Indian Journal of Agronomy **54**(2): 215–220 (June 2009)

Medicinal and aromatic plants for crop diversification and their agronomic implications

E.V.S. PRAKASA RAO*

Central Institute of Medicinal and Aromatic Plants, Resource Centre, Allalasandra, GKVK Post, Bangalore, Karnataka 560 065

ABSTRACT

Medicinal and aromatic plants fit very well in the current scheme of crop diversification in different agro-climatic regions of India. While considering lateral crop diversification, vertical diversification in processing and value addition vastly improves the crop economics. Agronomists are posed with challenge of scientifically fitting most suitable medicinal and aromatic plants (MAPs) in different agroclimatic regions. This paper deals with different areas *viz.* nutrients and water and their management, cropping systems, utilization of waste/marginal lands, organic farming, quality of end products in relation to agronomic interventions, soil-health and related environmental issues related to MAPs and finally land use efficiency and economics of production systems involving MAPs.

Key words: Crop diversification, Economics, Environment, Essential oil crops

Indian agriculture is at cross roads presently. Increasing demand for food, fibre crops coupled with issues of economics and environment in agriculture has posed challenges to scientists, policy makers, farmers and industry. Though there have been substantial increases in production of food and other crops, the need for diversification of crops/cropping systems has been felt more than any time in agriculture. Diversification laterally through diversified crops/cropping systems and vertically through processing and value addition has been a significant approach of agronomists. Issues of food security and environment have been subjects of debate while considering non-food crops as candidates for diversification. A paradigm shift to consider issues of scientific study of new crops/cropping systems, their economic feasibility and environmental interaction has compelled agronomists to develop models of crop diversification best fit in different agronomic environments. It appears that there are no single/simple answers to these complex questions of agronomy of new crops in relation to economics and environment.

The present paper proposes to highlight the role of medicinal and aromatic plants (MAPs) as diversification crops. Also, various dimensions of scientific study of the agronomy of these crops and issues related to economics and environment are discussed.

Correspondence address: (E-mail: cimapfsbangalore@vsnl.net; cimaprcbangalore@gmail.com)

Agro-ecological zones and MAPs

India has 20 agro-ecological zones (NBSS&LUP, 1992). Agronomists have been able to fit the best-suited crops/cropping systems in all the zones. However, a very little work has been done in the identification of most suitable medicinal and aromatic plants (MAPs) in different agro-ecological zones. It is important that for commercial production of MAPs and also for better utilization of problem/degraded soils, scientific studies are required to fit the most suitable MAPs to different agro-ecological zones. An effort was made to fit suitable MAPs in different agro-ecological zones of Karnataka (Table 1). This effort helps the policy makers to plan cropping systems involving MAPs in different agro-ecological zones of the country and also farmers to decide on the suitable MAPs for their farms.

In Uttarakhand, evaluation of some important medicinal plants for their economical performance has been done (Gera *et al.*, 2006). Recently, some effort has been made to work out economics of cultivation of some aromatic crops in Gujarat (Srivastava *et al.*, 2005).

Agronomic interventions

The need for scientific data on various agronomic aspects for the cultivation of MAPs cannot be over-emphasized.

Nutrients and their management

Till 1980s, meagre information was available on the

Table 1. Recommended land use and crop sequences in Karnataka (Souce : NBSS & LUP, Bangalore)

