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CONTINUOUS APPLICATION OF ORGANIC AMENDMENTS ENHANCES SOIL HEALTH, PRODUCE QUALITY AND SYSTEM PRODUCTIVITY OF VEGETABLE-BASED CROPPING SYSTEMS IN SUBTROPICAL EASTERN HIMALAYAS

By D. P. PATEL†, ANUP DAS‡§¶, MANOJ KUMAR‡, G. C. MUNDA‡, S. V. NGACHAN‡, G. I. RAMKRUSHNA‡, JAYANTA LAYEK‡, NARO PONGLA‡, JURI BURAGOHAIN‡ *and* UPENDER SOMIREDDY§

†*National Institute of Abiotic Stress Management, Baramati 413115, Maharashtra, India,* ‡*ICAR Research Complex for NEH Region, Umiam 793103, Meghalaya, India and* §*Carbon Management and Sequestration Center, Ohio State University, Columbus, OH 43210, USA*

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SUMMARY

The hill ecosystem of Northeastern Himalayas is suitable for organic farming due to negligible use of fertilizer (<12 kg ha^{-1}) and agrochemicals, abundance of organic manure, especially plant biomass, and favourable climatic conditions for diverse crops. For successful organic farming, efficient cropping systems and organic amendments are to be identified to sustain soil health on one hand and productivity and enhanced income on the other. The efficacy of three organic amendments, namely, farmyard manure (FYM), vermicompost (VC) and integrated nutrient source (INS; 50% recommended dose of nitrogen (N) through FYM + 50% N through VC) on performance of three-vegetable-based cropping systems, namely, maize + soybean (2:2 intercropping)–tomato, maize + soybean–potato and maize + soybean–French bean was evaluated for five consecutive years (2005–06 to 2009–10) under subtropical climate at Umiam, Meghalaya, India (950 m above sea level). All the organic amendments were applied on N equivalent basis and phosphorus (P) requirement was compensated through rock phosphate. The results revealed that the yield of vegetables, except root vegetables, was maximum with FYM as soil amendment. Total system productivity in terms of maize equivalent yield (MEY) was significantly higher under FYM followed by INS. Pooled analysis revealed that MEY was enhanced by 200 and 191% with continuous application of FYM and INS, respectively, over control (no manure). Maize + soybean–tomato system recorded the highest MEY (28.78 Mg ha^{-1}; Mg – megagram) followed by maize + soybean–French bean (24.37 Mg ha^{-1}). INS as organic amendment resulted in maximum improvement in soil organic carbon (SOC), available P and potassium (K), soil microbial biomass carbon and water holding capacity and was similar to those under FYM. The SOC concentration under INS (23.6 g kg^{-1}), FYM (23.3 g kg^{-1}) and VC (22.3 g kg^{-1}) after five years of organic farming were 31.0, 29.4 and 23.8% higher than the initial and 26.2, 24.6 and 19.3% higher than those under control, respectively. The quality traits of tomato such as total soluble solids (5%), ascorbic acid (28.6 mg 100 g^{-1}) and lycopene content (19.35 mg 100 g^{-1}) were higher under FYM application than other amendments. The study indicated that FYM and INS are equally good as organic amendment and their continuous application not only improves soil health but also crop productivity. FYM application was also found to be cost effective as it resulted in a higher benefit: cost ratio (4.4:1) compared to other amendments irrespective of cropping sequences during transition to organic farming.

¶Corresponding author. Email: anup_icar@yahoo.com

INTRODUCTION

Most of the cultivated areas (about 2 million ha) in the North Eastern Region (NER) of India comprising the states of Arunachal Pradesh, Assam, Tripura, Meghalaya, Mizoram, Nagaland, Manipur and Sikkim of the Indian Republic are adopting organic farming practices for generations (Sanwal *et al.*, 2007). The region has numerous advantages to go for organic food production, such as minimum use of fertilizer ($<$12 kg ha^{-1}), availability of plant- and livestock-excreta-based organic manure and pesticides, and favourable climatic conditions for growing a wide range of crop species. The net cultivated area of the region is about 4 million ha and the estimated availability of organic manure is about 46 million megagram (Mg) which is almost sufficient for the region to go organic (Bujarbaruah, 2004). The soils of the region are much degraded owing to cultivation in steep slopes, negligible nutrient supplementation and biomass burning under traditional practices (Saha *et al.*, 2012). Cultivation of exhaustive crops such as ginger, turmeric, maize etc. on sloping land without proper soil and water conservation measures exacerbate the degradation process, making the soil unfit for cultivation (Saha *et al.*, 2012; Salahin *et al.*, 2013). Thus, necessitating the need for appropriate soil management practices involving efficient cropping systems and nutrient management practices for sustainable hill agriculture (Das *et al.*, 2010a, 2013). Organic farming is considered as one of the best options for protecting/sustaining soil health and produce healthy foods (Das *et al.*, 2013; Surekha *et al.*, 2013). Organic farming is a production system which avoids, or largely excludes, the use of synthetic fertilizers, pesticides, growth regulators and livestock feed additives. The objectives of environmental, social and economic sustainability can be met through organic farming (Stockdale *et al.*, 2001). The key characteristics of organic farming include protecting the long-term fertility of soils by maintaining organic matter (OM) levels, fostering soil biological activity, nitrogen (N) self-sufficiency by the inclusion of legumes, effective recycling of OM including crop residues and livestock wastes, and weed, disease and pest control relying primarily on crop rotations, natural predators, diversity, organic manuring, and resistant varieties (Yadav *et al.*, 2013). The soil fertility is maintained by returning all the residues to it through composts, thereby, minimizing the gap between nutrient addition and removal from the soil (Chhonkar, 2002).

In view of growing demand for organic food products worldwide including India, the NER of India has vast opportunity to emerge as major suppliers of organic products. By March 2011, India had brought more than 4.43 million ha area under organic certification process (Yadav, 2012). The world market for organic products was estimated at more than US$ 25 billion in 2003 and it rose by about 20% per year from 2001 to 2005 (Willer and Yussefi, 2005). Such expansion of organic market makes it possible for farmers to reap the benefits of trade with relatively high price premiums (Gopinath *et al.*, 2008). Economic and environmental concerns have been the drivers for increasing demand for organically produced food (Ngouajio and McGiffen, 2002). The organic food production in Asian countries is mainly for the export market as the domestic consumption is still emerging (IFOAM, 2004). Due to growing purchasing power and health cautiousness, organic food products are being preferred by the consumers (Urkurkar *et al.*, 2010) and demand for organic vegetables is steadily increasing not only in international markets but also in domestic markets (Carolyn and Oberholtzer, 2009; Das *et al.*, 2013). Vegetables constitute an important part in the diet of Eastern Himalayan population. Growing of vegetables like carrot, potato, tomato and French bean after *kharif* maize not only increases the cropping intensity but also utilizes the land efficiently while providing employment and economic benefits to the farmers who are mostly small and marginal in nature (Das *et al.*, 2013). A study carried out on five crops in Japan showed that application of OM enhanced root growth and nutrient uptake resulting in higher yields compared to that under conventional farming (FFTC, 1998).

Crop rotations, including a mixture of leguminous fertility building crops and cash crops are the main mechanism for nutrient supply within organic systems. Rotations can also be designed to minimize the spread of weeds, pests and diseases (Altieri, 1995). The development and implementation of well-designed crop rotations are central to the success of organic production systems (Das *et al.*, 2013; Lampkin, 1990; Stockdale *et al.*, 2001). Organic rotations are divided into phases, one phase increases the level of soil N and another one depletes it (Altieri, 1995). The N building and depleting phases must be in balance, or show a slight surplus, if long-term fertility is to be maintained (Berry *et al.*, 2003; Watson *et al.*, 2002).

Organic production systems have the potential to achieve sustainability of agricultural systems (Rigby and Caceres, 2001; Van Diepeningen *et al.*, 2006). Many of the sustainability issues are related to soil quality (Nannipeeri, 1994). Soil quality includes microbial activity and soil fertility, which are closely related because it is through the biomass that the mineralization of the important organic elements occur (Frankenberger and Dick, 1983). Higher levels of total soil organic carbon (SOC), total N, soluble P, microbial activity and soil microbial biomass carbon (SMBC) were reported from soils under organic production system (Cavero *et al.*, 1997; Clark *et al.*, 1998; Mader *et al.*, 2002). Organic manure increases soil productivity by enhancing the soil's physical, chemical and biological properties (Ramesh *et al.*, 2009; Tester, 1990). Significant improvements in soil health have been reported in several organic farming experiments (Carpenter *et al.*, 2000; Pathak *et al.*, 1992). Higher microbial activity and SMBC were found in soils under organic farming practices. However, some researchers found no difference in bacterial biodiversity (Lawlor *et al.*, 2000) or in fungal communities (Franke-Snyder *et al.*, 2001) between organically and conventionally managed soils.

