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Organic Production of Tuberous Vegetables: Agronomic, Nutritional and Economic Benefits

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Abstract

Global awareness of health and environmental issues has stimulated interest in alternative agricultural systems like organic farming. Elephant foot yam (*Amorphophallus paeoniifolius*) and yams (*Dioscorea* spp.) are ethnic starchy vegetables with high energy, nutritive and medicinal values. Field experiments were conducted at the Central Tuber Crops Research Institute, Thiruvananthapuram, India, during 2004-2011 to assess the agronomic, nutritional and economic advantages of organic farming over conventional system in these crops. Organic farming resulted in 10-20% higher yield over conventional practice in these crops. A net profit of Rs 2,15,776 ha^{-1}, which was 28% higher over chemical based farming was obtained under organic management in elephant foot yam. Elite and local varieties responded equally well to organic and conventional farming in elephant foot yam. White yam, greater yam and lesser yam responded similarly to both the systems, with slightly higher yield under organic practice. Soil physico-chemical properties and microbial count were also improved under organic management. Organic farming scored significantly higher soil quality index (1.93) than conventional practice (1.46). The soil quality index was driven by water holding capacity, pH and available Zn followed by soil organic matter. Tuber quality was improved with higher dry matter, starch, crude protein and lower oxalate contents. Cost effective technologies were field validated.

Key words: Eco-friendly farming, root crops, tuber yield, tuber quality, soil quality index, economics

Introduction

The growing public concern about food safety, environmental protection and personal health have generated great interest in sustainable alternative agricultural systems like organic farming (Carter et al., 1993). Organic farming is an ecological management system that focuses on soil health, environmental protection and human health by largely excluding the use of synthetic chemicals and with maximum use of on-farm generated resources. Though the use of chemical inputs cannot be completely avoided, their use in agriculture has to be reduced. Organic farming gives a solution to some of the problems by reducing energy use and CO_2 emissions besides offering opportunities for employment generation, waste recycling and export promotion (Reganold et al., 2001; Stockdale et al., 2001). The high quality, nutritious and safe organic foods fetch a premium price in world markets. At present there is dearth of scientific evidence about the productivity, food quality and soil quality under organic management. Research and development on organic farming is a new focus and hence is growing at a slow pace.

Tropical tuber crops form an important staple or subsidiary food for about 500 million of the global population. Elephant foot yam (*Amorphophallus paeoniifolius* (Dennst.) Nicolson) and yams (*Dioscorea* spp.) are high energy tuberous vegetables with good taste and medicinal values. They are food security crops in tropical countries mainly West Africa, South East Asia, Pacific Islands, Papua New Guinea islands and the Caribbean.There is ample scope for organic production in these crops as they respond well to organic manures

(Suja et al., 2009; Suja et al., 2010; Suja et al., 2012). There is a great demand for organically produced tuberous vegetables among affluent Asians and Africans living in Europe, United States of America and Middle East. This paper explores the comparative advantages of organic farming over conventional practice in terms of yield, quality, economics as well as soil physico-chemical and biological properties under elephant foot yam and yams.

Materials and Methods

Three field experiments were conducted during 2004-2011 at the Central Tuber Crops Research Institute (CTCRI), Thiruvananthapuram, Kerala, India, in an acid Ultisol (pH: 4.3-5.0). The impact of conventional, traditional, organic and biofertilizer farming was evaluated in elephant foot yam for five years in Randomized Block Design (RBD) with five replications. Comparative response of five varieties of elephant foot yam (three elite varieties-Gajendra, Sree Padma, Sree Athira and two locals each from Pothupara, Peerumade, Peerumade Development Society (PDS) and Palakkad, Vegetable and Fruit Promotion Council Keralam (VFPCK)) under organic and conventional farming was evaluated in split plot design. Three species of edible *Dioscorea* (white yam: *D. rotundata* (var. Sree Priya), greater yam: *D. alata* (var. Sree Keerthi) and lesser yam: *D. esculenta* (var. Sree Latha)) were evaluated under conventional, traditional and organic farming systems in split plot design. In split plot design, varieties/species were assigned to main plots and production systems to sub plots and replicated thrice. The treatment details are given in Table 1. Organically produced planting materials were used.

