Journal of Spices and Aromatic Crops 9 (1) : 13-22 (2000)

Agronomic studies in cymbopogons - a review

K Singh, S K Kothari, D V Singh, V P Singh & P P Singh

Central Institute of Medicinal and Aromatic Plants
Lucknow - 226 015, India.

Received 18 August 1998; Revised 22 October 1999; Accepted 27 November 1999.

Abstract

Research on agronomic aspects of cymbopogons, Java citronella (*Cymbopogon winterianus*), palmarosa (*C. martinii*) and lemongrass (*C. flexuosus*) with respect to soil and climatic conditions, propagation, manures and fertilizers, irrigation, weed control and harvesting schedules to manipulate their yield potential and quality of produce has been reviewed.

Key words: agronomy, cymbopogons, Java citronella, lemongrass, palmarosa.

Introduction

Aromatic species of *Cymbopogon* (Family : Graminae) are widely adapted to various agro-climatic zones in India and mostly grow wild as natural vegetation. The total area under these crops ranges between 30,000 and 40,000 ha and is spread over Kerala, Assam, Madhya Pradesh, South Gujarat, Karnataka, Maharashtra, Andhra Pradesh and Uttar Pradesh. The total oil production from these crops is unpredictable; it fluctuates widely mainly due to lack of control over growth of these crops in their natural habitat and their performance is largely influenced by vagaries of weather conditions. A great deal of manipulation with regard to agronomic practices is necessary for enhancing the production of essential oils from these crops. These are foliage rich grasses which through steam distillation produce, essential oils (volatile oil) which are a source of natural citral, geraniol, citronellal and citronellol, widely used in flavouring of food and in cosmetic and pharmaceutical industries.

Soil

Cymbopogons are hardy in nature and can be grown in a wide range of soils from rich loam to poor laterite. But well drained sandy loam soils are best suited as these grasses cannot withstand water logging. Palmarosa and lemongrass may be grown on marginal and sub-marginal lands.

According to Singh & Anwar (1985), lemongrass, palmarosa and citronella can be grown without reducing herb and oil yields up to 11.5, 10.0 and 5.5 EC mmhos/cm, respectively. Sharma *et al.* (1972) observed that palmarosa can be successfully grown up to pH 10. In case of Java citronella under irrigated conditions, a foliage yield of 500 q/ha has been reported with an oil content of 1.00 to 1.25% on sandy loam soil, alkaline in reaction and containing 20% exchangeable sodium. Palmarosa grows successfully even on moderately saline soils of Orissa (Patra & Dutta 1979). In case of lemongrass, herb yield, oil and citral A and citral B contents increased significantly at neutral pH (7.5) over lower pH (4.8) in Assam hills (Singh, Pathak & Bordoloi 1983). Lemongrass and Java citronella grow well up to EC 8 ds/m of water. Increasing salinity levels enhanced N and Na contents and decreased P, K, Ca and Mg contents (Pal *et al.* 1989). Singh *et al.* (1994) reported that increasing water salinity reduced dry matter production, yield, and P, K, Ca and Mg contents and increased N and Na contents. However, increasing fertilizer levels increased growth characteristics, dry matter production, oil and nutrient contents. The optimum dose of NPK fertilization for Java citronella under saline conditions is 120, 40 and 40 kg/ha, respectively.

Climate

Cymbopogons can be grown successfully in tropical and sub-tropical parts of the country. Usually they prefer high temperature and humid

weather coupled with abundant sunlight round the year. The ideal elevation for commercial cultivation is up to 300 m above MSL although in natural habitats they are found to occur even at an elevation of 1500 m above MSL. Guenther (1950) reported that the best elevation for growth of Java citronella ranged between 180 m and 230 m above MSL in Java, less than 500 m in Formosa, 180 and 418 m in Guatemala and 13 and 26 m in Honduras. In India, Sarma, Bordoloi *et al.* (1977) reported successful cultivation of citronella at an altitude of 1200 m above MSL in Yaonyimson village in Nagaland. For proper growth, cymbopogons require well distributed rainfall of 1500 to 2000 mm along with temperatures between 10 and 40°C. Palmarosa and lemongrass can perform satisfactorily even in semi-arid regions receiving low to moderate rainfall (400 to 1000 mm per annum). These crops are highly susceptible to low temperatures and frost as both inhibit growth and the latter sometimes causes high mortality of growing shoots. In Assam, Singh & Ganguly (1973) observed that citronella requires a relative humidity of about 70% and temperatures between 9 and 33°C for optimum yield. Shai & Singh (1981) noted that rainfall is the only feature for significant reduction in oil content and that temperature and relative humidity have no effect on yield and quality of lemongrass oil.

Propagation and planting

Aromatic grasses are perennial in nature; once they are properly established, the plantation can give economic yield for 3 to 5 years depending on the management practices adopted, climate and soil fertility. Palmarosa and lemongrass can be raised directly by sowing seeds and citronella by transplanting rooted slips. Lemongrass can also be raised by planting rooted slips depending on their availability. Besides direct seeding, palmarosa and lemongrass seedlings are often raised in the nursery and subsequently transplanted in the field at 6–7 leaf stage. Gupta (1972) suggested direct seeding of palmarosa as it is less expensive and bestows initial advantage of early vegetative growth, but to ensure an uniform population, transplanting may be preferred. Forty day old seedlings recorded 8–20% higher plant establishment and produced 20% higher yield over both younger and older seedlings. Fertilization of nursery beds (25 kg N, 12.5 kg P_2O_5 and 12.5 kg K_2O) enhanced the yield by 12% over those raised without fertilization (Singh *et al.* 1993). Evaluation of methods of planting namely, broadcasting, dibbling, transplanting of seedlings and planting of slips carried out at Odakalli (Kerala) under rainfed conditions indicated that transplanted seedlings gave significantly higher herb and oil yield as compared to dibbling and broadcasting (Thomas 1993). An increase in economic life span was also observed when the plantation was raised through seedlings. In palmarosa, transplanting of seedlings was better than rooted slips as the former gave higher yield of geraniol content (Kanjilal *et al.* 1981). Planting during 1–10 July significantly increased plant height, leaf length, tillering, fresh herbage and oil yield over August planting. Oil content showed an increasing trend in delayed planting. However, citral content remained unchanged (Pal *et al.* 1994).

