Industrial Crops and Products 33 (2011) 78–83

Contents lists available at ScienceDirect

Industrial Crops and Products

journal homepage: www.elsevier.com/locate/indcrop

Impact of intercropping of medicinal and aromatic plants with organic farming approach on resource use efficiency in arecanut (*Areca catechu* L.) plantation in India

S. Sujatha*, Ravi Bhat, C. Kannan[1], D. Balasimha

Central Plantation Crops Research Institute, Regional Station, Vittal 574 243, Karnataka, India

ARTICLE INFO

Article history:
Received 28 August 2009
Received in revised form 2 August 2010
Accepted 3 September 2010

Keywords:
Asparagus racemosus
Bacopa monnieri
Vetiveria zizanoides
Piper longum
Cymbopogon flexuous
Ocimum basilicum
MAPs
Intercropping
Arecanut

ABSTRACT

The present investigation was conducted at Vittal, Karnataka, India during 2004–2007 to study the feasibility of intercropping of medicinal and aromatic plants (MAPs) in arecanut plantation. The results revealed that MAPs can be successfully grown as intercrops in arecanut plantation with increased productivity and net income per unit area. Kernel equivalent yield of MAPs varied between 272 kg ha^{-1} in case of *Piper longum* to 1218 kg ha^{-1} in *Cymbopogon flexuosus*. Pooled data indicated that *Asparagus racemosus* produced fresh root yield of 10,666 kg ha^{-1} of arecanut plantation and contributed to maximum kernel equivalent yield of 1524 kg ha^{-1} among all medicinal and aromatic plants. Intercropping of MAPs in arecanut was found economical. The net return per rupee investment was highest in *C. flexuosus* (4.25) followed by *Bacopa monnieri* (3.64), *Ocimum basilicum* (3.46) and *Artemisia pallens* (3.12). The total system productivity of arecanut + MAPs intercropping system varied from 2990 to 4144 kg ha^{-1}. Arecanut + *O. basilicum* intercropping system registered significantly higher production efficiency 8.2 kg ha^{-1} day^{-1} than other systems. Intercropping of MAPs had more positive effect on soil pH in arecanut based cropping system. The soil pH was 5.6 in 2004 and it was 0.3–0.9 units higher in 2007. Soil organic carbon (SOC) content varied significantly due to intercropping of MAPs at the end of experiment. The SOC content increased in *Aloe vera*, *A. pallens*, *P. longum* and *B. monnieri*, while it depleted in grasses and rhizomatic MAPs. Based on demand and marketing opportunities for MAPs, farmers are advised to grow aromatic plants in large areas on a community basis to meet huge industrial demand and variety of medicinal crops in small areas to meet the requirement of traditional systems of medicine.

1. Introduction

Medicinal and aromatic plants (MAPs) are looked upon not only as a source of affordable health care products but also as a source of income. There is a growing demand for plant based medicines, health products, essential oils, fragrances, cosmetics and natural aroma chemicals in the national and international markets. Several reports highlighted the global importance of MAPs due to huge volume of trade at national and international levels (Kuipers, 1997; ICMAP, 2003). The Task Force report indicated that international market for medicinal plants is over US$ 60 billion per year and herbal drug market continues to grow at the rate of 7–30% annually (GOI, 2000). As per the estimates of the World Health Organization (WHO), the global market for plant based medicine will hit 5 trillion US$ mark by the year 2050. The world essential oil production at raw material level is estimated at around $10 billion annually. There has been significant increase in production and trade of essential oils and aroma chemicals over last two decades.

Systematic collection and conservation of MAPs is lacking in India. Many plants have become endangered or vulnerable or threatened as 90% collection of medicinal plants is from wild source and 70% collection involved destructive harvesting (GOI, 2000). With dwindling supplies from natural resources and increasing global demand, expanding the cultivation of MAPs appears to be an important strategy (Rao et al., 2004). As there is no scope for horizontal expansion of cultivated area, it is viable to grow MAPs as intercrops with the predominant crops of the region by devising suitable cropping schedules. Kamla Singh et al. (1985) observed that medicinal and aromatic plants like *Mentha* sp., *Cymbopogon martini*, *Cymbopogon flexuosus*, *Rauwolfia serpentina*, *Vetiveria zizanoides* and *Piper longum* performed better as intercrops

* Corresponding author. Tel.: +91 8255 239222; fax: +91 8255 239666.
E-mail address: s_sujatha68@rediffmail.com (S. Sujatha).
[1] Present address: Directorate of Weed Science Research, Jabalpur, Madhya Pradesh, India.

0926-6690/$ – see front matter
doi:10.1016/j.indcrop.2010.09.001

Table 1
Agro-techniques adopted for medicinal and aromatic plants as intercrops in arecanut plantation.

