Research Article

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Sustainability of soil health and system productivity through arecanut based cropping system in the NE region of India

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Abstract

The North-Eastern part of India contains seven states out of which, Assam is the major producer of arecanut. An attempt was made to study the impact of arecanut based multiple cropping system with proper utilization of recyclable resources on the long-term sustainability of acid soil at Kahikuchi. A long term arecanut based High-Density Multispecies Cropping System garden comprised of two models *viz*., Model-1 (M1): arecanut (*Areca catechu*), black pepper (*Piper nigrum*), banana (Musa spp.), citrus (*Citrus limon*) and clove (*Syzygium aromaticum*) and Model-2 (M2): arecanut, black pepper, banana, citrus and nutmeg (*Myristica fragrans*) as component crops was used. Both the models were sub-divided into three treatments *viz*., Full dose of recommended fertiliser (T1), 2/3rd of the recommended dose (T2) and 1/3rd of the recommended dose (T3) combined with treatment-wise recycling available biomass in the form of vermicompost and each treatment was replicated thrice. The results indicated that the quantity of recyclable biomass generated ranged between 8.27 to 12.23 t ha^{-1} $year^{-1}$ and 8.11 to 12.38 t ha^{-1} $year^{-1}$ in model-1 and model-2, respectively and revealed that the T2 treatment in both models improved the soil properties with respect to soil pH, organic carbon, available N, P and K status. Economics of the cropping system revealed that the maximum return was obtained from both Models under T2. The average benefit:cost ratio of T1, T2 & T3 were 3.38, 4.42 & 3.47 under model-1 and 3.34, 4.08 & 3.40 under model-2, respectively. Sustenance of soil pH above 5.0 over the years in the arecanut rhizosphere in both the models were found under T2, but T1 and T3 treatments showed a slow declining of pH towards increasing soil acidity.

Keywords: Arecanut, acid soils, cropping system, nutrient, vermicompost

Introduction

Arecanut (*Areca catechu* Linn.) is one of the important plantation crops, and about 90 per cent of total arecanut production in India is mainly contributed by Karnataka, Kerala and Assam. The North-Eastern part of India contains seven states out of which Assam is the major producer of arecanut. In India, arecanut is grown in an area of 518.71 thousand hectares producing 901.78 thousand metric ton of arecanut (chali-dried arecanut kernel), and Assam ranks third in production. In Assam, it is grown in an area of 80.81 thousand hectares with an annual production of 77.90 thousand metric tons (Horticultural Statistics at a Glance, 2018). Though arecanut cultivation is confined within the homestead garden in North-Eastern states, it is also extensively cultivated as an important commercial crop. Lack of awareness of recent technological development and non-application of nutrients to the arecanut palms lead to poor production of the crop. In a state where arecanut is associated with economic as well as the religious purpose of the people, application of fertilizers and manures is of utmost importance for

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the crop which is supposed to provide an economic return for a period of 40-50 years. An ecological approach through the utilization of both organic and inorganic nutrient inputs will help in sustainable yield production of the crops. Nutrient input enhancing and recycling on existing crop land is required for intensifying food production for food security. Crop yields are highly affected mainly due to compaction of soils, acidification and decrease in organic matter of soils (Dalal *et al.,* 1991). Organic matter application to the soil will help in replenish soil nutrients and also improve soil physical, biological and chemical properties. Among organic inputs, vermicompost is the richest source of organic fertilizer as it is rich in NPK, humus, micronutrients and also beneficial soil microbes like actinomycetes and nitrogen-fixing and phosphate solubilising bacteria. Compared to other conventional composts, vermicompost is highly porous and high water holding capacity mainly due to high humus content (Suhane, 2007). Besides, vermicompost is a rich source of different enzymes like lipase, cellulase, chitinase and amylase, these breaks organic matter continuously and make nutrients available to roots of the plants (Chaouri *et al*., 2003).