Cymbopogons are generally planted in the rainy season (June–July) when they get easily established. Planting of Java citronella during February in *tarai* region of Uttar Pradesh increased herb yield by 38%, oil yield by 28% and net income by 40% as compared to the normal July planting, while the planting date did not influence oil recovery. This is because rainy season planting is encountered with severe weed infestation which affects early establishment. On the other hand, if it is planted in February–March, the crop is well established before the onset of monsoon and gives an additional yield in rainy season harvest (Singh, Kothari *et al.* 1991). In lemongrass also wherever irrigation is available, planting could be done in spring season (February–March).

Plant spacings, both row to row and plant to plant, play a significant role in the production of aromatic grasses. It is governed by various edapho-climatic factors to a large extent leading to varying results at different locations. Guenther (1950) reported that Java citronella is planted at a spacing of 90 cm between rows and 60 cm between plants (18,500 plants/ha) in Formosa and Honduras, and at 90 cm x 15 cm (74,000 plants/ha) in Guatemala. According to Virmani & Dutta (1973), a spacing of 75 cm x 75 cm was optimum for Java citronella at Lucknow, which produced a record herb yield of 44.5 t/ha per year. Chatterjee & Ghosh 1977 recorded a maximum yield at a spacing of 90 cm x 60 cm in West Bengal. Similarly Dimri *et al.* (1973) suggested 60 cm x 60 cm spacing (27,000 plants/ha) for peninsular India, while Ganguly (1973) suggested 90 cm x 60 cm spacing for North East Indian conditions. A recent

study at Bangalore has, however, revealed a linear increase in both herb and oil yields due to increase in levels of plant population from 20,000 to 50,000/ha. (Rao *et al.* 1989). Under Lucknow conditions, maximum oil yield was obtained at 60 cm x 30 cm spacing (Yadav *et al.* 1984).

A significant effect of spacing on oil yield and growth parameters of palmarosa was reported by Verma *et al.* (1984). A wider row spacing of 60 cm x 60 cm and 45 cm x 30 cm is recommended for North India (Virmani *et al.* 1977a). But recent studies emphasized closer spacings (30 cm x 30 cm or 45 cm x 30 cm) for obtaining higher yields in Assam, Bangalore, Hyderabad, Delhi, Kerala and Punjab (Hazarika *et al.* 1981; Rao *et al.* 1985a; Pareek *et al.* 1981a; Nair *et al.* 1980; Sarma JS *et al.* 1977; Rao *et al.* 1990). Maheshwari *et al.* (1991) reported that herbage and oil yield was significantly higher at 30 cm x 15 cm spacing and tiller and leaf numbers were enhanced to a sizeable extent.

Singh, Pathak & Bordoloi (1983) studied the spacing requirement of lemongrass in Assam. They compared three levels of spacing (30 cm x 30 cm, 45 cm x 45 cm and 60 cm x 60 cm) and found that closer spacing (30 cm x 30 cm) with 11,000 plants/ha to be optimum for producing maximum herb and oil yields. In North India, it is, however, planted at a spacing of 60 cm x 45 cm or 60 cm x 60 cm on clayey loam or sandy loam soils rich in organic matter. A spacing of 15 cm x 10 cm for lemongrass was recommended for higher production in Kerala (Nair & Chandrashekharan 1974).

Manures and fertilizers

In general, aromatic grasses respond well to application of manures and fertilizers. The magnitude of such responses is high in Java citronella and low in palmarosa and lemongrass. Brown & Mathews (1951) reported that though citronella is a soil exhaustive crop, plantations are not manured to the desired extent. Native producers of Java citronella in Sri Lanka, Guatemala, Haiti and Java generally use spent grass or its ash as fertilizers (Guenther 1950). In Java, green manuring is a common practice. Joachin & Panditteseker a (1953) studied the effects of organic and inorganic fertilizers on herb and oil yields of citronella. The oil yield obtained in 6 years was maximum (716 kg/ha) with NPK fertilization, medium (426 kg/ha) with nitrogen alone and the lowest (308 kg/ha) with no fertilizer application.