Crop	Family	Uses	Spacing (cm)	Planting material	Habit and duration	Price (Rs. kg^{-1})
Vetiveria zizanoides (Vetiver)	Poaceae	Ulcers and skin diseases, essential oil used in perfume and cosmetics	45 × 30	Root slips	15 months	45 (dry roots)
Asparagus racemosus (Asparagus)	Liliaceae	Lactogogue, improves lost body weight, aphrodisiac, dysentery, diabetes	60 × 60	Roots	18 months	10 (fresh roots)
Piper longum Linn. (Long pepper)	Piperaceae	Bronchitis, muscular pains, insomnia, epilepsy, stomach disorders, tuberculosis	60 × 60	Rooted cuttings	Perennial	80 (dry spikes)
Bacopa monnieri (Brahmi)	Scrophulariaceae	Epilepsy, insanity and memory loss	20 × 10	Rooted cuttings	Perennial	20 (dry herbage)
Nilgirianthus ciliatus	Acanthaceae	Rhumaltagia, Lumbago, chest congestion, cough, bronchitis	60 × 60	Cuttings	15 months	35 (shoot and root)
Catharanthus roseus (L.) G. Don.(Periwinkle)	Apocynaceae	Cancer and high blood pressure	30 × 20	Seed	12 months	10 (dry leaves) 20 (dry roots)
Aloe vera Linn (Aloe)	Liliaceae	Used externally to treat skin cuts, burns and eczema. Sap reduces inflammation	60 × 45	Suckers	Perennial	2000/t fresh leaves
Cymbopogon flexuous (Lemon grass)	Poaceae	Used in soaps and cosmetics. Raw material for synthesis of ionones and vit. A	45 × 45	Root slips	Perennial	300 (oil)
Cymbopogon martini Stapf. Var. *motia* (Palmarosa)	Poaceae	Essential oil used in soaps and perfumes	45 × 30	Seed	Perennial	450 (oil)
Ocimum basilicum (Basil)	Lamiaceae	Aromatic, stomachic, cough and cold	45 × 30	Seed	3 months	350 (oil)
Artemisia pallens) (Davana)	Asteraceae	Perfumes, food flavouring and medicine	30 × 15	Rooted cuttings	Perennial	8000 (oil)
Pogostemon patchouli Pellet. (Patchouli)	Lamiaceae	Oil of patchouli is extensively used in perfumery industry	45 × 45	Rooted cuttings	12 months	10 (fresh leaves)

in agroforestry system with Eucalyptus, *Leucaena leucocephala* and poplar. Several reports emphasized the need for conservation and cultivation of MAPs in agroforestry systems (Lambert et al., 1997; Dery et al., 1999; McNeelay, 2004; Rao et al., 2004).

Arecanut (*Areca catechu* L.) is an important plantation crop cultivated in 0.38 million hectares in India as per 2005–2006 statistics (GOI, 2008). The economic part of the palm is called as 'betel nut' and is mainly used for masticatory purpose in many parts of Asia. It has several alternate uses and all parts of the palm are useful. It is essentially a crop of small and marginal holders with insufficient income to sustain dependent families. Arecanut with its compact crown, raised well above the ground (10–15 m), allows more sunlight to transmit to ground and maintains high humidity. Studies indicated availability of congenial microclimate and less utilization of resources for intercropping in arecanut plantations (Balasimha, 2004; Bhat and Sujatha, 2008). The scope for intercropping in plantation crops is well documented (Viswanathan et al., 1992; Maheswarappa et al., 1998; Reddy and Biddappa, 2000; Sujatha and Bhat, 2010).

Cultivation of MAPs has several advantages like higher net returns per unit area, low incidence of pests and diseases, improvement of degraded and marginal soils, longer shelf life of end products and foreign exchange earning potential (GOI, 2000; Rao et al., 2000, 2004). However, lack of standardized cultivation aspects, supply of good quality planting material and marketing facilities are identified as major limitations in cultivation of MAPs (Rao et al., 2004). Intensive cultivation of MAPs requires suitable management strategies in arecanut tract. The quality of the economic products of MAPs is an absolute necessity. As the demand for organic products is increasing rapidly in the world market, adoption of organic farming approach would be a feasible option. With this background, the present study was undertaken to examine the impact of intercropping of MAPs with organic approach on resource use efficiency in arecanut based intercropping system.

2. Materials and methods

2.1. Details of experimental site

The investigation was conducted at Central Plantation Crops Research Institute, Regional Station, Vittal, Karnataka, India (12°15′N latitude and 75°25′E longitude, 91 m above MSL) during June 2004 to December 2007. The average annual rainfall at this location over last 30 years (1978–2008) is 3670 mm and is typically distributed over a 120-day period. The annual rainfall during experimental period varied between 3190 in 2005 to 3778 mm in 2006. Mean temperature ranges from 21 °C (minimum) to 36 °C (maximum). The average relative humidity varies between 61 and 94%. The soil of the experimental site is sandy clay loam (laterite) with a pH of 5.6, 1.5% organic carbon, 10 mg kg^{-1} P and 53 mg kg^{-1} K at 0–30 cm soil depth. The soil is well drained deep laterite comprising 54.6% sand, 14.4% silt and 36% clay at 0–60 cm soil depth. The bulk density of soil is 1.61 g cm^{-3} and field capacity 18–22%.