Agro-climatic zone	Characteristics		Major crops of the zone	Recommended medicinal and aromatic plants
	Dominant soils	Length of crop growing period		
North-eastern transition zone	Black soils (Deep/medium and shallow) and lateritic	120 to 180 days	Sorghum, pulses, *pearl millet*, sugarcane	Ashwagandha, Lemongrass, *Citronella*, Hippali, Vetiver, Periwinkle, *Coleus*
North-eastern dry zone	Black soils (deep/medium/ shallow/alluvial loamy soils/shallow and gravelly clay	90 to 180 days	*Rabi* sorghum, *pearl millet*, groundnut, cotton, wheat, rice	Lemongrass, Citronella, Hippali, Vetiver, Periwinkle, *Coleus*
Northern dry zone	Deep black soils/shallow black soils/moderately deep and gravelly clay/alluvial clay	< 90/90-180 days	*Rabi* sorghum, maize, *pearl millet*, groundnut, cotton, wheat, sunflower, pulses, sugarcane and rice	Lemongrass, *Citronella*, Hippali, Vetiver, Periwinkle, Patchouli, Ashwagandha, *Coleus*, Marigold, *Amla*, *Phyllanthus amarus*
Central dry zone	Deep red gravelly clay/deep red clay/deep calcareous black soils	< 90/90-150 days	*Ragi, kharif* sorghum, pulses, groundnut, coconut, rice, *pearl millet*, cotton	*Aloe vera, Coleus,* Ashwagandha, *Safed musli*, Marigold, Patchouli, *Citronella*, Lemongrass, *Amla, Acorus calamus, Geranium*, Marigold
Eastern dry zone	Alluvial clayey soils/deep red gravelly and non gravelly clay soils, deep lateritic soils	120-180 days	*Ragi*, pulses, groundnut, maize, mulberry, rice, vegetables and flowers	Davana, *Citronella, Eucalyptus citriodora*, Patchouli, Lemongrass, *Geranium*, Ashwagandha, *Coleus*, Amla
Southern dry zone	Red clayey soils (deep/moderate deep) alluvial clay soils	90-180 days	Rice, *ragi*, pulses, millets, mulberry, sugarcane and coconut	*Coleus*, Patchouli, *Citronella*, Lemongrass, Amla, Palmarosa, *Eucalyptus citriodora*, Vetiver, Vanilla, *Geranium*, Ashwagandha, Marigold
Southern transition zone	Red/non-gravelly clay/alluvial clay/black soils	150-210 days	Rice, *ragi*, pulses, sorghum and tobacco	Patchouli, *Coleus*, Ashwagandha, *Piper longum*, Amla, Marigold, *Citronella*, Lemongrass, Palmarosa, *Eucalyptus citriodora*, Vetiver, Vanilla, *Geranium*, *Safed musli*, Hippali, *Stevia*
Northern-transition zone	Black soils/red gravelly/non gravelly clay/red loamy soils	120-180 days	Sorghum, groundnut, pulses, rice, sugarcane, cotton, wheat	*Coleus*, Vetiver, *Citronella*, Ashwagandha, Lemongrass, Palmarosa, *Eucalyptus citriodora*
Hilly zone	Lateritic soils/red gravelly/non-gravelly clay soils/deep black soils	180-240/> 270 days	Coffee, rice, arecanut, pulses, spices	Patchouli, *Citronella*, Lemongrass, *Geranium*, Ashwagandha, *Coleus*, Amla, Marigold, Palmarosa, Rosemary, Ginger
Coastal zone	Lateritic soils/alluvial soils	180-240 days	Rice, groundnut, pulses, cashew, coconut	Patchouli, Vetiver, *Citronella*, Lemongrass, Ashwagandha, *Coleus*, Amla

nutrient studies in MAPs. A series of field experiments conducted at CIMAP, Resource Centre, Bangalore have thrown light on the concentrations and uptake of major nutrients by some commercially important MAPs (Table 2). These studies have facilitated further studies to improve N use efficiency in some of these crops (Prakasa Rao *et al.*, 2000). Some evidence suggests that the quality of essential oil of some crops, *viz.* French basil could be influenced by N applications. Economics of N use in production of essential oils have been highlighted (Table 3). Soil potassium depletion could affect production of rosemary (Puttanna *et al.*, 2008) and palmarosa (Prakasa Rao *et al.*, 2001).