As per FAO definition, "sustainable development" is the management and conservation of the natural resource base and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Adoption of more profitable and improved technologies by the small/marginal farmers to obtain increased yields is a pre-requisite for long-term sustainability on cropping system of acid soils of North-Eastern region of India. As agriculture remains a soil-based industry, there is no way to sustain yield without ensuring the good plant and soil interactions. So, building-up of organic carbon pool in acid soil recognized as a storehouse of most of the plant nutrients essential for growth make the soil fertile and sustainable. The integrated cropping system approach is the needs of the day to improve the utilisation of natural resources such as soil, water and solar radiation, which is especially true for widely spaced crops like arecanut and coconut *etc.*

Natural resources are not completely utilised in arecanut as a sole crop. The compact nature of crown of the arecanut crop allows good sunlight penetration to the ground and maintains good humidity which favours and allows the growing of shade-loving crops. Studies conducted at ICAR-Central Plantation Crops Research Institute (CPCRI) indicates that depending on the time of the day, the canopy of arecanut crop permits 32 to 48 per cent of incident radiation to penetrate ground (Muralidharan, 1980). Only 30 per cent of the land is utilised in palms planted at 2.7 m x 2.7 m spacing as revealed by the rooting pattern of the crop (Shama Bhat and Leela, 1968). The normal cultural operations are also confined within about 75-80 cm radius from the base. Thus the areca palm exploits 2.27 Sq.m (r = 0.85 m) area of land area out of 7.29 Sq.m (2.7 m x 2.7 m). The concept of high-density multi-species cropping system (HDMSCS) involving compatible crops in arecanut garden was conceived by Bavappa *et al*. (1986). Hence, an attempt was made to study the impact of economically viable arecanut based multiple cropping system with proper utilization of recyclable resources for strategic research on the long-term sustainability of acid soil.

Materials and methods

Two arecanut based cropping system models, literally called as arecanut based high-density multispecies cropping system model was developed at ICAR-CPCRI, Research Centre, Kahikuchi, Guwahati, Assam (India), which is positioned at 20° 18'N latitude and 91° 78'E longitude with a mean altitude of 48 m from Mean Sea Level. The area receives an average annual rainfall of 2500 to 3000 mm and 90 per cent of which received during south-west monsoon (June-August/September). There is a dry spell from November to March with occasional showers from March to May. The mean maximum and minimum temperature vary from 15 to 34°C and 6 to 22°C, respectively. The experimental site was texturally classified as clay loam. Initial soil pH ranged from 5.28 to 5.32 in surface (0-30 cm) and 5.35 to 5.37 in subsurface (30-60 cm) soil and organic carbon content varied from 0.90 to 0.91 per cent in surface and 0.62 to 0.63 per cent subsurface soil estimated by standard methods (Jackson, 1973).

Initial available N, P and K content varied from 107.3 to 115.5, 12.00 to 13.72 & 85.5 to 88.5 mg kg^{-1}, respectively in surface soil and from 86.6 to 90.8, 7.89 to 8.23 and 77.0 to 88.5 mg kg^{-1}, respectively in subsurface soil which was estimated by following standard methods. The arecanut based high-density multi-species cropping system (HDMSCS) was initiated in old arecanut (var: Kahikuchi) garden during 2000. Details of the experiment, including component crops, spacing, plant population per hectare, recommended dose of inorganic fertilizers per year are given below in tabulated form (Table 1). The arecanut based HDMSCS garden comprised of two models: Model-1 (M1) comprised of black pepper (var: Karimunda), banana (var: Chenichampa), citrus (var: Assam lemon) and clove and Model-2 (M2) with black pepper (var: Panniyur 1), banana (var: Chenichampa), citrus (var: Gandharaj) and nutmeg as component crops.

Both models were sub-divided into three treatments with three levels of inorganic fertilizers (N, P & K), *i.e.*, full recommended dose (T1), 2/3rd of the recommended dose (T2) and 1/3rd of the recommended dose (T3) and each treatment was replicated thrice in completely randomised design (CRD). Sources of inorganic N, P and K fertilizers were urea, single super phosphate and muriate of potash. Treatments were applied in two half splits, one at the onset of south-west monsoon (April-May) and another during the post-monsoon season (October-November). In addition to these inorganic fertilizers, biomass produced in each treated plot was recycled to each plant with uniform distribution in the form of vermicompost. Inorganic fertilizers along with vermicompost were applied at the rhizospheric zone of each crop by making about six-inch depth ring around the plant, mixed well with soil followed by irrigation. Both the models were irrigated during non-rainy periods through check basin method and/or perforated irrigation system based IW/CPE ratio of 1.0. All the necessary agronomic practices were followed, and plant protection measures were carried out when required. Available N, P and K content in soil and total N, P and K content in arecanut leaf (base crop of the garden) over the years were analysed by following standard procedures (initial and during 2015) (Piper, 1966). As the experiment revolved around a complete system covering a unit area, soil parameters of component crops were not considered. Yearly recording of the quantities of inputs such as fertilizers, plant protection chemicals, labour used for maintenance and sustenance of the models were carried out. Economic produce was harvested at appropriate stages from experimental blocks separately. The market price for both inputs and outputs for the corresponding year was considered to work out the economics of the systems *viz*., gross return, net return and B:C ratio.