2.2. Experimental details

The arecanut plantation was established in December 1985 at a spacing of 2.7 m × 2.7 m. A field plot size of 2443 m^2 was selected for intercropping of MAPs. Raised beds of 64.8 m^2 size were made at a distance of 75 cm from the arecanut trunk for planting of intercrops. The net plot area for each intercrop was 145.8 m^2, which was inclusive of arecanut area. This implies intercrops occupied 44% of land in arecanut plantation. A sole block of arecanut (474 m^2 area) was maintained and this could not be included in the statistical analysis as sole crops of MAPs failed to establish in open conditions. The experiment was laid out in Randomised Block Design with 16 crops as treatments and five replications. Based on demand and export potential, medicinal and aromatic plants viz., *V. zizanoides* (vetiver), *Asparagus racemosus* (asparagus), *P. longum* (long pepper), *Bacopa monnieri* L. Pennel (brahmi), *Nilgirianthus ciliatus*, *Catha-*

Table 2
Yield of MAPs and kernel equivalent of MAPs in arecanut plantation.

Crop	Yield of MAPs (kg ha^{-1})				Kernel equivalent of MAPs (kg ha^{-1})			
	2004–2005	2005–2006	2006–2007	Mean	2004–2005	2005–2006	2006–2007	Pooled
Vetiveria zizanoides	1262	808	948	1006	944de	606^{cd}	569^{c}	706de
Asparagus racemosus (fresh wt)	14,310	–	7022	10,666	2045^{f}	–	1003^{e}	1524^{g}
Piper longum	171	272	250	231	225^{a}	358^{a}	233^{a}	272^{a}
Bacopa monnieri	2504	2788	2419	2070	729^{bcd}	796^{e}	691^{d}	739de
Nilgirianthus ciliatus								
Leaf	7423	7022	6817	7087	1715^{f}	1433^{g}	1138^{f}	1429^{g}
Root	1191	1066	794	1017				
Catharanthus roseus								
Leaf	2125	2631	2194	2317	590^{bc}	570^{bc}	951^{e}	704de
Root	671	395	115	394				
Aloe vera (fresh wt)	13,580	16,844	16,048	15,490	453^{ab}	562^{bc}	397^{b}	471^{bc}
Cymbopogon flexuous	8581	8810	7989	8460	1286^{e}	1409^{g}	958^{e}	1218^{f}
Cymbopogon martini	4452	2046	–	3249	625^{bcd}	346^{a}	–	485^{bc}
Ocimum basilicum	8128	8456	7807	8130	406^{ab}	423^{ab}	364^{b}	398^{ab}
Pogostemon cablin	7662	9722	9861	9082	817^{cd}	1037^{f}	736^{d}	863^{e}
Artemisia pallens	5756	5248	2210	5248	822^{cd}	749de	316^{ab}	629^{cd}
LSD (0.05)	–	–	–	–	352	156	83	162

Note: The data of 2004–2005 and some data of 2005–2006 was published by Sujatha et al. (2006) but utilized for mean data in this paper. Means in the same column with different letters are significantly ($P < 0.05$) different.

ranthus roseus (periwinkle), *Aloe vera* (aloe), *Withania somnifera* (aswagandha), *Cassia anguistifolia* (senna), *Chlorophytum borivillianum* (safed musli), *Cymbopogon flexuous* (lemon grass), *C. martini* (palmarosa), *Ocimum basilicum* L. (basil), *Artemisia pallens* (davana), *Pogostemon cablin* (patchouli) and *Pelargonium* sp. (geranium) were selected. However, *C. anguistifolia*, *C. borivillianum*, *W. somnifera* and *Pelargonium* sp. did not establish initially and thus only 12 crops were considered for final analysis. *O. basilicum* and *C. roseus* were sown as intercrops after heavy rains in monsoon season, i.e., August or September as they were found sensitive to waterlogging due to heavy rainfall in July.

2.3. Cultivation details about MAPs and arecanut

The details about cultivation of MAPs and their uses are given in Table 1. Agro-techniques recommended by CIMAP (Central Institute for Medicinal and Aromatic Plants, Lucknow, India) for MAPs were followed. Organic manure in the form of Farm Yard Manure (FYM) was applied to each intercrop as per sole crop recommendation. Farm Yard Manure at 10 t ha^{-1} year^{-1} was applied to *V. zizanoides*, *A. racemosus* and *C. flexuous*. Other crops were supplied with 5 t of FYM ha^{-1} year^{-1}. The NPK content in FYM was analysed using standard procedures (Jackson, 1973). FYM contained 0.5% N, 0.12% P and 0.45% K. All the MAPs were grown in open condition also for comparison. Though crops like *C. flexuous*, *Cymbopogon ÿmartinii*, *V. zizanoides*, *A. pallens* and *O. basilicum* performed well both as inter- and sole-crops, the cultivation of MAPs in open condition was discontinued from second year as many crops did not establish as sole crops due to their partial shade requirement. Arecanut invariably needs irrigation during post-monsoon season. In this trial, sprinkler irrigation equivalent to pan evaporation was given to arecanut.

