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Review/Overview Article

Agronomic research on medicinal and aromatic plants in India – Status and future research needs

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ABSTRACT

Medicinal and aromatic plants (MAPs) are increasingly perceived as diversification crops in Indian agriculture. Development of suitable agronomic practices for MAPs is crucial to convert these plants into economically viable components in existing cropping systems. The agronomic research conducted on various MAPs in different regions in India has been reviewed. The review covers different areas of agronomic research such as nutrient management, cropping systems, water management, weed control, crop husbandry, environmental factors and secondary metabolite production, post harvest methods, utilization of marginal/problem soils and organic farming. Establishing value chains to develop MAPs based enterprises in rural areas has been emphasized. An attempt has been made to highlight important research carried out on these crops along with suggestions for future research in the above areas. New directions for conducting agronomic research in MAPs have been given.

Key words: Medicinal and aromatic plants, Secondary metabolites, Diversification of crops

Though minor crops, medicinal and aromatic plants (MAPs) contribute significantly to rural economy and health security of the country. More than 90% of the formulations under the Indian systems of medicine contain plant-based raw materials. International market of medicinal plants is over US $ 60 billion per year. India exports herbal materials and medicines to the tune of nearly ₹ 600 crores annually (Planning Commission, 2000). While about 2000 medicinal plants are used in the Indian systems of medicine, 500 of these are more commonly used. However, less than 50 medicinal plants are considered on priority for development of agro-techniques by National Medicinal Plants Board, Government of India. While W.H.O. published guidelines for GACPS (Good Agricultural and Collection Practices) for medicinal plants, it is necessary for individual countries to develop agrotechnologies for medicinal plants. It is estimated that medicinal plants are cultivated over more than 1.10 lakh ha and aromatic plants over more than 2 lakh ha in the country. Herbal based drug industry in the country is valued at more than 4000 crores annually. India is a leader in the production of a variety of essential oils (Lawrence, 2009). Some important medicinal and aromatic plants, their active/principal constituents and their uses are given in table 1.

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The present review covers some important MAPs on which significant agronomic research was conducted in different parts of India. Even some relatively old references have been included to highlight the fact that agronomic research in these crops is relatively new compared to other field crops. The crops covered in the present review include mint species (*Mentha arvensis, M. piperita, M. citrata, M. spicata*), *Cymbopogon* species (*Cymbopogon winterianus, C. flexuosus, C. martinii*), coriander, *Ocimum sanctum, Ocimum basilicum,* scented geranium, davana, musk (*Abelmoschus moschatus*), vetiver, *Eucalyptus citriodora, Jasminum grandiflorum, Jasminum sambac,* tuberose, *Rosa damascena,* German chamomile among aromatic plants and ashwagandha, senna, *Coleus forskohlii,* opium, *Gloriosa superba, Centella asiatica, Bacopa monnieri* among medicinal plants.

Nutrient Management

Yield

Work on nutrient management in medicinal and aromatic plants (MAPs) is fairly a recent phenomenon; a little more than three decades. Information on nutrient concentrations, their uptake and relation between nutrients and yields had been reviewed (Prakasa Rao, 1992). Subsequently, a few reviews appeared on the subject (Prakasa

Rao, 1993a; Prakasa Rao *et al.,* 1998b, Prakasa Rao, 2000a). Several workers have conducted studies on a variety of MAPs in different agroclimatic regions of India; major work was carried out in *Mentha* sp. and *Cymbopogons.* The response of different mint spp. is presented in table 2. The data showed that in general the demand of mint species for nitrogen is in the order :*M. citrata* > *M. spicata* > *M. piperita* > *M. arvensis.*

Recommended dose of N for *M. arvensis* varies from 40 to 200 kg N/ha (Table 2). The nitrogen depletion and loss of organic matter over years is reported with higher N levels (150 kg/ha) as compared to 80 kg N/ha from *Tarai* region of Uttar Pradesh (Kothari *et al.,* 1987b, Singh *et al*., 1989a). While urea has been a common source of N, Ram *et al.,* (1987) found the use of USG (urea super granules) or NCU (neem coated urea) or LCU (lac coated urea) to be more beneficial in Japanese mint. While most research was focused on N, some work on use of phosphorus in *M. arvensis* at Pantnagar (Singh, 1979, Chauhan *et al.,* 1991) and Lucknow (Sharma and Singh, 1980) was done. Very little work is done in secondary/micronutrients in mints. However, reports on S-deficiency in *M. arvensis* in Haryana (Singh *et al.,* 1986), and its response to Zn and Fe in Central Uttar Pradesh (Ram *et al.,* 1996), and to Zn, Mn, Cu, B, Mo, Fe at Pantnagar (Singh *et al.,* 1981d) are available. However, work on more efficient methods of nutrient management and resolving emerging major/micronutrient deficiencies in different soil conditions as also on integrated nutrient management in *M. arvensis* is warranted.

Cymbopogon sp. consisting of citronella (*Cymbopogon winterianus*), lemongrass (*C. flexuosus*) and palmarosa (*C. martinii* var. motia) are very important aromatic plants yielding essential oils used widely in flavour/fragrance industries. Being perennial, these crops tend to remove certain nutrient elements continuously thus necessitating their appropriate management. Prakasa Rao (2000a) reviewed work on nutrient management in *Cymbopogons*. While wide spread response to N was found, occasional response to other nutrient elements have been reported in this group of crops. Response of citronella up to 450 kg N/ha in red soils of south India (Prakasa Rao *et al.,*

Table 1. Some important medicinal and aromatic plants, their active constituents and uses