In India, Java citronella is reported to respond well to fertilizer application, particularly nitrogen. Khan & Narayan (1972) showed high monetary returns with application of 100 kg N (as urea in six splits) and 50 kg P_2O_5 (as SSP in two splits)/ha per year in addition to 15 t of farm yard manure applied before planting on red sandy loam soils of Bangalore which increased the oil yield level from 85 to 150 kg/ha per year. Dutta & Mishra (1973), working at Bhubaneswar (Orissa) on sandy loam soil having pH 6.1, suggested the application of 25 kg P_2O_5 and 20 kg K_2O at the time of planting followed by 60 kg N application as top dressing for the first year and 120 kg N, 40 kg each of P_2O_5 and k_2O per ha for the second and subsequent years. Ganguly & Thyagarajan (1976) recommended 200 kg N/ha for North East India. Dimri *et al.* (1973), working at Bangalore, on sandy loam soil (pH 7.3) having very low organic carbon and available P and high amount of available K, obtained maximum oil yield from 3 years crop with the application of 450 kg N (in six split doses), 100 kg P_2O_5 and 125 kg K_2O in addition to application of FYM @ 30 t/ha at the time of planting. Bommegowda *et al.* (1983), working on red loamy sand of low to medium fertility and pH 7.5, observed a linear increase in both herb and oil yields due to increase in the levels of N from 75 to 150 kg/ha. There was, however, no response to potassium beyond 42 kg K_2O/ha. In *tarai* conditions of Uttar Pradesh, application of 80 kg N and 40 kg P_2O_5/ha per year without potassium application was found suitable for obtaining optimum herb and oil yields (Singh, Singh & Singh 1983). In the foot hills of West Bengal, application of 200 kg N, 25 kg P_2O_5 and 60 kg K_2O/ha was recommended for optimum yield (Ghosh & Chatterjee 1978). Rao *et al.* (1985a), working at Bangalore, observed maximum oil yield with the application of 400 kg N/ha per year. Neem cake coated urea (NCU) was effective at higher N levels, i.e., 300 and 400 kg N/ha per year. In another study at the same location, urea super granules were a better source than prilled urea (Rao *et al.* 1984). Application of 41.5 kg K/ha in four splits significantly increased total dry herbage yield, oil yield and nutrient uptake of Java citronella as compared with a basal application and 83 hg K/ha in sandy loam soil (Singh *et al.* 1990). Bommegowda *et al.* (1983) suggested 80% N through soil application and rest 20% through foilar spray. Singh, Chowdhri *et al.* (1991) observed that yields were significantly increased

with 44 and 83 kg/ha per year of P and K, respectively. However, the response equation showed 35 and 36 kg/ha in first and second year, respectively, and 62 kg/ha is recommended for both the years to get optimum yields. Rao & Singh (1991) found that the yield per unit area of citronella differed significantly between years. The yield increased up to the second year after which it started to decline. During the first two years, N application up to 300 kg/ha per year increased the oil yield significantly. However, during third and fourth years the response to N was quadratic. This shows that it is possible to reduce the application of N after 2 years, while still maintain the same content and quality of essential oil. The oil content and chemical composition of oil did not change as the age of the crop increased. Singh & Singh (1992) observed that herbage and oil yield with prilled urea and urea supergranules increased up to 200 kg N/ha per year while with NCU the response was only up to 150 kg N/ha. The estimated recovery of N from NCU, urea supergranules and prilled urea were 38, 31 and 21%, respectively. NCU significantly increased the uptake of N, P and K by 17, 15, and 25% respectively, over ordinary urea. NCU increased apparent recoveries by 90% (from 8.4% to 16.0%) and by 45% (from 11.4 to 16.5%) over ordinary urea at 300 and 400 kg N/ha per year, respectively. NCU reduced NH_3 volatilization losses by 31% (from 38% to 29%) over ordinary urea, during a 25 day period indicating that NCU is economical (Rao 1993).

Application of K did not affect the oil content and its quality in Java citronella. However, the same were significantly influenced in the crop harvested in different seasons. Higher oil content (1.37%) was obtained during winter season harvest followed by rainy season (1.32%) and spring season (1.29%) which were significantly superior over summer season. Citronellal content during rainy, winter and spring season harvests recorded 31.59, 28.10 and 29.55%, respectively, over 25.68% in summer season harvest. Citronellol content was high during spring season while in rainy season it was low (Singh *et al.* 1997).

Singh, Chowdhri & Singh (1996) reported that diuron @ 1.5 kg a i /ha checked weed growth and weed dry matter production (51%) at Lucknow. The weeded and diuron treated crops showed increase in dry matter and oil yield by 29.7 and 15.2 and 27.2 and 14.5% respectively, over untreated crop. Diuron treated crops also resulted in 18% higher utilization of applied N over untreated crop. Application of N up to 150 kg/ha significantly increased oil yield.

The demand for nutrients in palmarosa is low to moderate in Indian soils. Being a perennial crop, replenishment of nutrients in the soil maintains a continued good harvest for several years. Sharma *et al.* (1980) recommended application of 40 kg N in addition to 10 t FYM/ha for obtaining optimum yield at Lucknow. Gupta (1972) recommended application of 40 kg N, 40 kg P_2O_5 and 20 kg K_2O per ha for North India. Hazarika & Bora (1977) obtained maximum herb yield with 60 kg N and 40 kg P_2O_5/ha in Assam. Later, at the same location, maximum oil yield was obtained by combined application of 40 kg each of N, P_2O_5 and K_2O/ha (Hazarika *et al.* 1978). On an average, it requires 75 kg N, 40 kg P_2O_5 and 40 kg K_2O/ha for obtaining three harvests per year. Of this, the entire amount of P_2O_5 and K_2O and 12.5 kg N may be placed 5 to 7 cm below the seed at the time of sowing. A similar dose of 12.5 kg N may be applied after 1 month of sowing, after first harvest and 3 months after first harvest. Then, 25 kg N/ha in two splits should be top dressed after taking second harvest in June. The same schedule may be repeated for subsequent years (Pareek *et al.* 1981b). Rao *et al.* (1985b), working on sandy loam soil, suggested application of 240 kg N/ha per year for getting higher oil yield (239.2 kg/ha in 2 years). Sharma *et al.* (1980) worked out the economics of N application. It gave a net return of Rs. 23.38 per kg N at 75 kg N/ha which decreased to Rs. 18.87 at 150 kg N/ha. Application of phosphorus also increased the net return per kg P_2O_5 of Rs 11.83 at 50 kg P_2O_5 /ha, while K_2O did not affect the yield. Application of 150 kg N, 42 kg K_2O/ha increased the biomass and essential oil yields, while P did not show significant response (Rao *et al.* 1991).

