



Productivity and carbon sequestration potential of coconut-based cropping system as influenced by integrated nutrient management practices

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Abstract

A field experiment was carried out at Regional Coconut Research Station, Bhatye (DBSKKV, Dapoli), Maharashtra State (India) during 2013-2018 to study the productivity and carbon sequestration potential as influenced by integrated nutrient management (INM) practices in coconut based cropping system. INM practices viz., T1- 75 per cent of Recommended Dose of Fertilizers (RDF) + 25 per cent of N through organic recycling with vermicompost, T2- 50 per cent of RDF + 50 per cent of N through organic recycling with vermicompost + vermiwash application + bio-fertilizer application + *in situ* green manuring (cowpea), T3- fully organic: 100 per cent N through organic recycling with vermicompost + vermiwash application + bio-fertilizer application + *in situ* green manuring (cowpea) and green leaf manuring + composted coir pith, husk incorporation and mulching with coconut leaves were imposed in coconut based cropping system involving nutmeg, cinnamon, banana and pineapple. For comparison, T4- control: monocrop of coconut with recommended NPK and organic manure was maintained. Four treatments were laid out in blocks of 0.11 ha area each. Among the different INM practices, treatment T1 sequestered the highest amount of above ground (coconut + nutmeg) carbon stock (31.1 t ha⁻¹) followed by T2 (30.3 t ha⁻¹) and T3 (27.3 t ha⁻¹). In contrast, the treatment T4 - coconut monocrop alone had sequestered 25.6 t ha⁻¹. The below-ground soil carbon stock in the rhizosphere of different crops was the highest in the nutrient management under T3 followed by T2 and T1, whereas, it was the lowest in coconut monocrop. The productivity of the system was higher in the intercropping garden. The coconut nut yield (5-year average) was higher yield under T1 (147.2 nuts palm⁻¹ year⁻¹), followed by T2 (138.4 nuts palm⁻¹ year⁻¹) and T3 (123.6 nuts palm⁻¹ year⁻¹), whereas, monocrop had recorded a significantly lower number of nuts (97.2 nuts palm⁻¹ year⁻¹).

Keywords: Carbon sequestration, coconut, INM, intercrops, productivity

Introduction

Coconut (*Cocos nucifera* L.) is an important commercial plantation crop grown for its multifarious uses and cultivated in the country predominantly by smallholders in tropical regions in 2.17 million ha with a production of 21,384 million nuts and productivity of 9,815 nuts hectare⁻¹. Kerala, Tamil Nadu, Karnataka and Andhra Pradesh are the four major coconut producing states in India, accounting for more than 91 per cent of the share in area and production (Anonymous, 2019). Monocropping of

coconut is unsustainable as it utilizes only 45-50 per cent of solar radiation, 21 per cent of land area and the income derived from such a system is not sufficient to sustain even the small families (Maheswarappa *et al.*, 2010). Furthermore, coconut growers are frequently exposed to economic risks and uncertainties owing to rapid price fluctuations. The growers of this crop were badly affected for more than two decades due to low price/price stagnation of coconut and the escalating cost of cultivation. Given this context, a coconut-based cropping system is a viable option and amenable

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for the integration of INM packages, which play a significant role in improving the soil properties and productivity of the system (Krishnakumar and Maheswarappa, 2010; Naveen Kumar *et al.*, 2016 and 2017; Maheswarappa *et al.*, 2013).

In recent past, it is a well-known fact that due to climate change, there is an increase in the concentration of carbon dioxide (CO₂) and other greenhouse gases (GHGs) leading to global warming. The key activities involved to bring down the global concentrations of GHGs are; to reduce the anthropogenic emissions of CO₂ and create or promote carbon (C) sinks in the biosphere which could be achieved by promoting land-use practices such as agroforestry and intensive cropping system (Montagnini and Nair, 2004). Carbon sequestration is a mechanism for the removal of carbon from the atmosphere by storing in the biosphere (Chavan and Rasal, 2012). The coconut-based cropping systems, involving the cultivation of compatible crops especially fruit crops in the interspaces will offer considerable scope for increasing production and productivity per unit area, time and input by more efficient utilization of resources like sunlight, soil, water and labour. Besides, it will mimic a forest system and will have large scope for storage of carbon and fixing of carbon dioxide from the atmosphere, thus playing a pivotal role in sustaining the environment (Bhagya *et al.*, 2017). Of late, humans can manage soils to accumulate carbon or avoid high losses of it with cultivation (Lal, 2010). The soil organic carbon, which traditionally has been a sustainability indicator of agricultural systems, has now acquired the supplemental role as an indicator of environmental health. Addition of soil amendments can increase the rate of plant growth and hence the amount of carbon sequestered in the soil ecosystem. There are reports that application of soil amendments can increase the