Plant	Active/principalconstituents	Uses
Cassia angustifolia, Cassia acutifolia	sennosides	laxative
Plantago ovata	psyllium mucilage	-do-
Glycyrrhiza glabra	glycyrrhetiaic acid	antiinflammatory
Commiphora mukul	guggul sterones	-do-
Opium poppy	opiumalkaloids papavarin narcotine	analgesic
Gloriosa superba	colchicine	gout treatment
Rauvolfia serpentina	reserpine	hypotensive
Catharanthus roseus	vinblastine vincristine ajmalicine	anticancer anticancerhypotensive
Taxus baccata	taxol	anticancer
Podophyllum emodi	podophyllotoxine etoposide tenoposide	-do-
Mappia foetida	camptothecin	-do-
Digitalis lanata	digoxin, lanatoside	cardiotonic
Berberis sp.	berberine	antidiarrhoel
Cinchona ledgeriana	quinine	antimalarial
Artemisia annua	artemisinin	-do-
Cymbopogon winterianus Jowitt.	citronellal citronellol geraniol	perfumery, raw material for various aroma chemicals
Coriandrum sativum L.	linalool, linalyl acetate	flavouring food and pharmaceuticals, perfumery
Artemisia pallens Wall.	davanone,davanofurans	flavouring cakes,pasteries,tobacco, beverages high grade perfumes
Eucalyptus citriodora Hook.	citronellal,isopulegol,citronellol	perfumery
Pelargonium graveolens L.Her.ex Ait.	l-citronellol,geraniol,linalool	perfumery and flavouring
Jasminum grandiflorum L.	linalool, benzylacetate, indole,eugenol, benzyl benzoate	perfumery
Cymbiopogon flexuosus (stend) Wats.	citral	flavours, cosmetics, perfumes, manufacture of vitamin A
Bursera delpechiana Poisson ex Engl.	linalool, linalyl acetate	cosmetics, soaps
Cymbopogon martinii(Roxb.)Wats.	geraniol,geranyl acetate,linalool	perfumery
Pogostemon cablin Benth.	patchouli alcohol, sesquiterpenehydrocarbons	perfumery
Rosmarinus officinalis L.	1,8-cineole, linalool myrcene, camphene	perfumery
Santalum album L.	a-santalol, b-santalol, a- & b-santalene	perfumery

1985b), 200 kg N/ha in Assam (Singh *et al.,* 1980) and 180 kg N/ha in Lucknow (Yadav *et al.,* 1984) was observed. Lemongrass responded up to 40 kg N/ha in Ranchi (Prasad and Mukherjee, 1980), 300 kg N/ha in Aligarh (Samiullah *et al.,* 1988) and 200 kg N/ha in Jorhat (Sarma *et al.,* 1993) and Bangalore (Singh *et al.,* 2002). In palmarosa, application of up to 240 kg N/ha/yr in red soils of Bangalore (Prakasa Rao *et al.,* 1985a), 40 kg N/ha in Delhi (Pareek *et al.,* 1983a), 25.50 kg N/ha in Indore (Maheswari *et al.,* 1992), 25 kg N/ha in Kerala (Chinnamma *et al.,* 1988), 80 kg N/ha in Tamil Nadu (Barooah and Khader, 1990) was recommended. Low recoveries of N especially by citronella have been studied in detail (Prakasa Rao *et al.,* 1983b) and improved methods of N application such as split application (Prakasa Rao 1988d), use of NCU (Prakasa Rao *et al.,* 1985b), USG (Prakasa Rao *et al.,* 1984b), amelioration of Fe deficiency (Puttanna *et al.,* 1993), use of organics (Puttanna and Prakasa Rao, 1997) were found to improve the NUE in citronella (table 3). Being perennial, gradual depletion of P and K in long run and need for application of these nutrients in palmarosa has been emphasized (Prakasa Rao *et al.*, 2001). Response of palmarosa to Zn, Cu and Mn was reported in Kerala (Geetha & Thomas, 1993). Iron chlorosis and its effect on oil quality in *Cymbopogon* sp. was reported from Hyderabad (Rajeswara Rao *et al.,* 1996).

Coriander responded to 50 kg N/ha (Prakasa Rao *et al.,* 1983a) in Bangalore and to 40 kg N/ha in Pantnagar (Singh *et al.,* 1983). Application of 100 kg N/ha gave more essential oil and eugenol yields of *Ocimum sanctum* (Dey and Choudhuri, 1984). Musk (*Abelmoschus moschatus*) responded to 120 - 35 kg N-P/ha (Hegde *et al.,* 1984). *Eucalyptus citriodora* requires 150 kg N/ha (Sirsi *et al.,* 1984). Patchouli (*Pogostemon cablin*) responds to 200 kg N/ha in red soils of Bangalore (Puttanna *et al.,* 2005b, Bhaskar, 1995) and also response to P was observed (Hariprakasa Rao and Vasant Kumar, 1989). Application of 60 – 52 - 200 g N - P - K/plant/year along with 30 kg FYM for *Jasminum grandiflorum* (Natarajan and Madhava Rao, 1979) and 240 g each of N, P and K along with 10 kg FYM plant/year for *Jasminum sambac* (Natarajan *et al.,* 1981) were recommended in Coimbatore. Scented geranium required 240 kg N/ha in plains (Prakasa Rao *et al.,* 1988c) and 60 kg each of N, P and K in Kodai hills (Mani *et al.,* 1981). Use of modified urea materials was found advantageous in scented geranium (Rajeswara Rao *et al.,* 1990b). Application of 80 kg N/ha in davana (Prakasa Rao *et al.,* 1997) and 150 kg N and 100 kg K/ha in rosemary (Puttanna *et al.,* 2010a) was suggested in red soils of Bangalore. In Kashmir, 200 : 44 : 42 kg N : P : K/ha was recommended for Rose (*Rosa damascena*) (Jhon *et al.,* 1992). Nitrogen @ 60 kg/ha was recommended for German chamomile (*Matricaria chamomile*) in Himachal Pradesh (Johri *et al.*, 1992). Use of biofertilisers has been studied in patchouli and use of *Trichoderma harzianum* (Puttanna *et al.,* 2010b) and the mycorrhizal treatment, *Glomus etunicatum* (Arpana *et al.,* 2008) gave high yields of patchouli oil. A microbial con-