Although grain yield under organic farming is often lower than that under conventional farming, it is feasible to have increased yields under the former (Chitra and Janaki, 1999), especially in hills (Das *et al.*, 2010b, 2013). Organic agriculture enables ecosystems to better adjust to the effects of climate change, and also improves carbon sequestration potential of soil (Bhooshan and Prasad, 2011). While there are reports that organic cropping systems are less profitable than conventional systems (Dobbs and Smolik, 1997), some other studies have shown that returns from organic farm management are equal to, or exceed those from conventional management systems (Das *et al.*, 2013).

Farmers in NER of India rarely add any fertilizer or manure to field crops. However, whatever quantity of organic manure available is with them, it is provided to remunerative vegetable crops at the rate of 5–10 Mg ha^{-1} depending upon availability, either alone or rarely in combination with chemical fertilizers (Das *et al.*, 2008). Manures are provided without considering the crop needs and soil fertility. Inclusion of manures within a crop rotation can have positive effects on yields and crop quality (Stein-Bachinger and Werner, 1997). There is limited research on effects of organic sources of nutrients on growth, yield and quality of crops and soil properties.

Maize is the most potential and predominant rainy season crop on the hills of NER of India (Das *et al.*, 2010a). Exhaustive nature, wider spacing and poor ground cover under maize encourage soil loss through erosion and degrade soil (Saha *et al.*, 2012). Cover crops such as soybean are suitable intercrops with maize to utilize the land efficiently, increase ground cover while providing N through biological fixation and add organic manure to soil. The potential effects of leguminous green manure crops in cropping systems under organic crop production have been widely reported (Mueller and Thorup-Kristensen, 2001; Poutala *et al.*, 1994). Green manures and cover crops have also been shown to have positive effects in keeping the diseases under control in vegetable crops (Abawi and Widmer, 2000). Intercropping of cereals and legumes offers the opportunity to increase the use of symbiotically fixed N without compromising grain yield (Bulson *et al.*, 1997; Jensen, 1996). Tomato, French bean and carrot are potential pre-*kharif* (January to May) vegetables of the region and have good domestic demand (Das *et al.*, 2013). Potato is also a potential crop of the hills and is a constituent of daily diet of the population along with staple food rice (Kumar *et al.*, 2012). Considering the potential and demand, these crops were included in the diverse cropping systems with the objective to identify component crops with optimum productivity, profitability and emphasis on soil health and crop quality parameters.

Farmyard manure (FYM) and vermicompost (VC) are the most available composts in the region and are made from livestock excreta, farm wastes, and crop and weed biomass available within the farm. FYM is more voluminous in nature compared to other composts but available in limited quantity with most of the farmers. On the other hand VC is comparatively less voluminous than FYM. Most of these manures are rich in N and K but deficient in P. VC is considered to be rich in micro-nutrients and growth hormones in addition to primary nutrients (Hazarika *et al.*, 2006) and required in comparatively lesser quantity than FYM (Das *et al.*, 2013). Research is needed to identify efficient organic amendments (sole or combinations of organic manures) for sustaining crop and soil productivity and providing optimum economic returns to the farmers.

Hence, we evaluated the efficacy of different organic amendments on performance of vegetable-based cropping systems as well as on soil health, crop nutrient uptake and produce quality during transition to organic farming in mid-altitude regions (950 m above sea level) of subtropical Meghalaya, India. The hypothesis tested was that application of nutrients through organic amendments would positively influence crop performance, soil health and produce quality depending upon their chemical compositions, physical properties and nutrient release pattern.

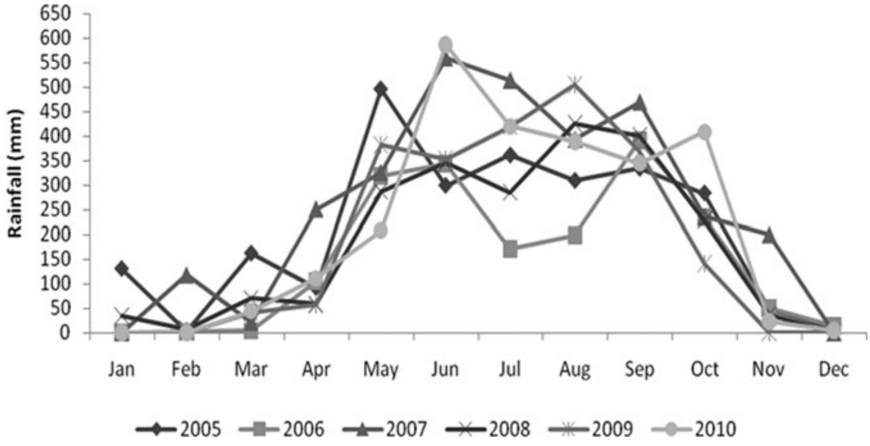

Figure 1. Average monthly rainfall during the experimental period (2005–10).

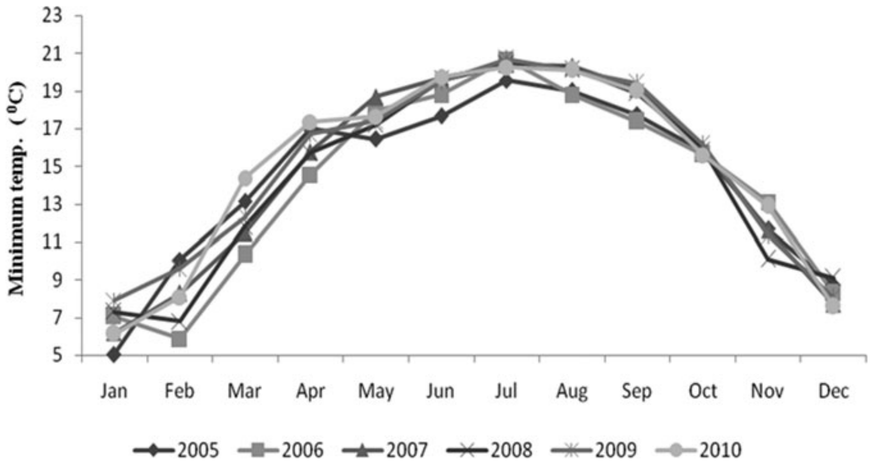

Figure 2. Average monthly minimum temperature during the experimental period (2005–10).

MATERIALS AND METHODS

Experimental site

Field experiments were conducted during pre-*kharif* (January to April) and *kharif* (May to October) seasons for five consecutive years from 2005–06 to 2009–10 at the research farm of Indian Council of Agricultural Research (ICAR), Research Complex for North Eastern Hill (NEH) Region, Umiam, Meghalaya, India. Total annual rainfall at the experimental site varied between 1365.15 mm and 2528.6 mm during the five years of experimentation and average annual rainfall was 2020.66 mm during that period (Figure 1). The monthly mean maximum and minimum temperatures (Figures 2 and 3) during the study period ranged from 20.74 to 28.54 °C and 6.61 to 20.33 °C, respectively. The experimental soil had pH 4.8, SOC 18.0 g kg^{-1}, available

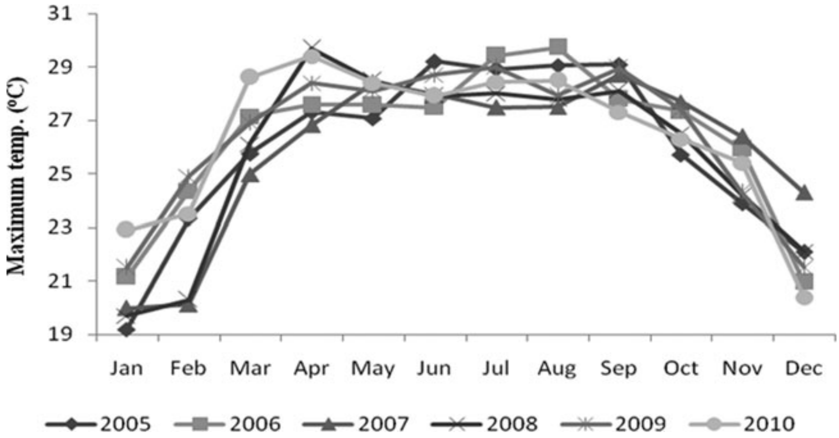

Figure 3. Average monthly maximum temperature during the experimental period (2005–10).

N 255.61 kg ha^{-1}, available P 19.19 kg ha^{-1} and available K 232.10 kg ha^{-1}. The soil was sandy loam in texture.

Experimental details and crop management

The experimental site was under maize (*Zea mays*)-toria (*Brassica campestris*, var. toria) cropping system and integrated nutrient management comprising 50% NPK through synthetic fertilizers (urea, single super phosphate and muriate of potash) and 50% through organic manure (FYM) during five years preceding the initialization of this present experimentation.

Keeping the prevailing cropping pattern and availability of organic nutrient sources in mind, field experiments were laid out in a split plot design with treatment combinations of three cropping sequences, namely, maize + soybean–tomato (CS1), maize + soybean–potato (CS2) and maize + soybean–French bean (CS3) in main plots, along with three sources of nutrients, 100% N through FYM, VC, integrated nutrient source (INS; 50% recommended doses of N through FYM + 50% recommended N through VC), and control (no manure) as four sub-plots.