2.4. Soil and leaf analysis

Soil samples were collected at 0–30 cm depth in each crop bed. Samples were air dried, cleaned for debris, ground and sieved through a 2 mm screen. Soil samples were analysed for pH, organic carbon, available P and K using standard procedures (Jackson, 1973). Soil pH was measured in 1:2 soil water suspension. Soil organic carbon was measured by Walkley and Black method. Fruit rot incidence caused by *Phytopthora palmivora* is generally high in arecanut belt and spraying of 1% Bordeaux Mixture was sprayed for prevention of this disease. The copper content in leaves of MAPs was analysed using diacid digestion method and Atomic Absorption Spectrophotometer to ascertain the impact of spraying of BM to base crop.

2.5. Yield and yield components

For computation of yields of MAPs, the economic products obtained from each intercrop during June–May every year was quantified and expressed as kg per hectare of arecanut plantation. In case of *O. basilicum* and *C. roseus*, one season data was available in a year as their performance was not good in post-monsoon season. For all other crops, economic products were harvested as and when ready throughout the year. In case of aromatic crops, essential oil content was determined through distillation in Clevenger apparatus (Guenther, 1972). Light availability using LI-6200 Portable Photosynthesis System (Li-Cor Inc., Nebraska, USA) was measured in March between 10.00 and 12.00 h. The preliminary yield data of MAPs published by Sujatha et al. (2006) was used for calculating overall mean of yield levels, production efficiency and net return per rupee investment in this paper. As the economic products of MAPs are different, the yields of MAPs were converted to arecanut kernel equivalent yield for statistical analysis. The kernel equivalent yield of MAPs was estimated using the following formula.

$$\text{kernel equivalent yield of MAPs} = \frac{\text{yield of MAPs}\ \ (\text{kg ha}^{-1}) \times \text{price of MAPs}\ \ (\text{Rs. kg}^{-1})}{\text{price of arecanut kernel}\ \ (\text{Rs. kg}^{-1})}$$

The price of MAP's is given in Table 1. The price of arecanut kernel was Rs. 70 kg^{-1}. Ripe nuts of arecanut were harvested during October–March every year, sun dried, dehusked and expressed as kg dry kernel per hectare. System productivity was obtained by adding kernel yield of arecanut to kernel equivalent yield of MAPs in arecanut + MAPs intercropping system. Production efficiency (kg ha^{-1} day^{-1}) was calculated by dividing the cumulative total yield in the system by the total duration of crops in arecanut + MAPs system. For calculating production efficiency, cumulative yield obtained during experimental period was considered as growth duration of some perennial crops was spread over different years.

Table 3
Economic analysis of MAPs in arecanut plantation.

Crop	Cost of cultivation (Rs. ha^{-1})			Net returns (Rs. ha^{-1})			Net return per rupee investment (Re. Rs^{-1})			
	2004–2005	2005–2006	2006–2007	2004–2005	2005–2006	2006–2007	2004–2005	2005–2006	2006–2007	Mean
Vetiveria zizanoides	18,500	10,000	12,000	38,200	26,400	30,600	2.07	2.64	2.55	2.42
Asparagus racemosus	39,000	–	20,000	104,100	–	50,000	2.67	–	2.50	2.59
Piper longum	7500	5000	5700	6180	16,760	14,300	0.82	3.35	2.50	2.22
Bacopa monnieri	13,575	10,300	10,000	36,520	45,114	38,400	2.69	4.38	3.84	3.64
Nilgirianthus ciliatus	17,000	13,750	6250	40,800	33,275	23,940	2.40	2.42	3.83	2.88
Catharanthus roseus	10,000	10,000	6500	24,760	24,204	17,900	2.47	2.42	2.75	2.54
Aloe vera	18,350	8350	9500	8810	25,338	23,370	0.48	3.03	2.46	1.99
Cymbopogon flexuous	19,800	11,000	12,370	57,300	59,475	55,000	2.89	5.40	4.45	4.25
Cymbopogon martini	11,800	11,000	–	23,800	20,740	–	2.02	1.88	–	1.95
Ocimum basilicum	5000	5000	5000	14,000	20,156	17,750	2.80	4.03	3.55	3.46
Pogostemon cablin	15,000	15,000	15,000	42,560	37,480	18,150	2.84	2.50	1.21	2.18
Artemisia pallens	15,000	13,000	13,000	38,000	49,600	39,260	2.53	3.81	3.02	3.12

Note: The data of 2004–2005 and some data of 2005–2006 was published by Sujatha et al. (2006) but utilized for mean data in this paper.

2.6. Economic and statistical analysis

Prices of most of the MAPs considered for computing returns (Table 1) were as per the rates given by CIMAP (Central Institute for Medicinal and Aromatic Plants, Lucknow, India) in Journal of Medicinal and Aromatic Plant Sciences, 2008. However, for *Nilgirianthus ciliates* the prices prevailing in the local market were considered. The cost of cultivation for each crop included labour, planting material and manures. In case of perennials, cost of planting material was included in first year as planting was done only once. For estimating net return per rupee investment, net returns were divided by cost of cultivation. Experimental design used five randomised blocks and twelve crops as treatments. Data was subjected to analysis of variance (ANOVA) using MSTATC. As the economic products of MAPs are different, it is difficult to compare statistically due to large variations in yield levels because of differences in their growth habits and duration. Thus, the yields of MAPs were converted to arecanut equivalent yield, i.e., kernel equivalent yield in order to test for statistical significance. After converting the MAPs yield to kernel equivalent yield, the means of different MAPs were compared.