growth and productivity as well as the carbon sequestered in the above-ground biomass and soil ecosystem too (Naveen Kumar *et al.*, 2016 and 2017; Maheswarappa *et al.*, 2013). The perennial spice crops like nutmeg, cinnamon and fruit crops *viz.*, banana and pineapple have been found compatible and economical intercrops in well-spaced coconut gardens (Nagwekar *et al.*, 2014). Given these facts, studies on the influence of cropping system and INM on productivity and carbon sequestration potential was carried out in coconut garden.

Materials and methods

The investigation was carried out under ICAR-All India Coordinated Research Project on Palms at Regional Coconut Research Station, Bhatye (DBSKKV, Dapoli) Maharashtra, India during 2013-14 to 2018-19. The experimental station is situated at 17.00°N latitude, and 73.40°E longitude at an elevation of 3.0 m above mean sea level. The experimental site represents red sandy loam soil with acidic pH (5.8), medium organic carbon content (0.62%) and medium-fertility status. The average annual rainfall received is 3500 mm, of which 82 per cent is received during the monsoon months (June-September). The mean temperature ranges from 21°C (min.) to 36°C (max.), the average relative humidity varies between 60 and 95 per cent. The experiment was laid out in a 32-year-old coconut garden which was planted at a distance of 7.5 m × 7.5 m in a square system. The crops in the cropping system were managed with the recommended package of practices. The experimental block of each treatment was laid out in 0.11 ha coconut garden and intercropping with released varieties of spices and fruit crops in Maharashtra State was adopted. Pictorial representation of spice and

Table 1. Fruit and spice crop species grown in coconut-based INM system

Common name	Scientific name	Plants block ⁻¹	Plants ha ⁻¹
Coconut var. D x T (COD x WCT)	<i>Cocos nucifera</i> L.	20	177
Nutmeg var. Konkan Swad	<i>Myristica fragrans</i>	12	135
Cinnamon var. Konkan Tej	<i>Cinnamomum verum</i>	62	615
Banana var. Safed Velchi	<i>Musa acuminata</i>	62	615
Pineapple var. Kew	<i>Ananas comosus</i>	960	10800