Barooah & Khader (1990) reported that highest percentage of P was derived from $N_{80}P_{60}$ (69.11%) followed by $N_{80}P_{60}$ (67.86%). The fertilizer use efficieny was however found to be highest at N_{80} and P_{60} levels. Oil yield and oil recovery percentage and geraniol content were influenced by micronutrient application. Application of Zinc produced the highest oil yield which was significantly superior to control. Soil application of copper sulphate also produced higher oil yield and geraniol content in palmarosa (Thomas 1993).

In lemongrass, Nair & Chandrashekaran (1974) recommended application of 2.5 t of compost and 1.87 t/ha of ash as basal application during land preparation under Kerala conditions. Chatterjee & Ghosh (1977) suggested application of 60 kg N, 50 kg P_2O_5 and 35 kg K_2O/ha for getting maximum yield in hilly tracts and Gangetic plains of West Bengal. Prasad & Mukherjee (1980) sugested application of 40 kg N and 40 kg P_2O_5 /ha for getting higher yield of lemongrass oil. Rao *et al.* (1985a) also obtained increased herb yield with N application. Application of P and K, however, did not show any appreciable increase in lemongrass oil. Prasad (1978), while studying the effect N, P and K on lemongrass (*C. citratus*) noted beneficial effect of P and K interaction with N. For Jammu lemongrass (*C. pendulus*), Singh *et al.* (1976) suggested application of 250 kg N/ha under Jammu conditions.

Pal *et al.* (1992) reported from Jammu that there was no significant difference in lemongrass yield by increasing the level of nitrogen between 120 to 150 kg N/ha in the first year crop. The maximum yield was obtained at 180 kg N/ha in the variety CKP-25. In the second year crop, the highest dose of 340 kg N/ha gave significantly increased oil yield. The citral content did not differ significantly due to graded levels of N. Vitkare *et al.* (1990) observed that application of N significantly increased the aldehyde content in lemongrass oil while P did not show any significant effect. Absence of N and P fertilization yielded an oil which had low aldehyde and citral contents. However, geraniol content of the oil was very high. The performance of four lemongrass strains namely, wild lemongrass, CO-14, SD-68 and Jorlab-2 were tested at Jorhat. Jorlab-2 gave higher yield under the spacing of 60 cm x 70 cm accommodating approximately 27,710 plant population. Oil yield was significantly higher at 200 kg N/ha (Sarma *et al.* 1993).

The effect of micronutrients has not been studied adequately in cymbopogons. In nature, however, the deficiency of micronutrients occurs frequently, particularly in Java citronella and palmarosa. It appears in both new as well as old plantations and more often during regrowth after harvesting the crop. Mostly, it disappears slowly with subsequent growth. In certain situations, however, it continues till the crop is harvested. The specific micronutient(s) involved in this process is not yet clearly known. Gupta *et al.* (1974) observed leaf chlorosis of Java citronella in ratoon crop. They suggested spraying of composite micronutrient salts containing 0.2% Zn, 0.4% Mn, 0.6% Fe and 0.1% Cu followed by two more sprayings of 0.6% Fe at weekly intervals. However, this was a preliminary study and hence needs further investigation. Specific micronutrient deficiency symptoms are also yet to be established. In Kerala, Cu application is recommended for obtaining higher yield of lemongrass oil (Nair, Nair & Chinnamma 1979). Pareek *et al.* (1984) observed beneficial effect of $FeSO_4$ and $MnSO_4$ (0.5%) sprays on palmarosa. Similarly, Sharma *et al.* (1980) reported higher yield of palmarosa in all the four harvests with application of 25 kg $ZnSO_4$/ha.

Thus, it appears that fertilizer requirement of these crops varies to a large extent depending upon the fertility status of the soil and the climatic conditions under which they are grown. In general, the requirement of nutrients, particularly N, is high in citronella and comparatively less in palmarosa and lemongrass. Variable results have been reported in respect of responses to P and K application on these crops. Therefore, it is advisable to apply fertilizers on the basis of soil test values.

Irrigation

Aromatic grasses are generally raised as rainfed crops. However, their growth and yield can be manipulated to a large extent with supplemental irrigation during hot and dry summer months. Palmarosa and lemongrass can be grown without irrigation but with life saving irrigation during summer. Herb and essential oil yields of lemongrass increased due to increased levels of water regime from 0 (control) to 0.8 IW : CPE ratio (Irrigation Water : Cumulative Pan Evaporation) (Singh 1997). However, the information available on this aspect is very meagre. Virmani *et al.* (1977b) suggested 4–6 supplemental irrigations during summer season in lemongrass to boost herb as well as oil yield under North Indian conditions. Apart from these supplementary irrigations, these crops require one or two irrigations after transplanting for establishment. If sufficient soil moisture is available or there is rainfall during or immediately after planting, no irrigation is required for establishment. Among these grasses Java citronella has very shallow root system. Singh, Govind & Rao (1996) reported that Java citronella produced maximum yield when irrigated soil metric potential reaches 60 Kpoar or IW/CPE ratio reaches 0.08. However, palmarosa

and lemongrass have adventitious deep root system which enables them to tolerate soil moisture stress. Maheshwari *et al.* (1984) reported that palmarosa can be successfully grown under rainfed conditions in Madhya Pradesh.

