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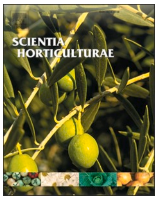

How sustainable is organic management in cassava? Evidences from yield, soil quality, energetics and economics in the humid tropics of South India

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ABSTRACT

Sustainable alternative agricultural practices like organic farming have evinced interests due to public consciousness about food safety, environmental pollution, soil quality and human health. The study aimed to evaluate the productivity, soil quality, energetic and economic aspects under organic vs conventional management in cassava (*Manihot esculenta* Crantz). Field experiments were conducted over a three year period at ICAR-Central Tuber Crops Research Institute, Thiruvananthapuram, India in split plot design with three varieties of cassava, H-165, Sree Vijaya and Vellayani Hraswa, in main plots and five production systems, traditional, conventional, integrated and two types of organic (without and with microbial inoculants) in sub plots. Organic management (without microbial inoculants) (27.26 t ha^{-1}) produced insignificant yield increase (+2.40%) over conventional system (26.62 t ha^{-1}). The industrial (H-165) as well as domestic varieties (Sree Vijaya, Vellayani Hraswa) of cassava exhibited similar performance under the different production systems. At the end of the third crop, soil chemical properties like pH and organic C were significantly enhanced by 1.15 unit and 22.58% under organic (with microbial inoculants) over conventional system, whereas the soil porosity, cation exchange capacity and exchangeable Ca were significantly higher by 9.36, 27.32 and 29.10% in the organic (without microbial inoculants) over conventional. Besides, biological improvement of the soil with higher counts of bacteria, fungi and actinomycetes and greater activity of soil enzymes like acid phosphatase and dehydrogenase were also observed under organic (with microbial inoculants) system. Both the organic practices (without and with microbial inoculants) scored higher soil quality index (SQI) over the rest, but similarly (0.98 and 0.94 respectively). The soil pH, exchangeable Ca, dehydrogenase enzyme activity and porosity were the decisive factors that governed SQI in the present study. Organic system (without microbial inoculants) proved to be the most energy efficient as evidenced from the highest energy output (152.63 × 10^{3}MJ ha^{-1}), net energy (143.55 × 10^{3}MJ ha^{-1}), energy use efficiency (16.80) and energy productivity (3.00 kg MJ^{-1}). Organic system generated the highest net income (US $ 4977.57 ha^{-1}) statistically similar to conventional (US $ 4833.10 ha^{-1}) and organic with microbial inoculants (US $ 4720.69 ha^{-1}). Hence organic practices can be recommended for sustainable cassava production.

1. Introduction

There is a great demand for ecologically-produced foods for ensuring food safety and security, environmental protection and biodiversity as well as human well-being (FAO, 2010; De Schutter, 2011; SCAR, 2011). In India, the agro-technological revolution, “green revolution”, enabled self-sufficiency with enhancement in food grain production from 50.80 million tonnes during 1950 to 295.67 million tonnes during 2019–2020 (www.indiastat.com). However, the consequences of chemical intensive agriculture that relied on excessive chemical inputs and lesser additions of carbon sources were soil erosion, soil salinity, receding ground water table, soil ill health due to low organic C contents, nutrient imbalance, land degradation, loss of biodiversity, pesticide pollution and adverse effects on human health (Suja et al., 2015).

According to the UN millennium ecosystem assessment, “land degradation” is one of the world’s greatest environmental challenges. About 40% of the world’s arable land is seriously degraded and 11% of such arable land is unsuitable for farming in Asia (The Hindu, 2007). Maintaining soil quality is vital not only for crop production but also for providing wider ecosystem services for local and global societies (Bai

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et al., 2018). Considering the quality of soil and thereby land as fundamental to future peace, “Organic farming” would serve as an alternative for improved conservation of soil and vegetation besides restoration of degraded land.

Hence, there has been a growing interest to practice alternative agricultural systems like organic farming for soil and water conservation and protection of the environment and human health. Organic farming focusses on sustainable and safe food production by largely excluding the use of synthetic chemicals and with the best use of on-farm generated resources and minimal use of off-farm inputs.

Cassava (*Manihot esculenta* Crantz) is an important tropical tuber crop that plays a significant role in the food and nutrition security in rural livelihoods (Ceballos et al., 2010). Recent estimates suggest that its storage roots provide 8% or more of the minimum calorie requirement of more than 750 million people (Park, 2012). Besides, it serves as a raw material for starch, sago and animal feed industries. The cassava starch has wide industrial applications in textile, pharmaceutical, paper, and food industries as well as a biofuel. Cassava has high biological efficiency, adapted to marginal environments, low input management, adverse soil and climatic conditions, particularly drought and acidic soil conditions and thus exhibits a great flexibility to thrive under different systems (Ceballos et al., 2010). In India, presently, cassava is cultivated in an area of 0.163 m ha, with a production of 4.98 m tons and productivity of 30.55 t ha^{-1} (www.fao.org/faostat/en).

A decade of research in various tuber crops indicated that organic farming is an eco-friendly strategy that enables 10–20% higher yield, quality tubers and maintenance of soil health (Suja et al., 2012; Suja and Sreekumar, 2014; Suja et al., 2017). Elephant foot yam was the most responsive one followed by yams and taro (Suja et al., 2015). Although the impact of organic farming on yams and aroids are well documented, the performance of cassava, the major tropical tuber crop, under organic agriculture is presently unknown. There is little informtion till date about the influence of organic cultivation on the productivity, soil properties and economic and environmental aspects in cassava. Hence, the impact of organic management on productivity, soil properties, soil quality index, energetic and economic aspects in cassava were assessed and technologies for organic cassava production were developed.

2. Materials and methods

2.1. Site characteristics

Field experiments were conducted at ICAR-Central Tuber Crops Research Institute (CTCRI) (8°29′N, 76°57′E, 52 m altitude), Thiruvananthapuram, Kerala, India, during June-December for three years (2011 - 2013). In the land used for this study, prior to the start of the present investigation, green manure cowpea was raised and incorporated. The green manure addition was 15 t ha^{-1}. Chemical inputs were not used in the land for a year before taking up the present study. The weather and soil parameters of the study area are given in Table 1. The site experiences a typical humid tropical climate. The soil of the experimental site was acidic in reaction, with low available N, high available P and organic C and medium available K.

Table 1

. Weather and soil parameters of the test site.

Weather/soil parameter	Value
Annual rainfall	1817 mm
Maximum temperature	31.52 °C
Minimum temperature	24.32 °C
Mean relative humidity	76.50%
pH	4.79
Organic C	1.01%
Available N	0.0071%
Available P	0.0073%
Available K	0.0072%

Weather parameters are the average of three years, 2011–2013.

2.2. Experimental details

The experiment was laid out in split plot design with three varieties, H-165, Sree Vijaya and Vellayani Hraswa in main plots and five production systems, traditional, conventional, integrated and two types of organic in sub plots (Table 2). The 15 treatment combinations were replicated thrice. Each treatment was imposed in the gross plot size of 5.4 m x 5.4 m accommodating 16 net plants and 20 border plants. The crop was planted each year (15 June 2011, 12 June 2012, 17 June 2013) with the onset of South West monsoon season under rainfed condition and harvested six months after planting.

2.3. Crop management

The experimental site was ploughed thoroughly and brought to a fine tilth. In plots designated for organic practices, green manure cowpea seeds were sown at 20 kg ha^{-1} on 25 April in the respective growing seasons. The incorporation of green manure crop was undertaken at 45 DAS (when about 50 percent flowering occurred) as per the quantity specified in Table 2 along with farmyard manure at 12.5 t ha^{-1}and crop residue of cassava at 7 t ha^{-1} at the time of land preparation on 12 June, 10 June and 15 June respectively in 2011, 2012 and 2013. Wood ash was also added at 2 t ha^{-1} to the field as basal dose on the above dates in each year. Likewise the entire dose of P in the form of Musoorie rock phosphate (20% P_2O_5) was also given in the conventional and integrated plots on the above dates in each year. Nutrient concentrations and contribution from the various organic resources was also accounted (Tables 3 and 4). Stem cuttings from mature healthy stems were used for planting. Cassava stem cuttings of 20 cm length with 8–10 nodes were planted in the center of the mounds at a spacing of 90 × 90 cm to accommodate 12,345 plants ha^{-1}.