3. Results and discussion

3.1. Yield of MAPs in arecanut plantation

The yields and kernel equivalent yields of MAPs are presented in Table 2. Pooled data of 3 years indicated that *A. racemosus* produced fresh root yield of 10,666 kg ha^{-1} of arecanut plantation and contributed to maximum kernel equivalent yield of 1524 kg ha^{-1} among all medicinal and aromatic plants. *N. ciliatus* produced root yield of 1017 kg ha^{-1} and shoot yield of 7087 kg ha^{-1}, which was equivalent to kernel yield of 1429 kg ha^{-1}. Aromatic plants performed well with kernel equivalent yield varying between 398 kg ha^{-1} in *O. basilicum* to 1218 kg ha^{-1} in *C. flexuosus*.

Based on kernel equivalent yield of MAPs (Table 2) and yield of arecanut (Table 4) in arecanut + MAPs intercropping, it can be concluded that intercropping of MAPs contributed to productivity increase per unit area of arecanut plantation. MAPs performed better with yield advantage in intercropping situations compared to open conditions (Sujatha et al., 2006). This can be attributed to partial shade for intercrops (515–638 μmol m^{-2} s^{-1}) in this study and congenial microclimate in arecanut plantation. Several workers highlighted better adaptation of MAPs to partial shaded conditions (Maheswarappa et al., 1998; Vyas and Nein, 1999; Rao et al., 2004).

There is a need to consider the effect of intercropping on oil content of aromatic plants. In this study, the aromatic oil content in *C. flexuosus* (0.6%), *C. martini* (0.6%), *O. basilicum* (0.5%) and *Arternesia pallens* (0.2%) was comparable to sole crops. Earlier reports also substantiate these results (Kamla Singh et al., 1985, 2000; Singh et al., 1990; Rao et al., 2000). The copper content in leaf samples of MAPs varied from 6 ppm in *V. zizanoides* to 17 ppm in *B. monnieri* in 2007. This indicates that the copper levels in plant samples are in optimum range and spraying of BM to arecanut has no adverse affect on intercrops.

3.2. Economic benefits

The details about cost of cultivation and net returns for MAPs were given in Table 3. It is clear from Table 3 that intercropping of MAPs in arecanut plantations was profitable. The cost of cultivation was generally high in first year for perennials due to inclusion of planting material cost and it reduced in subsequent years. Our results indicated that the cost of planting material of MAPs is high amounting to 30–50% of cost of production during first year. Thus, it is advisable to multiply the planting material by the growers themselves in order to reduce the cost of production. Net return per rupee invested was more than 2.0 for all intercrops except for *C. martini* and *A. vera*. The economic benefit in terms of net return per rupee investment was highest in *C. flexuosus* (4.25) followed by *B. monnieri* (3.64), *O. basilicum* (3.46) and *A. pallens* (3.12). Net return per rupee investment was lowest in *C. martini* (1.95) due to lesser yield levels in intercropping situations. However, if *C. martini* can be replanted once in 2 years, this crop could be successfully grown as an intercrop in arecanut plantation. Common irrigation facility for arecanut and MAPs and less weed growth due to intercropping resulted in significant savings in cost of production. Rao et al. (2004) also opined that MAPs are remunerative alternate crops to the traditional ones for smallholders in tropics and may be targeted to niche markets to secure higher premium on the premise of better quality.

Indian systems of medicines depend on variety of medicinal plants for synthesis of single substance/drug, while essential oil industries require raw material of aromatic plants in large quantities for distillation. Considering the demand and marketing facilities, farmers are advised to grow aromatic plants like *V. zizanoides*, *C. flexuous*, *C. martini*, *O. basilicum*, *A. pallens* and *P. cablin* in large areas on a community basis and variety of medicinal crops *A. racemosus*, *P. longum*, *B. monnieri*, *N. ciliatus*, *C. roseus* and *A. vera* in small areas. Several reports suggested increase in global demand for MAPs, negligible area under MAPs and short supply of raw material of MAPs (GOI, 2000; ICMAP, 2003; Rao et al., 2004). Therefore, it is visualized that glut in the market and price crash of MAPs are unlikely as these items will be in greater demand in coming years.