Soybean was grown as intercrop with maize in a 2:2 row ratio and maize and soybean were sown at a spacing of 60 × 20 cm and 30 × 15 cm, respectively. Soybean grows well due to favourable climatic condition at mid altitude and produces excessive biomass. Hence, at about 45 days after sowing, when the crop reaches maximum vegetative growth, one pruning was done by de-topping at a height of 25 cm uniformly. The fresh soybean biomass generated (pooled over five years) under FYM, VC, INS and control was 2.18 ± 0.37, 1.96± 0.41, 2.55± 0.47 and 1.42 ± 0.29 Mg ha^{-1}, respectively, which was used as *in situ* mulch. Well-decomposed FYM and VC were applied on the basis of N equivalent and P requirement was supplemented through rock phosphate. P supplementation is necessary as the soil in this region is acidic and P availability is very low (Das *et al.*, 2008). As with conventional agriculture, the primary limiting nutrient in organic systems is N (Stockdale *et al.*, 1995; Torstensson, 1998). Application of

Table 1. Details of crop cultivar and agronomic practices adopted in the experiment.

Crop	Cultivar	Duration (days)	Spacing	Recommended N:P:K (kg ha^{-1})
Maize	RCM-1-1	115	60 × 20 cm	80:60:40
Soybean	JS-80-21	130	30 × 15 cm	30:60:40
Tomato	Rocky	105	50 × 50 cm	100:60:40
Potato	Kufri jyoti	115	50 × 20 cm	100:60:40
French bean	Naga local (local)	90	30 × 10 cm	60:60:40

Table 2. N–P–K and micronutrient concentration in different organic amendments used in the experiment.

Organic sources	N (%)	P_2O_5 (%)	K_2O (%)	Fe (ppm)	Cu (ppm)	Zn (ppm)	Mn (ppm)
Farmyard manure	0.93 ± 0.05	0.29 ± 0.03	0.91 ± 0.04	3520 ± 17.50	57 ± 6.90	315 ± 7.16	281 ± 9.25
Vermicompost	1.70 ± 0.08	0.65 ± 0.05	1.00 ± 0.07	8618 ± 19.30	61 ± 4.85	328 ± 10.22	345 ± 9.90
Rock phosphate	–	18.0.	–	–	–	–	–
Soybean prunings	2.63 ± 0.16	0.21 ± 0.03	1.73 ± 0.17	–	–	–	–

Note: ± indicates standard deviation from mean.

organic manure not only improves the SOC but also increases soil N. However, N-use efficiency is comparatively low particularly in high rainfall areas (>2000 mm average annual rainfall) where it is difficult to retain N in soil due to leaching, volatilization and denitrification. Among the major plant nutrients supplied through external sources, N is required in higher quantity and hence, it is the primary focus among all nutrients in organic farming systems (Margar, 2004). Thus, N was supplied through various organic sources in the present study. The treatment combinations were replicated three times and fixed plots were maintained for respective treatments during the five years of experimentation. The gross plot size was 5 × 5 m. The details of cultivars used, their duration, spacing and nutrient contents of organic amendments are presented in Tables 1 and 2.

Water management

The *kharif* (rainy season) crops were raised as rainfed crop, whereas, pre-*kharif* crops (January to May) were raised with life saving irrigation. For tomato, frequent life saving irrigations (weekly intervals) were given during seedling establishment after transplantation. In the case of potato, two irrigations were provided, one before earthing up (25 DAS) and another during tuber formation stage. Staking was done in French bean for providing support using bamboo sticks. Irrigations were adjusted as per the rainfall received during the season.

Pest and disease management

For the management of soil-borne pathogens, neem cake was added uniformly in all the plots @150 kg ha^{-1} during last ploughing and mixed with the soil. Derisom (a botanical pesticide, fractions of *Derris indica*) @2.5 ml lit^{-1} was applied at flowering stage and 15 days after first spray to manage insect pests. Diseased leaves were stripped off manually whenever possible.

Plant and soil sampling

Five random plant samples were collected from the earmarked area of each plot during harvesting. Plant samples were kept in a hot air oven at 60–70 °C till constant weights were obtained and oven-dried plant samples were used for determination of N, P and K content. Soil samples were collected after harvesting from 0–20-cm depth to determine the available nutrients after five years. Soil samples were also collected before the start of the experiment from 0–20-cm depth and analysed to establish the initial soil fertility status of the experimental plot. In the case of tomato and French bean, multiple pickings were done and yield was recorded each time. For other vegetable crops, such as carrot and potato, the tuber yields were recorded at harvest from the net plot area and expressed as Mg ha^{-1}. The yields of *kharif* crops such as maize and soybean were recorded when the grain moisture content reached 14% after sun drying. Performance of all the crops was evaluated in terms of yield and yields of vegetable crops were converted to Maize Equivalent Yield (MEY) to compare cropping systems. The MEY of different crops under various nutrient management practices were calculated on the basis of prevailing market prices of various inputs and outputs.

Chemical analysis

The nutrient concentration of different crops was determined at harvest by following standard procedures. The grain/economic parts and straw/residues of rice and vegetable biomass were analysed for total N through micro-Kjeldahl method, while total P and K were determined using sulphuric-nitric-perchloric acid digest (Prasad *et al.*, 2006). Soil samples were analysed for various physico-chemical and biological parameters. The soil pH was determined in a 1:2.5 soil:water suspension (Jackson, 1973), SOC was determined using Walkley and Black method (1934), available N by alkaline potassium permanganate method (Subbiah and Asija, 1956), available P by Bray method (Bray and Kurtz, 1945) and available K by ammonium acetate extraction method (Jackson, 1973). The SMBC was determined by ethanol-free chloroform fumigation extraction method (Vance *et al.*, 1987) using K_c value of 0.45 (Jenkinson and Ladd, 1981).

Economics analysis

The costs of the organic amendments, other inputs and outputs were estimated as per the prevailing market price (2009–10 price). The gross returns, net returns and benefit: cost (B:C) ratio for different nutrient management and cropping systems were assessed by computing the cost of the inputs and price of the produce/output. The net returns were obtained by deducting cost of cultivation from gross returns. The B:C ratio was computed by dividing gross returns with cost of cultivation. The prevailing market price was considered for economic assessment without any premium price as the local populations are not yet ready to pay higher price.

The prices of various inputs used in the present study were: FYM \$12 Mg^{-1}, VC \$40 Mg^{-1}, rock phosphate \$60 Mg^{-1}, Maize kernel (seed) \$400 Mg^{-1}, soybean seed

\$1000 Mg^{-1}, French bean seed \$3000 Mg^{-1}, potato tuber (seed) \$300 Mg^{-1} and tomato seed \$1000 kg^{-1}. The output prices were: maize kernel \$200 Mg^{-1}, soybean seed \$400 Mg^{-1}, French bean green pod \$300 Mg^{-1}, potato tuber \$200 Mg^{-1} and tomato fruit \$200 Mg^{-1}. The labour wage was \$2.4 man-day^{-1}. The prices of inputs and outputs are subject to market demand, availability, time factor and other uncontrolled factors and hence, the economics presented in this paper is indicative and may change according to situation.

Statistical analysis

The analysis of variance method (Panse and Sukhatme, 1978) was followed to analyse the data. The significance of different sources of variations was tested by error mean square of Fisher Snedecor's 'F' test at 5% probability level ($p = 0.05$). In the summary tables of the results, the standard error mean (SEm (±)) and critical difference (CD) were provided to compare the means.

RESULTS AND DISCUSSION

Crop productivity

Maize grain yields during 2005–06 and 2006–07 were higher under FYM treatment followed by those under INS and VC in all the three cropping systems (Table 3). Whereas, in the third (2007–08), fourth (2008–09) and fifth (2009–10) years, INS as organic amendment produced higher maize yield compared to sole application of FYM and VC. The higher yield with INS could be due to the fact that FYM contains more OM and VC contains substances like hormones, auxins, vitamins, antibiotics and other beneficial microorganisms (Hazarika *et al.*, 2006). Maize grain yield was significantly ($p = 0.05$) higher with FYM in the first and second years of the experimentation; from the third year (2007–08) onwards, yield under INS was at par with the FYM treatment. However, the pooled grain yield recorded with VC and INS was at par with each other. Ramesh *et al.* (2010) also reported higher crop productivity with combined application of FYM, VC and poultry manure under organic farming. In the present study, the five years pooled maize grain yield was 3.96, 3.76 and 4.24 Mg ha^{-1} in the cropping systems CS1, CS2 and CS3, respectively. Pooled seed yield of soybean was recorded significantly higher in INS followed by sole application of FYM in the CS1 and CS3 cropping systems. Similar findings were also reported by Ramesh *et al.* (2010).