Table 3. Efficient N management techniques in Java citronella

Technique	% improvement over conventional method
Split application	16
Urea supergranules	12-15
Neem-cake coated urea	25
DCD-treated urea	31
Fe-deficiency correction	36
Combination of organics and inorganics	33

(Prakasa Rao *et al.,* 2000b)

Table 2. Recommended dose of nitrogen for mint species in different parts of India

Crop	Region	Fertiliser dose (kg/ha)	Reference
Mentha arvensis	Central Uttar Pradesh	200 N	Sharma & Singh, 1980
	Uttar Pradesh (*Tarai*)	150 N	Kothari *et al.,* 1987b
	West Bengal	100 N	Munsi & Mukherjee, 1982
	Maharastra	40 N	Shelke and Morey, 1978
M. piperita	Himachal Pradesh	160 N	Bhardwaj *et al.,* 1980
	Uttar Pradesh (*Tarai*)	100 N	Singh *et al.,* 1979c
	Central Uttar Pradesh	80 N	Yadav *et al.,* 1985
M. citrata	Himachal Pradesh	300 N	Bhardwaj *et al.,* 1979
	Uttar Pradesh (*Tarai*)	120 N	Singh *et al.,* 1979b
	Punjab	125 N	Randhawa *et al.,* 1984b
	Central Uttar Pradesh	150 N	Singh *et al.,* 1992
	Kodaikanal	75	Rajeswara Rao *et al.,*1983
M. spicata	Uttar Pradesh (*Tarai*)	120 N	Singh and Duhan, 1979
	Himachal Pradesh	225 N	Bharadwaj *et al.,* 1979
	Central Uttar Pradesh	150 N	Singh *et al.,* 1992

sortia including *Glomus etuncatum* and plant growth promoting rhizo-microorganisms like *Azotbacter chroococcum*, *Trichoderma harzianum* (biocontrol agent), *Burkholderia cepacia* (P solubilizer) was found beneficial , especially in combination with 50% recommended fertilizers for patchouli oil production (Arpana *et al.,*2010).

Research on medicinal plants (MPs) is not as extensive as in aromatic plants. Thirty kg N/ha was recommended for ashwagandha (*Withania somnifera*) in Maharastra (Dahatonde *et al.*, 1983). Application of 30 kg N along with 10 t FYM/ha in Delhi (Pareek *et al.,* 1989) and 50 kg N/ha in Tamil Nadu (Ilangovan *et al.,* 1989) was recommended for senna (*Cassia angustifolia*) where N delayed flowering and P hastened it. FYM @ 5t/ha and 50 kg N/ha gave higher yield, sennoside content in senna in Hyderabad (Pratibha *et al.,* 2010). *Coleus forskohlii* requires 40 – 26 – 45 kg N - P - K/ha (Veeraragavathatham *et al.,* 1988). Application of 50 kg N and 10.75 kg P/ha (Turkhede *et al.,* 1981b), foliar spray (1%) of urea (Ramanathan, 1982) and integrated nutrient management using 10 t FYM and 25.8 kg P/ha (Singh and Turkhede, 1983) were found beneficial to opium (*Papaver somniferum*). Isabgol responded up to 30 kg N/ha in N deficient soils of Gujarat (Kalyanasundaram *et al.,* 1982). *Gloriosa superba* requires 160 kg N/ha in red soils of Bangalore (Kumaraswamy *et al.,* 1994). The various recommendations for Dioscorea are : 100 kg N/ha in Bangalore (Hegde, 1983), 150 - 67 kg N - K/ha in Jorhat (Singh *et al.,* 1981b), 200 - 22 kg N - P/ha in Lucknow (Singh *et al.,* 1981a), 350 kg N/ha in 2 splits in lime treated soils of Darjeeling (Saha and Chatterji, 1991). In periwinkle, 50 kg N/ha was recommended (Prakasa Rao *et al*., 1988a). Combination of organics and inorganics were found beneficial in *Centella asiatica* (Puttanna *et al.*, 2006), ashwagandha (Puttanna *et al*., 2005a) and *Bacopa monnieri* (Prakasa Rao *et al*., 2005a). Pyrethrum responded to N and P in acidic soils of Kodaikanal (Rajeswara Rao *et al*., 1983). Application of 15t FYM in combination with 100 : 13 : 25 (N : P : K) gave high yield of gel in *Aloe vera* in red soils (Prakasa Rao *et al.,* 2008a). Prakasa Rao and Puttanna (2009) reviewed micronutrient fertilizer use in MAPs.

Quality – Secondary Metabolites

In opium poppy, application of 50 kg N/ha increased morphine content; but not P application (Turkhede *et al.,* 1981b). Application of N, P and K at 20 kg each/ha gave maximum alkaloid content in *Catharanthus roseus* (Munsi *et al.,* 1985). In *Artemisia annua,* boron and iron significantly increased herb yields; however copper and manganese were inhibitory to herb yields and artemisinin content was significantly positively associated with herb yields (Srivastava and Sharma, 1990). In *Andrographis paniculata*, 75 kg N/ha recorded the highest andrographolide content (Muniramappa *et al.,* 1997). In senna (*Cassia angustifolia*) 50 kg N/ha increased sennoside yield by 44% over control (Kalyanasundaram *et al.,* 1981).