Vermicompost production

The collected biomass of different crops was chopped into pieces, weighed and put on the soil surface to allow half decompose by sprinkling water during the non-rainy season and then put into pits of size 4.5 m x 1.5 m x 0.9 m by spreading the biomass in a thin layer and sprinkled with fresh cow dung @ 10 per cent by fresh weight of biomass. The upper surface was covered with 5-10 cm layer of mixture of mud and cow dung followed by release of earthworms (*Eudrillus euginae*). During non-rainy periods, pits were sprinkled with water to maintain the moisture to create favourable condition for earthworm for vermicomposting which became

Table 1. Crop details of arecanut and component crops under cropping system model

Common name & Scientific name of crops	Population hectare^{-1}	Spacing (m x m)	The recommended dose of N, P & K fertilizers g plant^{-1}year^{-1}
Arecanut (*Areca catechu*)	1371	2.7 x 2.7	100:40:140
Black pepper (*Piper nigrum*)	1371	2.7 x 2.7	100:40:140
Banana (*Musa* spp.)	685	2.7 x 5.4	160:160:320
Citrus (*Citrus latifolia*)	685	2.7 x 5.4	450:300:430
Nutmeg (*Myristica fragrans*)	228	5.4 x 8.1	300:250:750
Clove (*Syzygium aromaticum*)	228	5.4 x 8.1	300:250:750

ready in about 100 to 120 days. This was done twice in a year with the collected biomass in every six months and the produced vermicompost was applied at the time of inorganic fertilizer treatments. N, P and K content of vermicompost were analysed by standard methods (Piper, 1966).

Results and discussion

Recyclable biomass

The recyclable biomass of different treatments under two different models is presented in Table 2. It revealed that quantity of recyclable biomass being generated ranged between 8.27 to 12.23 t ha^{-1} $year^{-1}$ and 8.11 to 12.38 t ha^{-1} $year^{-1}$ in model-1 and model-2, respectively. This was comparatively much higher than the biomass production from sole arecanut crop, which generated 5.3 to 6.8 t ha^{-1} $year^{-1}$. Hussain *et al*. (2008) recorded 5.08 to 6.28 t ha^{-1} $year^{-1}$ biomass generation in four years of study on sole arecanut plantation in the same region. The increase in the biomass content in all the treatment plots under both the models was due to accommodation of various component crops. Plantation crops produce a huge amount of biomass for recycling (Biddappa *et al*., 1996) and the waste from plantation crops account for more than 30-50 per cent of the produce. It is about 8.0 t ha^{-1} $year^{-1}$ in arecanut (Nampoothiri, 2001). The biomass generation was the highest under T2 in both the models, whereas it was at par under T1 and T3 treatments at both the models. The recovery percentage of recyclable biomass was varied from 66.5 to 77.4 per cent irrespective of the treatments under both the models. As high as 80 per cent recovery of vermicompost was found by using the earthworms (*Eudrilus eugeniae*) from the biomass of areca leaves, bunch waste, arecanut husk, cocoa prunings and leaf fall, banana suckers, leaves and the plants and the weed biomass (Bhat and Sujatha, 2004). Chowdappa *et al*. (1999) also had reported beneficial nutrient composition of vermicompost produced by areca wastes through *Eudrilus eugeniae* earthworm.