3.3. Effect of intercropping MAPs on yield of arecanut

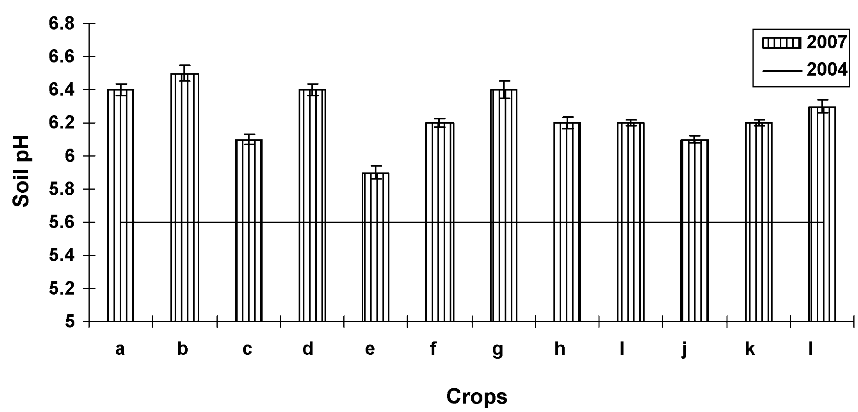
The kernel yield of arecanut was not affected adversely due to intercropping of MAPs in initial years (Sujatha et al., 2006), but

Table 4
Kernel yield of arecanut, system productivity and production efficiency of arecanut + MAPS intercropping system.

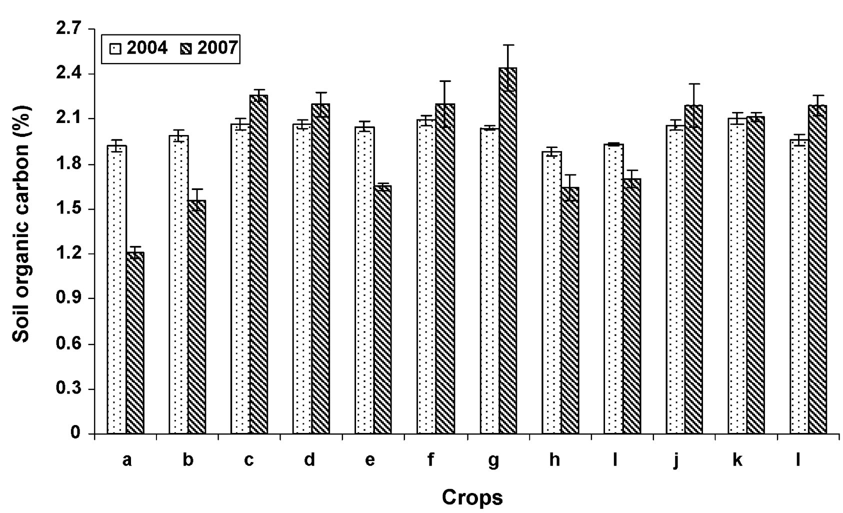
Crop	Pooled data of 3 years		Cumulative of 3 years for arecanut + MAPs system		
	Kernel yield of arecanut (kg ha^{-1})	System productivity (kg ha^{-1})	Total yield from system (kg ha^{-1})	Total duration of system (days)	Production efficiency of arecanut + MAPs system (kg ha^{-1} day^{-1})
Vetiveria zizanoides	2515^{ab}	3231^{abc}	9195^{ab}	2460	3.7^{a}
Asparagus racemosus	2835^{bcef}	4359^{e}	13,077^{e}	2190	6.0^{d}
Piper longum	2718^{bce}	2990^{a}	8971^{a}	2190	4.1^{b}
Bacopa monnieri	3586^{fg}	4325^{e}	12,975^{e}	2190	5.9^{d}
Nilgirianthus ciliatus	1884^{a}	3313^{abc}	9939^{abc}	2460	4.0^{b}
Catharanthus roseus	3440^{efg}	4144de	12,432^{de}	1635	7.6^{e}
Aloe vera	3081^{bcefg}	3552^{bc}	10,656^{bc}	2190	4.9^{c}
Cymbopogon flexuous	3121^{bcefg}	4338^{e}	13,015^{e}	2190	5.9^{d}
Cymbopogon martini	2678^{bc}	3164^{ab}	9491^{ab}	2190	4.3^{b}
Ocimum basilicum	3311^{cefg}	3708^{bcd}	11,125^{cd}	1365	8.2^{f}
Pogostemon cablin	3362^{cefg}	4225de	12,676^{e}	2190	5.8^{d}
Artemisia pallens	3595^{g}	4224de	12,673^{e}	1635	7.8^{e}
LSD (0.05)	756	553	1497	–	0.32

The data of 2004–2005 and some data of 2005–2006 was published by Sujatha et al. (2006) but utilized for pooled data in this paper. Means in the same column with different letters are significantly ($P < 0.05$) different.

varied significantly when pooled over 3 years (Table 4). Crops like *N. ciliatus* and *V. zizanoides* significantly reduced the arecanut yield compared to other intercrops. The bushy nature of *N. ciliatus* with NS-EW spread of 1.0–1.2 m might be responsible for yield reduction of arecanut. If this crop has to be taken up as an intercrop in arecanut plantation due to local market demand, it is advisable to plant in a single row in interspaces instead of two rows to avoid competition with base crop.



a. Soil pH (LSD (0.05)– 0.25)



b. Soil organic carbon (LSD (0.05)- NS in 2004 and 0.364 in 2007)

Fig. 1. Variation in soil pH and organic carbon at 0–30 cm depth as influenced by intercropping of medicinal and aromatic plants in arecanut plantation. Bars indicate the standard error. (a) *Vetiveria zizanoides*, (b) *Asparagus racemosus*, (c) *Piper longum*, (d) *Bacopa monnieri*, (e) *Nilgirianthus ciliatus*, (f) *Catharanthus roseus*, (g) *Aloe vera*, (h) *Cymbopogon flexuous*, (i) *Cymbopogon martini*, (j) *Ocimum basilicum*, (k) *Pogostemon cablin* and (l) *Artemisia pallens*.