Micronutrients also play a vital role in the biosynthesis of essential oils and their constituents. Various researchers have indicated critical limits of some micronutrients in mints (Misra and Sharma, 1991 and Misra, 1995), response of certain aromatic crops to secondary/micronutrient additions (Chattopadhyay *et al.*, 2000; Rajeswara Rao and Chand, 1996). Interaction of nitrogen and iron has been studied in *Java citronella* (Fig. 1). Improved cropping systems involving intercropping of food crops in some aromatic crops lead to mining of soil nutrients (Table 4) which needs attention of soil fertility managers.

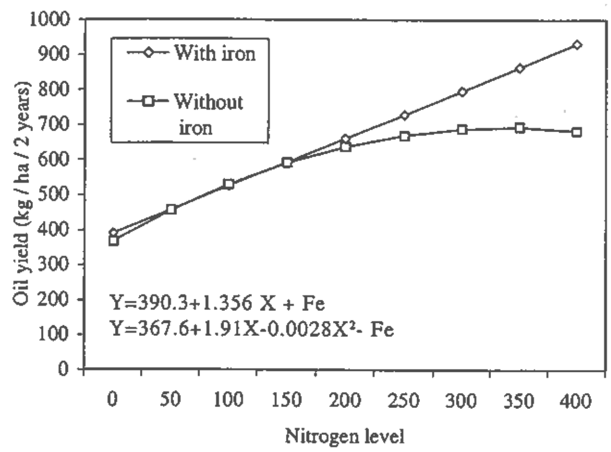

Fig. 1. Response of citronella to iron spray at different nitrogen application rates Puttanna *et al.*, 1993)

Table 3. Response of aromatic crops to N in red soils

Crop	N dose (kg/ha/yr)*	kg essential oil/kg N applied**	Returns (Rs./- per rupee investment)
Java citronella	300-400	0.50	175
Lemongrass	100	0.31	132
Palmarosa	240	0.26	104
Geranium	240	0.07	294
Davana	150	0.02	500
Coriander	50	0.05	700
Rosemary	300	0.52	1,300
Patchouli	200	0.30	1,050

* Level of N upto which response obtained
** At optimum N application; Cost of N :Rs.10.50/kg
Source : Prakasa Rao *et al.* (1998).

Water management

In literature very few studies have been made on the water relations and its management in MAPs. In semi-arid tropical conditions, optimum schedule of irrigations and its relation to yield and quality of essential oils have been reported (Prakasa Rao *et al.*, 2000). In northern Indian plains, some workers have highlighted the role of optimum water management in economically important mint species (Singh *et al.*, 1989). These studies essentially highlighted the importance of irrigation water in improving crop production in MAPs; however, studies on relation of water-stress to secondary metabolite production in MAPs are scanty. These studies are important keeping in view of

Table 2. Nutrient concentrations % and removal (kg/ha) by some aromatic crops

Crops	N	P	K
Java citronella (2 yrs)	181.0	32.8	255.3
(*Cymbopogon winterianus* Jowitt)	(0.5-1.8)	(0.2-0.3)	(1.0-1.8)
Lemongrass (2 yrs)	160.4	31.5	194.2
(*Cymbopogon flexuosus* L.)	(0.73-1.23)	(0.12-0.28)	(0.8-1.14)
Palmarosa (2 yrs)	430.4	62.2	339.4
(*Cymbopogon martinii*)	(0.84-1.6)	(0.11-0.28)	(0.72-1.51)
Geranium (1 yr)	179.7	23.7	137.3
(*Pelargonium graveolens*)	(1.64-2.61)	(0.21-0.29)	(1.01-1.73)
Coriander (1 yr)	30.2	4.2	35.7
(*Coriandrum sativum*)	(0.34-0.7)	(0.03-0.11)	(0.82-0.96)
Davana (1 yr)	179.0	25.8	170.9
(*Artemisia pallens* Wall.)	(1.63-3.5)	(0.3-0.6)	(1.4-3.4)

Source : Prakasa Rao and Puttanna (2006); Prakasa Rao *et al.* (1997).
Figures in parenthesis are concentrations.