The different nutrients, N, P and K were applied to the respective plots in the form of urea (46% N), Musoorie rock phosphate (20% P_2O_5) and muriate of potash (KCl) (60% K_2O) as chemical sources in appropriate quantities according to the treatment schedule. The N, P and K microbial inoculants, *Azospirillum lipoferum, Bacillus megaterium* and *Bacillus sporothermodurans* received from the Department of Microbiology, College of Agriculture, Vellayani at concentrations of 5×10^7 colony forming units per g respectively were applied @ 3 kg ha^{-1} each

Table 2.

Treatment details of production systems tested.

Production systems	Name of inputs and quantity
Traditional (farmers' practice)	Farmyard manure at 12.5 t ha^{-1} and ash at 2 t ha^{-1}
Conventional (Package of Practices (POP) Recommendations)	Farmyard manure at 12.5 t ha^{-1} and NPK at 100:50:100 kg ha^{-1}
Integrated	Farmyard manure at 12.5 t ha^{-1} + NPK at 50:25:100 kg ha^{-1}+ *Azospirillum* at 3 kg ha^{-1} and phosphobacteria at 3 kg ha^{-1}
Organic	Farmyard manure at 12.5 t ha^{-1}, in situ green manuring (produced green matter of 12.65, 10.85 and 12.50 t ha^{-1} respectively during the three growing seasons) crop residue incorporation (generates fresh biomass at 7 t ha^{-1}) and ash at 2 t ha^{-1}
Organic (with microbial inoculants)	Farmyard manure at 12.5 t ha^{-1}, in situ green manuring (produced green matter of 12.50, 11.25 and 12.25 t ha^{-1} respectively during the three growing seasons), crop residue incorporation (generates fresh biomass at 7 t ha^{-1}), *Azospirillum* at 3 kg ha^{-1}, phosphobacteria at 3 kg ha^{-1} and K solubilizer at 3 kg ha^{-1}

Table 3

Estimated nutrient concentrations of the various organic manures.

Nutrient content	Farmyard manure	Ash	Green manure cowpea	Crop residue of cassava
N (g kg^{-1})	5.00	6.00	27.70	33.90
P (g kg^{-1})	2.00	16.00	5.70	4.90
K (g kg^{-1})	2.80	71.10	18.60	10.64
Ca (g kg^{-1})	0.80	150.00	4.14	6.23
Mg (g kg^{-1})	0.75	13.00	3.88	3.77
Fe (mg kg^{-1})	1465.00	5125.00	1324.77	252.90
Mn (mg kg^{-1})	70.00	2850.00	509.03	608.50
Zn (mg kg^{-1})	40.00	625.00	78.10	69.20
Cu (mg kg^{-1})	3.00	122.00	11.83	7.60

within a week of sprouting of cassava setts (30 June, 25 June and 29 June in the respective years) after mixing with cowdung and applied in soil. Half doses of N and K were given after sprouting and emergence in the conventional and integrated system on 5 July during all the growing seasons. Dried and unsprouted stem cuttings were removed and gap filling was done with stem cuttings of longer size within 15 DAP. Excess sprouts were removed at one month after planting after retaining two healthy sprouts. Remaining quantity of chemical fertilizers, half doses of N and K, was applied one month after the application of first dose of fertilizers along with weeding and earthing up on 5 August in all years . During the growing season, the cassava crop was weeded twice at 30 DAP and 60 DAP in all growing seasons.

2.4. Plant, soil and economic measurements

2.4.1. Yield and yield attributes

All plants from the gross plot area were uprooted and harvested manually by pulling out at six months after planting during 16 December 2011, 13 December 2012 and 18 December 2013. The plot wise fresh samples of tubers were collected at the time of harvest and the tuber yield and yield attributes, number of tubers, mean weight of tuber, length and girth of tuber were recorded from the central plants (16 plants).

2.4.2. Soil physical properties

Physical properties of the soil such as bulk density, particle density, water holding capacity and porosity were determined before (22 April 2011) and after the experiment by the core method (Gupta and Dakshinamoorthy, 1980) (15 December 2011, 12 December 2012 and 17 December 2013). Aggregate stability was calculated based on wet sieving technique developed by Yoder (1936).

2.4.3. Soil micro-climate

The soil CO_2 flux, soil temperature, soil moisture and photosynthetically active radiation (PAR) were measured at the grand growth period (4 MAP) of the crop in the second and third years using LI-8100 A Automated Soil CO_2 Flux System. Soil surface CO_2 flux was measured in the space between the mounds of cassava from three random places per plot. Soil temperature and soil moisture were measured using the respective probes at 15 cm depth. PAR was measured at ground level using the quantum sensor designed for the same.

2.4.4. Soil chemical properties

Soils were sampled at 0–15 cm depth initially before the start of the experiment on 22 April 2011 and after harvest of the crop in every year, 17 December 2011, 14 December 2012 and 19 December 2013. The soil samples were air-dried and sieved through 2-mm sieve before analysis.

The soils were analyzed for pH (1:2.5 soil : water suspension), electrical conductivity, organic carbon (Walkley and Black), available N by alkaline permanganate method (Subbiah and Asija, 1956), available P (Bray I), available K (in neutral 1 N ammonium acetate extract), exchangeable Ca and Mg (in neutral 1 N ammonium acetate extract), available Fe, Mn, Zn and Cu (HCl extract) (Sims and Johnson, 1991) by standard procedures (Jackson, 1973).

2.4.5. Soil enzyme activity

The soil samples were collected at the end of the experiment (15 December 2011, 12 December 2012 and 17 December 2013) to assess the activity of soil enzyme dehydrogenase by determination of triphenyl formazan (TPF) production according to Klein et al. (1971). Tetrazolium salts are quaternary NH_4^+salts and, as such, possess a high degree of water solubility. This colourless or pale-coloured tetrazolium salt (tri phenyl tetrazolium chloride (TTC)) possess the property of being easily transformed into intensely coloured, water-insoluble, methanol-soluble formazan by reduction. The apparent redox potential of TTC is about −0.08 V, which makes this compound act as an acceptor for many dehydrogenases. The method is based on extraction with methanol and colorimetric determination of the TPF (tri phenyl formazon) produced from the reduction of TTC in soils.

Of the various methods available for assay of phosphodiesterases (acid phosphatase) activity in soils, the method developed by Tabatabai and Bremner (1969) is the most rapid, accurate and precise. It involves colorimetric estimation of the p-nitrophenol released by phosphodiesterase activity, when the soil is incubated with buffered (at pH 6.5 for acid phosphatase) sodium p-nitrophenyl phosphate solution and toluene. Alkaline phenol has a yellow color, allowing it to be estimated colorimetrically.

Urease activity was determined based on Broadbent et al. (1958).

Table 4

Total nutrient inputs added (kg ha^{-1}).