In *M. arvensis*, high N concentrations decreased menthol content and increased menthone content (Singh *et al.,* 1977, Kothari, *et al.,* 1993). Menthol accumulation rate was the highest (264 gms/ha/day) at 120 kg N and lowest (213 gm/ha/day) at no N application (Yadav *et al.,* 1981b). N increased linalool and decreased linalyl acetate in *Mentha citrata* and slightly increased carvone content in *Mentha spicata* and menthol and menthone content in *Mentha piperita* (Singh *et al.,* 1981c).

In *O. basilicum,* application of N increased concentration of methyl chavicol and decreased linalool (Prakasa Rao *et al.,* 2007). Prakasa Rao *et al.,* (1995) studied seasonal variations in essential oil concentration and chemical composition in scented geranium. Weather parameters such as atmospheric temperatures and rainfall have influenced the oil content and concentrations of citronellol, geraniol and citronellyl formate in the oil. Deficiencies of P and K resulted in changes in essential oil composition and content in some aromatic plants grown in red soils (Prakasa Rao *et al.,* 1996).

Thus although some information is available in nutrient management of MAPs in India, it is not adequate. Further, with changing cropping patterns that include MAPs in intercropping systems etc. which deplete significantly more nutrients (Prakasa Rao *et al.,* 2000b) (Table 4), strategizing nutrient management and also amelioration of emerging deficiencies of macro/micro nutrients while correlating nutrient supply with the secondary metabolite production in MAPs need continuing research efforts. There is also a scope to customize fertilizers for secondary metabolite production in MAPs (Prakasa Rao and Puttanna, 2007).

Cropping Systems

MAPs are generally considered as diversification crops. While it is agronomically possible to cultivate MAPs as pure crops; it is prudent to incorporate MAPs in existing/improved cropping systems in order to improve land use efficiency and economic gains while minimizing risks to the farmers (Figs. 1 & 2). Research conducted in different parts of the country shows ample evidence of the possibilities of incorporating MAPs in different cropping systems (Tables 5, 6, 7).

Mints and *Cymbopogons* have been considered by many researchers for incorporation in food crop systems.

Table 4. Nutrient removal by some aromatic crop based intercropping systems

Cropping system	Nutrient removal (kg/ha)			% Increase in NPK uptake
	N	P	K	
Palmarosa sole	156.5	31.3	180.4	-
Palmarosa (Blackgram-blackgram)	249.7	44.1	230.2	42.3
Palmarosa (Jowargrain-blackgram)	245.8	65.3	224.4	45.4
Palmarosa (Jowar fodder-ratoon)	213.1	48.0	236.0	35.0
Geranium sole	215.2	32.2	194.3	-
Geranium + cowpea	315.9	41.0	261.4	40.0
Geranium + blackgram	265.8	36.7	212.2	3.5
Citronella Pure	60.26	10.40	87.44	-
Citronella + Fm-Fm	115.54	26.36	198.33	115
Citronella + Cp-Fm	149.24	24.51	216.73	147
Citronella + Cp-Cp	222.45	29.11	239.18	210
Citronella + Sb-Fm	278.51	33.09	174.04	207
Citronella + Sb-Sb	356.95	38.97	175.48	261

Fm – Fingermillet, Cp- Cowpea, Sb-soybean

(Singh *et al.,* 2001; Prakasa Rao *et al*., 2000b)

Fig. 1. Intercropping of blackgram in palmarosa (*Cymbopogon martinii* var.motia)

Fig 2. Intercropping of patchouli in coconut plantations

In Punjab, *M. arvensis* can successfully follow potato, senji, toria, oats; in case of water logged soils rice can follow after first cut of mentha (Randhawa *et al.,* 1983). In North Central India, radish, okra and cowpea when intercropped with *M. arvensis* gave higher returns (Singh *et al.,* 1998). Onion is also a profitable intercrop in *M. arvensis* (Kothari *et al.,* 2000, Gill *et al.,* 2007). In *Tarai* and Central Uttar Pradesh *Tulsi*-potato-mentha and rice-potato-mentha crop rotations were most profitable (Ram *et al.,* 2002). Intercropping *Mentha* sp. in sugarcane in Uttar Pradesh gave higher land use efficiencies and returns (Kothari *et al.,* 1987a, Kothari *et al.,* 1995). In sub temperate climate of Himachal Pradesh, *Toria*- *M. piperita*–ratoon system was found an efficient system (Bhardwaj *et al.,* 1983).

Cymbopogons, being perennial and slow growing initially are ideal candidates for inclusion of intercrops. Intercropping systems based on incorporation of blackgram and cowpea gave the best land use efficiency (LUE) in Java citronella (*C. winterianus*) in red soils of South India (Prakasa Rao *et al.,* 1988b). Similarly, intercropping of legumes in lemongrass (*C. flexuosus*) (Singh, 1995) and in palmarosa (*C. martini*i var. motia) (Prakasa Rao *et al.,* 1994) was found to significantly increase LUE.

Cultivation of MAPs as intercrops has been suggested in plantation crops (Prakasa Rao, 2002). In 20 year coconut plantations in Kerala with 27-35% light interception, adaptability and performance analysis showed that rose coloured leadwort (*Plumbago rosea*) gave the best returns (BCR of 3.50) as compared to four other medicinal plants, *Shatavari* (*Asparagus racemosus*), vasaka (*Adatoda beddomei),* jivanti (*Holostemma adakodien)* and kacholam (*Kaempferia galanga*) (Kurian *et al.,* 2003). In guava orchards in Rajasthan, citronella, lemongrass and palmarosa intercropping was found promising (Singh and Bajpai, 2001). Under heavy shade of rubber, the medicinal plants, S*trobilanthes heyneanus, Plumbago rosea* and

Adhatoda vasica can be intercropped in Kerala (Sathik *et al.,* 1995).