Table 4. Nutrient removal (kg/ha) by some aromatic crop based intercropping systems

Cropping system	N	P	K
Palmarosa sole	156.5	31.3	180.4
Palmarosa (Blackgram-blackgram)	249.7	44.1	230.2
Palmarosa (Jowargrain-blackgram)	245.8	65.3	224.4
Palmarosa (Jowar fodder-ratoon)	213.1	48.0	236.0
Geranium sole	215.2	32.2	194.3
Geranium + cowpea	315.9	41.0	261.4
Geranium + blackgram	265.8	36.7	212.2

Source : Prakasa Rao *et al.* (2000).

growing shortage of irrigation water for crop production as well as the need to utilize water stressed soils for production of MAPs.

Cropping systems

While diversifying crops, the need to maintain current levels of cropped area under food and related crops, need not be overemphasized. Thus, research has to be directed towards incorporating MAPs in existing cropping systems such as intercrops, crop rotations, under crops etc. There is an excellent body of literature on the improvised cropping systems involving MAPs. These systems not only improve the production systems but also improve economics, equity and opportunities for knowledge based rural enterprise. MAP based cropping systems in north India have shown that farmers gain significantly higher profits from their lands (Kumar and Patra, 2000; Kothari *et al.*, 1987). These systems have not only influenced the economics but also paved way for agro-based enterprise in the region. Similarly, several aromatic and medicinal crop based intercropping systems have been studied in semi-arid tropical conditions (Table 5). The philosophy of incorporating MAPs in existing cropping systems has been higher agronomic efficiency of crop production and associated enhancement of quality of life through knowledge based enterprises. However, agronomists have to keep in sight the implications of such systems on soil health and social objectives.

Utilisation of waste lands, marginal lands and problem lands

Generally, MAPs are perceived to be hardy and suitable for cultivation in waste lands, marginal lands and problem lands. Not all the MAPs are suitable for such environments. Therefore, studies are required to test and recommend suitable MAPs in such lands. Some reports suggest that crops such as palmarosa, *Eucalyptus citriodora* etc. are suitable under marginal conditions (Prakasa Rao, 1993). Their economics in such situations need attention; some data is available in dryland conditions (Pratibha and

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

Source : Prakasa Rao *et al.* (2000).

Korwar, 2003). Also, some MAPs are known to tolerate saline-alkaline soil conditions; tolerance limits for some species have been worked out (Patra and Singh, 1995). Thus, efficient agronomic management of MAPs under such conditions needs to be developed for their economical production.

Organic farming

Organic farming has gained attention of scientists, farmers and policy makers in recent years, especially in products such as medicinal herbs and essential oils which are used in therapy and hold promise in market. Organic production of MAPs has to be market driven for it to be successful. Meagre scientific data is available on organic methods of cultivation of MAPs and effect of these methods on soil quality and product quality. Pioneering studies made at CIMAP, Resource Centre, Bangalore have given certain projections on production levels, quality issues and soil health (Table 6). Thus, organic production of MAPs with an appropriate agronomic management needs attention of agronomists especially paying attention to the market demand and economics. A science-based and market driven approach to the organic methods of MAP production has to replace the current emotional/rhetorical approach to organic farming.

Quality of end products in relation to agronomic interventions

While agronomists are in constant endeavour to increase crop production, seldom the issue of quality of crops is studied. In crops such as MAPs, the quality of end product is very important; the secondary metabolites from MAPs are valued in commerce. Therefore, several agronomic studies taken up on MAPs invariably examine the quality in relation to agronomic management (Prakasa Rao *et al.*, 1997). Several nutrient and water studies made in semi-arid tropical region have shown that quality of essential oils were not affected (Prakasa Rao *et al.*, 1998). However, a few isolated studies have shown that the

Table 6. Yield and quality of aromatic plants under organic and conventional farming practices