Vegetables are profitable component in farming systems and highly responsive to organic amendments (Yadav *et al.*, 2013). Significantly higher tomato fruit yield (Table 4) was recorded with FYM followed by INS in all the years except in the first year (2005–07). The tomato fruit yields recorded under FYM were 20.9, 28.4, 28.2, 44.0 and 27.35 Mg ha^{-1} in the first, second, third, fourth and fifth years, respectively. In the fifth year, lower tomato fruit yield was due to leaf blight infestation during fruiting stage. Pooled fruit yield of tomato was also significantly higher with FYM followed by VC and INS. Tomato fruit yields from VC and INS were at par with each other. Significantly higher tomato fruit yield with the application of FYM was also reported

Table 3. Maize and soybean seed yield (Mg ha^{-1}) as influenced by various organic amendments and cropping systems.

Treatments	Maize						Soybean (intercrop)					
A. Cropping systems	Y_1*	Y_2	Y_3	Y_4	Y_5	Pooled	Y_1	Y_2	Y_3	Y_4	Y_5	Pooled
Maize + soybean–tomato	2.96	3.00	3.27	3.03	4.97	3.45	1.30	1.34	1.47	1.41	0.84	1.27
Maize + soybean–potato	2.37	2.34	3.38	2.81	5.15	3.21	1.08	1.10	1.41	1.26	0.93	1.15
Maize + soybean–French bean	2.78	2.86	3.34	3.22	5.02	3.44	1.37	1.52	1.44	1.40	0.78	1.30
SEm (±)	0.07	0.19	0.054	0.15	0.07	0.03	0.04	0.055	0.06	0.046	0.05	0.04
CD ($p = 0.05$)†	0.27	NS‡	NS	NS	NS	NS	0.16	0.22	NS	NS	NS	NS
B. Nutrient sources												
FYM§	3.38	3.42	3.80	3.17	5.68	3.89	1.40	1.48	1.74	1.50	1.00	1.42
Vermicompost	2.49	2.49	3.50	3.23	5.42	3.43	1.22	1.31	1.57	1.45	0.82	1.27
FYM + vermicompost	2.82	2.88	3.84	3.64	5.82	3.80	1.30	1.36	1.40	1.57	1.04	1.33
Control	2.13	2.15	2.18	2.03	3.26	2.35	1.08	1.13	1.04	0.90	0.55	0.94
SEm (±)	0.067	0.11	0.11	0.23	0.11	0.13	0.04	0.065	0.10	0.061	0.044	0.056
CD ($p = 0.05$)	0.20	0.32	0.42	0.68	0.34	0.38	0.21	0.20	0.30	0.18	0.13	0.17

*Y_1: 2005–06; Y_2: 2006–07; Y_3: 2007–08; Y_4: 2008–09; Y_5: 2009–10; †CD: critical difference; ‡NS: non-significant; §FYM: farmyard manure.

Table 4. Yield (Mg ha^{-1}) of vegetables as influenced by various organic amendments and cropping systems.

	Tomato						Potato						French bean					
Nutrient sources	Y_1*	Y_2	Y_3	Y_4	Y_5	Pooled	Y_1	Y_2	Y_3	Y_4	Y_5	Pooled	Y_1	Y_2	Y_3	Y_4	Y_5	Pooled
FYM†	20.9	28.4	28.2	44.0	27.4	29.8	10.6	12.3	12.6	29.9	11.5	15.4	13.3	13.5	13.1	24.6	17.7	16.4
Vermicompost (VC)	20.4	24.2	23.9	42.4	26.8	27.5	11.7	13.6	13.0	30.7	11.8	16.2	11.3	11.5	11.7	23.9	17.0	15.1
FYM + VC	18.7	24.4	24.1	43.1	27.1	27.5	11.0	12.3	11.3	24.5	11.3	14.1	11.7	11.6	13.0	26.0	18.5	16.2
Control	9.1	6.29	6.00	20.0	9.42	10.2	6.15	5.80	5.56	17.1	4.63	7.85	7.24	7.07	6.92	21.5	3.39	9.2
SEm (±)	0.19	0.25	0.17	0.15	0.38	0.21	0.26	0.25	0.31	0.12	0.43	0.24	0.13	0.29	0.28	0.23	0.33	0.23
CD ($p = 0.05$)	0.66	0.86	0.57	0.48	1.17	0.65	0.81	0.78	0.98	0.37	1.30	0.75	0.41	0.88	0.85	0.69	1.0	0.71

*Y_1: 2005–06; Y_2: 2006–07; Y_3: 2007–08; Y_4: 2008–09; Y_5: 2009–10; †FYM: farmyard manure.

by Parray *et al.* (2007). The higher yields of tomato and cabbage with application of INS, compared to other organic amendments and conventional practices has been reported by Choudhary *et al.* (2003).

Unlike tomato, higher potato tuber yield was recorded with VC followed by FYM and INS during all five years of experimentation. Pooled potato yield was also higher in VC (16.15 Mg ha^{-1}) followed by FYM (15.4 Mg ha^{-1}) and INS (14.10 Mg ha^{-1}). The pooled potato tuber yields recorded with VC and FYM were 105 and 95% higher than control, respectively. Similar findings of significantly higher potato tuber yield with VC, compared to FYM and poultry manure application under high altitude of NER of India were reported by Kumar (2009). Upadhyay *et al.* (2008) reported superiority of VC over FYM for potato production. Mourao *et al.* (2008) also reported that organically grown potato yielded 66% higher than those under conventional practices.

French bean green pod yield was significantly higher with FYM, followed by those under INS and VC in the first (2005–06) and second (2006–07) years of the experimentation. In third year, French bean yields under FYM and INS organic amendments were similar to each other. During the fourth and fifth years, the French bean green pod yield was significantly higher with INS followed by FYM alone. Whereas, five years pooled data showed that FYM as organic amendment produced higher green pod yield, followed by INS, which were at par with each other. The results are in conformity with the findings of Yadav and Kumari (2003).

In low-input agriculture, the crop productivity under organic farming is comparable to that of conventional farming. There is no risk associated with organic farming as the ethnic population practices low-input, no-chemical farming (Sanwal *et al.*, 2007). Rather, there is opportunity for productivity enhancement in the region with scientific organic farming (Das *et al.*, 2013). Gradual increase in grain yield with the use of organic amendments over a period of time has been widely reported (Surekha, 2007; Urkurkar *et al.*, 2010). Tamaki *et al.* (2002) reported better crop productivity under continuous organic farming than with conventional farming. Agro-economic study of practices of growing maize with compost and liquid manure (cow urine, vermiwash etc.) top dressing in low-potential areas showed significantly better performance than those of current conventional farmer practice of a combined application of manure and mineral fertilizers (Onduru *et al.*, 2002). Thus, the present study showed the potential benefits of organic crop production in subtropical climate which was also substantiated by the available literatures (Das *et al.*, 2010b, 2013; Yadav *et al.*, 2013).

System productivity

Total productivity of a cropping system is important to farmers for assessing the efficiency of various cropping systems. Total system productivity (assessed in terms of MEY) among the cropping systems tested under this experiment was higher in FYM as organic amendment followed by INS up to the third year of experimentation, whereas, during the fourth and fifth years of the experiment, INS recorded higher MEY followed by those under FYM and VC (Table 5). Among the cropping systems,

Table 5. System productivity (Mg ha^{-1}) in terms of Maize Equivalent Yield (MEY), net returns and B:C ratio as influenced by various organic amendments and cropping systems.

Treatments	MEY (Mg ha^{-1})						Net return	B:C
A. Cropping systems	Y_1*	Y_2	Y_3	Y_4	Y_5	Pooled	(\$ ha^{-1})	ratio
Maize + soybean–tomato	21.68	24.84	25.26	43.22	28.90	28.78	5760	4.81
Maize + soybean–potato	14.22	15.28	16.62	30.87	16.38	18.67	2989	2.62
Maize + soybean–French bean	18.11	16.80	17.49	42.04	27.40	24.37	5511	4.74
SEm (±)	0.39	0.52	0.42	0.27	0.32	0.54	5.44	0.003
CD ($p = 0.05$)	1.20	1.13	1.24	0.83	1.00	1.16	21.4	0.013
B. Nutrient sources								
FYM	22.73	23.51	23.77	42.43	28.96	28.28	5710	4.73
Vermicompost	18.61	20.66	22.23	42.33	28.02	26.37	5184	3.79
FYM + vermicompost	18.66	20.91	22.79	43.10	29.45	26.98	5417	4.09
Control	12.01	10.82	10.37	26.97	10.48	14.13	2702	3.61
SEm (±)	0.37	0.34	0.26	0.34	0.29	0.36	5.81	0.005
CD ($p = 0.05$)	1.12	1.06	0.81	1.05	0.88	1.07	17.3	0.014

*Y_1: 2005–06; Y_2: 2006–07; Y_3: 2007–08; Y_4: 2008–09; Y_5: 2009–10.

maize + soybean–tomato produced maximum MEY followed by maize + soybean–French bean in all the five years. Pooled MEY under FYM and INS were 28.28 and 26.98 Mg ha^{-1}, respectively. Das *et al.* (2008) also reported suitability of including tomato in field-crop-based systems for higher system productivity compared to other crop sequences in the NER of India. Vegetables such as tomato, French bean, carrot etc. have high yield potential under subtropical hill climate and because of their good market demand and higher prices than cereals, contribute to higher equivalent yield which results in higher farm income (Das *et al.*, 2008, 2013).