Production systems	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu
2011									
Traditional	74.50	57.00	177.20	310.00	35.38	28.56	6.58	1.75	0.28
Conventional	162.50	75.00	135.00	10.00	9.38	18.31	0.88	0.50	0.04
Integrated	137.50	75.00	135.00	10.00	9.38	18.31	0.88	0.50	0.04
Organic	212.38	81.22	245.46	332.83	52.78	32.42	9.08	2.09	0.33
Organic (microbial inoculants)	224.55	74.05	127.70	32.71	26.67	22.13	3.36	0.83	0.08
2012									
Traditional	74.50	57.00	177.20	310.00	35.38	28.56	6.58	1.75	0.28
Conventional	162.50	75.00	135.00	10.00	9.38	18.31	0.88	0.50	0.04
Integrated	137.50	75.00	135.00	10.00	9.38	18.31	0.88	0.50	0.04
Organic	202.41	79.17	238.76	331.36	51.38	31.94	8.90	2.06	0.32
Organic (microbial inoculants)	217.63	72.63	123.05	31.69	25.69	21.80	3.24	0.81	0.08
2013									
Traditional	74.50	57.00	177.20	310.00	35.38	28.56	6.58	1.75	0.28
Conventional	162.50	75.00	135.00	10.00	9.38	18.31	0.88	0.50	0.04
Integrated	137.50	75.00	135.00	10.00	9.38	18.31	0.88	0.50	0.04
Organic	211.55	81.05	244.90	332.71	52.67	32.38	9.06	2.08	0.33
Organic (microbial inoculants)	223.17	73.77	126.77	32.51	26.47	22.06	3.34	0.83	0.08

The method is designed for estimation of the rate of urea hydrolysis in soil. It involves colorimetric determination of the urea remaining after incubation of soil with the urea solution at 30 °C for 24 h. The amount of urea hydrolyzed (g $^{-1}$ of soil h $^{-1}$) is estimated from the difference between the initial amount of urea added and that recovered after incubation.

2.4.6. *Microbial population*

Fresh soil samples collected from each plot from the rhizosphere using a shovel before (22 April 2011) and after the investigation (15 December 2011, 12 December 2012 and 17 December 2013) were used for the estimation of the microbial population by serial dilution and plate technique using appropriate medium as proposed by Sherman and Cappuccino (2005). Microbial density in the form of colony forming units per gram soil (CFUg^{-1} soil) of important physiological group of micro organisms, bacteria, fungi and actinomycetes were enumerated.

2.4.7. *Soil quality index*

The soil quality index was computed based on the method by Karlen and Stott (1994) and Singh et al. (2013). The three main steps in this technique include the selection of minimum data set (MDS) of soil quality indicators, scoring of the indicators based on their performance of soil functions and integrating the scores into a comparative indicator of soil quality. For selection of MDS the standardized principal component analysis (PCA) was carried out using the data that showed significance difference among the different production systems. The principal component scores were computed using R environment for statistical computing. From each vector of principal component scores, the variables with high coefficients were selected as a member of MDS. For a particular PC each variable received a weight based on the percentage of variance explained by the PC among the total number of PCs included for computation of the index. In the second step scoring functions were defined for the MDS indicators based on their performance of soil functions. Every observation of the MDS indicators was transformed for all the four treatments using nonlinear scoring functions were the y-axis ranged from 0 to 1 and the x-axis represented the expected range of the indicator variable in the study (Karlen and Stott, 1994). Once transformed, the MDS variables for each observation were weighted using the PCA weighing factor and summed in the third step to get the soil quality index (SQI) as follows:

$$\mathrm{SQI} = \Sigma WixSi$$

Where, W_i is the weighing factor derived from PCA and S_i is the transformed scores for attributes.

2.4.8. *Energetic aspects*

The energy equivalents of inputs used in the production of cassava like planting material, farmyard manure, ash, green manure, crop residue, microbial inoculants, nutrient inputs in form of N, P and K, labor, mechanical tractor, rotovator, diesel and output energy related to tuber yield were estimated according to Devasenapathy et al. (2009). The net energy was calculated using the equation proposed by Bamgboye and Kosemani (2015). Based on the energy equivalents of the inputs and the output, the energy ratio/energy use efficiency (EUE) and energy productivity were calculated using the equations used by Mandal et al. (2002) and Singh et al. (1997) as follows:

$$\mathrm{Net}energy = Energy\,output\left(MJha^{-1}\right) - energy\,input\left(MJha^{-1}\right)$$

$$\mathrm{EUE} = \frac{\mathrm{Output\,energy}\left(\mathrm{MJha}^{-1}\right)}{\mathrm{Input\,energy}\left(\mathrm{MJha}^{-1}\right)}$$

$$\mathrm{Energy}productivity = \frac{\mathrm{Output}\,\left(\mathrm{kgha}^{-1}\right)}{\mathrm{Input\,energy}\left(\mathrm{MJha}^{-1}\right)}$$

2.4.9. *Economic aspects of cultivation*

Total cost of cultivation and gross returns were calculated from the average input cost and average market price of the produce during the period of investigation. The net return and benefit cost ratio (B:C ratio) were computed from these:

Net return = Gross income (US \$ ha^{-1}) – cost of cultivation (US \$ ha^{-1})

Benefit: cost ratio = Gross income (US \$ ha^{-1}) / Cost of cultivation (US \$ ha^{-1})

2.5. *Statistical analysis*

The experimental data were analysed statistically using SAS (2010) by applying the technique of analysis of variance (ANOVA) for split plot design. Wherever significant differences between treatments were detected through ANOVA, critical differences (CD) at 5% level of significance are provided for effective comparison of means. ANOVA for the comparison of the soil quality in different production systems were carried out and the significant differences are shown with different letter alphabets in the bar diagram. Standard error bars are provided in diagrams.

3. Results

3.1. *Tuber yield*

Tuber yield was significantly influenced by the various production systems ($p = 0.002$) in the second year and pooled analysis ($p = 0.0014$) (Table 5). In the second year, organic farming (without microbial inoculants) produced higher yield (+6.5%), over conventional practice (29.24 t ha^{-1} and 27.45 t ha^{-1} respectively). Integrated management produced lowest yield (21.81 t ha^{-1}) statistically similar to traditional management (22.09 t ha^{-1}). In the pooled analysis, higher tuber yield was obtained under organic practice without microbial inoculants (27.26 t ha^{-1}), which was similar to conventional (26.62 t ha^{-1}) and organic practice with microbial inoculants)(26.19 t ha^{-1}).

Variety x production system interaction effects was significant ($p = 0.021$) only during the second year (Fig. 1). However, H-165, the industrial variety as well as Sree Vijaya and Vellayani Hraswa, the domestic varieties of cassava performed similarly under both systems. However, H-165, the industrial variety of cassava, yielded higher by 47.45% under organic (without microbial inoculants) (28.06 t ha^{-1}) over conventional management (19.03 t ha^{-1}). Sree Vijaya yielded higher (+7.78%) under conventional practice (37.68 t ha^{-1}) and remained on par with organic (without microbial inoculants) (34.96 t ha^{-1}). Vellayani Hraswa performed almost equally in organic (without microbial inoculants) (24.71 t ha^{-1}) as well as conventional system (25.63 t ha^{-1}). In all the systems, except organic (with and without microbial inoculants), H-165 was inferior. Likewise, Vellayani Hraswa

Table 5
Tuber yield of cassava as influenced by treatments.

Treatments	Yield (t ha^{-1})			
	2011	2012	2013	Average
Varieties				
H-165	30.10	21.93	20.54	24.86
Sree Vijaya	26.50	32.40	25.29	28.08
Vellayani Hraswa	22.50	21.30	22.51	21.44
CD (0.05)	NS	NS	NS	NS
Production systems				
Traditional	23.30	22.09^{b}	21.41	22.26^{bc}
Conventional	26.90	27.45^{a}	25.52	26.62^{a}
Integrated	25.20	21.81^{b}	17.94	21.64^{c}
Organic	29.40	29.24^{a}	23.15	27.26^{a}
Organic (with microbial inoculants)	27.20	25.45^{ab}	25.89	26.19^{ab}
CD (0.05)	NS	3.985	NS	4.242