3.4. System productivity and production efficiency of arecanut + MAPs intercropping

In this study, the total system productivity varied from 2990 to 4144 kg ha^{-1} due to intercropping of MAPs in arecanut (Table 3). The arecanut yield registered in sole block was 2795 kg ha^{-1}. Increase in system productivity due to intercropping of MAPs is a positive point for arecanut farmers as average productivity of arecanut in India is 1400 kg ha^{-1} (GOI, 2008) and in experimental fields of this station is less than 3500 kg ha^{-1} (Bhat et al., 2001, 2007). Though *N. ciliatus* reduced the arecanut yield, the system productivity from arecanut + *N. ciliatus* system was higher (3313 kg ha^{-1}). The production efficiency (kg ha^{-1} day^{-1}) varied between 3.7 in case of arecanut + *V. zizanoides* to 8.2 in arecanut + *O. basilicum* (Table 2). The results indicated that short duration intercrops registered higher production efficiency in arecanut based intercropping system. The above results highlight the importance of intercropping MAPs in arecanut for improving the resource use efficiency.

3.5. Soil pH and organic carbon (SOC)

Fig. 1 illustrates the differences in spatial and temporal variability in soil pH at 0–30 cm soil depth. Intercropping of MAPs had positive effect on soil pH. The soil pH was 5.6 in 2004 and it was 0.3–0.9 higher in 2007. This can be attributed to cultivation of intercrops and irrigation water quality. The irrigation water contained 0.2 mg kg^{-1} P, 9–11 mg kg^{-1} K, 6.5–20 mg kg^{-1} Ca and 1.5–4.0 mg kg^{-1} Mg. The irrigation water had a pH of 6.9–7.0 and naturally occurring calcium and magnesium ions, resulting in accumulation of these nutrients in upper soil depth. Treder et al. (1997) and Bhat and Sujatha (2009) also noticed increase in soil pH due to irrigation water containing a high amount of calcium and magnesium.

Spatial differences in SOC at 0–30 cm depth were more pronounced at the end of experimentation in 2007 compared to initial SOC status in 2004 (Fig. 1). Significant variation in SOC was noticed due to different intercrops. The increase in SOC content was noticed in *A. vera*, *A. pallens*, *P. longum* and *B. monnieri* during experimental period. However, the SOC content decreased from 1.92 to 1.21% in *V. zizanoides* and 1.99 to 1.56% in *A. racemosus*. This might be due to removal of root biomass in the harvested products resulting in the smaller input of C to the soil and also due to faster decomposition of organic matter in tropics. Depletion of SOC content was also noticed in *C. flexuosus* (13%) and *N. ciliatus* (19%). This can be attributed to higher biomass production in these crops. The loss of organic matter via plant harvest was reported earlier (Magdoff and Weil, 2004). Several reports indicated that root systems are major pathway for the input of carbon to soil (Young, 1997; Rajeew Kumar et al., 2006). Though the productivity increase was considerable with crops like *A. racemosus* (46%) and *V. zizanoides* (33%), depletion of SOC was noticed due to intercropping of these crops. Our results suggest that rhizomatic MAPs need more organic manure application and crop rotation to avoid depletion of soil organic carbon and to sustain higher yield levels.

4. Conclusions and recommendations

The study clearly indicated that arecanut plantation offers congenial conditions for intercropping of MAPs with improvement in resource use efficiency in terms of productivity and net return per unit area. The study also highlights that intensive cultivation of MAPs as understorey crops in arecanut plantation requires maintenance of soil organic carbon in laterite soils. Growing of MAPs as intercrops in arecanut plantation had complementary effect on base crop. Based on this 4-year study, farmers are advised to grow aromatic plants in large areas on a community basis to meet huge industrial demand and variety of medicinal crops in small areas based on local demand.

References

Balasimha, D., 2004. Cropping systems. In: Balasimha, D., Rajagopal, V. (Eds.), Arecanut. CPCRI, Kasaragod, pp. 103–130.

Bhat, R., Sujatha, S., 2008. Root distribution of arecanut (*Areca catechu* L.) as influenced by drip fertigation in a laterite soil. Indian J. Agric. Sci. 78 (9), 804–807.

Bhat, R., Reddy, V.M., Jose, C.T., 2001. Effect of intercrops on arecanut yield. J. Plantation Crops 29 (1), 66–67.

Bhat, R., Sujatha, S., Balasimha, D., 2007. Impact of drip fertigation on productivity of arecanut (*Areca catechu* L.). Agric. Water Manage. 90 (1/2), 101–111.