Economics

Economic analysis of various vegetable-based cropping systems under organic cultivation revealed that maximum net returns were recorded with maize + soybean–tomato cropping system followed by maize + soybean–French bean (Table 5). Among the organic amendments, the highest net returns and benefit: cost (B:C) ratio was recorded with FYM followed by INS. Higher net returns and B:C ratio with maize + soybean–tomato cropping system were mainly due to higher production potential of tomato and good market price which were instrumental for attaining higher MEY. Increase in system productivity and farmers' income, due to inclusion of tomato in cropping systems, has been also reported by other researchers (Das *et al.*, 2008, 2013). Comparatively lower costs involved in supplying nutrients through FYM than VC resulted in higher income under FYM followed by INS.

Nutrient uptake

Higher total N, P and K uptake (Figure 4) were recorded with INS as source of nutrient supply followed by sole application of FYM than control. This is in line with the fact that the organic amendments when applied in combination are efficient

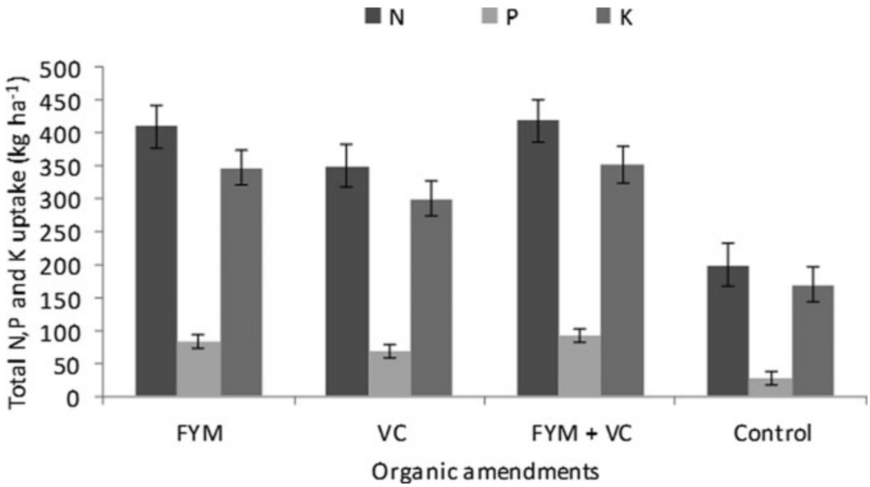

Figure 4. Total N, P and K uptake (kg ha^{-1}) as influenced by diverse organic amendments (vertical bar indicates standard error).

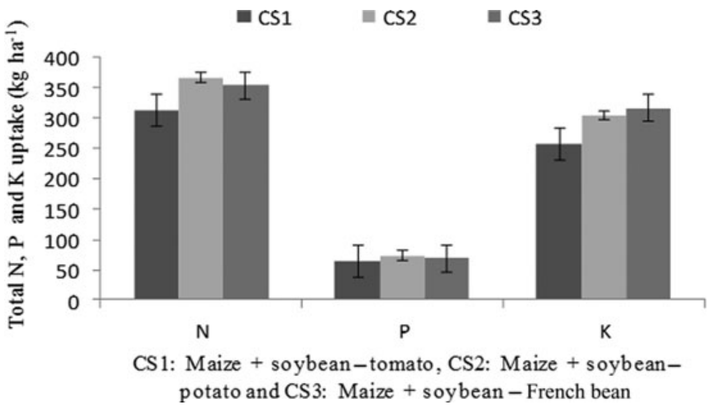

Figure 5. Total N, P and K uptake (kg ha^{-1}) as influenced by diverse cropping systems (vertical bar indicates standard error).

in contributing to higher nutrient accumulation in plant parts. Among the cropping systems, maximum total N and P uptake was recorded in maize + soybean–potato followed by maize + soybean–French bean cropping systems, whereas, total K uptake was maximum in maize + soybean–French bean cropping system (Figure 5). Higher nutrient uptake due to supply of nutrients through combined source might be due to better soil health and less nutrient fixation (Das *et al.*, 2004). Stein-Bachinger and Werner (1997) observed higher yields and nutrient uptake due to the addition of different manures within a crop rotation. Higher nutrient removal by potato compared to tomato, carrot has also been reported by Das *et al.* (2008). Conjunctive application of VC and FYM increased soil nutrient status (N and P) and thereby their uptake by the cropping system. The increased N uptake was due to mineralization of N from

OM and mineralization effect upon native N (Sims, 1987). The increased P uptake under INS is due to solubilization effect on the native P (Dahiya and Singh, 1980; Singh *et al.*, 1981). The decomposition of organic manure results in the formation of CO_2, which helps in the solubilization of the native P, which forms the phospho-humic complexes that can be easily assimilated by the plants or isomorphous replacement of phosphate ions by humate ions, and coating of sesquioxide particles by humus to form a protective cover that reduces the P-fixing capacity of the soil (Singh *et al.*, 1981).

Soil fertility

The role of organic manures in improving soil fertility and productivity is well documented (Baran *et al.*, 1998). In addition to their richness in essential plant nutrients, organic manures also supply plant growth promoting substances and humus forming microbes in the soil. Thus, the application of VC and FYM improved the overall physico-chemical properties of the soil, which caused improvement in growth and yield attributes, yield, N and P content and uptake in dry matter (Jat and Ahlawat, 2006).

At the end of five cropping cycles, higher soil pH (5.01), SOC (22.0 g kg^{-1}), available N (244.77 kg ha^{-1}), P (31.61 kg ha^{-1}) and K (241.88 kg ha^{-1}) were observed under maize + soybean–French bean cropping system compared to those under maize + soybean–potato and maize + soybean–tomato cropping systems (Table 6). Among the amendments, INS as nutrient source recorded maximum pH (5.10), SOC (23.6 g kg^{-1}), available P (34.29 kg ha^{-1}) and K (249.98 kg ha^{-1}) compared to other amendments. However, available N (251.47 kg ha^{-1}) was maximum in FYM as organic amendment. Percentage increase in SOC, pH, and available N, P and K due to FYM as organic amendment were 22.2, 6.65, 6.73, 26.98 and 23.70%, respectively, compared to control after five cropping cycles. Maximum SMBC and water holding capacity were recorded under INS as source of organic amendment followed by those under FYM and VC, which were at par with each other. Minimum bulk density (BD) was recorded with VC (1.11 Mg m^{-3}) followed by INS (1.12 Mg m^{-3}) and FYM (1.14 Mg m^{-3}) as organic amendments. However, the response of all three organic amendments on BD was not different from each other.

SOC is considered as an indicator of N-supplying capacity of soils. It helps in economizing the external supply of N besides supplying a substantial proportion of N utilized by the crop from mineralizing SOM (Sahrawat, 2006). Continuous application of organic amendments were reported to improve the SOC, available N, P and K in soil, thereby sustaining the soil health (Das *et al.*, 2013; Panwar *et al.*, 2010). Maximum improvement in soil health related to SOC, available nutrient status and soil microbial population was observed with organic N sources alone or along with biofertilizers (Yadav *et al.*, 2013). The increase in available P might be due to organic acids which were released during microbial decomposition of OM, which helped in solubility of native phosphates (Bhardwaj and Omanwar, 1994; Chitra and Janaki, 1999). The higher availability of K might be due to beneficial effect of OM on the reduction of K fixation, added OM interacted with K clay to release K from non-exchange fraction

Table 6. Soil parameters as influenced by various cropping systems and organic amendments after five cropping cycles.