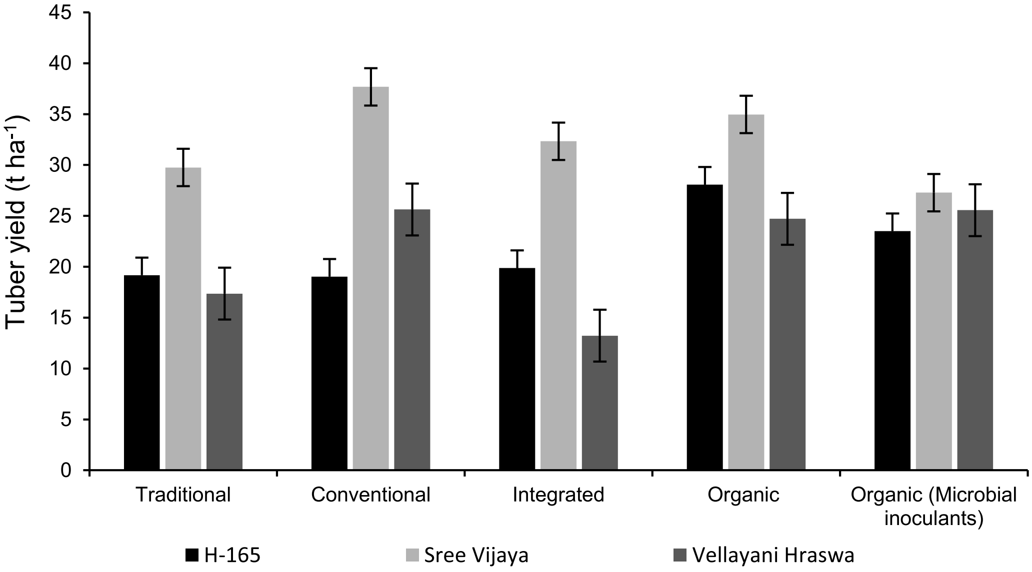

Fig. 1. Tuber yield of cassava varieties under different production systems during 2012.

proved inferior under integrated and traditional systems. Sree Vijaya under conventional management was the most productive (37.68 t ha^{-1}) and Vellayani Hraswa in integrated management was the least productive (13.23 t ha^{-1}). Averaging over three years, the varieties behaved similarly under the different production systems due to the lack of significant effect of varieties x production system interaction.

3.2. Soil physical indicators

The physical properties of the soil, bulk density (1.53–1.66 Mg m^{-3}), particle density (2.29–2.39 Mg m^{-3}) and water holding capacity (16.18–19.14%) remained unaltered under the influence of the various production systems. However, porosity was significantly higher (p = 0.0185) in organic (without microbial inoculants) plots (35.18%). Aggregate stability, which is the most important determinant of soil quality, was enhanced by 24.67% (p = 0.0471) under organic management (with microbial inoculants) over conventional practice (Fig. 2).

3.3. Soil micro-climate

The micro-environment properties like soil CO_2, soil moisture and PAR were insignificantly favoured in the organic (either of the two) or integrated practices (Table 6). The soil temperature was significantly higher (p = 0.003) under integrated practice, followed by the organic practice with microbial inoculants.

3.4. Soil pH, organic C, EC and CEC

In general, the production systems imparted significant effect on soil pH, organic C and CEC. Soil pH (p = 0.002, p = 0.001) and organic C (,p = 0.003, p = 0.001) were significantly influenced by the production systems in the last two years. Higher soil pH was noticed under organic (with or without microbial inoculants) treatments, which was statistically similar to the traditional system in the last two years. The soil pH under organic (without and with microbial inoculants) treatments was higher by 1.06 and 1.15 units over conventional practice during the above periods. This increase was +1.48 units compared to initial pH in

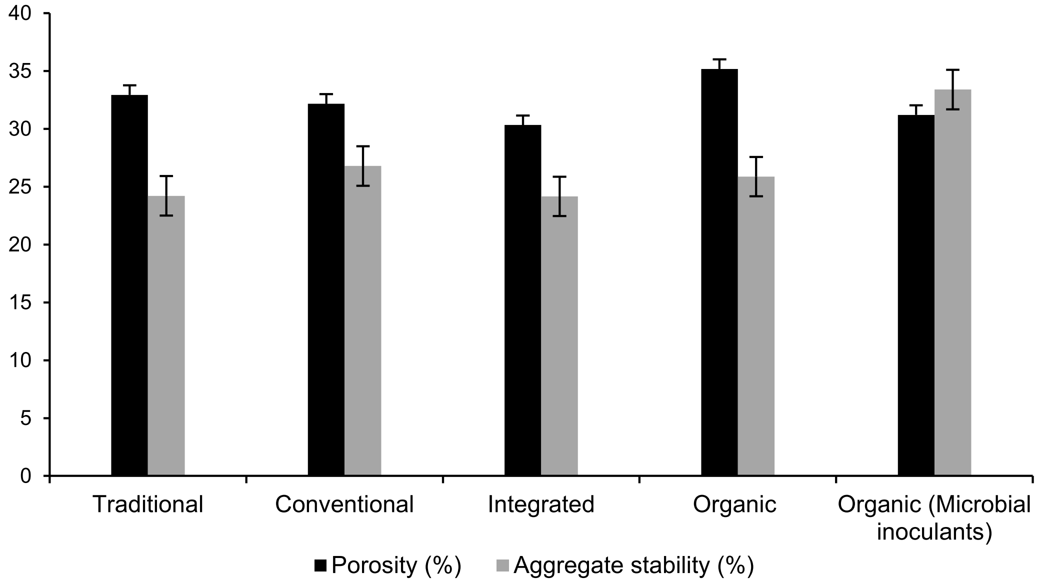

Fig. 2. Porosity and aggregate stability of the soil as influenced by the different production systems.

Table 6
Micro-climate of the soil as affected by production systems at the grand growth period.

Production systems	Soil CO_2 flux (μmol m $^{-2}$ s $^{-1}$)		Soil moisture (m^3 m $^{-3}$)		PAR (μmol m $^{-2}$ s $^{-1}$)		Soil temperature (°C)
	2012	2013	2012	2013	2012	2013	2012
Traditional	1.70	1.48	−0.055	0.060	685	789	30.87^{b}
Conventional	1.64	1.47	0.027	0.050	899	588	31.55^{b}
Integrated	1.50	1.53	−0.012	0.050	1135	619	38.29^{a}
Organic	1.43	1.11	0.012	0.060	791	640	31.19^{b}
Organic (with microbial inoculants)	1.71	1.62	0.029	0.060	1066	583	33.74^{b}
CD (0.05)	NS	NS	NS	NS	NS	NS	3.555

organic (with microbial inoculants) plots (4.79), while it was only +0.33 unit in conventional plots at the end of three years of cropping. In the second year, organic C content was higher under both the organic treatments (1.32% and 1.22% respectively), which was statistically similar to the conventional system (Table 7). Organic C content under organic practice with microbial inoculants was higher by 9% over conventional system. In the third year, both the organic treatments resulted in significantly higher organic C contents (1.52% and 1.47%). The conventional plots exhibited significantly ($p = 0.001$) lowest organic C content (1.24%). Thus after three years, organic (with microbial inoculants) enhanced soil organic C status by 22.58% over conventional plots. When compared to the organic C status before the start of trial (1.01%), it was enhanced by 50.49% in organic (with microbial inoculants) plots vs 22.77% in the conventional plots. The EC did not vary significantly due to the production systems. The CEC was significantly higher ($p = 0.0003$) under both the organic practices (12.58 cmol kg^{-1} and 11.48 cmol kg^{-1}). The CEC of the soil in organic plots was 27.32% higher over the conventional plots (9.88 cmol kg^{-1}) (Table 7).

3.5. Available N, P and K status of soil

Significant difference was not observed in the status of available major nutrients among the production systems during 2011, 2012 and 2013. In all the treatments, available N was generally low and available P and K was high in all the years. At the end of 2011, insignificant improvement in the available N content was noticed under organic practice (without microbial inoculants) (328 kg ha^{-1}) (Table 8). During 2012 and 2013, conventional plots showed slight improvement in the available N status. Available P and K contents were slightly higher in the conventional plots at the end of the first year, organic plots in the second year and traditional plots in the third year. Even though the available P status was slightly higher under conventional plots in the first year, a 10% increment in the available P status of the soil under organic treatment was observed over conventional system in the last two years. Available K content was improved by 16% in the second year and 30% in the third year under organic (without microbial inoculants) treatment over conventional treatment.