Crop	Herb yield/harvest (t/ha)		Oil %		Major constituents (%)	Organic	Conventional
	Organic	Conventional	Organic	Conventional			
Citronella	10-12	10-15	0.8-1.1	0.9-1.2	Citronellal	33.7-47.0	35-45
					Citronellol	10.9-12.3	10.9-12.3
					Geraniol	19.5-23.3	19.5-23.3
Lemongrass	12.5-14	10-15	1.1-1.36	1.0-1.4	Citral	74.0-82.0	75.0-80.0
Ocimum sanctum	10-12	10-12.5	0.30-0.35	0.29-35	Methyl eugenol	70-73	70-72.5
					Caryophyllene	11-13	10-13
Geranium	11.8-12.5	10-15	0.38	0.2-0.35	Citronellol	26.2	22-30
					Geraniol	20.2	18-25
Patchouli	6.4-8.0	10-15	3.9	3.0-5.0	Patchouli alcohol	34.7	28-37
					α–Bulnesene	10.2-18.2	10.0-18.5
					α-Guainene	8.6-12.3	8.0-12.5
E. citriodora	6.4-11.0	10-15	1.66	1.2-1.6	Citronellal	66.2-78.2	75-80
Palmarosa	7.4-14	10-15	0.43	0.4-0.5	Geraniol	74.3-80.7	75-80
					Geranyl acetate	12.1-21	18-25
Rosemary	6.6-10	8-10	1.03	1.0-1.1	Cineole	26.2	25-28
					Camphor	23.5	23-25
					Verbenone	8.6	5-10

Source : Puttanna *et al.* (2007).

chemical constituents in essential oils can be influenced by application of fertilizers as evidenced in a recent study where methyl chavicol increased and linalool reduced in essential oil of sweet basil (*Ocimum basilicum*) with N applications (Prakasa Rao *et al.*, 2007a). Also, deficiencies of micronutrients can have adverse impact on quality of essential oils (Rajeswara Rao *et al.*, 1996). Alkaloid content in crops such as *Catharanthus roseus* are affected by N fertilizers (Sreevalli *et al.*, 2004).

Soil health and related environmental issues : Normally, when diversification of agricultural crops is envisaged, it is prudent to study not only the production economics of such crops but also their impact on soil health and environment in both short-and long-term. Such scientific data are valuable for proper planning of diversification of crops.

A few studies can be seen on this subject with respect to MAPs. The evidence of changing soil properties (Prakasa Rao *et al.*, 1999), nutrient depletion (Prakasa Rao *et al.*, 2007, Prakasa Rao and Puttanna, 2006), changes in SOC (soil organic carbon) (Puttanna *et al.*, 2007). There is an urgent need to study the role of especially perennial MAPs on soil carbon sequestration; which may help the country to get carbon credits. Also, there is evidence that perennial aromatic *Cymbopogon* grasses arrest soil erosion (CSWCRTI, 1994).

Land use efficiency and economics of production systems: Agronomists have to work out the land use efficiency and economics of production systems involving MAPs. Several examples are available where land use efficiencies have increased from 13 to 46% (Table 5). Also, economics (both in monetary terms and in terms of equivalent yields) have been reported in different intercropping systems and crop rotation systems involving MAPs (Prakasa Rao and Puttanna, 2003; Prathiba and Korwar, 2003 and Rajeswara Rao *et al.*, 2000).

End-to-end approach in horizontal and vertical diversification

In the process of diversification of crops, vertical diversification in processing and value addition is of paramount importance. In MAPs, the secondary metabolites, viz. essential oils and their fractions, alkaloids etc. have to be extracted/isolated. In an agricultural system, all the components such as good agronomic methods, buy back arrangements, processing and value addition and marketing have to be considered in harmony especially for new diversification crops such as MAPs. Several examples are available wherein the end-to-end mission approach has been adopted in some economically important MAPs in a biovillage approach (Prakasa Rao *et al.*, 2007b). The role of agronomists in bringing about a paradigm shift in the way agricultural systems are handled for increased production, value addition, diversification of rural enterprise is immense.