Leaf nutrient status of arecanut

Nitrogen content in the arecanut leaf varied from 1.58 to 1.76 per cent among all the treatments for both the models. In model-1, T2 treatment recorded the highest content of nitrogen (mean 1.74%) followed by T1 (mean 1.66%) and T3 (mean 1.64%), and all three treatments were significantly different from each other. In contrast, in Model-2, T2 treatment showed the significantly higher (mean 1.73%) and treatments T1 (mean 1.64%), and T3 (mean 1.62%) were at par. Phosphorus content in the leaf ranged from 0.12 to 0.16 (mean 0.14) per cent in all the treatments. T2 treatment showed the highest content of phosphorus (mean 0.15% and 0.16%, respectively) in both the models at the end of the experiment. But its content was at par in T1, and T3 treatments in both models and T2 was significantly different. The content in the leaf was in the order of T2>T1=T3. Among all the treatments in both the models, leaf potassium ranged from 1.10 to 1.28 (mean 1.15) per cent. It was found that there was no significant difference among the treatments

Table 2. Recyclable biomass (dry weight, ton per hectare) from different crops in arecanut based HDMSCS models M1 and M2 (2005 to 2015)

Crops	Growth period (year)											Pooled mean
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	
M1T1	9.91	10.07	10.36	10.97	11.31	11.26	10.96	11.82	11.31	11.92	11.40	11.03
M1T2	10.05	10.29	10.65	11.27	11.85	11.75	11.60	12.15	12.16	12.14	12.23	11.47
M1T3	8.27	8.53	8.94	9.86	10.30	10.32	10.01	10.22	10.92	10.42	10.68	9.86
CD (0.05) = 0.68, CV (%) = 7.28												
M2T1	9.685	9.99	10.29	10.57	10.89	10.94	10.53	11.24	11.15	11.13	11.84	10.75
M2T2	9.833	10.06	10.51	10.86	11.23	11.11	10.90	11.81	11.83	12.11	12.38	11.1
M2T3	8.113	8.39	8.93	9.55	9.79	9.79	9.52	9.25	10.42	10.64	10.66	9.55
CD (0.05) = 0.67, CV (%) = 7.34												

which may describe the enhancement in potassium uptake by application of vermicompost to increase in the availability of potassium by shifting the equilibrium from relatively exchangeable form to soluble form in the soil (Tharmaraj *et al*., 2011).

Vermicompost is one of the preferred organic sources as it contains readily available nutrients and different beneficial microbes and growth-promoting substances (Sultan, 1997). Fresh vermicompost bears a lot of cocoons and very young worms (Murali and Neelanarayanan, 2011) when applied in the soil makes it as natural vermicomposting unit and soil become more fertile and nutrient in the vermicompost releases slowly (Ansari, 2008a; 2008b). But the application of inorganic fertilizers like urea, muriate of potash *etc.,* may kill these important natural resources and disturb biological processes that may be the result of less content of N and P in arecanut leaf in T1 treatment where the full dose of inorganic fertilizers was used. However, to meet the nutrient requirements of perennial crop like arecanut, a judicious mixture of organic and inorganic sources, *i.e.,* T2 treatment may be an appropriate combination that may be attributed to the highest content of nutrient in leaf.

N, P and K content in the soil

Available N, P and K content in surface (0-30 cm) and subsurface (30-60 cm) soils of this experiment are presented in the tabulated form as Table 3. Available N content in surface soil varied from 107.3 to 144.44 mg kg^{-1} soil and in subsurface soil from 86.6 to 136.1 mg kg^{-1} soil under the model-1. Results showed an increase in the available N content in surface soil over initial by 12.93, 15.90 and 5.45 per cent in T1, T2 and T3 under model-1, respectively. T1 and T2 were at par, but these were significantly different from T3. For subsurface layer, at the final stage of the investigation, the increase in available N content in T2 treatment was 22.02% over initial content. Similar results were found for model-2 in surface soil, but all the treatments were statistically significantly different. The treatment receiving 2/3rd dose of inorganic fertilizer with recyclable vermicompost (T2) showed the highest increase in the available N content (21.34%) in surface soils over initial content for model-2. At the 2nd depth, available N content in soil decreased with decreasing organic carbon content of the soil. Its content varied from 90.8 to 140.3 mg kg^{-1} soil. T2 treatment resulted highest available N content at the final stage of the study, which was 17.46% increase over the initial value that was significantly comparable to T1 and T3 treatments.