The site experiences a typical humid tropical climate. The mean annual rainfall was 1985 mm, maximum and minimum temperatures were 31.35^{0}C and 24.50^{0}C respectively and relative humidity was 76.65%. Chemical inputs were not used in the test sites for an year before the experiments. In general for all the three sites, prior to experimentation, the fertility status of the soil was medium to high for organic C (0.75-1.03%), low for available N (159-255 kg ha^{-1}) and high for available P (142-217 kg ha^{-1}) and available K (337-528 kg ha^{-1}).

Yield data was recored from the net plot and expressed in t ha^{-1}. Proximate analyses of tubers for dry matter, starch, crude protein and oxalates (AOAC, 1980) and mineral composition of tubers viz., P, K, Ca, Mg, Cu, Zn, Mn and Fe contents (Piper, 1970), chemical parameters of soil viz., soil organic matter (SOM), pH, available N, P, K, Ca, Mg, Cu, Zn, Mn and Fe status

Table 1. Description of treatments

Crop	Treatments/ Production systems	Description of production systems
Elephant foot yam	1. Conventional	FYM @ 25 t ha^{-1} + NPK @ 100:50:150 kg ha^{-1} (Package of Practices (POP) recommendation of KAU)
	2. Traditional	Farmers' practice (FYM @ 36 t ha^{-1} + ash @ 3 t ha^{-1})
	3. Organic	FYM(cow dung) + neem cake mixture (10:1) inoculated with *Trichoderma harzianum* + green manuring to generate 20-25 t ha^{-1}green matter in 45-60 days + neem cake @ 1 t ha^{-1} + ash @ 3 t ha^{-1}
	4. Biofertilizers	FYM @ 25 t ha^{-1} + biofertilizers (mycorrhiza @ 5 kg ha^{-1} *Azospirillum* @ 3 kg ha^{-1} and phosphobacteria @ 2.5 kg ha^{-1})
Yams	1. Conventional	FYM @ 10 t ha^{-1} + NPK @ 80:60:80 kg ha^{-1} (POP recommendation)
	2. Traditional	Farmers' practice (FYM @ 15 t ha^{-1} + ash @ 1.5 t ha^{-1})
	3. Organic	FYM @15 t ha^{-1} + green manuring to generate 15-20 t ha^{-1} of green matter in 45-60 days + neem cake @ 1 t ha^{-1} + ash @ 1.5 t ha^{-1} + biofertilizers (*Azospirillum* @ 3 kg ha^{-1}, mycorrhiza @ 5 kg ha^{-1} and phosphobacteria @ 3 kg ha^{-1})

(Page et. al., 1982), physical characters of the soil such as bulk density, particle density, water holding capacity (WHC) and porosity (Gupta and Dakshinamoorthy, 1980), plate count of soil microbes viz., bacteria, fungi, actinomycetes, N fixers and P solubilizers (Timonin, 1940) were determined by standard procedures. Economic analysis was done; net income and benefit cost ratio were computed. The analysis of variance of data was done using SAS (2008) by applying analysis of variance technique (ANOVA) for RBD and split plot design and pooled analysis of data of five years was also done.

The soil quality index (SQI) was computed in elephant foot yam based on the method of Karlen and Stott (1994). The three main steps in this technique included 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 significant difference among the different production systems. 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, where the y-axis ranged from 0 to 1 and the x-axis represented the expected range of the indicator variable in the study. 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:

$$SQI = \sum_{i=1}^{n} Wi \times Si$$

where, Si = score for the subscripted variable, Wi = weighing factor derived from PCA and n = number of selected parameters. The SQI treatment means were further compared using ANOVA and Duncan's Multiple Range Test (DMRT).

Results and Discussion

Varietal response

Varieties x production systems interaction was absent in elephant foot yam. This indicated that the high yielding as well as local varieties responded equally well to organic farming. However, Gajendra responded well to organic management and resulted in 9.56% higher yield over conventional practice (Fig.1).