3.6. Secondary and micro nutrient status of soil

After the first and second years, the secondary nutrient status was not significantly influenced (Table 9). By the end of the third year, exchangeable Ca was higher and statistically similar under organic (without microbial inoculants) and traditional systems, which in turn was significantly ($p = 0.004$) superior over conventional system.

Among the micro nutrients, the status of Mn alone was significantly affected by all production systems in the second year ($p = 0.025$) (Table 10). Conventional practice resulted in higher Mn content in the second year (50.10 mg kg^{-1}), which was statistically similar to traditional (43.80 mg kg^{-1}) and organic (without microbial inoculants) practices (38.40 mg kg^{-1}). The Fe content was slightly favoured under organic (with microbial inoculants) over conventional system throughout the experimentation. However, the content of available Zn was marginally improved under organic (with microbial inoculants) in the first year and under traditional practice in the subsequent years. Thus three years of organic management considerably improved the exchangeable Ca (+29.10%), Mg (+32.00%), available Fe (+19.08%) and Zn status over conventional practice (+27.17%) in an Ultisol under cassava.

3.7. Soil enzyme activity

Soil enzyme activity was affected significantly by the production systems ($p = 0.001$) (Table 11). The activity of dehydrogenase was significantly the highest under the organic (with microbial inoculants) treatment (15.13 μg TPF g $^{-1}$ h $^{-1}$). The acid phosphatase activity (512.7 μg p-nitro phenol g $^{-1}$ h $^{-1}$) was significantly higher under both the organic treatments. The urease activity was higher and similar under all the production systems, except conventional system. Significantly lowest activity of acid phosphatase and urease were observed under conventional practice.

Variety x production system interactions was significant ($p = 0.001$) for the activity of dehydrogenase and acid phosphatase. H-165 and Vellayani Hraswa under organic (microbial inoculants) practice significantly enhanced the activity of dehydrogenase (Fig. 3). Acid phosphatase activity was significantly higher under H-165 grown under both the organic practices and Sree Vijaya and Vellayani Hraswa under organic, integrated and organic (microbial inoculants) practices (Fig. 4).

3.8. Soil microbial population

The microbial population was significantly ($p = 0.0001$) influenced by the production systems in the first year, where the population of bacteria was significantly higher in the integrated (2.1×10^9cfu g $^{-1}$) followed by organic production systems, where microbial inoculants

Table 7
Major chemical properties of the soil as influenced by production systems.

Production systems	pH			Organic C (%)			EC (dS m $^{-1}$)		CEC (cmol kg^{-1})
	2011	2012	2013	2011	2012	2013	2011	2013	2013
Traditional	5.81	5.61^{ab}	5.67^{ab}	1.20	0.93^{c}	1.34^{b}	0.246	0.120	10.79^{bc}
Conventional	5.55	4.80^{c}	5.12^{bc}	1.09	1.21^{ab}	1.24^{c}	0.241	0.080	9.88^{cd}
Integrated	5.82	4.97^{bc}	4.95^{c}	1.13	0.91^{c}	1.31^{bc}	0.226	0.080	9.02^{d}
Organic	5.90	5.86^{a}	6.23^{a}	1.21	1.22^{ab}	1.47^{a}	0.254	0.110	12.58^{a}
Organic (microbial inoculants)	5.57	5.32^{b}	6.27^{a}	1.04	1.32^{a}	1.52^{a}	0.204	0.100	11.48^{ab}
CD (0.05)	NS	0.500	0.670	NS	0.301	0.108	NS	NS	1.190

Table 8
Available N, P and K status of the soil as influenced by production systems.

Production systems	Available N (kg ha^{-1})			Available P (kg ha^{-1})			Available K (kg ha^{-1})		
	2011	2012	2013	2011	2012	2013	2011	2012	2013
Traditional	280	100	282	166	280	309	266	398	353
Conventional	290	147	290	173	319	279	321	395	210
Integrated	242	123	280	163	277	263	266	384	234
Organic	328	125	282	172	354	307	309	458	273
Organic (microbial inoculants)	236	139	267	164	297	287	237	318	139
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 9
Secondary nutrient status of the soil as affected by production systems.

Production systems	Exchangeable Ca (cmol kg^{-1})			Exchangeable Mg (cmol kg^{-1})		
	2011	2012	2013	2011	2012	2013
Traditional	1.78	2.75	2.66^{a}	0.590	1.89	0.630
Conventional	1.31	1.90	2.13^{b}	0.510	1.69	0.500
Integrated	1.46	1.52	2.20^{b}	0.490	1.50	0.540
Organic	1.71	2.05	2.75^{a}	0.640	1.98	0.660
Organic (microbial inoculants)	1.25	2.50	2.22^{b}	0.470	1.44	0.570
CD (0.05)	NS	NS	0.39	NS	NS	NS

(1.27×10^{9} cfu g^{-1}) were used (Table 12). The count of fungi and actinomycetes did not vary significantly under the influence of the production systems throughout the period of investigation. However, the organic (microbial inoculants) production system had higher count of fungi over conventional practice by 34% in the first year, 28% in the second year and 117% in the third year. The count of actinomycetes was appreciably higher in the integrated and organic (microbial inoculants) production systems. On the whole, the microbial population was appreciably higher in all the production systems other than conventional system, where chemicals were not used or minimally used.

3.9. *Soil quality index*

The standardized PCA analysis extracted three principal components which explains a cumulative variance of 77% selected for constructing the index. The PC1 to PC3 had a relative contribution of 53, 31 and 15 percent respectively, which has been taken as the weighing factors for the indicators explained by each PCs (Table 13). Under PC1, pH, SOM and acid phosphatase were the three highest weighted variables with the factor loadings of 0.521248, 0.4565 and 0.462303 respectively. Exchangeable Ca and dehydrogenase enzyme were the highest weighted variables (factor loadings, 0.52735 and 0.64418 respectively) under PC2. Under PC3, porosity was the highest weighted variable with the factor loading of 0.793939. Soil pH had higher correlation with the other factors, SOM and acid phosphatase, under PC1. After examining the highly weighted variables under each PCs and the correlation among the highly weighted indicator variables, the retained indicator variables includes pH from PC1, exchangeable Ca and dehydrogenase enzyme from PC2 and porosity from PC3.

The SQI was computed using the weighing factors using the formula

$$SQI = 0.539 \times (S_{pH}) + 0.311 \times (S_{Ca} + S_{Dehydrogenase}) + 0.150 \times (S_{porosity})$$

where S_i is the transformed scores of the attribute value as given in methodology. Finally SQI rating for the different production systems were analysed using ANOVA and the result is presented in Fig. 5. Among the production systems, the organic practices (with and without microbial inoculants) scored higher SQI of 0.98 (T_4) and 0.94 (T_5), which were statistically similar. The SQI of the traditional system (0.62) was statistically similar to integrated system (0.55). Soil quality index of conventional system was lower (0.48), which was statistically similar to integrated system.

3.10. *Energetic analysis*

Based on the average yield of three years, the energy budget of the various production systems was determined (Table 14). The energy balance was positive for all the production systems. The organic management proved to be the most energy efficient as revealed from the highest energy output, net energy, energy use efficiency and energy productivity. On the contrary, the energy output of the integrated, traditional and conventional systems was lower. The energy input of the systems, where there was the non-use of chemicals ie, traditional and organic (with and without microbial inoculants) was lower. This was ultimately reflected in the energy productivity of the organic systems, which computed the highest energy productivity values of 3.00 and 2.90 kg MJ^{-1}respectively. The conventional system, which advocated the use of chemical fertilizers incurred the highest energy input and

Table 11
Enzyme activity of the soil as affected by production systems at the end of 2013 .