Treatments	PH	SOC* ($g\ kg^{-1}$)	Available N ($kg\ ha^{-1}$)	Available P ($kg\ ha^{-1}$)	Available K ($kg\ ha^{-1}$)	Bulk density ($Mg\ m^{-3}$)	SMBC† ($\mu g\ g^{-1}$ dry soil)	MWHC‡ (%)
A. Cropping systems								
Maize + soybean–tomato	4.97	22.0	242.88	30.56	237.98	1.12	204.60	55.18
Maize + soybean–potato	5.0	21.7	241.23	30.90	240.64	1.12	206.10	55.30
Maize + soybean–French bean	5.01	22.0	244.77	31.61	241.88	1.14	207.30	52.97
SEm (±)	0.04	0.30	1.58	1.02	1.32	0.03	0.09	1.44
CD ($p = 0.05$)	NS	NS	NS	NS	NS	NS	NS	NS
B. Nutrient sources								
FYM§	5.06	23.3	251.47	33.81	245.29	1.14	215.73	58.74
Vermicompost	5.04	22.3	245.46	32.58	240.08	1.11	200.18	54.57
FYM + vermicompost	5.10	23.6	249.12	34.29	249.98	1.12	220.33	61.48
Control	4.79	18.7	225.68	23.40	225.32	1.18	186.34	43.13
Initial	4.80	18.0	235.61	19.19	202.10	1.19	194.5	42.90
SEm (±)	0.06	0.30	2.20	0.68	1.53	0.03	0.8	0.82
CD ($p = 0.05$)	0.17	1.00	6.56	2.04	4.54	NS	2.40	2.45

*SOC: soil organic carbon; †SMBC: soil microbial biomass carbon; ‡MWHC: maximum water holding capacity, §FYM: farmyard manure.

to the available pool. Increase in soil pH due to application of organic amendment like FYM and VC was also reported by Gopinath *et al.* (2008). The differences in SOC with the application of diverse organic amendments were due to differential rate of oxidation of OM by microbes (Trehan, 1997). The slow decomposition of applied and native SOM due to prevailing anoxic conditions, low temperature and supply of OM through diverse manure increased the SOC (Yadvinder-Singh et *al.*, 2004). Increase in SOC due to organic farming has been also reported by other researchers (Babhulkar *et al.*, 2000; Das *et al.*, 2013; Goldstein and Young, 1987; Stolze *et al.*, 2000). Addition of organic sources provide a stable supply of C and energy for microorganisms and results in increased microbial activities (Chitra and Janaki, 1999). Superior soil fertility status on organic farms compared to soils under chemical fertilizers was also widely reported (Chitra and Janaki, 1999; Mader *et al.*, 2002). Soil nutrient status build-up in an organic system takes a long time due to slow mineralization and release of nutrients from organic sources (Das *et al.*, 2013). The highest available soil N in tomato and cabbage fields was recorded with INS, while maximum K and SOC were obtained with VC (Choudhary *et al.*, 2003). Organic compost contains bacteria, actinomycetes and fungi; hence, a fresh supply of humic material not only added microorganisms but also stimulate them (Balasubramanian *et al.*, 1972; Gaur *et al.*, 1973). Microbes in rhizosphere provide benefits to crops by better nutrient availability through mineralization of organic N, atmospheric N-fixation or solubilizing fixed mineral forms of P and other nutrients (Hegde *et al.*, 2007).

Quality parameters of tomato

Various quality parameters of tomato grown under diverse cropping systems and nutrient management practices were determined at the ripening stage. Total soluble solids, average juice volume, ascorbic acid, total sugars, reducing sugars and lycopene content of tomato were recorded higher under FYM as organic amendment, which was closely followed by those under INS and VC (Table 7). Maximum average fruit weight, specific gravity and fruit diameter, TSS, ascorbic acid, total sugar and lycopene content were recorded with FYM, whereas, reducing sugar content was found maximum in VC as organic amendment. On the other hand, acidity was found moderately higher in control treatment. The produce quality is controlled by a complex interaction of factors, including soil type and the ratio of minerals in added manures (Warman and Harvard, 1998). Parray *et al.* (2007) reported that phenol, chlorophyll, ascorbic acid, oxalic acid, acidity, lycopene and carotenoid contents were improved with the application of FYM compared to control. Ramesh *et al.* (2008) also supported with their findings that the management of organic manures and crop rotation can have significant effect on yield and produce quality.

CONCLUSIONS

FYM as organic amendment was found superior in respect to yield, nutrient uptake, produce quality and residual soil fertility status at equivalent N application rate followed by integrated application of equivalent amount of FYM and VC. Maize +

Table 7. Quality parameters of tomato fruit at maximum ripening stage under various organic management practices.

Quality parameters	FYM*	VC†	FYM + VC	Control
Fruit weight (g fruit^{-1})	48.80 ± 1.06	43.08 ± 0.66	43.40 ± 0.99	40.51 ± 0.70
Fruit diameter (mm)	44.23 ± 1.03	42.79 ± 0.91	43.73 ± 0.82	40.24 ± 0.81
Fruit volume (cm^3)	56 ± 1.05	56 ± 0.96	52 ± 0.70	48 ± 0.66
Fruit length (mm)	44.08 ± 0.98	40.73 ± 0.84	42.79 ± 0.91	39.69 ± 0.59
Fruit diameter (mm)	44.23 ± 1.03	42.79 ± 0.91	43.73 ± 0.82	40.24 ± 0.81
Specific gravity (g ml^{-1})	0.87 ± 0.01	0.77 ± 0.02	0.83 ± 0.01	0.84 ± 0.02
TSS (%)‡	5.0 ± 0.70	4.8 ± 0.63	4.6 ± 0.54	4.6 ± 0.48
Acidity (%)	0.64 ± 0.08	0.512 ± 0.05	0.596 ± 0.07	0.896 ± 0.06
Ascorbic acid (mg 100 g^{-1})	28.6 ± 0.89	28.6 ± 0.81	28.6 ± 0.86	25.7 ± 0.70
Juice content (ml fruit^{-1})	80.0 ± 1.83	71.0 ± 1.54	93.0 ± 1.68	65.0 ± 0.89
Reducing sugar (%)	2.56 ± 0.24	2.73 ± 0.15	2.43 ± 0.10	1.76 ± 0.04
Total sugar (%)	3.75 ± 0.13	3.59 ± 0.12	3.57 ± 0.11	3.00 ± 0.10
Lycopene content (mg 100 g^{-1})	19.35 ± 0.66	14.67 ± 0.46	17.63 ± 0.55	13.60 ± 0.51

*FYM: farmyard manure; †VC: vermicompost; ‡TSS: total soluble solids.
Note: ± indicates standard deviation from mean.

soybean–tomato cropping system produced maximum system productivity and gave the highest net returns. Hence, maize + soybean–tomato system with FYM as organic amendment is recommended for economical and sustainable organic crop production at mid altitude of Eastern Himalayas. The C-sequestration potential of continuous organic farming with respect to diverse organic amendments and cropping systems needs to be studied in comparison to conventional farming practices to assess the actual benefit of organic farming. More crops and organic manures need to be evaluated to establish the best combinations of crop and manure for sustainable organic crop production.

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REFERENCES

Abawi, G. S. and Widmer, T. L. (2000). Impact of soil health management practices on soil borne pathogens, nematodes and root diseases of vegetable crops. *Applied Soil Ecology* 15:37–47.

Altieri, M. A. (1995). *Agroecology: The Science of Sustainable Agriculture.* London: Intermediate Technology Publications.

Babhulkar, P. S., Wandile, R. M., Badole, W. P. and Balpande, S. S. (2000). Residual effect of long term application of FYM and fertilizer on soil properties (vertisols) and yield of soybean. *Journal of Indian Society of Soil Science* 48:89–92.

Balasubramanian, A., Siddaramappa, R. and Rangaswami, G. (1972). Effect of organic manuring on the activities of the enzymes hydrolysing sucrose and urea and on soil aggregation. *Plant and Soil* 37:319–328.

Baran, S., Bielinska, J. and Wisniewski, J. (1998). Effect of utilization of unconventional multi-component fertilizers on chosen properties of light soil. *Folia Universitatis Agriculturae Stetinesis, Agricultura* 72:11–20.

Berry, P. M., Stockdale, E. A., Sylvester-Bradley, R., Philipps, L., Smith, K. A., Lord, E. I., Watson, C. A. and Fortune, S. (2003). N, P and K budgets for crop rotations on nine organic farms in the UK. *Soil Use Management* 19:112–118.

Bhardwaj, V. and Omanwar, P. K. (1994). Long term effects of continuous rotational cropping and fertilization on crop yields and soil properties-II. Effect on EC, pH, organic matter and available nutrients of soil. *Journal of Indian Society of Soil Science* 42:387–392.

Bhooshan, N. and Prasad, C. (2011). *Organic Farming: Hope of Posterity*, 1–10. Lucknow: UP Council of Agricultural Research (UPCAR).

Bray, R. H. and Kurtz, L. T. (1945). Determination of total, organic and available forms of phosphorus in soils. *Soil Science* 59:39–45.

Bujarbaruah, K. M. (2004). Organic Farming: Opportunities and Challenges in North Eastern Region of India. Paper presented at *International Conference on Organic Food*, held at ICAR Research Complex for NEH Region, Umiam, Meghalaya, during 14–17 February 2004, pp. 13–23.

Bulson, H. A. J., Snaydon, R. W. and Stopes, C. E. (1997). Effects of plant density on intercropped wheat and field beans in an organic farming system. *Journal of Agricultural Science, Cambridge* 128:59–71.

Carolyn, D. and Oberholtzer, L. (2009). *Marketing U.S. Organic Foods: Recent Trends From Farms to Consumers*. Economic Information Bulletin No. 58. Published by U.S. Department of Agriculture Economic Research Service. 36 pp.

Carpenter, B. L., Kennedy, A. C. and Reganold, J. P. (2000). Organic and biodynamic management effects on soil biology. *Soil Science Society of America Journal* 64:1651–1659.