Yield and economics

Pooled analysis indicated that organic farming produced significantly higher corm yield (57.10 t ha^{-1}) and additional income of Rs. 47,716 ha^{-1}over conventional practice in elephant foot yam (Table 2) and significantly higher yield (20.34 t ha^{-1}) in yams (Table 3). In yams, species x production systems interaction was not significant and white yam, greater yam and lesser yam responded similarly to all the systems. However, in all the species, organic farming produced slightly higher yield than conventional practice. The yield increase observed under organic farming in elephant foot yam, white yam, greater yam and lesser yam was 20, 9.35, 10.51 and 6.85% respectively over conventional practice (Fig. 2). Yield under organic farming is

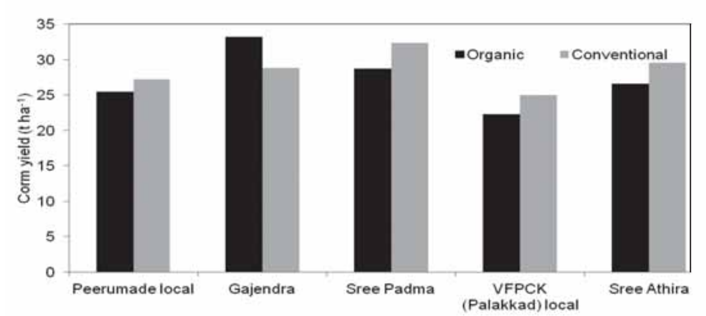

Fig.1. Varietal response to organic farming in elephant foot yam (Mean of 3 years)

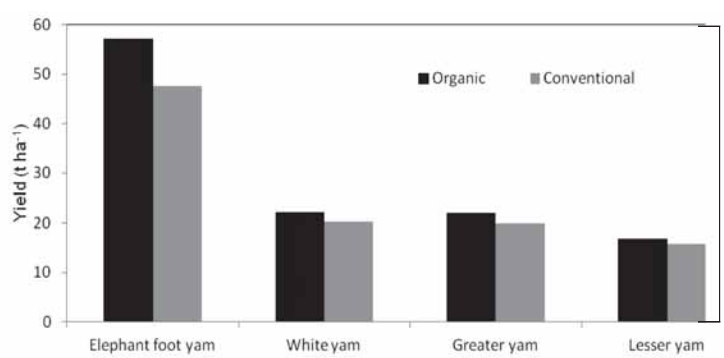

Fig. 2. Yield advantage of organic farming in tuberous vegetables (Mean of 5 years)

Table 2. Corm yield and quality and economics as influenced by production systems in elephant foot yam

Production systems	Corm yield (t ha^{-1})	Dry matter (%)	Starch (% FW basis)	Oxalate (% DW basis)	Net income (Rs. ha^{-1})	B:C ratio
Conventional	47.61	19.93	14.68	0.234	168060	1.79
Traditional	44.96	20.72	16.51	0.217	140880	1.64
Organic	57.10	21.41	16.54	0.186	215776	1.90
Biofertilizers	42.07	21.67	16.40	0.204	120288	1.56
CD (0.05)	3.55	1.06	0.94	0.026		

FW: fresh weight basis; DW: dry weight basis

Table 3. Effect of production systems on tuber yield and quality in yams

Production systems	Tuber yield (t ha^{-1})	Dry matter (%)	Starch (% FW basis)	Crude protein (% FW basis)	Tuber P (mg 100g^{-1}) (DW basis)	Tuber Ca (mg 100g^{-1}) (DW basis)
Conventional	18.64	31.36	26.77	1.92	472.35	57.67
Traditional	16.97	32.62	29.44	2.04	495.11	68.09
Organic	20.34	33.56	26.40	2.04	411.81	72.67
CD (0.05)	1.23	NS	NS	NS	39.79	11.35

FW: fresh weight basis; DW: dry weight basis

determined by the intensity of external input use before conversion (Stanhill, 1990). Elephant foot yam and yams are traditionally grown with low external inputs using organic wastes and manures available in the homesteads.The higher yield in these crops may be due to the overall improvement in soil physico-chemical and biological properties under the influence of organic manures (Clark et al., 1998; Colla et al., 2000; Stockdale et al., 2001). The yield increase observed in this study is contrary to the majority of reports that crop yields under organic management are 20-40% lower than for comparable conventional systems (Stockdale et al., 2001).

Tuber quality

In elephant foot yam, organic corms had significantly higher dry matter and starch contents and lower oxalate content (Table 2). The content of K, Ca, Mg (increase of 3-7%) and Fe (increase of 17%) in corms were slightly higher under organic farming. In yams, organic tubers had slightly higher dry matter and crude protein contents (Table 3). The P content of traditionally grown yam tubers and Ca content of organically produced tubers were significantly higher (Table 3). Rembialkowska (2007) also reported that organic crops contain more dry matter and minerals, especially, Fe, Mg and P (by 21%, 29% and 14% respectively) over conventionally produced ones.