Average available P content in surface soil varied from 12.00 to 19.60 mg kg^{-1} soil (Table 3) and 12.35 to 26.03 mg kg^{-1} soil in both the model, respectively. The increase in the content of available P in surface soil over initial was 26.53, 23.54, 14.92% for model-1 and 45.34, 45.23, 8.82%, for model-2 in T1, T2 and T3 treatment, respectively. But subsurface soil showed higher values than surface soil. The increase in the content of available P at the final stage of the investigation were 32.81, 26.74, 8.37% for model-1 and 48.42, 38.03, 10.21% for model-2 in T1, T2, T3 treatments, respectively. But available P content followed an order of T1>T2>T3 in both layers of soil. These may be attributed to the immobile nature of negative phosphate ions in the soil. Therefore, these results may suggest that the soil P availability increases proportionately with the amount of phosphatic fertilizer application.

The average content of available potassium (Table 3) in surface soil ranged from 85.5 to 178.18 mg kg^{-1} soil and 87.00 to 221.45 mg kg^{-1} soil respectively in both models. The increasing content of it over initial content in T1, T2 and T3 were 47.71, 37.31 and 10.32 per cent for model-1 and 60.28, 47.59 and 20.28 per cent in T1, T2 and T3 for model-2, respectively. But in subsurface soil it was increased over initial content were 85.85, 64.99 and 15.61 per cent for model-1 and 85.93, 48.54 and 20.12 per cent for model-2 in T1, T2 and T3 treatment respectively. Available K content in different treatments followed an order of T1>T2>T3 for models. From these result, it can be concluded that potassium availability in soil is directly proportional to the quantity of potassic fertilizer applied in the soil. The statistical analysis explains that the treatment plot applied with the full dose of inorganic fertilizer along with recyclable vermicompost (T1) and the plot applied with 2/3rd dose of inorganic fertilizer with recyclable vermicompost (T2) was at par in surface soil. But in the subsurface (30-60 cm), available potassium content was higher in all treatments that may be

Table 3. Available NPK content (mg kg^{-1}) content in soil under HDMSCS models M1 and M2

Treatments	Available N				Available P				Available K			
	Initial	Final	Pooled mean	% increase over initial	Initial	Final	Pooled mean	% increase over initial	Initial	Final	Pooled mean	% increase over initial
Surface soil (0 – 30 cm)												
M1T1	115.5	140.3	130.43	12.93	13.38	19.60	16.93	26.53	86.23	178.18	127.37	47.71
M1T2	115.5	144.4	133.86	15.9	13.72	18.80	16.95	23.54	85.50	170.55	117.40	37.31
M1T3	107.3	119.6	113.15	5.45	12.00	15.21	13.79	14.92	85.60	132.36	94.43	10.32
	CD (0.05) = 39.17, CV(%) = 39.17				CD (0.05) = 1.60, CV(%) = 12.67				CD (0.05) = 23.49, CV(%) = 26.11			
Subsurface soil (30 – 60 cm)												
M1T1	86.6	99	96.78	11.76	8.23	12.19	10.93	32.81	78.5	231.64	145.89	85.85
M1T2	86.6	136.1	105.67	22.02	7.89	11.57	10.00	26.74	77.0	198.55	127.04	64.99
M1T3	86.6	90.8	91.08	5.17	7.89	7.85	8.55	8.37	78.1	104.36	90.29	15.61
	CD (0.05) = 7.52, CV(%) = 9.66				CD (0.05) = 3.03, CV(%) = 22.96				CD (0.05) = 32.83, CV(%) = 32.92			
Surface soil (0 – 30 cm)												
M2T1	115.5	127.9	127.15	10.09	12.35	26.030	17.95	45.34	88.5	221.45	141.85	60.28
M2T2	115.5	152.6	140.15	21.34	12.69	19.80	18.43	45.23	87.0	198.55	128.40	47.59
M2T3	115.5	117.52	119.1	3.12	12.35	13.49	13.44	8.82	88.0	150.18	105.85	20.28
	CD (0.05) = 7.80, CV(%) = 7.65				CD (0.05) = 1.04, CV(%) = 13.24				CD (0.05) = 36.70, CV(%) = 38.10			
Subsurface soil (30 – 60 cm)												
M2T1	90.8	94.9	99.02	9.05	7.89	14.72	11.71	48.42	77.7	236.73	144.47	85.93
M2T2	90.8	140.3	106.65	17.46	8.23	14.30	11.36	38.03	88.5	213.82	131.46	48.54
M2T3	90.8	94.9	95.85	5.05	8.23	9.69	9.07	10.21	78.2	117.09	93.93	20.12
	CD (0.05) = 9.11, CV(%) = 11.4				CD (0.05) = 1.98, CV(%) = 23.27				CD (0.05) = 39.17, CV(%) = 40.00			