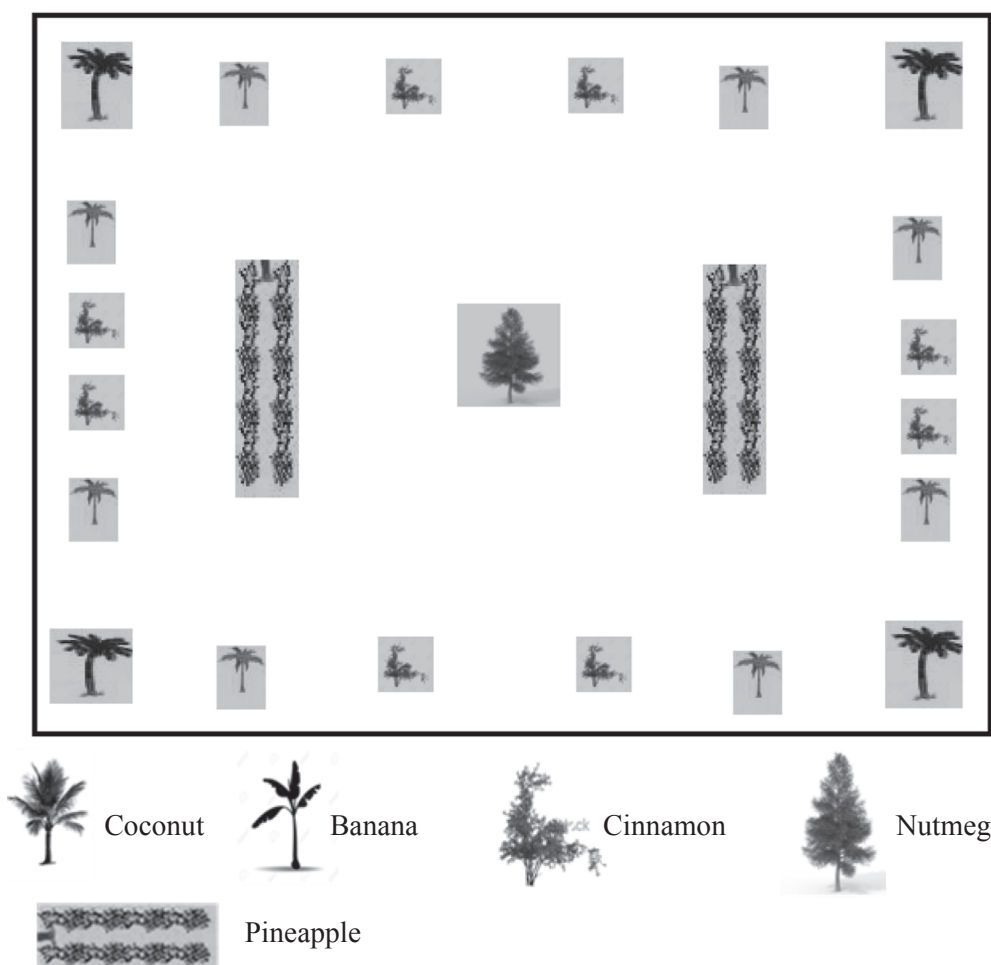


Fig. 1. Layout of single plot

fruit crops grown in the coconut garden is given in Figure 1.

Integrated nutrient management (INM) practices

- T1:** 75 per cent of Recommended Dose of Fertilizers (RDF) + 25 per cent of N through organic recycling with vermicompost.
- T2:** 50 per cent of RDF + 50 per cent of N through organic recycling with vermicompost + vermiwash application + bio-fertilizer application + *in situ* green manuring with cowpea.
- T3:** Fully organic: 100 per cent of N through organic recycling with vermicompost + vermiwash application + bio-fertilizer application + *in situ* green manuring with

cowpea and green leaf manuring (*Glyricidia* leaves) + composted coir pith, husk incorporation (once in three years) and mulching with coconut leaves.

- T4:** Control: monocrop of coconut with recommended NPK and organic manure.

The quantity of NPK and vermicompost applied under different INM practices has been described by Maheswarappa *et al.* (2011). As per the different INM practices, vermicompost was applied during September-October, and inorganic fertilizers in the form of urea, single super phosphate and muriate of potash were applied in three splits doses during June-July, September-October and January-February. Vermicompost was obtained by decomposing coconut leaves and other recyclable biomass as per the procedure explained by

Prabhu *et al.* (1998). The biomass was recycled back into the system after making vermicompost and recommended dose of fertilizer was applied both for coconut and component crops as per treatment details. The vermicompost was prepared and applied to meet the requirement of nutrients. The vermiwash collected was drenched in the basin of each crop by diluting it in the ratio of 1:10 with water and applied twice in the year for coconut @ 5 litres basin⁻¹, nutmeg @ 3 litres tree⁻¹, banana @ 2 litres plant⁻¹, pineapple 4 litres in a bed of 40 plants and cinnamon @ 2 litres plant⁻¹. In addition to this, *Glyricidia* plants were grown as green manuring crop at a border of plot and green leaves were incorporated in the rhizosphere of coconut and intercrops in June, during application of fertilizer. Irrigation was provided during winter and summer months with sprinkler irrigation system based on pan evaporation data of the region at IW/CPE of 1.0. The observations on above-ground standing biomass and soil carbon stock were estimated by taking 10 trees and palms randomly in each block during December 2019. The spice crop nutmeg girth was measured at 1.3 m height from the base, and the total height of the species was recorded from the base of treetop by using Dendrometer.

Above ground carbon sequestration in coconut

For above-ground standing biomass estimation, the non-destructive method was adopted (Naresh *et al.*, 2008). In coconut, the girth was measured at 1.5 m height from the base and height was taken up to the base of the crown.

Stem dry weight (SDW) (kg) = height (m) x girth (m)² x 41.14142,

Carbon stock generally, for any plant species, 50 per cent of its biomass is considered as carbon (Pearson *et al.*, 2005).