Cavero, J., Plant, R. E., Shennan, C. and Friedman, D. B. (1997). Nitrogen dynamics in processing tomatoes under conventional, low input and organic management systems. *Nutrient Cycling in Agroecosystems* 47:271–282.

Chhonkar, P. K. (2002). Organic Farming Myth and Reality. In *Proceedings of the FAI Seminar on Fertilizer and Agriculture Meeting the Challenges*, held at New Delhi, India (December).

Chitra, L. and Janaki, P. (1999). Combined effect of organic wastes and inorganic nutrients on the nutrient uptake and yield of rice in kar and pishanam seasons. *Oryza* 36:327–330.

Choudhary, R. S., Das, A. and Patnaik, U. S. (2003). Organic farming for vegetable production using vermicompost and FYM in Kokriguda watershed of Orissa. *Indian Journal of Soil Conservation* 31(2):203–206.

Clark, M. S., Horwath, W. R., Shennan, C. and Scow, K. M. (1998). Changes in soil chemical properties resulting from organic and low input farming practices. *Agronomy Journal* 90:662–671.

Dahiya, S. S. and Singh, R. (1980). Effect of farmyard manure and calcium carbonate on the dry matter yield and nutrient uptake by oats (*Avena sativa* L.). *Plant and Soil* 56:391–402.

Das, A., Baiswar, P., Patel, D. P., Munda, G. C., Ghosh, P. K., Ngachan, S. V., Panwar, A. S. and Chandra, S. (2010b). Composts quality prepared from locally available plant biomass and their effect on rice productivity under organic production system. *Journal of Sustainable Agriculture* 34(5):1–17.

Das, A., Patel, D. P., Munda, G. C. and Ghosh, P. K. (2010a). Effect of organic and inorganic sources of nutrient on yield, nutrient uptake and soil fertility of maize (*Zea mays*)–mustard (*Brassica campestris*) cropping system. *Indian Journal of Agricultural Sciences* 80(1):85–88.

Das, A., Patel, D. P., Munda, G. C., Hazarika, U. K. and Bordoloi, J. (2008). Nutrient recycling potential in rice–vegetable cropping sequences under *in situ* residue management at mid-altitude subtropical Meghalaya. *Nutrient Cycling in Agroecosystems* 82:251–258.

Das, A., Patel, D. P. Ramkrushna, G. I. Munda, G. C. Ngachan, S. V. Kumar, and J. Naropongla. (2013). Crop diversification, crop and energy productivity under raised and sunken beds: results from a seven-year study in a high rainfall organic production system, *Biological Agriculture and Horticulture* 30:73-87.

Das, A., Prasad, M., Shivay, Y. S. and Subha, K. M. (2004). Productivity and sustainability of cotton–wheat cropping system as influenced by prilled urea, FYM and Azotobacter. *Journal of Agronomy and Crop Science* 190:298–304.

Dobbs, T. L. and Smolik, J. D. (1997). Productivity and profitability of conventional and alternative farming systems: a long-term on-farm paired comparisons. *Journal of Sustainable Agriculture* 9:63–79.

FFTC. (1998). *Taiwan Microbial and Organic Fertilizers in Asia*. Food and Fertilizer Technology Centre Publication Database.

Frankenberger, W. T. and Dick, W. A. (1983). Relationship between enzyme activities and microbial growth and activities in soil. *Soil Science Society of America Journal* 47:945–951.

Franke-Snyder, M., Douds, D. D., Galvez, L., Phillips, J. G., Wagoner, P., Drinkwater, L. and Morton, J. B. (2001). Diversity of communities of arbuscular mycorrhizal (AM) fungi present in conventional versus low-input agricultural sites in eastern Pennsylvania, USA. *Applied Soil Ecology* 16:35–48.

Gaur, A. C., Sadasivam, K. V., Vimal, O. P., Mathur, R. S. and Kavimandan, S. K. (1973). Studies on the humification of organic matter in a red Rakar soil. *Zentralblatt fur Bakteriologie* 128:149–161.

Goldstein, W. A. and Young, D. L. (1987). An agronomic and economic comparison of a conventional and a low input cropping system in Palouse. *American Journal of Alternative Agriculture* 2:51–56.

Gopinath, K. A., Saha, R., Mina, B. L., Pande, H., Kundu, S. and Gupta, H. S. (2008). Influence of organic amendments on growth, yield and quality of wheat and on soil properties during transition to organic production. *Nutrient Cycling in Agroecosystems* 82:51–60.

Hazarika, U. K., Munda, G. C., Bujarbaruah, K. M., Das, A., Patel, D. P., Prasad, K., Kumar, R., Panwar, A. S., Tomar, J. M. S., Bordoloi, J. S., Meghna, S. and Girin, G. (2006). *Nutrient Management in Organic Farming*. Technical Bulletin No. 30. Published by Director, ICAR RC for NEH Region, Umiam, Meghalaya. 40 pp.

Hegde, D. M., Sudhakara, Babu, S. N., Qurershi, A. A. and Murthy, I. Y. L. N. (2007). Enhancing nutrient-use efficiency in crop production – a review. *Indian Journal of Agronomy* 52:261–274.

IFOAM (International Federation of Organic Agriculture Movement). (2004). *Developing Local Marketing Initiatives for Organic Products in Asia. A Guide for Small and Medium Enterprises*. Available at: http://infohub.ifoam.org/sites/default/files/page/files/ifoam_workshop_localmarketinginitiatives.pdf. Accessed on 17 December 2013.

Jackson, M. L. (1973). *Soil Chemical Analysis*. New Delhi: Prentice Hall of India.

Jat, R. S. and Ahlawat, I. P. S. (2006). Direct and residual effect of vermicompost, biofertilizers and phosphorus on soil nutrient dynamics and productivity of chickpea-fodder maize sequence. *Journal of Sustainable Agriculture* 28:41–54.

Jenkinson, D. S. and Lad, J. N. (1981). Microbial biomass in soil: measurement and turnover. In *Soil Biochemistry*, 451–471 (Eds. E. A. Paul and J. N. Ladd). New York, NY, USA: Marcel Dekker.

Jensen, E. S. (1996). Grain yield, symbiotic N2 fixation and interspecific competition for organic-N in pea-barley intercrop. *Plant and Soil* 182:25–38.

Kumar, M. (2009). *Integrated Nutrient Management in Potato Under Rainfed Condition of Meghalaya Hills*. Thesis submitted to Palli Siksha Bhavana, Visva-Bharati University, Sriniketan, West Bengal, India. 83 pp.

Kumar, M., Baisya, L. K., Ghosh, D. C., Gupta, V. K., Dubey, S. K., Das, A. and Patel, D. P. (2012). Productivity and soil health of potato (*Solanum tuberosum* L) field as influenced by organic manure, inorganic fertilizers and biofertilizers under high altitudes of Eastern Himalayas. *Journal of Agricultural Science* 4:223–234.

Lampkin, N. (1990). *Organic Farming*. Ipswich: Farming Press Books.

Lawlor, K., Knight, B. P., Barbosa-Jefferson, V. L., Lane, P. W., Lilley, A. K., Paton, G. I., McGrath, S. P., O'Flaherty, S. M. and Hirsch, P. R. (2000). Comparison of methods to investigate microbial populations in soils under different agricultural management. *FEMS Microbial Ecology* 33:129–137.

Mader, P., Fliebbach, A., Dubois, D., Gunst, L., Fried, P. and Niggli, U. (2002). Soil fertility and biodiversity in organic farming. *Science* 296:1694–1697.

Margar, S. S. (2004). Organic framing: technical feasibility, economic viability and social acceptance. *Journal of the Indian Society of Soil Science* 52:374–378.

Mourao, I., Brito, L. M. and Coutinho, J. (2008). Cultivating the Future Based on Science. Volume-1: Organic Crop Production. In *Proceedings of the 2nd Scientific Conference of the International Society of Organic Agriculture Research (ISOFAR), held at the 16th IFOAM Organic World Congress in Cooperation with the International Federation of Organic Agriculture Movements (IFOAM) and the Consorzio ModenaBio*, held at Modena, Italy (18–21 June 2008) 596–599. Published by International Society of Organic Agricultural Research (ISOFAR), Bonn, Germany.

Mueller, T. and Thorup-Kristensen, K. (2001). N-fixation of selected green manure plants in an organic crop rotation. *Biological Agriculture and Horticulture* 18:345–363.

Nannipeeri, P. (1994). The potential use of soil enzymes as indicators of productivity, sustainability and pollution. In *Soil Biota Management in Sustainable Farming Systems*, pp. 238–244 (Eds C. E. Pankhurst, B. M. Doube, V. V. S. R. Gupta, P. R. Grace). Melbourne. CSIRO.

Ngouajio, M. and McGiffen, M. E. (2002). Going organic changes weed population dynamics. *Horticulture* 12:590–596.