REFERENCES

Chattopadhyay, A., Prasad, A. and Gupta, N. 2000. Response of spear mint (*Mentha spicata*) to sulphur fertilization. *Journal of Medicinal and Aromatic Plant Sciences* **22**: 450-452.

CSWCRTI. 1994. *Annual Report,* 1994-95, Central Soil and Water Conservation Research and Training Institute, Dehradun.

Gera, M., Kumar, A., Sultan Z. and Ansari, M.Y. 2006. Financial analysis of cultivation of selected medicinal and aromatic plant species : a case study from Pithoragarh, Uttarakhand. *Journal of Medicinal and Aromatic Plant Sciences* **28** : 550-556.

Kothari,S.K., Ram, P. and Singh K. 1987. Studies on intercropping autumn planted sugarcane with bergamot, pepper and spear mints in *tarai* areas of Uttar Pradesh. *Indian Journal of Agronomy* **32**(4): 406-410.

Misra, A.1995. Critical manganese levels for Japanese mint *(Mentha arvensis* var. *piperascens)* grown in nutrient solution. *Journal of Essential Oil Research* **7** : 57-62.

Misra, A. and Sharma, S. 1991. Critical concentration of iron in relation to essential oil yield and quality parameters of Japanese mint. *Soil Science and Plant Nutrition* **37** : 185-190.

Patra, D.D. and Singh, D.V. 1995. Utilization of salt affected soil and saline/sodic irrigation water for cultivation of medicinal and aromatic plants. *Current Research on Medicinal and Aromatic Plants* **17** : 378-381.

Pratibha, G. and Korwar, G.R. 2003. Utilization of salt affected soil and saline/sodic irrigation water for cultivation of medicinal and aromatic plants. In : *Proceedings of First National Interactive Meet on Medicinal and Aromatic Plants,* CIMAP, Lucknow pp. 129-132.

Prakasa Rao, E.V.S. 1993. Aromatic crops for alternate land use systems in the development of wastelands on watershed basis. In : *"Horticultural Research-changing scenario", Golden Jubilee Symposium of Horticultural Society of India,* held at Bangalore from 24-28 May 1993.

Prakasa Rao E.V.S., Puttanna, K., Singh, M. and Ganesha Rao, R. S. 1997. Production technologies for improved essential oil production in red soils of semi-arid tropics of south India. In : *"Future Trends in Essential Oil Industry" 40th Anniversary Seminar of Essential Oil Association of India* held at Regional Research Laboratory, Jammu from 28-29 September 1997.

Prakasa Rao, E.V.S., Puttanna, K., Singh, M. and Ganesha Rao, R. S. 1998. Nutrient and water-management for sustainable production of aromatic plants in red soil region of semi-arid tropics. In : *Water and Nutrient Management for Sustainable Production and Quality of Spices.* pp 80-84. A.K. Sadanandan *et al.* (Eds.) Indian Society of Spices, Calicut.

Prakasa Rao, E.V.S., Puttanna, K., Ganesha Rao, R. S. and Gopinath, C.T. 1999. *Eucalyptus citriodora* - Agronomic potentials, distillation technology and soil fertility. *Flavours and Fragrance Association of India Journal.* July-Sept. 44-47.

Prakasa Rao, E.V.S., Puttanna, K. and Ganesha Rao, R.S. 2000. Prospect of commercial mediculture and recent advances in agrotechnologies of aromatic plants in south India. *Journal of Medicinal and Aromatic Plant Sciences* **22** : 207-213.

Prakasa Rao, E.V.S., Ganesha Rao, R. S. and Puttanna, K. 2001. Studies on *in situ* soil moisture conservation and additions of phosphorus and potassium in rainfed palmarosa (*Cymbopogon martinii* var. *motia*) in a semi-arid tropical region of India. *European Journal of Agronomy* **14**: 167-172.

Prakasa Rao, E.V.S. and Puttanna, K. 2003. Intercropping medicinal plants-an agro-economic need. In : *National Seminar on New Perspectives in Spices, Medicinal and Aromatic Plants,* held at Goa from 27-29 November 2003.