Production systems	Dehydrogenase (µg TPF g^{-1} h^{-1})	Acid phosphatase (µg p-nitro phenol g^{-1} h^{-1})	Urease (µg g^{-1} h^{-1})
Traditional	9.14^{b}	448.30^{d}	53.22^{a}
Conventional	12.93^{b}	426.20^{e}	47.14^{b}
Integrated	11.96^{c}	490.80^{c}	52.73^{a}
Organic	12.70^{b}	508.31^{a}	55.05^{a}
Organic (with microbial inoculants)	15.13^{a}	512.70^{a}	52.16^{a}
CD (0.05)	0.459	13.590	3.767

Table 10
Micro nutrient status of the soil as affected by production systems.

Production systems	Fe (mg kg^{-1})			Mn (mg kg^{-1})			Zn (mg kg^{-1})			Cu (mg kg^{-1})		
	2011	2012	2013	2011	2012	2013	2011	2012	2013	2011	2012	2013
Traditional	14.52	17.18	31.37	20.71	43.80^{ab}	29.64	4.11	3.18	5.30	0.869	0.700	1.68
Conventional	16.60	14.60	29.65	21.27	50.10^{a}	31.16	4.10	2.67	3.57	0.767	0.780	1.75
Integrated	13.66	15.76	31.50	22.38	35.10^{bc}	26.57	3.77	2.03	3.14	0.712	0.880	0.690
Organic	18.43	15.48	29.69	19.48	38.40^{abc}	32.27	4.02	2.49	4.54	0.709	1.09	0.960
Organic (microbial inoculants)	19.41	20.26	35.31	21.23	29.20^{c}	28.12	4.47	1.66	3.30	0.830	0.890	0.670
CD (0.05)	NS	NS	NS	NS	11.83	NS	NS	NS	NS	NS	NS	NS

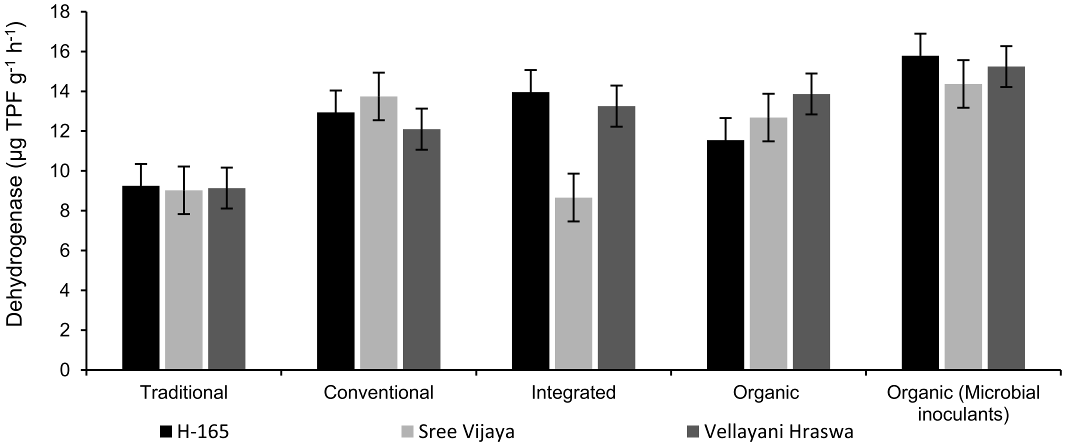

Fig. 3. Dehydrogenase activity as affected by variety x production system interaction.

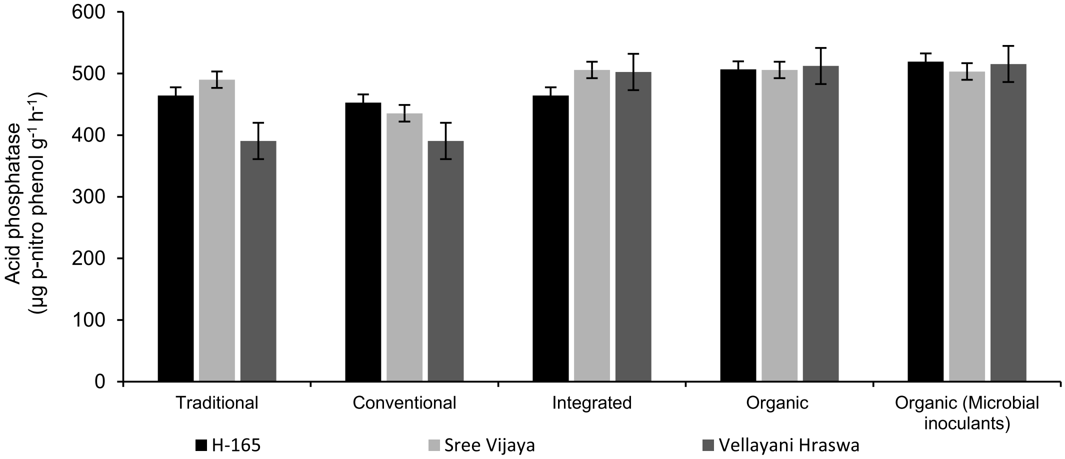

Fig. 4. Acid phosphatase activity as affected by variety x production system interaction.

Table 12
Microbial population of the soil as affected by production systems.

Production systems	Bacteria (cfu g^{-1} soil)			Fungi (cfu g^{-1} soil)			Actinomycetes (cfu g^{-1} soil)		
	2011	2012	2013	2011	2012	2013	2011	2012	2013
Traditional	2.67×10^{7c}	5.50×10^{6}	4.33×10^{6}	4.03×10^{5}	6.17×10^{4}	14.33×10^{4}	1.90×10^{5}	7.50×10^{5}	2.11×10^{5}
Conventional	2.19×10^{7c}	2.50×10^{6}	3.11×10^{6}	5.23×10^{5}	4.83×10^{4}	9.66×10^{4}	9.00×10^{4}	6.00×10^{5}	2.77×10^{5}
Integrated	2.10×10^{9a}	4.00×10^{6}	5.55×10^{6}	4.17×10^{5}	6.67×10^{4}	12.33×10^{4}	3.10×10^{5}	5.67×10^{5}	2.88×10^{5}
Organic	6.31×10^{7c}	4.17×10^{6}	6.11×10^{6}	4.15×10^{5}	6.17×10^{4}	20.33×10^{4}	1.70×10^{5}	5.67×10^{5}	4.44×10^{5}
Organic (microbial inoculants)	1.27×10^{9b}	3.3310^{6}	5.55×10^{6}	7.0×10^{5}	6.17×10^{4}	21.00×10^{4}	2.10×10^{5}	6.67×10^{5}	3.88×10^{5}
CD (0.05)	5.01×10^{8}	NS	NS	NS	NS	NS	NS	NS	NS

hence the lowest energy productivity.

3.11. Economic analysis

Averaging over the three years, the production systems significantly influenced the net income. Of the various production systems tested, organic system generated the highest net income (US \$ 4977.57 ha^{-1}) statistically similar to conventional (US \$ 4833.10 ha^{-1}) and organic with microbial inoculants (US \$ 4720.69 ha^{-1}) (Table 15). The B:C ratio of organic (3.84) was the highest, closely followed by the conventional practice (3.77). The integrated system resulted in the lowest net income (US \$ 3626.40 ha^{-1}) and B:C ratio (3.11) on par with the traditional practice (net income US \$ 3870.23 ha^{-1} and B:C ratio 3.38).

Table 13
The first three Principal Component Analysis scores and their relative contributions.