Bhat, R., Sujatha, S., 2009. Soil fertility and nutrient uptake by arecanut (*Areca catechu* L.) as affected by level and frequency of fertigation in a laterite soil. Agric. Water Manage. 96 (3), 445–456.

Dery, B.B., Otsyina, R., Ng'tigwa, C., 1999. Indigenous Knowledge of Medicinal Trees and Setting Priorities for their Domestication in Shinyanga Region, Tanzania. International Center for Research in Agroforestry, Nairobi, Kenya.

GOI, 2000. Report of the Taskforce on Medicinal Plants in India. Planning Commission, Government of India, Yojana Bhawan, New Delhi, India.

GOI, 2008. Area and Production Statistics of Arecanut and Spices. Directorate of Arecanut and Spices Development, Ministry of Agriculture, Government of India, Calicut.

Guenther, E., 1972. The Essential Oils, vol. 1. Robert E. Krieger Pub Co., Huntington, New York, pp. 316–319.

ICMAP, 2003. Resolutions of International Council for Medicinal and Aromatic Plants. In: Third World Congress on Medicinal and Aromatic Plants for Human Welfare-WOCMAP III, 03–07 February 2003, Chiang Mai, Thailand.

Jackson, M.L., 1973. Soil Chemical Analysis. Prentice Hall of India Pvt. Ltd., New Delhi.

Kamla Singh, Rao, B.R.R., Kothari, S.K., Singh, C.P., Kaul, P.N., Sushil Kumar, Singh, K., Kumar, S., 2000. Cultivation of aromatic crops in South India: problems and prospects. J. Medicinal Arom. Plant Sci. 22 (1B), 218–230.

Kamla Singh, Virendra Singh, Singh, J.P., Kothari, S.K., 1985. Cultivating medicinal and aromatic plants along agroforestry. Indian Farmers Digest 18 (9), 34–36.

Kuipers, S.E., 1997. Trade in medicinal plants. In: Bodeker, G., Bhat, K.K.S., Burley, J., Vantomme, P. (Eds.), Medicinal Plants for Forest Conservation and Healthcare, Non-Wood Forest Products, vol. 11. FAO, Rome, pp. 45–59.

Lambert, J., Srivastava, J., Vietmeyer, N., 1997. Medicinal Plants: Rescuing a Global Heritage. The World Bank, Washington, DC.

Magdoff, F., Weil, R.R., 2004. Soil organic matter management strategies. In: Magdoff, F., Weil, R.R. (Eds.), Soil Organic Matter in Sustainable Agriculture. CRC Press, Boca Raton, FL, pp. 45–65.

Maheswarappa, H.P., Hegde, M.R., Nanjappa, H.V., 1998. Kacholam (*Kaempferia galanga* L.)—a potential medicinal-cum-aromatic crop for coconut gardens. Indian Coconut J. 29 (5), 4–5.

McNeelay, J.A., 2004. Nature vs. nurture: managing relationships between forests, agroforestry and wild biodiversity. Agroforest. Syst. 61, 155–165.

Rajeew Kumar, Pandey, S., Pandey, A., 2006. Plant roots and carbon sequestration. Curr. Sci. 91 (7), 885–890.

Rao, E.V.S.P., Puttanna, K., Rao, R.S.G., Kumar, S., 2000. Prospect of Commercial mediculture and recent advances in agrotechnologies of aromatic plants in South India. J. Medicinal Arom. Plant Sci. 22 (1B), 207–213.

Rao, M.R., Palada, M.C., Becker, B.N., 2004. Medicinal and aromatic plants in agroforestry systems. Agroforest. Syst. 61, 107–122.

Reddy, D.V.S., Biddappa, C.C., 2000. Coconut based cropping/farming systems in India. J. Plantation Crops 28 (1), 1–18.

Singh, K., Singh, V., Hussain, A., Kothari, S.K., 1990. Aromatic crops as efficient intercrops under poplars (*Populus deltoids* Bartrama ex Marshall). Indian Forester 116, 189–193.

Sujatha, S., Bhat Ravi, Balasimha, D., Kannan, C., 2006. Crop diversification in arecanut plantation through intercropping of medicinal and aromatic plants. J. Plantation Crops 34 (3), 318–322.

Sujatha, S., Bhat, R., 2010. Response of vanilla (*Vanilla planifolia* A.) intercropped in arecanut to irrigation and nutrition in humid tropics of India. Agric. Water Manage. 97, 988–994.

Treder, W., Olszewski, T., Cieslinski, G., 1997. Changes of physico-chemical soil properties as a effect of a drip irrigation of plum trees. Acta Hortic. 448, 247–250.

Viswanathan, T.V., Radhakrishnan, V.V., Reghunath, B.R., Prasannakumari, K.T., 1992. Patchouli (*Pogostemon cablin*) as an intercrop in young coconut (*Cocos nucifera*) garden. Indian J. Agric. Sci. 62 (9), 616–617.

Vyas, S., Nein, S., 1999. Effect of shade on the growth of *Cassia unguistifolia*. Indian Forester 125, 407–410.

Young, A., 1997. The role of roots. In: Agroforestry for Soil Management. CAB International, UK, pp. 137–146.