Carbon stock (kg palm⁻¹) = Biomass (SDW) × 0.5 (50% of wood biomass is considered as the carbon stored).

h = height of palm (m)

g = girth (in m) = 2 πr

For estimation of CO₂ (t ha⁻¹) sequestered, multiplying carbon stock (t ha⁻¹) with 3.67 as factor.

$$C \text{ (t ha}^{-1}\text{)} = C \text{ (kg ha}^{-1}\text{)} \times 1000^{-1}$$

$$\text{CO}_2 \text{ (t ha}^{-1}\text{)} = C \text{ (t ha}^{-1}\text{)} \times 3.67$$

Note:

$$1 \text{ kg CO}_2 = 0.27 \text{ kg carbon}$$

$$1 \text{ kg C} = 3.67 \text{ kg CO}_2$$

$$1 \text{ Mega gram (Mg)} = 1 \text{ t}$$

Below ground carbon stock/soil carbon stock

For soil carbon stock estimation, soil samples were collected during December 2019 from the basin of the crops as per the standard procedures. The organic carbon content of the soil was estimated by adopting Walky-Black's method, and bulk density of the field was estimated by using core sampler at 0-30 and 31-60 cm depth described by Jackson (1967). Soil carbon stock was estimated by following the standard formula (Srinivasan *et al.*, 2012).

$$\begin{aligned} \text{Soil organic} \\ \text{carbon stock} \\ \text{(Mg ha}^{-1}\text{)} \end{aligned} \begin{matrix} \\ \\ \text{(0-30, 31-60)} \end{matrix} = \begin{matrix} [(\text{C concentration})_{\text{layer}} \text{ (kg Mg}^{-1}\text{)} \\ \times (\text{Bulk density})_{\text{layer}} \text{ (Mg m}^{-3}\text{)} \\ \times \text{Depth (m)} \times 10^{-3} \text{ Mg kg}^{-1} \times 10^4 \text{ (m}^2 \text{ ha}^{-1}\text{)}] \end{matrix}$$

Statistical analysis

As the experiment was laid out in a block of 0.45 ha area for each treatment, the weather parameters during the year influence the productivity of the system. Hence, in the analysis, the year effect was taken as a fixed effect in the ANOVA table and treatment effect as error. The statistical analysis was performed using Statistical analysis system 9.3 computer software (SAS Institute Inc., 1995). DMRT procedure was used at P = 0.05 level to determine the significance among the treatments.

Results and discussion

Yield of different intercrops

The five-year average yield of different intercrops under coconut based cropping system with INM practices and monocrop of coconut is represented in Table 2. The data indicated that the nutmeg yield was significantly higher in T1 treatment compared to other treatments. Cinnamon

Table 2. Yield of coconut and different component crops (plant⁻¹) under coconut based integrated nutrient management system (Pooled data 2014-15 to 2018-19)

Treatment	Coconut (nuts palm ⁻¹ year ⁻¹)	Nutmeg (nuts tree ⁻¹)	Nutmeg mace (g tree ⁻¹)	Cinnamon bark (kg tree ⁻¹)	Cinnamon leaves (kg tree ⁻¹)	Banana (kg plant ⁻¹)	Pineapple (kg plant ⁻¹)
T1	147.2	339.3	421.3	0.21	0.89	11.3	2.2
T2	138.4	312.5	378.1	0.19	0.73	10.6	2.0
T3	123.6	276.2	328.6	0.18	0.71	8.9	2.0
T4	97.2	-	-	-	-	-	-
SE m±	5.14	5.39	3.78	0.03	0.02	0.65	0.03
CD (P=0.05)	16.48	16.18	11.34	NS	0.07	1.98	NS

bark yield and pineapple yield did not differ significantly among the INM treatments. The banana yield was significantly higher under T1 (11.3 kg plant⁻¹) and was on par with T2 (10.6 kg plant⁻¹). With respect to coconut nut yield, T1 treatment recorded significantly higher nuts (147.2 nuts palm⁻¹ year⁻¹), and was at par with T2 and differed significantly with T3 and T4 treatments. The lowest yield of coconut (97.2 nuts palm⁻¹ year⁻¹) was recorded in coconut monocrop. Enhanced system productivity in coconut based cropping system with INM has been attributed to better growth of the crops, which was reflected in the yield of crops in

the system. The results conform with the findings of Maheswarappa (2008), Krishnakumar and Maheswarappa (2010), Maheswarappa *et al.* (2013) and Naveen Kumar *et al.* (2016; 2017).