Mentha arvensis, M. piperita, M. citrata, *Cymbopogon martinii* and *C. flexuosus* can be intercropped under poplar (*Populus deltoides)* (Singh *et al.,* 1985) and lemongrass under *Eucalyptus citriodora* plantation (Chauhan *et al.,* 1997) in *Tarai* region of Uttar Pradesh. Out of 64 species tried, *Acorus calamus, Adhatoda vasica, Aloe barbadensis, Artemisia vulgaris, Cannabis sativa, Centella asiatica, Curcuma amada, C. longa, Cymbopogon winterianus, Piper longum, Solanum indicum, Vetiveria zizianoides, Ammomum subulatum, Calotropis gigantea, Ocimum sanctum, Valeriana wallichi* and ginger were found most suitable for growing under poplar in Uttar Pradesh *Tarai* (Jha and Gupta, 1991). Under rainfed conditions in the hilly zones of Karnataka, arecanut, cashew nut and teak were suitable to intercrop medicinal plants (Channabasappa *et al.,* 2007). *Eucalyptus citriodora* and *Cinnamomum camphora* can have aromatic grasses as components in North India and Karnataka (Shiva and Jaffer, 1990).

Intercropping cowpea, greengram and blackgram in *kharif* and mustard and oats in *rabi* in vetiver and pigeonpea in palmarosa gave good results in Delhi (Pareek and Maheswari, 1993). Rose and saffron intercropping system gave higher land equivalent ratio (LER) (2.16), ATER (1.44), monetary equivalent ratio (0.83) in Kashmir (Tajuddin *et al.,* 1993). In spring planted citronella, intercropping blackgram and greengram was advantageous in North Central Uttar Pradesh (Ram *et al.,* 1998). Lentil intercropping in citronella in Uttar Pradesh *Tarai* (Ram *et al.,* 2000) was found efficient.

Table 5. Some improved cropping systems in aromatic crops

Cropping system	% improvement in land use efficiency
Citronella + (cowpea-fingermillet)	46
Citronella + (greengram-fingermillet)	45
Citronella + (greengram-groundnut)	43
Citronella + (greengram-sorghum)	40
Palmarosa + blackgram	15
Palmarosa + cowpea	13
Geranium + cowpea	29
Geranium + blackgram	33

(Prakasa Rao *et al.,* 2000b)

Table 6. Improved crop sequences involving agricultural and aromatic crops

Cropping System	Pure crop (essential oil) yield (kg/ha)	Geranium oil equivalent (kg/ha)
Sorghum + Redgram + 2 : 1 Clusterbean/greengram-Geranium+greengram	23.06	30.35
Pearlmillet + clusterbean/greengram-Geranium+greengram	23.18	28.36
Sunflower + redgram + 2 : 1 clusterbean/greengram-geranium + greengram	23.18	30.55
Geranium + clusterbean/greengram	39.68	42.07

(Rajeswara Rao *et al.,* 2000)

Table 7. Economic benefit of Java citronella based cropping system in *Tarai*

Cropping system	% increase in net returns over pure crop of Java citronella
Java citronella + pea	6.2
Java citronella + lentil	34.8
Java citronella + chickpea	13.9

(Ram *et al.,* 2000)

In geranium (*Pelargonium graveolens*), legumes in South Indian plains (Prakasa Rao *et al.,* 1984a) and crops such as garlic and wild marigold in North Central Uttar Pradesh (Ram and Kumar, 1998) were found efficient intercrops. Intercropping patchouli (*Pogostemon cablin*) in papaya gave higher economic returns in Lucknow (Ram *et al.,* 1999a). In semi-arid tropics, diversifications of crops with medicinal plants such as *Catharanthus roseus*, senna and aromatic crops such as ocimum, lemongrass, palmarosa was found feasible (Pratibha and Korwar, 2003). Continuous cropping of geranium intercropped with clusterbean or greengram in Hyderabad is more profitable; also sorghum, sunflower and maize based sequential cropping system involving geranium as rabi crop was advantageous (Rajeswara Rao *et al.,* 2000).

Most of the studies conducted have not taken into account the nutrient depletion that takes place in the changed/new cropping systems. Prakasa Rao (2000b) emphasized that nutrient mining in intensive cropping systems involving MAPs has to be studied and suitable strategies for nutrient management have to be evolved.

Water Management

Moisture stress is considered to be one of the environmental factors responsible for accumulation of secondary metabolites in plants. However, agronomists have found that supply of water is a significant factor for the production of MAPs.

In opium poppy (*P. somniferum*) moisture stress during rosette formation to flowering period reduced opium and morphine yields and the crop requires favourable moisture throughout, which amounts to a consumptive use of 376 mm (Turkhede *et al.,* 1981c). Opium production response to moisture levels (20, 40, 60, 80% ASM) was quadratic (Yadav *et al.,* 1982). Irrigation of *Aloe vera* at 0.8 IW:CPE ratio was recommended in semi-arid tropical conditions (Prakasa Rao *et al.*, 2008a).