Soil quality indicators

Physical properties

Water holding capacity was significantly higher (14.11%), bulk density (1.54 g cm^{-3}) and particle density (2.29 g cm^{-3}) were slightly lower and porosity (36.51%) higher in organic plots under elephant foot yam (Table 4). Almost similar trend was observed in the water holding capacity and particle density of organic plots under yams (Table 5). Several earlier workers have reported that aeration, porosity and water holding capacity of soils increased under organic management (Colla et al., 2000; Radhakrishnan et al., 2006; Ramesh et al., 2010). The improvement in soil physical conditions can be attributed to the increase in soil organic matter content, which dilutes the denser fractions of soil, reduces the strength of the surface crusts, favours the formation of stable soil aggregates especially macro aggregate stability and macro porosity (Stockdale et al., 2001).

Chemical properties

There was significant improvement in pH due to organic farming (0.77 and 0.46 unit increase over conventional system) in both elephant foot yam and yams (Tables 4 and 5). The pH increase under organic management may be due to elimination of ammoniacal fertilizers, addition of cations especially via green manure application,

Table 4. Soil quality indicators as influenced by management practices after five years of elephant foot yam cultivation

Production systems	pH	Soil organic matter ($g\ kg^{-1}$)	Water holding capacity (%)	Porosity (%)	Exchangeable Mg ($kg\ ha^{-1}$)	Available Cu (ppm)	Available Mn (ppm)	Available Fe (ppm)
Conventional	4.55	20.32	10.99	31.35	28.70	1.50	8.00	56.90
Traditional	5.45	20.11	13.99	35.94	41.00	2.40	11.30	63.30
Organic	5.32	24.19	14.11	36.51	39.70	3.60	17.40	77.20
Biofertilizers	4.68	22.15	10.57	33.44	28.70	2.00	20.80	93.10
CD (0.05)	0.28	NS	2.44	NS	9.02	1.06	8.15	16.38

decrease in the activity of exchangeable Al^{3+} ions in soil solution due to chelation by organic molecules and Ca content of the manures. After five years of cultivation of elephant foot yam and yams, the SOM increased by 19 % and 11% respectively in organic plots over conventional plots as evident from Tables 4 and 5. Higher soil organic matter status of organic plots might be attributed to the large addition of organic manures particularly green manure, cowpea. In both the crops, available N and P were higher and in yams, there was significant improvement of available K under organic management (Table 5). These may be due to the direct result of inputs and constituents of various manures. Exchangeable Mg and available Cu, Mn and Fe contents were also significantly higher in organic plots than in conventional plots in elephant foot yam (Table 4).

Soil microbial count

The microbial load in soil was not significantly influenced by the various production systems. However, the population of bacteria, fungi and N fixers were higher in organic plots than in conventional plots (Fig. 3). The higher microbial population may be due to higher decomposition of organic matter due to the addition of large quantities of organic manures/amendments like FYM, green manure, neem cake etc. to replace the chemical fertilizers in organic farming.

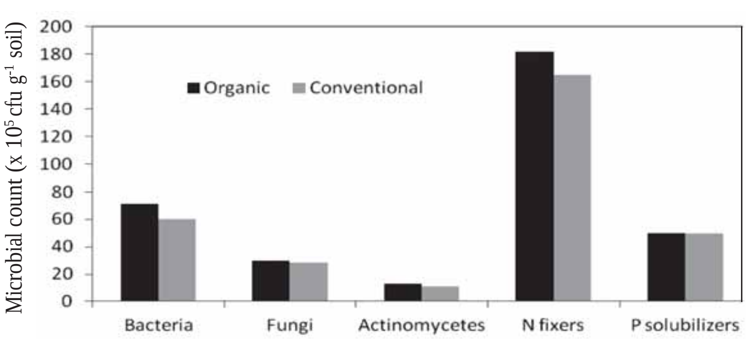

Fig. 3. Effect of production systems on soil microbial count in elephant foot yam

Soil quality index

The standardized PCA analysis extracted three principal components with a contribution of 0.624, 0.262 and 0.114% for PC1, PC2 and PC3 respectively, which has been taken as the weighing factors for the indicators explained by each PCs. After examining the highly weighted variables under each PCs and the correlation between the indicator variables for the computation, the retained indicator variables included available Zn, WHC and pH from PC1, SOM under PC2 and available Mn under PC3. The multiple regression of the selected MDS indicators as independent variable and yield as management goal was significant ($P < 0.001$) with a coefficient of determination of (r^2) of 0.35. This suggests that the MDS is indicative of the management goal.