Above ground carbon sequestration of crops

From the data (Table 3) it was observed that, among the different INM systems, the above-ground standing biomass (SDW) and above-ground carbon stock (353.3 kg plant⁻¹ and 31.1 t ha⁻¹, respectively) was significantly the highest in the treatment T1 followed by T2 (345.1 kg plant⁻¹ and 30.3 t ha⁻¹) and T3 (310.3 kg plant⁻¹ and 27.3 t ha⁻¹),

Table 3. Influence of intercrops and integrated nutrient management practices on above ground carbon stock and sequestration under coconut garden

Crop	Treatment	Plant height (m)	Plant girth (m)	Biomass (kg plant ⁻¹)	Carbon stock (kg plant ⁻¹)	Carbon stock (t ha ⁻¹)*	CO ₂ sequestered (t ha ⁻¹)*
Coconut	T1	11.8	0.84	343.5	171.8	30.4	111.6
	T2	10.7	0.89	335.6	167.8	29.7	109.0
	T3	11.6	0.79	303.4	151.7	26.8	98.5
	T4	10.4	0.81	288.8	144.4	25.6	93.8
	Mean	11.1	0.83	317.8	158.9	28.1	103.2
	SE m±	0.39	0.05	5.8	3.07	0.7	0.67
	CD (P=0.05)	1.24	0.17	18.6	9.82	2.24	2.14
Nutmeg	T1	3.04	0.28	9.7	4.87	0.66	2.42
	T2	3.18	0.26	9.5	4.75	0.64	2.35
	T3	2.53	0.23	6.9	3.46	0.47	1.72
	Mean	2.92	0.26	8.73	4.36	0.59	2.16
	SE m±	0.16	0.01	0.35	0.25	0.02	0.17
	CD (P=0.05)	0.56	0.04	1.22	0.86	0.06	0.58

Note:* indicates 177 palms ha⁻¹ in coconut and 135 nutmeg trees ha⁻¹ coconut garden
SDW = stem dry weight, C = carbon

respectively. The lowest above-ground biomass and carbon stock was observed in coconut monocrop (288.8 kg plant⁻¹ and 25.6 t ha⁻¹, respectively). This is because the intercrops in coconut based cropping system have added additional biomass production than monocrop, hence the carbon stock was the highest in the cropping system plots compared to monocrop of coconut. Furthermore, the CO₂ sequestered also followed the same trend and accordingly, the highest CO₂ sequestration was recorded in the treatment T1 (114.0 t ha⁻¹) followed by T2 (111.4 t ha⁻¹) and T3 (100.2 t ha⁻¹). The lowest CO₂ sequestration was noticed in coconut monocrop (93.8 t ha⁻¹). These results are in accordance with the research findings of Bhagya *et al.* (2017) who opined that coconut-based cropping system sequestered more carbon as compared to coconut alone. Trees are carbon reservoir on earth and in nature, forest ecosystem act as a reservoir of carbon and store a huge quantity of carbon and regulate the carbon cycle by the exchange of CO₂ from the

atmosphere. Thus, forest ecosystem plays a significant role in the global carbon cycle by sequestering a substantial amount of carbon dioxide from the atmosphere by storing it in the biosphere (Chavan and Rasal, 2012).

Soil bulk density and organic carbon

The data presented in Table 4 represents the bulk density of soil (g per cm³), soil organic carbon (%) and soil carbon stock (t ha⁻¹) at 0-30 and 31-60 cm depth in the rhizosphere of different crops in the system. With respect to bulk density, there was no significant difference found among the different cropping system and INM practices at both the depths during this study. Whereas, the organic carbon (OC) status differed significantly among the treatments at both the depths. Among the different crops, significantly higher soil organic carbon was observed in coconut basin at 0-30 and 31-60 cm depth (0.86% and 0.81%) in the treatment T3 which was on par with treatment T2 and T1. The coconut

Table 4. Effect of intercrops and integrated nutrient management practices on organic carbon, soil bulk density and soil carbon stock under coconut based cropping system (2019)