Irrigation at 1.0 IW/CPE ratio was found optimum in *Mentha arvensis* at Pantnagar (Saxena and Singh, 1996). At Lucknow, water requirement, consumptive use and WUE were 55 cm, 38.5 cm and 1.7 kg oil/ha-cm respectively. Under limited water availability, irrigation at 0.6 IW/CPE along with dust mulch was suggested (Singh *et al.,* 1999a). Five cm depth of irrigation at 60 mm of cumulative pan evaporation was recommended for *Mentha piperita* in Punjab (Randhawa *et al.,* 1984a). Incorporation of distillation waste served as an efficient measure of *in* situ moisture conservation in rainfed palmarosa, which improved the productivity of this aromatic grass (Prakasa Rao *et al.,* 2001). In Delhi, irrigation at IW : CPE ratios of 0.3, 0.4 and 0.6 was optimum for periwinkle, vetiver and palmarosa respectively (Pareek *et al.,* 1991). Irrigation at 60% ASM was optimum for *Jasminum grandiflorum* in Coimbatore (Thamburaj *et al.,* 1984). For *Cymbopogon winterianus* (citronella), irrigation at soil moisture potential of -60 kPa or at 0.8 IW : CPE ratio (Singh *et al.,* 1996a) was promising and nearly 30% water can be saved by adopting broad bed and furrow method of planting (Singh *et al.,* 1996c). Singh (1999a) fixed 0.75 IW : CPE ratio for irrigating lemongrass. Geranium has to be irrigated at 0.5 IW : CPE ratio (Singh *et al.,* 1996b). Irrigation of patchouli at 1.0 IW : CPE ratio and rosemary at 0.5 IW : CPE ratio was found optimum in Bangalore (Singh *et al.,* 1999b, Singh and Ramesh, 1999). In Uttar Pradesh *Tarai,* irrigation of *Tagetes minuta* at 0.2 IW : CPE ratio was suggested (Ram *et al.,* 1999b). Alternate furrow irrigation was efficient in geranium and patchouli (Prakasa Rao *et al.,* 1998a). The moisture levels did not affect the quality of essential oil. Irrigation just after each harvest of palmarosa was found best in Lucknow with two irrigations: 1 and 60 days after harvest (Singh *et al.,* 1999b).

Weed Control

Weed management in MAPs is important since weeds result in significant yield losses and also loss in quality of final produce and at the same time it is a costly, labour intensive farm operation. A number of studies have therefore been made on the use of herbicides in MAPs.

Weeds reduced essential oil yield by 58-73% in *Mentha arvensis* and pre-emergence application of terbacil (1.5 kg a.i/ha), pendimethalin (1 kg a.i./ha) or oxyfluorfen (0.25 kg a.i/ha) in Uttar Pradesh *Tarai* was found to be efficient and the herbicides did not affect the quality of oil (Kothari and Singh 1994). In Jammu, application of Amiben (10 G) and repeated applications of 3000 ppm of Gramoxone controlled dicot weeds and annual grasses (Khosla and Singh, 1978). Pre-emergence application of Sinbar, Terbutrax, Stomp and Karmex (0.75 kg/ha) was recommended in Punjab (Randhawa *et al.,* 1982). While the application of Simazine (Pre-emergence) @ 0.5 kg/ha + fusillade @ 0.15 kg + gramoxone @ 0.4 kg a.i/ha was found effective in *M. arvensis*; no herbicide residues were found in the essential oil as estimated by TLC technique (Singh and Aggarwal, 1988). In Himachal Pradesh, weeds reduced yields up to 88% and maintaining weed free conditions for 30-75 days after planting before first cut and 15-60 days after first cut were crucial for getting good yields of *M. arvensis* (Singh *et al.,* 1993). Some herbicides, alachlor and atrazine in combination with either isoproturon or pendimethalin proved phytotoxic to *M. arvensis* (Singh *et al.,* 1995). Paddy straw mulch @7.5 t/ha following pre-emergence application of pendimethalin @ 1.0 kg/ha was found very effective in managing weeds of *M. arvensis* (Shukla *et al.,* 1999). Application of Terbacil @ 1.5 kg/ha as pre-emergence spray and weeding after 40 days was effective in *M. piperita* in Himachal Pradesh (Katoch *et al.,* 1982). Keeping fields weed free for 105 days being critical, application of terbacil @ 1.5 kg a.i/ha (pre-emergence) + propanil @ 1.75 kg a.i/ha (post emergence) was found effective in *M. arvensis*, *M. piperita* and *M. citrata.*

Combined application of 2, 4-D (80% Na salt) @ 2.5 kg/ha and gramoxone @ 1 l/ha as post emergence application was recommended in *Cymbopogon pendulus* in Jammu (Khosla, 1979). In *C. winterianus*, weed free conditions for first 60 days is critical (Yadav *et al.,* 1981a). Weeds caused nearly 70% yield losses in citronella and application of atrazine @ 2 kg/ha was found beneficial in Uttar Pradesh *Tarai* whereas Diuron (@ 1.5 kg a.i./ha) was effective in Lucknow (Singh *et al.* 1996). In Delhi, application of 0.5 kg a.i/ha of 2, 4-D (ester) as post emergence or 0.75 kg a.i/ha of isoproturon was effective in *C. martinii* var. motia (Pareek *et al.,* 1991). Singh *et al.,* (1995) suggested application of 5 t/ha distillation waste for effective weed management and in case of non availability of organic materials, intercropping of blackgram controlled weed menace in *C. martinii* var. motia (Singh and Singh, 1997).

Pre-emergence application of nitrofen and alachlor in scented geranium (*Pelargonium graveolens*) in Kodaikanal was suggested (Srinivasan *et al.,* 1979). In opium poppy, pre-emergence application of alachlor and nitrofen with FYM or charcoal as protectants was found to control weeds effectively (Singh *et al.,* 1982). Weed removal during 5 to 11 weeks after planting in Jammu was crucial for *Matricaria chamomile* (Singh and Shahi, 1989) and application of 0.6 kg/ha oxyfluorfen in Lucknow was found an effective weed control measure in this crop (Singh *et al.,* 1989). Pre-emergence application of pendimethalin @ 1.25 kg/ha (Murthy and Gowda, 1992), gramoxone @ 3 l/ha + three post emergence sprays at 40 day intervals in West Bengal was found suitable in tuberose (*Polianthus tuberosa*). In vetiver, use of 0.5 kg a.i/ha oxadiazon or 0.5 kg atrazine as pre-emergence application was suggested (Pareek *et al.,* 1991). In Damask rose (*Rosa damascena*) combination of organic mulch (10 t/ha) with simazine or diuron was found effective (Singh and Singh, 2004).