due to high solubility and mobility of K^+ ions in the soil which undergo deposited to the lower depth due to high rainfall at that region of North-Eastern India and application of irrigation in non-rainy period at IW/CPE ratio of 1.0 through check basin method and/or through the perforated irrigation system. The magnitude of the increase in the availability of potassium in subsurface soil was more pronounced than that of surface soil.

Organic carbon and pH status

As this long term experiment is based on the combination of inorganic fertilizer and recyclable biomass in the form of vermicompost, there is a good opportunity to add decomposed organic substrate which helps to increase soil organic carbon status, nutrient availability as well as soil fertility status. The organic carbon content (Table 4) in different treatments for both the models varied from 0.90 to 1.99 per cent and 0.62 to 1.58 per cent at surface and subsurface soil during the period over the years. The increase in the content of organic carbon was highest in T2 treatment at both surface and subsurface soil in both models, but all the treatments were not significantly different. As production of biomass in all the treatments for both models were was at par, so recycled biomass that helped to increase soil organic carbon were not significantly different. These trends are very much important for changing the soil to a worthy state which improves soil physical, chemical and biological properties. Application of 2/3rd of the recommended dose of inorganic fertilizer along with recyclable biomass in the form of vermicompost showed the highest organic carbon content in both the models, which might have increased the

Table 4. pH and organic carbon content in soil under HDMSCS models M1 and M2

Treatments	pH			OC (%)		
	Initial	Final	Pooled mean	Initial	Final	Pooled mean
Surface soil (0 – 30 cm)						
M1T1	5.32	4.50	4.96	0.91	1.70	1.42
M1T2	5.28	5.01	5.10	0.90	1.83	1.50
M1T3	5.30	4.65	5.06	0.90	1.55	1.32
	CD (0.05) = NS, CV(%) = 4.29			CD (0.05) = NS, CV(%) = 19.18		
Subsurface soil (30 – 60 cm)						
M1T1	5.36	4.52	4.95	0.62	1.44	1.02
M1T2	5.35	5.06	5.16	0.63	1.56	1.11
M1T3	5.37	4.77	5.10	0.62	1.41	0.99
	CD (0.05) = NS, CV(%) = 4.63			CD (0.05) = NS, CV(%) = 33.31		
Surface soil (0 – 30 cm)						
M2T1	5.32	4.62	4.96	0.91	1.49	1.33
M2T2	5.32	5.02	5.12	0.91	1.57	1.35
M2T3	5.31	4.71	5.01	0.90	1.43	1.30
	CD (0.05) = NS, CV(%) = 3.99			CD (0.05) = NS, CV(%) = 14.77		
Subsurface soil (30 – 60 cm)						
M2T1	5.35	4.69	5.02	0.62	1.38	1.01
M2T2	5.35	5.08	5.01	0.63	1.44	1.06
M2T3	5.36	4.80	5.13	0.63	1.40	1.02
	CD (0.05) = NS, CV(%) = 3.71			CD (0.05) = NS, CV(%) = 30.67		

availability of available N content in both the layers under both the models. These results suggested that the increased organic carbon status in the soil of both the layer improved buffering capacity of the soil. Increased soil organic carbon maintained a similar range of soil pH over the long period (12 years) under perennial cropping system. At the initial stage, the soil pH was with a range of 5.30 to 5.36, and after that pH decreased in all the treatments. But the rate of decrease was less in T2 treatment for both models. At the final stage of the investigation, the decrease of soil pH over initial was lowest in T2 treatment (Table 4) at the surface (0.05, 0.06%) and subsurface (0.05, 0.05%) soil for both models, but all the treatments were statistically similar. Although, T2 treatment has maintained a similar level of soil pH above 5.0 over a long period for both the models, whereas T1 and T3 have resulted in slow increasing rate of soil acidity. A higher amount of inorganic fertilizer application along with higher annual rainfall coupled with full irrigation during non-rainy season helps in leaching of soluble base cations from the soil that may help to decrease the soil pH over the years in T1 treatment. Whereas, T3 treatment received 1/3rd recommended dose of fertilizer along with higher annual rainfall fasters leaching loss that leads to a decrease in soil pH more. The similar opinion of leaching of base cations due to high annual rainfall also coined by Paul *et al*. (2011). This observation suggested that leached base cations undergo deposition below 60 cm depth of soil at very high rainfall area like Assam.