Onduru, D. D., Diop, J. M., Van der Werf, E. and Jager, A. De. (2002). Participatory on-farm comparative assessment of organic and conventional farmers' practices in Kenya. *Biology Agriculture Horticulture* 19:295–314.

Panse, V. G. and Sukhatme, P. V. (1978). *Statistical Methods for Agricultural Workers*, 3rd edn. New Delhi: Indian Council of Agricultural Research.

Panwar, N. R., Ramesh, P., Singh, A. B. and Ramana, S. (2010). Influences of organic, chemical and integrated management practices on soil organic carbon and soil nutrient status under semi-arid tropical conditions in central India. *Communication in Soil Science and Plant Analysis* 41:1073–1083.

Parray, B. A., Ganai, A. M. and Fazili, K. M. (2007). Physico-chemical parameters and growth yield of tomato (*Lycopersicum esculentum*): role of farm yard manure and neem cake. *American-Eurasian Journal of Agriculture and Environmental Science* 2:303–307.

Pathak, H., Kushwala, J. S. and Jain, M. C. (1992). Evaluation of manurial value of biogas spent slurry composted with dry mango leaves, wheat straw and rock phosphate on wheat crop. *Journal of Indian Society of Soil Science* 40:753–757.

Poutala, R. T., Kuoppamaki, O., Korva, J. and Varis, E. (1994). The performance of ecological, integrated and conventional management systems in cereal cropping in Finland. *Field Crops Research* 37:3–10.

Prasad, R, Shivay, Y. S., Kumar, D. and Sharma, S. N. (2006). *Learning by Doing Exercises in Soil Fertility*, 68 p. New Delhi: Division of Agronomy, Indian Agricultural Research Institute.

Ramesh, P., Panwar, N. R. and Singh, A. B. (2010). Crop productivity, soil fertility and economics of soybean (*Glycine max*), chickpea (*Cicer arietinum*) and blond psyllium (*Plantago ovata*) under organic nutrient management practices. *Indian Journal of Agricultural Sciences* 80:965–969.

Ramesh, P., Panwar, N. R., Singh, A. B. and Ramana, S. (2008). Effects of organic manures on productivity, soil fertility and economics of soybean (*Glycine max*)–durum wheat (*Triticum durum*) cropping system under organic farming in *vertisols*. *Indian Journal of Agricultural Sciences* 78:1033–1037.

Ramesh, P., Panwar, N. R., Singh, A. B. and Ramana, S. (2009). Effects of organic nutrient management practices on the production potential, nutrient uptake, soil quality, input-use efficiency and economics of mustard (*Brassica juncea*). *Indian Journal of Agricultural Sciences* 79:40–44.

Rigby, D. and Caceres, D. (2001). Organic farming and sustainability of agricultural systems. *Agricultural System* 68:21–40.

Saha, R., Chaudhary, R. S. and Somasundaram, J. (2012). Soil health management under hill agroecosystem of North East India. *Applied and Environmental Soil Science* 2012:9.

Sahrawat, K. L. (2006). Organic matter and mineralizable nitrogen relationships in wetland rice soils. *Communications in Soil Science and Plant Analysis* 37:787–796.

Salahin, N., Begum, R. A., Hossain, S., Ullah, M. M. and Alam, M. K. (2013). Degradation of soil properties under ginger, turmeric, aroid, and *jhum* rice cultivation in hilly areas of Bangladesh. *Bangladesh Journal of Agricultural Research* 38:363–371.

Sanwal, S. K., Yadav, R. K. and Singh, P. K. (2007). Effect of types of organic manure on growth, yield and quality parameters of ginger (*Zingiber officinale*). *Indian Journal of Agricultural Sciences* 77:67–72.

Sims, J. T. (1987). Agronomic evaluation of poultry manure as a nitrogen source for conventional and no tillage corn. *Agronomy Journal* 79:563–570.

Singh, B. P., Chahal, R. S. and Singh, M. (1981). Fertilizer management through organic and inorganic fertilizers in *bajra*-wheat crop sequence. *Fertilizer News* 26:16–19.

Stein-Bachinger, K. and Werner, W. (1997). Effect of manure on crop yield and quality in an organic agricultural system. *Biological Agriculture and Horticulture* 14:221–235.

Stockdale, E. A., Lampkin, N. H., Hovi, M., Keatinge, R., Lennartsson, E. K. M., Macdonald, D. W., Padel, S., Tattersall, F. H., Wolfe, M. S. and Watson, C. A. (200l). Agronomic and environmental implications of organic farming systems. *Advances in Agronomy* 70:261–327.

Stockdale, E. A., Rees, R. M. and Davies, M. G. (1995). Nitrogen supply for organic cereal production in Scotland. In *Soil Management in Sustainable Agriculture*, 254–264. (Eds H. F. Cook and H. C. Lee). Ashford, UK: Wye College Press.

Stolze, M., Piorr, A., Haring, A. and Dabbert, S. (2000). *The Environmental Impact of Organic Farming in Europe*. Stuttgart-Hohenheim: University of Hohenheim.

Subbiah, B. V. and Asija, G. L. (1956). A rapid procedure for the determination of available nitrogen in soils. *Current Science* 25:259–260.

Surekha, K. (2007). Nitrogen-release pattern from organic sources of different C:N ratios and lignin content, and their contribution to irrigated rice (*Oryza sativa*). *Indian Journal of Agronomy* 52:220–224.

Surekha, K., Rao, K. V., Shobha Rani, N., Latha, P. C. and Kumar, R. M. (2013). Evaluation of organic and conventional rice production systems for their productivity, profitability, grain quality and soil health. *Agrotechnology* 1:87.

Tamaki, M, Itani, T. and Nakano, H. (2002). Effects of organic and inorganic fertilizers on the growth of rice plants of rice plants under different light intensities. *Japanese Journal of Crop Science* 71:439–445.

Tester, C. F. (1990). Organic amendment effects on physical and chemical properties of a sandy soil. *Soil Science Society of America Journal* 54:827–831.

Torstensson, G. (1998). Nitrogen delivery and utilization by subsequent crops after incorporation of leys with different plant composition. *Biological Agriculture and Horticulture* 16:129–143.

Trehan, S. P. (1997). A rapid method for the estimation of potential immobilization of N after addition of cattle slurry to soil. *Journal of Indian Society of Soil Science* 45:14–19.

Upadhyay, R. C., Khan, M. A. and Singh, O. P. (2008). Prospect of Organic Production in India. *Global Potato Conference,* held at New Delhi, India (9–12 December 2008).

Urkurkar, J. S., Chitale, S. and Tiwari, A. (2010). Effect of organic v/s chemical nutrient packages on productivity, economics and physical status of soil in rice (*Oryza sativa*)–potato (*Solanum tuberosum*) cropping system in Chhattisgarh. *Indian Journal of Agronomy* 55:6–10.

Vance, E. D., Brookes, P. C. and Jenkinson, D. S. (1987). Microbial biomass measurements in forest soils: the use of the chloroform fumigation incubation method in strongly arid soils. *Soil Biology and Biochemistry* 19: 697–702.

Van Diepeningen, A. D., De Vos, O. J., Korthals, G. W. and Van Bruggen, A. H. C. (2006). Effects of organic versus conventional management on chemical and biological parameters in agricultural soils. *Applied Soil Ecology* 31:120–135.

Walkley, A. and Black, J. A. (1934). Estimation of soil organic carbon by chromic acid titration method. *Soil Science* 17:29–38.

Warman, P. R. and Harvard, K. A. (1998). Yield, vitamin and mineral contents of organically and conventionally grown potatoes and sweet corn. *Agriculture Ecosystem and Environment* 68:207–216.

Watson, C. A., Bengtsson, H., Ebbesvik, M., Loes, A. K., Myrbeck, A., Salomon, E., Schroder, J. and Stockdale, E. A. (2002). A review of farm-scale nutrient budgets for organic farms as a tool for management of soil fertility. *Soil Use and Management* 18:264–273.

Willer, H. and Yussefi, M. (2005). The World of Organic Agriculture – Statistics and Emerging Trends, pp. 196. Bonn: International Federation of Organic Agriculture Movements (IFOAM).

Yadav, A. K. (2012). Status of organic agriculture in India. *Organic Farming News Letter* 8:11–12.

Yadav, S. K., Babu, S., Yadav, M. K., Singh, K., Yadav, G. S. and Pal, S. (2013). A review of organic farming for sustainable agriculture in Northern India. *International Journal of Agronomy*. http://dx.doi.org/10.1155/2013/718145.

Yadav, H. and Kumari, V. (2003). Influence of vermicompost with organic and inorganic manures on biometric and yield parameters of chilli [(*Capsicum annum* L.) var. plri]. *Crop Research* 25:236–243.

Yadvinder-Singh, B.-S., Ladha, J. K., Khind, C. S., Khera, T. S. and Bueno, C. S. (2004). Effects of residue decomposition on productivity and soil fertility in rice-wheat rotation. *Soil Science Society of America Journal* 68:854–864.30.