Pre-emergence application of nitrofen @ 1 l/ha along with hand weeding 45 days after the spray effectively controlled weeds in pyrethrum in Kodaikanal (Srinivasan *et al.,* 1982).

Pre-emergence application of 0.5 kg/ha isoproturon controlled *Chenopodium album* and other weeds in isabgol in Gujarat (Patel and Mehta, 1986) while 0.6 kg/ha oxyfluorfen application was found effective in Lucknow (Singh *et al.,* 1989). In periwinkle (*Catharanthus roseus*), application of fluchloralin @ 0.75 kg a.i/ha (pre plant incorporation) or alachlor @ 1.0 kg a.i/ha (pre-emergence) was found to control weeds (Pareek *et al.,* 1991). In *Artemisia annua*, an anti-malarial plant, high density planting combined with 0.5 kg a.i/ha pendimethalin was found effective in weed control (Ram *et al.,* 2001). Allelopathic effect of *Coleus ambonicus* was exploited to control water hyacinth (Kathiresan, 2000).

Crop Husbandry

Improved varieties of some commercially important MAPs have contributed to improved production of secondary metabolites (Table 8). Optimum time of planting resulted in higher productivity. For example, planting time of *M. spicata* in March in Himachal Pradesh (Katoch *et al.,* 1979) and in second half of December in Lucknow (Singh *et al.,* 1995) were found most suitable. Planting of *Artemisia annua* in October in Bangalore gave best results (Singh *et al.,* 2009). Planting spacings play an important role in the productivity of several MAPs. For example, 40 cm row spacing in *M. spicata* in Himachal Pradesh (Katoch *et al.,* 1979) and 30 cm in Punjab (Randhawa *et al.,* 1984c) were found optimum. For palmarosa, 45 x 30 spacing in Bangalore (Prakasa Rao *et al.,* 1985a), 30 x 30 cm in Kerala (Nair *et al.,* 1980), 60 x 30 cm in Haryana (Verma *et al.,* 1984) and 40 x 40 cm in Assam (Hazarika *et al.,* 1981) were recommended. Proper time and method of harvesting also plays a significant role in the productivity of MAPs. Some examples are: 1) maintaining a minimum harvest interval of 5 months for first and sixth harvests, 4 months for second harvest and 2 months for other harvests in lemongrass (Prakasa Rao *et al.,* 2005b); 2)

Table 8. Some improved varieties of MAPs

Crop	Name of the variety	Yield potential
Aromatic plants		
Lemongrass	Krishna	209 kg essential oil/ha/yr
Citronella Java	Bio-13	243 kg essential oil/ha/yr
Palmarosa	PRC-1	80 kg essential oil /ha/harvest
Mentha arvensis	Kosi	193 kg essential oil/ha
M. piperita	Kukrail	90 kg essential oil/ha
M. spicata	MSS-5	125 kg essential oil/ha
M. citrata	Kiran	239 kg essential oil/ha
Rosa damascena (Damask rose)	Ranisahiba	40 kg essential oil/ha
Vetiver	Gulabi	34 kg essential oil/ha
Ocimum basilicum	CIM-Saumya	197 kg essential oil/ha
Matricaria chamomila	Vallary	6.6 kg essential oil/ha
Tagetes minuta	Vanphool	61 kg essential oil/ha
Medicinal plants		
Artemisia annua	CIM-Arogya	48 q herb/ha
Periwinkle	Nirmal	55-65 q/ha
Senna	Sona	11 q leaf, 4 q pod/ha
Ashwagandha	Poshita	14 q/ha
Pyrethrum	Hansa	20.6 q/ha
Ocimum sanctum	CIM-Ayu	200 q/ha
Poppy	Sweta	75-80 kg opium/ha

(Patra & Kumar, 2005)

proper harvesting methods in *M. citrata* in Jammu (Choudhury *et al.,* 1979), in Himachal Pradesh (Bhardwaj and Srivastava, 1984) and 3) optimum harvesting of *M. spicata* in Uttar Pradesh *Tarai* (Singh *et al.,* 1991).

Harvest Time and Post Harvest Handling

In palmarosa (*Cymbopogon martinii* var. motia), oil quality improved when harvested at 95 days or beyond (Chinnamma and Aiyer, 1988). Oil content decreased linearly with increase in intensity of shade in *Ocimum gratissimum* (Pillai and Chinnamma, 1994). Delayed harvest beyond flowering stage increased linalool content in the essential oil, but decreased cineole and methyl chavicol concentrations in *Ocimum basilicum* (Gill and Kaur, 2007).

Post harvest handling of MAPs is important to derive quality products (Prakasa Rao, 2006). Post harvest drying of davana (*Artemisia pallens*) and patchouli (*Pogostemon cablin*) has been standardized to derive maximum essential oil yield with desirable oil quality; davana : > 50% davanone and patchouli : 25-30% patchouli alcohol (Khanuja *et al.,* 2004; Narayana and Dimri, 1990). Shade drying of harvested herb up to 2 days in comparison with open drying was recommended in *Mentha arvensis* (Hazra *et al.,* 1990). Storage of geranium (*Pelargonium graveolens*) for 24 hrs at 30ºC prior to distillation resulted in 16% loss in oil yield with slight improvement in oil quality (Chandravadana and Vasant Kumar, 1989). In hot climatic conditions, drying biomass for more than few hours decreased oil recovery and yield in scented geranium (Rajeswara Rao *et al.,* 1990a). Extraction method and stage of harvesting were standardized to achieve maximum essential oil yield of coriander; grinding by blender 0.5 - 3 minutes gave significantly higher essential oil yield as compared to manual grinding (Agrawal *et al.,* 1995). Shade drying of leaves of *Mentha spicata* gave a good product with green colour and minimum loss of volatile oil compared to other drying methods. Carvone to limonene ratios were 2.2 : 1.0 and 2.3 : 1.0 in the oil from fresh and shade-dried spearmint respectively (Raghavan *et al.,* 1994). Post harvest schedules have been arrived at for *Mentha arvensis, M. spicata, M. piperita, Cymbopogon winterianus* and *C. martinii* (Singh and Naqvi, 1996). Storage studies for 13 weeks on oil of *Tagetes minuta* showed that *cis*-b-ocimene and dihydrotagetone increased and *trans*-tagetone and *cis*-tagetenone decreased at room temperature, which suggested the storage at 10º C under refrigeration (Prakasa Rao *et al*., 2000a).