Weed control

Weeds are major constraints for successful cultivation of aromatic grasses. Generally, aromatic grasses are planted at the onset of the monsoon and hence face severe competition with rainy season weeds. Once these grasses are established, they can very well compete with the weeds. Therefore, the initial period during the first harvest is considered very critical when the field should be maintained free of weeds. Yadav *et al.* (1981a) while studying the requirement of weed free period of Java citronella under Lucknow conditions, observed that 15 to 60 days period after planting is very critical for weed-crop competition. In another study at the same location, it was observed that weeds caused up to 50.0% reduction in herb yield in the first year and 17.3% in the second year (CIMAP 1984). Generally, two weedings during first harvest and one weeding within a month after each harvest, are recommended. But during rainy season manual weeding is not always possible. Therefore, to supplement manual weeding, the possibilities of using chemicals for weed control were explored. Duhan & Gulati (1973) obtained 86.25% control of weeds with 2, 4-D ester @ 2 kg ai/ha at Pantnagar. *Portulaca oleracea* L., *Cyperus rotundus* L. and *Cynodon dactylon* Pers. were, however, not controlled with the herbicide. Singh & Rawat (1978) also suggested 2, 4-D application @ 0.5 kg ai/ha (post emergence) for effective control of dicot weeds in Java citronella. Similarly, Khosla (1979) noted a good control of dicot weeds with 2, 4-D (80% sodium salt) @ 2.5 kg/ha (post emergence) on lemongrass at Jammu. Few grasses and some resistant and semi-resistant dicot weeds to 2, 4-D were controlled with repeated post-emergence application of gramoxone @ 5 kg ai/ha. Yadav *et al.* (1981b) tested six herbicides (fernoxone, diuron, simazine, atrazine and nitrofen) for weed control in Java citronella and found diuron and simazine to be most effective.

Weeds caused an average of 40% reduction in herb and oil yield in the first year as against 6% in the second year of harvest. Organic mulch @ 3 t/ha, oxyflurofen @ 0.5 kg/ha, diuron 5 kg/ha and simazine @ 1.5 kg/ha gave herb and oil yield equal to weed check. Palmarosa followed by lemongrass had a better weed suppressing effect than Java citronella (Singh, Singh & Singh 1991). A recent study at Pantnagar revealed that pendimethalin (1.5 kg/ha), terbacil (1.5 kg/ha), oxyfluorofen (0.30 kg/ha), and a combination of simazine and atrazine 1 kg each, were at par with each other and provided 93%, 90%, 87% and 85% oil yield respectively, of that obtained under weed-free conditions. Mulching alone @ 5 t/ha immediately after planting was not effective and it provided only 66% oil yield of that under weed-free conditions (CIMAP 1986).

Harvesting

Time of harvesting is important for obtaining higher oil yield with superior quality. Aromatic grasses are mostly leafy crops and leaves are the sites for both synthesis and accumulation of oil. In palmarosa, however, oil is present in the inflorescence at a higher concentration than in leaves and stems. So its inflorescence is considered most important for obtaining higher oil yield. Usually, the number of harvests feasible in a year is governed by temperature, humidity and soil fertility. In *tarai* conditions of Uttar Pradesh, three harvests of these grasses are possible on highly fertile soil under warm and humid climate whereas in Assam and Kerala, four harvests are feasible because of mild temperature and high humidity round the year. In North India, because of low temperature during winter, only two major harvests are possible. These are harvested 15 to 20 cm above ground level to fasten regrowth and to check mortality of growing shoots.

Rao *et al.* (1948) observed that 7 to 10 days after flowering to be the best time of palmarosa harvest for getting maximum oil yield. Pareek *et al.* (1981c) suggested harvesting at early seeding stage for production of perfumery grade oil. They also ob-served higher percentage of free geraniol with su-perior odour value of oil at early seeding stage as compared to oil at maximum flower open stage. Herbage and oil yield of palmarosa increased in irrigated regions when harvested at full bloom (70% flowering) stage. Herbage and oil yield, oil content and geraniol content were reduced at 70% seed formation stage (Maheshwari *et al.* 1992).

In lemongrass, Nair Chinnamma & Pushpakumari (1979) suggested first harvest at 90 days after planting and subsequent harvests at 50 to 55 days

interval under Kerala conditions. Simi-larly, in Java citronella, maximum of four harvests are possible during September, December, March and June under Assam conditions (Singh & Ganguly 1973). In general, June and September harvesting give higher herb and oil yields than other harvests. The first harvest should be taken 90 days after planting to boost tillering.

Future work

Cymbopogons are widely adapted to different agroclimatic zones of the country. However, they are very sensitive to environmental conditions (rainfall, humidity, temperature and soil fertility) under which they are grown. Therefore, there is wide variation in both yield and quality of oil produced at different locations. These crops (palmarosa and lemongrass) are best suited for utilization in wasteland, particularly saline soils, alkaline soils, hill slopes and marginal lands of semi arid regions with low to moderate rainfall. Besides fulfilling the indigenous requirement, they can earn a sizeable amount of foreign exchange, provided cost effective agrotechnology including improved high oil yielding varieties are evolved for specific locations. The major areas in agronomy where research is to be intensified in the future are mentioned here.

Palmarosa and lemongrass thrive well in low to moderate rainfall areas and hence package of practices should be developed for dry land agriculture since there is already a great deal of pressure on arable land for food crops. The possibility of growing these grasses in various categories of wasteland is to be studied. Preliminary studies at CIMAP, Lucknow, has opened new avenues of cultivating these grasses in both saline and alkaline soils. Palmarosa and lemongrass are reported to be very hardy in nature because of their deep adventitious roots with soil binding properties, so they can be tried in areas subjected to erosion of top soil and in marginal lands of semi-arid regions. The feasibility of intercropping of these grasses in agroforestry systems are also to be explored.

At present, very little information is available on nutrient management of these grasses. Being perennial crops, periodic replenishment of nutrients is essential to keep the plantation viable for several years. The present recommendations are based on one or two years of field study without any consideration to micro-nutrient uptake pattern. This has led to a situation of widespread occurrence of chlorosis resulting in poor oil yield. Therefore, requirement of both macro and micronutrients should be worked out with prime consideration to soil test values and biological yield potential for specific locations. The best period and method of application of the efficient form of fertilizer also need to be worked out at various agroclimatic zones in which they are cultivated. Studies are also necessary to examine the potentiality of non-symbiotic, free living bacteria, like *Azotobacter* and *Azospirillum* and V A mycorrhizae to minimize inorganic fertilizer reqirements.