Attributes	PC1	PC2	PC3
Porosity	0.220612	0.403889	**0.793939**
pH	**0.521248**	−0.09674	0.001547
SOM	**0.4565**	−0.16591	0.195427
Exchangeable Ca	0.254504	**0.52735**	−0.10976
Urease	0.421058	0.222518	−0.5067
Acid phosphatase	**0.462303**	−0.2396	−0.11189
Dehydrogenase	0.12431	**−0.64418**	0.22396
Eigen value	2.930823	1.692826	0.815077
Proportion of variance explained	0.4187	0.2418	0.1164
Cumulative	0.4187	0.6605	0.777
Factor loading	**0.538937**	**0.311237**	**0.149826**

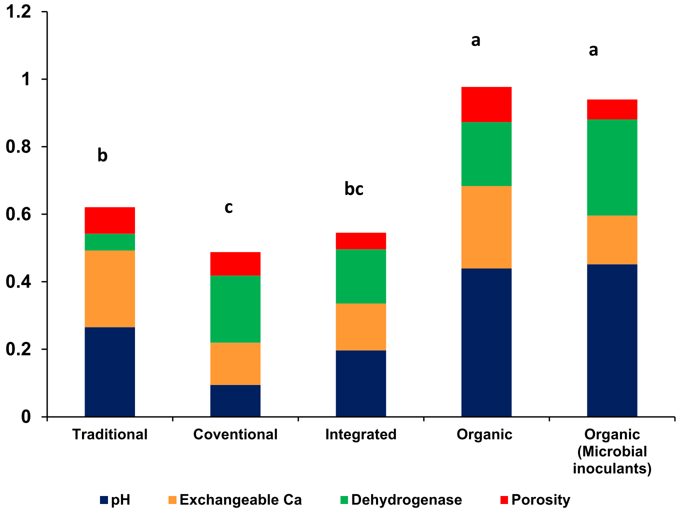

Fig. 5. Effect of production systems on soil quality index.

Table 14
Energetic parameters of the production systems (average of three years).

Production systems	Energy output (*10^3MJ ha^{-1})	Energy input (*10^3MJ ha^{-1})	Net energy (*10^3MJ ha^{-1})	Energy use efficiency	Energy productivity (kg MJ^{-1})
Traditional	124.65	8.65	116.00	14.41	2.57
Conventional	149.08	15.83	133.25	9.42	1.68
Integrated	121.19	12.58	108.61	9.63	1.72
Organic	152.63	9.08	143.55	16.80	3.00
Organic (with microbial inoculants)	146.64	9.02	137.62	16.26	2.90

Table 15
Economic analysis of the production systems (average of three years).

Production systems	Gross income (US $ ha^{-1})	Gross costs (US $ ha^{-1})	Net income (US $ ha^{-1})	B:C ratio
Traditional	5498.48	1628.24	3870.23	3.38
Conventional	6575.89	1742.79	4833.10	3.77
Integrated	5345.67	1719.28	3626.40	3.11
Organic	6732.61	1755.04	4977.57	3.84
Organic (with microbial inoculants)	6468.32	1747.63	4720.69	3.70

Planting material: 60 US $ ha^{-1}; Farmyard manure: 154.38 US $ ha^{-1}; Chemical fertilizers: N 0.26 US $ kg^{-1}, P 0.68 US $ kg^{-1}, K 0.46 US $ kg^{-}1; Microbial inoculants: 0.49 US $ kg^{-1}; Green manure seeds: 19.80 US $ ha^{-1}; Labour cost: Per worker per day 8.23 US $; Worker days: 170 (Traditional); 175 (Conventional); 175 (Integrated); 183 (Organic); 185 (Organic with microbial inoculants); Price of tubers: 250 US $ t^{-1}.

4. Discussion

4.1. Tuber yield

The study has added new information that on an average, organic management (without microbial inoculants) performed better than all the existing management options and enhanced yield by 2.40% over conventional practice, 25.97% over integrated practice and 22.46% over traditional practice. Higher yield under organic farming has been reported earlier in other tropical tuber crops (Suja et al., 2012; Suja, 2013; Suja and Sreekumar, 2014). Tuber yield under organic management was 76% of conventional in validation trials of cassava intercropped in coconut plantation in northern Kerala (Suja et al., 2020). However in another set of on-farm validation trials under intercropping in coconut gardens in southern Kerala, cassava yield in organic was 13% higher over conventional (Byju et al., 2021). The higher yield under organic system in cassava may be due to the overall improvement in soil physico-chemical and biological properties under the influence of organic manures (Stockdale et al., 2001).

Interestingly, the yield increase of 2.40% observed in the present study under organic management is contrary to the majority of reports that arable crop yields under organic management were 20–40% lower than for comparable conventional systems (Ponti et al., 2012; Seufert and Ramankutty, 2017).

The variety x production system effect was significant only during the second year. However, the industrial as well as domestic varieties of cassava performed similarly under both systems indicating their similar performance under organic vs conventional management.

The major bottleneck faced by organic growers is the lack of varieties evolved for organic management and/or non-identification of locally adapted crop varieties that can thrive under organic management conditions (Maddox, 2015). Experimental evidence on the adaptation of varieties developed for chemical intensive system to organic management is meager (Fagnano et al., 2012). Hence the present study demonstrates the adaptability of certain cassava varieties orginally bred for a chemical system, to organic management also. It will be useful for the promotion of organic cassava farming even with those existing varieties.

It is reported that yields in organic farming were directly related to the quantity of chemical inputs used for farming in the prevailing conventional system before conversion (Ramesh et al., 2010). This means that in areas of intensive chemical farming turning to organic agriculture would decrease yield as the intensity of external input use before conversion was high (Stockdale et al., 2001).

4.2. Soil physical indicators

At the end of three years of experimentation, there was insignificant lowering of bulk density (−1.83%), significantly higher porosity (+9.36%) and improvement in water holding capacity (+11.47%) and aggregate stability (+25%) of the soil under organic management as compared to conventional system in cassava (Fig. 2). The higher organic C status in organic plots in the present study might have resulted in the formation of stable soil aggregates leading to slight decrease in bulk density and increase in porosity and water holding capacity. This result conforms to the reports of Colla et al. (2000) that even a modest increase in soil organic matter content may help to explain the observed differences in water holding capacity. Though it is well established that measurable changes in soil physical properties may take decades to establish (Stockdale et al., 2001), the data generated from the current research underscores the importance of organic farming in soil health maintenance.

4.3. Micro-climate

The soil temperature was significantly higher under integrated practice, followed by organic (with microbial inoculants) due to higher microbial activity consequent to the application of microbial fertilizers in these practices. The soil CO_2 flux remained unaffected by production systems, though a slightly higher value was observed under organic practice (with microbial inoculants) over conventional system. This may be due to the higher respiration rate as a result of enhanced microbial activity and root metabolism. The warming of the soil also probably enhanced the soil CO_2 efflux due to enhanced microbial activity. Similar results of higher soil CO_2 emissions under alternative soil management practices involving organic amendments was reported by Montanaro et al. (2012). The soil moisture was insignificantly promoted under organic management (with or without microbial inoculants). Our results agree with the findings of Tang et al. (2005) that luxuriant crop canopy under organic management increased the photosynthesis, which in turn led to higher soil respiration, soil temperature and moisture.

4.4. Soil chemical indicators

Higher soil pH was noticed in those treatments that advocated the non-use of synthetic fertilizers viz., organic (with or without microbial inoculants) treatments, which was on par with the traditional system in the last two years of study. Thus there was an increasing trend in pH with progressing years in the strictly organic with or without microbial inoculants and traditional plots. Significant increase in soil pH with time under organic farming system reflects the importance of organic manure and other organic inputs in buffering the soil (Zulkefli et al., 2011). Continuous use of synthetic fertilizers, especially urea, in the conventional and integrated plots, might have led to a drop in pH by year 2 and 3.

It has been well established by Tisdale et al. (1993) that lasting changes in soil pH occurred largely due to displacing cations or addition of sources of acidity such as H^+ and Al^{3+} on the exchange complex of soils. In the present study, significantly higher pH nearing neutrality under organic management was apparent due to the non-use of NH_4 fertilizers (Barak et al., 1997) and addition of organic manures especially, green manure cowpea and crop residue of cassava. Adding cowpea green manure and cassava crop residue in the organic system may provide extra cations possibly from lower soil depths, which are released at the soil surface through leaching and decomposition of nutrients. The observed increase in soil pH in organically managed soil might also be attributed to decrease in the activity of exchangeable Al^{3+}ions in soil solution due to chelation by organic molecules and self-liming effect of the soil due to Ca content in farmyard manure (0.08%), green manure (0.41%), and ash (15%) under organic management (Prabhakaran and Pitchai, 2002; Prakash et al., 2002; Suja et al., 2017; Seena Radhakrishnan and Suja, 2019).