INM practices	Crop	Organic carbon (%)		Bulk density (g cm ⁻³)		Soil carbon stock (t ha ⁻¹)	
		0-30 cm	31-60 cm	0-30 cm	31-60 cm	0-30 cm	31-60 cm
T1	Coconut	0.81 a	0.77 a	1.62	1.64	39.4 a	37.9 a
	Nutmeg	0.64 b	0.61 bc	1.60	1.63	30.7 b	29.8 b
	Cinnamon	0.61 cd	0.56 c	1.61	1.63	29.5 bc	27.4 c
	Banana	0.63 b	0.57 cd	1.62	1.64	30.6 b	28.0 cd
	Pineapple	0.60 cd	0.54 cd	1.60	1.62	28.8 cd	26.2 d
T2	Coconut	0.83 a	0.78 a	1.63	1.64	40.6 a	38.4 a
	Nutmeg	0.66 b	0.62 bc	1.62	1.63	32.1 b	30.3 b
	Cinnamon	0.63 cd	0.58 d	1.62	1.64	30.6 bc	28.5 c
	Banana	0.67 b	0.61 cd	1.63	1.64	32.8 b	30.0 bc
	Pineapple	0.62 cd	0.56 d	1.60	1.62	29.8 bc	27.2 d
T3	Coconut	0.86 a	0.81 a	1.64	1.64	42.3 a	39.9 a
	Nutmeg	0.67 b	0.62 b	1.62	1.63	32.6 b	30.3 bc
	Cinnamon	0.66 b	0.60 cd	1.62	1.64	32.1 b	29.5 c
	Banana	0.68 b	0.63 b	1.62	1.64	33.0 b	31.0 b
	Pineapple	0.65 bc	0.60 cd	1.62	1.64	31.6 bc	29.5 c
T4	Coconut (monocrop)	0.60 cd	0.51 cd	1.58	1.60	28.4 cd	24.2 d
	Interspace	0.46 e	0.44 e	1.59	1.60	21.9 e	21.1 e
	CD (P=0.05)	0.048	0.79	NS	NS	2.1	3.3

basin in the monocropping recorded, significantly, the lowest organic carbon at both the depths (0.60 and 0.51 %). The rhizosphere of intercrops like nutmeg, cinnamon, pineapple and banana also recorded higher organic carbon content, whereas, in the interspace of monocropping, it was significantly lower (0.46 and 0.44 %). Growing intercrops in the coconut garden have led to the addition of recyclable biomass from the intercrops and which has resulted in improvement in the organic carbon content. Similar results were also reported by Maheswarappa (2008) and Naveen Kumar and Maheswarappa (2019) in coconut based cropping system with INM.

Soil carbon stock

The soil carbon stock was significantly influenced by the coconut-based cropping system and INM practices (Table 4). Among the different crops under investigation, the coconut rhizosphere in the treatment T3 had significantly higher soil carbon stock (42.3 t ha⁻¹ and 39.9 t ha⁻¹) in the depths of 0-30 and 31-60 cm followed by treatment T2 (40.6 t ha⁻¹ and 38.4 t ha⁻¹) and T1 (39.4 t ha⁻¹ and 37.9 t ha⁻¹). The lowest soil carbon stock of 28.4 t ha⁻¹ and 24.2 t ha⁻¹ at 0-30 and 30-60 cm depth was noticed in the coconut rhizosphere in monocrop (T4). Among the different INM practices in coconut based cropping system, significantly higher soil carbon stock was observed in the treatment T3 at 0-30 and 31-60 cm depth in the rhizosphere of different crops followed by T2 and T1. The lowest soil carbon stock in the coconut monocrop (T4) might be due to the absence of intercrops in the interspace, which might not have contributed to the soil carbon pool. Furthermore, the coconut basin rhizosphere has recorded higher carbon stock at both depths (0-30 and 31-60 cm), which might be due to increase in organic carbon in the soil owing to decomposition of root system over a period of time as compared to other crops and organic manure incorporation to the coconut crop and interaction effect of organic manure and green manure incorporation. Similar findings were observed in orchard wherein, the beneficial effects of sustainable practices (residue incorporation, cover crop retention and compost application) on yield which was improved as compared with conventionally managed orchards (Xiloyannis *et al.*, 2014;

Bhagya *et al.*, 2017; Naveen Kumar and Maheswarappa, 2019).

Conclusion

The present study on coconut-based cropping system with different intercrops under INM practices in the coastal ecosystem of Maharashtra has substantially contributed towards improving the above and below ground carbon stock of the system. The above-ground standing biomass and carbon stock recorded was the highest in T1, followed by T2 and T3, and the lowest was in coconut monocrop. In respect of soil carbon stock, among the different crops under investigation, the coconut rhizosphere in the treatment T3 had significantly higher soil carbon stock followed by treatment T2 and T1. In contrast, the lowest sequestration of soil carbon stock was noticed in coconut monocrop. The productivity of the system was higher in the intercropping garden with INM practices, whereas monocrop had recorded significantly lower productivity. Thus by intercropping with spice and fruit crops in coconut garden along with INM practices, the carbon stock is higher along with an increase in the system productivity over a period of time as compared to the monocropping system of coconut.

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