No systemetic work has been initiated on the irrigation requirement of these crops under intensive cultivation. Supplemental irrigation is required during initial establishment and summer season to maximize oil yield. Therefore, frequency of irrigation along with critical stages needs to be ascertained.

Though weeds pose a severe problem, particularly during initial establishment and early stages of crop growth, very little systematic work has been done on this aspect. An integrated and cost effective weed management practice (including use of herbicides) has to be worked out for specific locations. Plant spacing manipulates crop-weed competition favourably and hence closer spacing with different planting geometry may be tried to minimize weed infestation. Planting of these grasses during rainy season results in severe weed infestation and therefore the possibility of shifting planting time to spring (February–March) for citronella and lemongrass and summer (April–May) for palmarosa, should be explored under irrigated conditions. Harvest management, old plantation management and use of distillation waste for recycling of organic matter also need attention.

In aromatic crops the initial growth is slow and they remain dormant during winter season. Therefore, studies on intercropping with suitable short duration crops like moong, urad, cowpea, lentil and toria which may be beneficial for increasing productivity, requires attention.

References

Barooah H & Khader M D A 1990 Studies on phosphorus utilization by palmarosa (*Cymbopogon martinii* var. *motia*). Indian Perfumer 34 : 147-151.

Bommegowda A, Krishnamurthy K & Narayana M R 1983 Agronomic investigation on Java citronella -macronutrient studies. Indian J. Agron. 28 : 115-117.

Brown E & Mathews W S A 1951 Notes on the aromatic grasses of commercial importance. Colon. Pl. Anim. Prod. 23 : 178-181.

Central Institute for Medicinal and Aromatic Plants (CIMAP) 1984 Annual Report 1984. Central Institute for Medicinal and Aromatic Plants, Lucknow.

Central Institute for Medicinal and Aromatic Plants (CIMAP) 1986 Annual Report 1986. Central Institute for Medicinal and Aromatic Plants, Lucknow.

Chatterjee S K & Ghosh M L 1977 Cultivation of essential oil yielding plants in the hilly tracts and Gangetic plains of Western Bengal. Indian Perfumer 21 : 31-34.

Dimri B P, Narayana M R & Khan M N A 1973 Java citronella. A package of practices for high yield under irrigated conditions. Proc., First Workshop, All India Coordinated Improvement Project on Medicinal and Aromatic Plants (pp. 172-178) University of Agricultural Sciences, Bangalore.

Duhan S P S & Gulati B C 1973 Chemical weed control studies in citronella, Java type (*Cymbopogon winterianus* Jowitt.) : Effect of 2, 4-D on control of weeds, herb and oil yield. Indian Perfumer 17 : 77-82.

Dutta P K & Mishra B C 1973 Progress Report. Regional Research Laboratory, Bhubaneswar.

Ganguly D 1973 Commercial production of citronella oil in North East India. Problems and progress. Indian Perfumer 17 : 48-51.

Ganguly D & Thygarajan G 1976 Factors contributing to the growth of citronella oil industry in North East India. Cultivation and utilization of medicinal and aromatic plants. Regional Research Laboratory, Jammu.

Ghosh M L & Chatterjee S K 1978 Growth and essential oil content of Java citronella in Burdwan, West Bengal. Indian Perfumer 22 : 264-268.

Guenther E 1950 Individual essential oils of the plant family. In : The Essential Oil. IV. D. Van Norstrand Co. Inc., Toronto.

Gupta R 1972 Grow palmarosa oil grass for rose like perfumes. Indian Fmg. 22 (1) : 17-20.

Gupta R, Saini A D & Pandey P C 1974 Possible causes of chlorosis in Java citronella crop. Indian Perfumer 18 : 27-30.

Hazarika J N Barua A & Barooah A K S 1978 Effect of NPK fertilizers on the yield of palmarosa (*Cymbopogon martinii* var. *motia*) under the influence of seasonal variation. Indian Perfumer 22 : 36-39.

Hazarika, J N & Bora A C 1977 Effect of varying concentration of NPK fertilization on oil yield of palmarosa (*Cymbopogon martinii* var. *motia*). Indian Perfumer 21 : 55-53.

Hazarika J N Mishra B P & Bora A C 1981 Effect of spacing on the yield of herb and oil of palmarosa (*Cymbopogon martinii* var. *motia*) grown under Jorhat conditions. Indian Perfumer 25 : 56-59.

Joachin A W R & Panditteseker a D G 1953 Investigation on the cultivation of citronella in Ceylon. I. The effects of organic and artificial fertilizers on the yield of grass and oil. Trop. Agric. Mag. Ceylon Agric. Soc. 109 : 185-194.

Kanjilal P B, Singh R S, Pathak M G & Bordoloi D N 1981 Studies on population pressure and performance of crop raised by seedlings vs. slips on yield of palmarosa (*Cymbopogon martinii* var. *motia*). Indian Perfumer 25 : 51-55.

Khan M N A & Narayan M R 1972 Citronella promises high return to Mysore farmer. Indian Fmg. 21 (12) : 15-17.

Khosla S N 1979 Chemical weeding with gramaxone and 2, 4-D in *Cymbopogon pendulus* Wats. Nees ex. Steud (Jammu lemongrass or RRL-16). Indian Perfumer 23 : 125-127.

Maheshwari S K, Chauhan G S & Trivedi K C 1992 Response of palmarosa oil grass to irrigated and unirrigated sward and harvesting stage. Indian Perfumer 36 : 54-56.

Maheshwari S K, Gangrade S K & Chuhan S 1991 Influence of planting geometry on irrigated palmarosa oil grass. Indian Perfumer 33 : 177-180.