Moreover, the organic reducing substances formed during decomposition of green manure may reduce Fe and Mn oxides causing soil pH to rise because protons are consumed in the course of the reduction of oxides. Increased soil pH may also result through mineralisation of organic anions to CO_2 and water thereby removing H^+ (Singh et al., 1992).

Over the years of study there was an increasing trend in organic C in the two types of organic treatments. Higher organic C status of organic plots might be attributed to considerable addition of organic manures particularly green manure cowpea and crop residue of cassava. However, in the traditional, integrated and conventional plots there was a drop by the second year, and resurgence by third year. The second year of study was the driest (with total rainfall during the second year crop cycle of 996 mm as against 1094 mm in the first year and 1285 mm in the third year), and hence the soil organic C could not be replenished much from the fallen cassava leaves in these treatments during the second year.

The CEC of the soil in organic plots was 27.32% higher over the conventional plots, which can be attributed to the direct addition of cations from the various organic manures, especially green manure cowpea and cassava crop residue. Soil CEC, sum of the exchangeable cations in soil, is important because it represents the primary soil reservoir of available K, Ca, Mg, Na and several micronutrients. Most of the variations in soil CEC are closely related to soil organic C. The observed increase in soil organic C might have contributed to higher soil CEC as well.

A slight initial improvement in the available N content was noticed under organic practice, which was quite unexpected. Later on conventional practice involving chemical fertilizers led to higher available N status due to rapid release of available N from the added chemical fertilizers when compared to organic manures. There was a huge drop in available N in the second year in all plots due to insufficient mineralization on account of low quantum of rainfall obtained in the second year as discussed earlier. It can also be inferred that the effect of mineralization was more conspicuous in alternate years under the influence of adequate rainfall. The temporal trend of available P was similar in all the treatments and not a matter of concern. There was a progressive increase in available K in all the plots up to the end of second year, with highest status in the organic plot. By the end of the third year there was a steep fall in all treatments, which might be due to high K requirement of a tuber crop like cassava. Available P and K status were favoured by 10 and 30% respectively under organic management. Increase in soil organic matter, soil pH, available P and K have been observed in some organic systems (Scow et al., 1994; Clark et al., 1998).

The high exchangeable Ca status at the initiation of experimentation fell sharply by the end of first crop due to substantial crop uptake. Thereafter it was seen progressively maintained almost similar to the initial level by the end of third year. In the case of exchangeable Mg, the sharp increase observed by the end of second year was significantly reduced in the third year probably due to substantial loss by crop removal and leaching due to high rainfall in the third year (1285.1 mm).

However there was considerable improvement in the exchangeable Ca, Mg, available Fe and Zn status under organic management in the present study solely due to the substantial contribution of all essential major, secondary and micro nutrients, especially, Ca, Mg, Fe, Mn, Zn and Cu contained in the organic manures viz., FYM, green manure cowpea, crop residue of cassava and ash used under organic management, while the chemical fertilizers are only sources of major nutrients.

4.5. Soil enzyme activity

In the present study, the activity of dehydrogenase, acid phosphatase and urease enzymes under organic, especially organic (with microbial inoculants) treatment, was higher by 17.01%, 20.29% and 16.78% over conventional system. Higher enzyme activity under organic management in cassava was promoted due to greater biological/microbial activity under the impact of large C additions from the organic resources, especially green manure cowpea and cassava crop residue and non-use of chemical inputs.

4.6. Soil microbial population

In this experiment, the organic manures, farmyard manure, green manure, crop residue and ash, were used to substitute chemical fertilizers. Of these, the most important component was green manuring with cowpea (incorporation of 10–12 t ha^{-1} of green matter) and crop residues of cassava (fresh biomass of 7 t ha^{-1}). The decomposition of these organic manures for release of plant available nutrients involves microbial activity to a greater extent than that in chemical fertilizer applied conventional plots, which might have contributed to higher microbial population in the organic/integrated plots, where there was practically no use or minimal use of chemical inputs. The study supports the benefit of organic farming in improving the soil biological activity and thereby soil quality.

4.7. Soil quality index

Among the production systems, the organic practices (with and without microbial inoculants) scored higher SQI in this study. The SQI was governed by pH, exchangeable Ca, dehydrogenase enzyme activity and porosity. In the present study, organic farming, which is a supplemental C management practice (SCMP) significantly changed a number of soil properties including soil pH, organic C, porosity, CEC, exchangeable Ca, dehydrogenase, acid phosphatase and urease activity. Thus the indicator properties could be changed mainly through soil organic matter building practices brought about by the sole use of organic manures, especially green manuring and crop residue incorporation continuously for three years under organic management. This framework emphasizes that soil quality assessment is a tool that can be used to evaluate the effects of land management on soil function.

4.8. *Energetic analysis*

Though the energy balance was positive for all the production systems, organic management proved to be the most energy efficient as revealed from the highest energy output, net energy, energy use efficiency and energy productivity. This is certainly due to lower energy input by avoiding synthetic fertilizers and higher energy output on account of slightly higher tuber yield in the organic practice. The energy input in the organic practice was lower by 42.62% when compared to conventional practice; whereas the energy output was slightly higher by 2.38%. Titonell (2013) reported that since the onset of the green revolution, energy inputs in agriculture increased 50 times compared to traditional agriculture due to the use of high-energy chemical inputs. More than 30% of the energy input in agriculture is used in the manufacture of chemical fertilizers, 19% for the operation of field machinery and 16% for transport. On average, energy use by organic agriculture is about one third as compared to conventional agriculture due to higher efficiency in biological N fixation.

The use of organic manures, especially green manure cowpea and cassava crop residue in organic cassava production helped greatly to offset the yield reduction in the absence of easily and rapidly available nutrient sources, “the chemical fertilizers”. This ultimately led to higher efficiency of nutrients, precisely, by way of biological N fixation through green manuring, curbing the energy use and enhancing the energy use efficiency.

4.9. *Economic analysis*

Due to higher yield, the organic system generated the highest net income, though on par with conventional and organic (with microbial inoculants). This trend of higher yield was also reflected in the interaction, with the varieties performing comparatively better under organic management with higher net returns and B:C ratio. Amongst these, the domestic and short-duration variety, Sree Vijaya raised under organic system proved to be the most profitable, generating the highest net income, B:C ratio and added profit on account of higher productivity. The integrated practice resulted in lowest net returns. These calculations were made without inputting premium price for the organic produce. Higher premium price for the organic produce, in addition to lower costs will help to compensate for reduced yields and result in similar or higher gross margins for organic crops than conventional produce (Stockdale et al., 2001).

5. Conclusions

The three year study indicates that organic farming produced higher tuber yield (+2.4%) over conventional practice in cassava. The physico-chemical-biological properties and microbial count of soil, activity of soil enzymes like urease, acid phosphatase and dehydrogenase, soil micro-climate parameters, soil temperature and soil CO_2 flux were all improved under organic farming, which ultimately led to higher SQI (0.98). The SQI was driven by pH (+1.15 unit), exchangeable Ca (+29.10%), dehydrogenase enzyme activity (+17.01%) and porosity (+9.36%), which were all higher in organic plots. Organic management was found to be the most energy efficient production system with the highest energy output, net energy, energy use efficiency and energy productivity and Sree Vijaya was the most productive and profitable cassava variety under organic farming. Hence organic farming of cassava involving farmyard manure, green manure, crop residue and biofertilizers can be recommended for higher productivity, sustainability, soil quality and better income.

CRediT authorship contribution statement

A.R. Seena Radhakrishnan: Investigation, Validation, Formal analysis, Data curation, Visualization, Writing – original draft. **G. Suja:** Conceptualization, Methodology, Resources, Writing – review & editing, Supervision, Project administration, Funding acquisition. **J. Sreekumar:** Software, Methodology, Resources.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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