The SQI was computed using the weighing factors by the formula:

SQI = 0.624 × (S available_Zn + S WHC + S pH) + 0.262 × S SOM + 0.114 × (S available Mn)

Using this formula, the WHC, pH and available Zn appear to drive the SQI followed by SOM. The organic system scored significantly higher SQI of 1.93, which was on par with the traditional system (1.91). Soil quality indices of conventional and biofertilizer

Table 5. Soil quality indicators as influenced by management practices after five years of yam cultivation

Production systems	pH	Soil organic matter (g kg^{-1})	Available K (kg ha^{-1})	Particle density (g cm^{-3})	Water holding capacity (%)
Conventional	5.01	12.94	256.40	2.40	12.38
Traditional	5.24	13.82	261.70	2.49	11.35
Organic	5.47	14.75	343.50	2.27	14.21
CD (0.05)	0.22	NS	40.21	0.14	1.60

systems were significantly lower compared to organic and traditional systems (Fig.4). Karlen et al. (1999) and Susan Andrews et al. (2002) also computed higher SQI scores in organic plots over conventional plots.

Soil quality is the capacity of a soil to function within natural or managed ecosystem boundaries to sustain plant and animal productivity to maintain or enhance water and air quality and support human health and habitation (Karlen et al., 1997). In the present study, organic farming which is a supplemental C management practice (SCMP) significantly changed a number of soil properties including soil pH, SOM, exchangeable Mg, available Cu, Mn and Fe contents and WHC. Thus the indicator properties could be changed mainly through SOM building practices brought about by the strict use of organic manures especially green manuring continuously for five 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.

The package

The organic farming package standardized for elephant foot yam is farmyard manure @ 36 t ha^{-1} (cow dung + neem cake mixture (10:1) inoculated with *Trichoderma harzianum*), green manuring

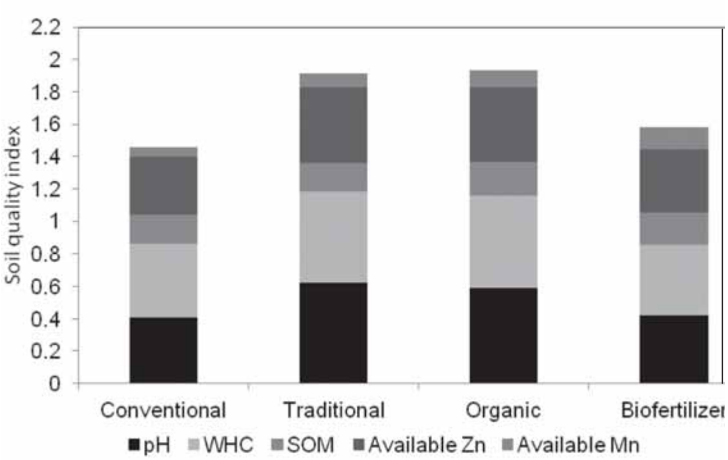

Fig.4. Effect of production systems on soil quality index in elephant foot yam

with cowpea to generate 20-25 t ha^{-1} of green matter in 45-60 days, neem cake @ 1 t ha^{-1} and ash @ 3 t ha^{-1}. This was validated and popularized through on farm trials in 10 sites (5 ha) under National Horticulture Mission funded programme (Suja et al., 2010) and included in the POP recommendations for crops by KAU (2011). The technology for organic production in yams comprised of application of FYM @ 15 t ha^{-1}, green manure (to yield 15-20 t ha^{-1} of green matter in 45-60 days), ash @ 1.5 t ha^{-1}, neem cake @ 1t ha^{-1} and biofertilizers (*Azospirillum* @ 3 kg ha^{-1}, mycorrhiza @ 5 kg $ha^{-1}$and phosphobacteria @ 3 kg ha^{-1}). This requires further field validation.

Conclusion

Organic farming is a feasible option in tuberous vegetables for getting sustainable yield of quality tubers and higher profit besides maintaining soil quality.

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