Utilisation of Marginal/Problem Soils

MAPs are generally perceived as crops that can be grown in marginal/problem soils which is not entirely true. However, several researchers have explored suitability and cultivation of some MAPs in such soils.

Aromatic plants can be utilized for alternate land use systems in the development of wastelands on watershed basis (Prakasa Rao, 1993b). Patra and Singh (1995) found some aromatic crops viz., palmarosa, lemongrass, vetiver, German chamomile and medicinal crops like periwinkle, ergot of rye, Egyptian henbane, isabgol suitable for cultivation in salt affected conditions. In saline-alkali soils, cultivation of *Matricaria chamomilla* (Misra and Kapoor, 1978); palmarosa, periwinkle and *Solanum khasianum* in Orissa (Patra and Dutta, 1979), periwinkle with up to EC 12 dS/m of irrigation water in Agra (Pal *et al.,* 1988), *Ocimum canum* (Jain *et al*., 1989), *Artemisia annua* (up to 6.0 dS/m soil salinity) (Prasad *et al.,* 1997) and *Tagetes* sp. (Prasad *et al.,* 2003) was found feasible. Liming of acid soils helped to increase geranium oil yield (Prasad and Chattopadhyay, 1999). *Datura innoxia* was used for phytoextraction of Cd and Pb from soils (Ghosh and Singh 2003). In Orissa, palmarosa could be successfully grown in chromite overburdens (Behura *et al.,* 1988). Thus, it is feasible to utilize marginal/problem soils for economic exploitation of certain MAPs.

Development of Entrepreneurial Capabilities and Creation of Value-chains

Since MAPs yield products which are used exclusively in herbal drug and fragrance industries, it is important that clusters of farming of MAPs along with their post harvest processing, quality control and marketing have to be taken up. Such an endeavour also establishes entrepreneurial capacities in rural areas. Gupta (2000) suggested that since aromatic crop based industry is not able to compete well in global markets, utilization of new technological innovations can give advantages in terms of cost, quality and size of production. Agronomists have a vital role to play in creating value chains involving farmers, processors, industry and developmental agencies. Prakasa Rao *et al.* (2008b) demonstrated such a mission programme on patchouli oil production in Karnataka.

Organic Cultivation of MAPs

Organic cultivation of MAPs has attracted the attention of scientists and farmers. Most of the medicinal plants which are collected from wild are organically produced by default. However, rapid loss of biodiversity, increasing needs to cultivate several species of MAPs and prospects of higher returns from organically produced MAPs have opened the possibilities of organic cultivation of MAPs. That organic production of essential oils in India was pos-

Table 9. Yield and quality of some aromatic plants grown under organic and conventional methods

Aromatic plant	Herb yield/harvest (t/ha)		% oil		Remarks
	Organic	Conventional	Organic	Conventional	
Citronella	10-12	10-15	0.8-1.1	0.9-1.2	
Lemongrass	12.5-14	10-15	1.1-1.36	1.0-1.4	No change in chemical
Scented geranium	11.8-12.5	10-15	0.38	0.2-0.35	constituents of all
Patchouli	6.4-8.0	10-15	3.9	3.0-5.0	the essential oils
Eucalyptus citriodora	6.4-11.0	10-15	1.66	1.2-1.6	was observed
Palmarosa	7.4-14	10-15	0.43	0.4-0.5	
Rosemary	6.6-10	8-10	1.03	1.0-1.1	

(Puttanna *et al.*2007)

sible was reported by Prakasa Rao and Puttanna (1997). Organic production methods for citronella, lemongrass, palmarosa etc. were developed (Prakasa Rao *et al.* 2006). Puttanna *et al.* (2007) reported yield behaviour and changes in chemical constituents in some organically and conventionally grown aromatic plants and a summary of their findings are presented in Table 9.

India being a leader in the production of MAPs and their products in the world, the way forward is quite optimistic. Keeping in view the valuable agronomic research conducted on MAPs in the country, agronomists play a significant role in making India a global leader in herbal plants and products. Some of the key areas for further agronomic research are :

- Site specific nutrient management, cropping system based nutrient recommendations, role of inorganics/ organics on productivity, quality of MAPs as well as of soil, use of customized fertilizers to target secondary metabolite production, extensive data base on nutrient concentrations and uptake by MAPs and emerging deficiencies of primary, secondary and micronutrients.
- Cropping systems research should focus on agronomic and economic suitability, pattern of nutrient depletion and pest/disease dynamics, allelopathic influences; multiple options for inclusion of a variety of MAPs in existing cropping systems based on sound scientific data and market perceptions.
- Water research should focus on water stress related to secondary metabolite production under field conditions, improved methods of water management for higher WUE and modeling of soil moisture and environmental factors in relation to secondary metabolite production in MAPs.
- Studies on invasive weeds in newly developed MAP based cropping systems, monitoring herbicide residues in MAP products, exploitation of allelopathic effects of MAPs in weed dynamics.
- Use of tools such as Geographic Information System (GIS) to delineate most suitable MAPs in different agroclimatic regions of India.
- Role of perennial MAP systems in carbon sequestration and climate.

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