Economics of the system

Economics of the cropping system (average of 2003 to 2015) revealed that the maximum return was obtained from Model-1 under 2/3rd dose of recommended fertilizer. The net return under this treatment varied from ₹ 1.85 to 2.35 lakh per hectare

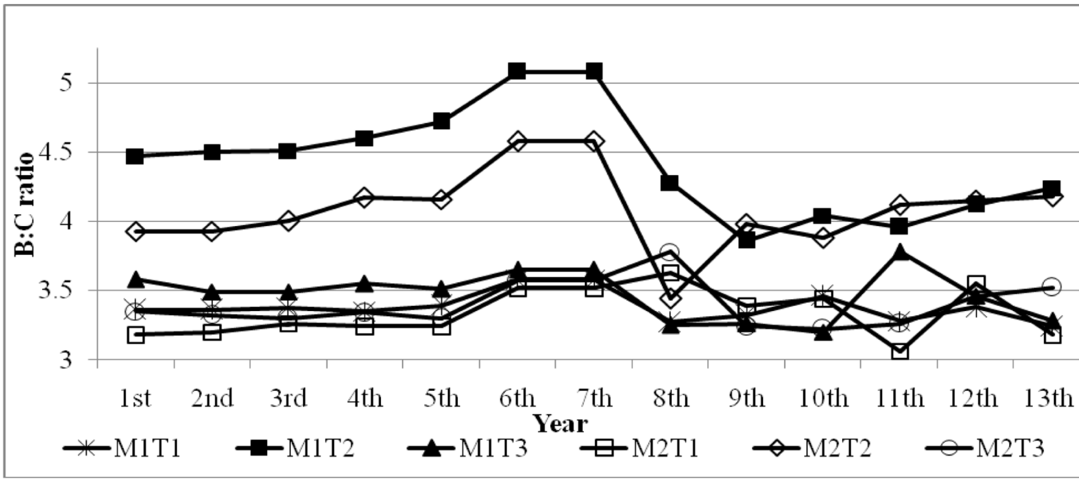

Fig. 1. Yearwise Benefit: Cost ratio under both the models

and B:C ratio ranged between 3.86 to 5.08 (Fig. 1). The average benefit: cost ratio of T1, T2 & T3 was 3.38, 4.42 & 3.47 under model 1 and 3.34, 4.08 & 3.40 under model 2, respectively. This higher B:C ratio over the years of different crops in the system indicated the overall mutual benefit of the different crops in the garden that might be due to favourable microclimate creation, improvement in soil physico-chemical and biological properties of the high-density multi-species cropping system garden along with recycling the biomass in the form of vermicompost, which was rich in nutrients.

These results conform with the work of many workers in arecanut and coconut-based cropping system gardens (Bavappa *et al*., 1986; Bhat *et al*., 1999; Maheswarappa *et al*., 2005 and 2013). These results explained except banana, arecanut, and other component crops produced higher yield under 2/3rd dose of fertilizer. In the case of banana, full dose helped in producing higher yields in both the models. A similar report was reported by Hussain *et al*. (2011). In coconut-based HDMSCS at CPCRI, Kasaragod also it has been reported that application of 2/3rd level of recommended fertilizer recorded higher yield (CPCRI, 2002). These models were able to generate additional employment opportunities of 400-450 man-days per hectare as compared to monocrop. Similar results were also reported from the arecanut garden in Vittal, Karnataka (Bhat *et al*., 1999).

Conclusion

The experimental results have proved the fact that treatment receiving 2/3rd dose of inorganic fertilizer combined with recyclable biomass in the form of vermicompost in both the models improved the soil health and gives maximum benefit. It might be the best combination for keeping soil sustainable by maintaining soil pH in acid soil region. The Model-1 was a comparatively better one than model-2 under the economic point of view. This offers ecological and economic sustainability to the farmers of the North-Eastern Region of India.

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