Prakasa Rao, E.V.S., Puttanna, K. and Ganesha Rao, R.S. 2005. Response of *Bacopa monnieri* to inorganic and organic sources of nutrients. *Journal of Tropical Medicinal Plants* **6**(1) : 117-122.

Prakasa Rao, E.V.S. and Puttanna, K. 2006. Major nutrient concentrations, their uptake and production of some major essential oil bearing plants of south India. In : *Seventy-Sixth Annual Session, Symposium and Concluding Function of Platinum Jubilee Celebrations* held at The National Academy of Sciences, Mumbai during 6-8 October 2006, pp.8-9.

Prakasa Rao, E.V.S., Puttanna, K., Ganesha Rao, R.S. and Ramesh, S. 2007a. Nitrogen and potassium nutrition of French basil (*Ocimum basilicum* Linn.). *Journal of Spices and Aromatic Crops* **16**(2) : 99-105.

Prakasa Rao E.V.S., Gopinath, C.T. and Ravindra, N.S. 2007b. Creating value chain in patchouli oil production – some case studies of CIMAP's initiative. In : *Seminar on Business Enabling of Aromatic Plants and Products,* held at Dehradun from 21-22 November 2007.

Puttanna, K., Narayana, M.R. and Prakasa Rao, E.V.S. 1993. Bicarbonate - induced iron chlorosis in Java citronella. *Communications in Soil Science and Plant Analysis* (USA) **24**(19&20): 2545-2551.

Puttanna, K., Prakasa Rao, E.V.S., Chandrashekara, R.S. and Ganesha Rao, R.S. 2005. Organic and inorganic nutrition for *Withania somnifera. Journal of Tropical Medicinal Plants* **6**(2) : 215-219.

Puttanna K., Prakasa Rao, E.V.S., Gopinath, C. T., Parameswaran, T. N., Kalra, Alok, Ramesh, S. and Singh, R. P. 2007. Organic Production Technologies for Medicinal and Aromatic Plants. In : *India Organic 2007 International Seminar on "Indian Organic Agribusiness: At the Threshold of Growth",* held at New Delhi from 29-30 November 2007.

Puttanna K., Prakasa Rao, E. V. S., Singh, Rakshapal. and Ramesh, S. 2008. Influence of nitrogen and potassium fertilization on yield and quality of rosemary in relation to harvest number. *Communications in Soil Science and Plant Analysis* (in Press).

Rajeswara Rao, B. R. and Sukhmal Chand. 1996. Response of Lemon grass to zinc application. *Journal of Indian Society of Soil Science* **44**(2) : 344-346.

Seghal, J., Mandal, D.K., Mandal, C. and Vadivelu, S. 1992. *Agroecological Regions of India,* Ed. 2, NBSS&LUP Publication, No. 24, p. 130.

Singh, V.P., Kothari, S.K., Singh, K. and Singh, D.V. 1989. Effect of irrigation and nitrogen on herbage and oil yield of Japanese mint (*Mentha arvensis*). *Journal of Agricultural Science,* Cambridge **113** : 277-279.

Sreevalli, Y., Kulkarni, R.N., Baskaran, K. and Chandrashekara, R.S. 2004. Increasing the content of leaf and root alkaloids of high alkaloid content mutants of periwinkle through nitrogen fertilization. *Industrial Crops and Products* **19** : 191-195.

Srivastava, R.K., Alok Lehri. and Singh, D.P. 2005. Integration of aroma bearing crops with agriculture in tribal areas of Gujarat for uplifting rural economy – a rural study. *Flavours and Fragrance Association of India Journal* **7**(1) : 63-69.

Sushil Kumar. and Patra, D.D. 2000. Integration of mediculture with agriculture for sustainable higher productivity, profits and employment. *Journal of Medicinal and Aromatic Plant Sciences* **22**: 751-754.