first harvest . Applications of nitrogen through NCU, USG and LCU

produced 36.2, 31.7 and 24% higher dry matter yield than PU in 1983, in 1984 corresponding values were 23, 22 and 8%. Application of nitrogen at the rate of 120 kg/ha produced more than those recorded at 60 kg N/ha (20%), fertilizing at 60 kg N/ha caused 53% increase in yield over control (no fertilizer) and this difference was also statistically significant. Basal application of nitrogen was found superior to its split applications during first harvest of the crop. Total dry matter production increased by two split applications of nitrogen in 1983 more particularly in case of PU, in 1984, however, productivity due to two and three split applications did not differ much. On an average of both the crop seasons, application of fertilizer in two split applications proved superior to its basal application, particularly in case of prilled urea; in case of NCU and USG, however, this difference was reduced.

5. Application of nitrogen through NCU, USG and LCU increased the LAI more than PU. The LAI increased significantly by the application of nitrogen at 120 kg N/ha as compared to the control treatment and at 60 kg N/ha. Basal application of nitrogen through NCU, USG and LCU increased the LAI at first harvest while the effect of three split applications was observed to be superior to

basal application when nitrogen was applied in the form of PU. Two split application of nitrogen through all N-carriers was found to be superior to basal application in regenerated crop.

6. Application of nitrogen through NCU, USG and LCU produced 22.6, 18.8 and 14% higher herbage yield than PU, respectively during 1983; in 1984, the corresponding values were 24, 18 and 9%, respectively. Application of 120 kg N/ha was found significantly superior to control and to 60 kg N/ha. Split application of nitrogen was found to be superior to basal application in case of PU but not in cases of NCU, USG and LCU; LCU, however, had a bit inconsistent behaviour.

7. On an average of both the years, amongst different N-carriers, the lowest oil content (0.61%) was recorded in the crop fertilized with PU followed by NCU, USG and LCU (0.62%). Nitrogen reduced oil content in the herbage. The extent of decrease in oil concentration was maximum from control to 60 kg N/ha. At 120 kg N/ha although there was further reduction in oil concentration but the magnitude of reduction was lesser than those recorded between control and 60 kg N/ha.

8. NCU, USG and LCU produced higher total oil yield than PU. Total oil production increased by 36% in 1983

and 26% in 1984 due to the application of nitrogen through NCU over PU. USG excelled PU by 34 and 21% in 1983 and 1984, respectively. Application of 120 kg N/ha increased the oil yield significantly over control and over 60 kg N/ha. Split applications showed their superiority over basal application in case of PU but not much in others. But the differences between two and three split were very minor.

9. In general, at the beginning menthol accumulation was less and menthone content was high. With the advancement in crop age, menthone content decreased with the increase in menthol content and slight increase in menthyl acetate content. Menthol content attained a peak at 120 days after planting. At 60 days after planting, plant fertilized with NCU showed 52.9% menthol, 26.1% menthone and 2.6% menthyl acetate, USG treated crop recorded 50.2% menthol, 27% menthone and 2.5% menthyl acetate content. At maturity (120 days after planting) menthol content reached to its peak and in NCU treated crop, the plants had 67.25, 14 and 6.8% menthol, menthone and menthyl acetate contents, respectively. The corresponding values in crop fertilized with USG were 66.9, 14.5 and 5.7% , respectively. The menthol contents were less in crop fertilized with PU and LCU. Increasing levels of nitrogen (upto 120 kg N/ha) slightly increased the menthol content.

10. Maximum production of menthol was observed in plants fertilized with NCU followed by USG. The menthol yield was improved by 49, 45 and 27% due to the applications of NCU, USG and LCU over PU in 1983, the corresponding values in 1984 were 40, 30 and 18%. Menthol yield increased successively with the increased application of nitrogen doses. A dose of 120 kg N/ha almost doubled the menthol production as compared to control.

11. In general, the biological efficiency of nitrogen application (BENA) increased with the advancement in crop age during both the years. The biological efficiency of nitrogen when applied in the form of NCU, USG and LCU were significantly superior to PU at all the growth stages except at 60 days after planting in 1984. Higher BENA was observed at 60 kg N/ha than 120 kg N/ha. At the time of first harvest BENA were 16 and 13% at 60 and 120 kg N/ha, respectively in 1983 and 17 and 10% in 1984. The similar trend of variation in BENA was observed in the regenerated crop. Basal application of nitrogen increased the BENA over split applications at first harvest while in second harvest of regenerated growth two split application was significantly better than basal application, particularly where PU was used as a source of nitrogen. Total biological efficiency of nitrogen application was significantly better when nitrogen was applied in splits through PU only than its basal application.

12. Use of urea as a source of fertilizer caused higher losses of nitrogen through leaching and volatilization in *Mentha arvensis* L. Leaching losses were minimised from 29.7% in PU to 10.7% in NCU and 12.1% in USG. Ammonia volatilization losses were reduced from 9% in PU to 2.5% in NCU and 3% in USG.

13. There was inverse relationship between nitrogen and oil contents in plants. But LAI and menthol content were positively correlated. The relationship between oil concentration and menthol content was close and positive.

As source of nitrogen fertilizer NCU and USG were the most efficient fertilizers and gave higher benefit: cost ratio than LCU and PU. Considering their efficiency in oil production, broadly speaking, 60 and 120 kg N/ha in the form of prilled urea was equivalent to 50 and 90 kg N/ha in the form of NCU or USG.

7. FUTURE SCOPE OF WORK

In the present investigation the nitrogen level was tried upto 120 kg N/ha but the crop has the potentiality of utilizing still further amount for production. Efficiency of these fertilizers need to be evaluated at still higher level of nitrogen. Further, instead of having wide gaps between levels, the differences can be scaled down to 20 or 30 kg N/ha. For regeneration of crop after first harvesting it appears, application of nitrogen is very important. The efficacy of giving a reduced dose of prilled urea after first harvest in plots receiving NCU and USG as basal dose, need also to be worked out.

The extent of utilization of nitrogen from different fertilizers can be best studied through the use of N^{15}, otherwise there may be some errors involved in such indirect determinations.

Use of <u>Mentha</u> spent material as a mulch or as a source of bulky organic matter, for increasing the efficiency of inorganic fertilizer use, need to be investigated as well.

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* Original not seen

APPENDIX-I

Weather data

Month	Relative humidity (%)	Maximum temperature (°C)	Minimum tempera-ture (°C)	Rainfall (mm)
		1983		
January	69.98	19.92	6.62	20.5
February	50.77	26.35	9.05	0.2
March	54.84	33.78	14.13	-
April	62.84	31.43	19.03	23.6
May	67.32	38.38	23.66	39.9
June	77.30	36.85	27.08	218.4
July	84.28	35.53	31.15	404.3
August	83.92	33.95	26.28	236.0
		1984		
January	56.50	23.18	6.25	5.2
February	50.95	24.18	5.33	2.8
March	54.35	32.23	13.35	-
April	57.75	28.80	15.90	15.3
May	67.63	37.00	22.96	-
June	67.66	39.45	26.88	267.8
July	84.91	35.20	26.84	178.4
August	81.50	34.58	26.63	184.1