Maheshwari S K, Yadav S & Gupta R S 1984 Fertilizer need of palmarosa oil grass (*Cymbopogan martinii* var. *motia*) under rainfed condition of Madhya Pradesh. Indian Perfumer 28 : 77-81.

Nair E V G & Chandrashekaran K 1974 Studies on the cultural practices of lemongrass (*Cymbopogon flexuosus* Stapf). Indian Perfumer 18 : 17-18.

Nair E V G, Chinnamma N P & Pushpakumari R 1979 A quarter century of research on lemongrass at Lemongrass Research Station. Indian Perfumer 23 : 218-219.

Nair E V G, Chinnamma N P & Puspakumari R 1980 Influence of spacing on the grass and oil yield of palmarosa (*Cymbopogon martinii* var. *motia*). Indian Perfumer 24 : 25-26.

Nair E V G, Nair K C & Chinnamma N P 1979 Field experiments with micronutrients on yield of grass and oil and citral content of oil of East Indian lemongrass (*Cymbopogon flexuosus*) variety OD-19. Indian Perfumer 23 : 55-58.

Pal B, Singh K K, Jadaun S P S & Parmar A S 1989 Effect of water salinity on herb and oil yield and composition of some *Cymbopogon* species. Indian Perfumer 33 : 196-199.

Pal S, Balyan S S, Dutt P & Rao B L 1994 Effect of time of planting an growth and oil yield in CKP-25 Lemongrass. Indian Perfumer 38 : 65-67.

Pal S, Chandra S, Balyan S S, Singh A & Rao B L 1992 Nitrogen requirement of new lemongrass strain CKP-25. Indian Perfumer 36 : 75-80.

Pareek S K, Maheshwari M L & Gupta R 1981a Cultivation of palmarosa oil grass. Indian Fmg. 31 (4) : 22-26.

Pareek S K, Maheswari M L & Gupta R 1981b Effect of N P K fertilizers on yield and quality of oil of palmarosa grass under cultivation. Indian J. Agron. 26 : 122-129.

Pareek S K, Maheswari M L & Gupta R 1984 Effect of farmyard manure and micronutrients on yield and quality of palmarosa oil grass (*Cymbopogon martinii* var. *motia*). Indian Perfurmer 28 : 108-111.

Pareek S K, Saxena D B, Maheshwari M L & Gupta R 1981c Study of palmarosa oil grass for higher yield, oil and its quality under cultivation. Indian Perfumer 25 : 64-70.

Patra P & Dutta P K 1979 Studies on salinity tolerance in aromatic and medicinal plants. J. Orissa Bot. Soc. 1 (1) : 17-18.

Prasad L K 1978 Effect of nitrogen, phosphorus and potassium on the yield of lemongrass (*Cymbopogon citratus*). Sci. Cult. 44 : 167-168.

Prasad L K & Mukherjee S K 1980 Effect of nitrogen, phosphorus and potassium on lemongrass. Indian J. Agron. 25 : 42-44.

Rao B R R, Rao E V S P, Singh K, Singh M, Kaul P N & Bhattacharya A K 1991 Fertilizer effect on palmarosa (*Cymbopogon martinii*) under semi-arid tropical condition of India. Indian J. Agric. Sci 61 : 499-501.

Rao B R R, Singh K, Kaul P N & Bahattacharya A K 1990 Response of palmarosa (*Cymbopogon martinii* var. *motia*) to plant spacing and nitrogen fertilizer application. Intl. J. Trop. Agri. 8 : 177-183.

Rao E V S P & Singh M 1991 Long term studies on yield and quality of Java citronella (*Cymbopogon winterianus* Jowitt) in relation to nitrogen application. J. Essen. Oil Res. 3 : 419-424.

Rao E V S P, Singh M & Ganesha Rao R S 1985a Effect of N P K fertilizers on yield and nutrient uptake in lemongrass. Int. J. Trop. Agric. 3 : 123-127.

Rao E V S P, Singh M & Ganesha Rao R S 1985b Effect of plant spacing and application of nitrogen fertilizer on herb and essential oil yield of palmarosa (*Cymbopogon martinii* var. *motia*). J. Agric. Sci. (Camb.) 104 : 477-479.

Rao E V S P, Singh M, Narayan M R & Chandrasekhar G 1984 Relative efficiency of prilled urea and urea supergranules in Java citronella *Cymbopogon winterianus* Jowitt.). Fert. Res. 5 : 435-437.

Rao E V S P 1993 Potential use of neem-cake coated urea to improve nutrient uptake, N recoveries and to reduce N losses in perennial aromatic grass, Java citronella, Bangalore.

Rao E V S P, Singh M & Rao R S G 1989 Nitrogen and spacing studies in Java citronella (*Cymbopogon winterianus* Jowitt.). Indian J. Agron. 34 : 455-457.

Rao T V S, George A A, Rao R L & Desikacher M 1948 Palmarosa oil (Part I). Indian Group. J. 14 (6) : 159.

Sarma J S, Saini S S & Bains D S 1977 Influence of row spacing and N and P application on the fresh herb and oil yield of palmarosa (*Cymbopogon martinii* var. *motia*). Indian Perfumer 21 : 44-46.

Sarma T C, Bordoloi D N, Ganguly D S & Thyagarajan G 1977 Development of citronella oil industry in village Yaongyimsom in Nagaland and future scope. Indian Perfumer 21 : 94-98.

Sarma T C, Sharma P C & Bordoloi D N 1993 Response of Jor L2 - An improved strain of lemongrass to population density and nitrogen levels. Indian Perfumer 37 : 171-177.

Shai A K & Singh A 1981 Climatological parameters and correlation studies on the oil content and quality of Jammu lemongrass. Indian Perfumer 25 : 124-126.

Sharma M L, Pandey M B, Khanna R K & Kapoor L D 1972 Essential oil from plants raised on alkaline soils. Indian Perfumer 16 : 27-30.

Sharma S N, Singh A & Tripathi R S 1980 Response of palmarosa to nitrogen, phosphorus, potassium and Zinc. Indian J. Agron. 25 : 719-723.

Singh A, Balyan S S & Shahi A K 1976 Cultivation of Jammu lemongrass in North India under irrigated conditions. In: Cultivation and Utilization of Medicinal and Aromatic Plants. Regional Research Laboratory, Jammu.

Singh A, Singh K & Singh D V 1991 Suitability of organic mulch (distillation waste) and herbicides for weed management in perennial aromatic grasses. Trop. Pest Management 37 : 162-165.

Singh A, Singh M & Singh D V 1993 Effect of age of seedlings and nursery seed nutrient management on plant establishment. Indian Perfumer 37 : 155-160.

Singh D V & Anwar M 1985 Effect of soil salinity on herb and oil yield and quality of some *Cymbopogon* species. J. Indian Soc. Soil Sci. 33 : 362-365.

Singh H S & Ganguly D 1973 Studies on the cultivation of Java citronella (*Cymbopogon winterianus* Jowitt) in Assam. Part I. Growth of the plants and yield of the leaves in relation to various factors. Indian Perfumer 16 : 29-37.

Singh H S & Rawat K S 1978 Factors affecting growth and yield of Java citronella (*Cymbopogon winterianus* Jowitt) in North Bengal. Indian Perfumer 22 : 104-106.

Singh K, Chowdhri A & Singh D V 1996 Effect of diuron and nitrogen on weed growth, oil yield and N utilization in Citronella Java (*Cymbopogon winterianus*). Indian Perfumer 40 : 47-52.

Singh K, Chowdhri A, Subhrahmanyam K, Chatterjee B N & Singh D V 1990 Influence of amounts and methods of potassium application on yield and quality of citronella Java (*Cymbopogon winterianus* Jowitt). J. Agric. Sci. (Camb.) 115 : 247-252.

Singh K, Chowdhri A, Subhrahmanyam K, Chatterjee B N & Singh D V 1991 Growth and yield response on Java citronella to phosphorus and potassium at higher nitrogen. J. Potassium Res. 7 (1) : 35-46.

Singh K & Singh D V 1992 Effect of rates and sources of nitrogen application on yield and nutrients uptake of citronella Java (*Cymbopogon winterianus* Jowitt). Fert. Res. 33 : 187-191.

Singh K, Singh D V & Singh V P 1997 Effect of harvesting seasons and levels of Potassium on quality of essential oil of Citronella Java (*Cymbopogon winterianus* Jowitt). Indian Perfumer 41 : 53-56.

Singh M 1997 Growth, herbage, oil yield, nitrogen uptake and nitrogen utilisation efficiency of different cultivars of lemongrass (*Cymbopogon flexuosus* Stapf.) as affected by water regimes. J. Med. Aromatic Plant Sci. 19 : 695-699.

Singh M, C Govind D C & Rao E V S 1996 Oil and herb yield of Java citronella (*Cymbopogon winterianus* Jowitt) in relation to nitrogen and irrigation regimes. J. Essential Oil Res. 8 : 531-534.

Singh R P, Singh B & Singh V 1994 Effect of fertility levels on Citronella Java in relation to water salinity. Indian Perfumer 38 : 47-50.

Singh R S, Pathak M G & Bordoloi D N 1983 Citral of lemongrass under different plant population and soil pH. Pafai J. 5 (1) : 33-36.

Singh V P, Kothari S K, Duhan S P S & Singh D V 1991 Response of citronella (*Cymbopogon winterianus* Jowitt) to date of planting and frequency of harvest in subtropical India. Intl. J. Trop. Agric. 9 : 71-77.

Singh V P, Singh K & Singh K 1983 Responses of citronella Java (*Cymbopogon winterianus* Jowitt) to nitrogen, phosphorus and potassium fertilization. Indian Perfumer 27 : 153-155.

Thomas J G K 1993 Effect of micronutrients on oil yield and quality of palmarosa (*Cymbopogon martinii* var. *motia*). Indian Perfumer 37 (1) : 45-47.

Verma P K, Sharma G D, Dhindsa K S & Sangwar N K 1984 Spacing and growth attributes and oil content in palmarosa (*Cymbopogon martinii* var. *motia*). Indian Plant Sci. 2 (1-2) : 45-49.

Virmani O P & Dutta S C 1973 Farm Bull. No. 1. Central Indian Medicinal Plants Organisation, Lucknow.

Virmani O P, Srivastava R & Srivastava G N 1977a Palmarosa and its cultivations in India. Farm Bull. No. 7. Central Indian Medicinal Plants Organisation, Lucknow.

Virmani O P, Srivastava R & Srivastava G N 1977b Lemongrass in India. Farm Bull. No. 6. Central Indian Medicinal Plants Organisation, Lucknow.

Vitkare D G, Phasate S N, Zade K B & Paulkar K S 1990 Effect of nitrogen and phosphorus fertilization on the oil content and oil quality of lemongrass (*Cymbopogon flexuosus*). Punjab Rao Krishi Vidhyapeeth Res. J. 14 (1) : 64-66.

Yadav R L, Anwar M & Ram M 1984 Fertilizer nitrogen recovery and growth of Java citronella as influenced by row spacing and nitrogen. Indian J. Agron. 29 : 305-308.

Yadav R L, Mohan R & Singh D V 1981a Requirement of weed free period for optimum herb and oil yield of citronella Java. Indian Perfumer 25 : 37-40.

Yadav R L, Mohan R & Singh D V 1981b The effect of herbicides on weed population, essential oil content and herb yield of citronella Java. Indian Perfumer 25 : 47-52.