Indian Journal of Agricultural Sciences **83** (11): 1153–8, November 2013/Article

Comparison of tuber yield, nutritional quality and soil health under organic versus conventional production in tuberous vegetables

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Received: 22 June 2011; Revised accepted: 23 September 2013

ABSTRACT

Field experiments were conducted at the Central Tuber Crops Research Institute, Thiruvananthapuram, Kerala for 5 years during 2004-09 in RBD and 2006-11 in split plot design to assess the comparative agronomic and nutritional advantages of organic management over conventional system in elephant foot yam and yams (*Dioscorea* spp.), respectively. Organic management resulted in significantly higher yield of 20% (57.10 tonnes/ha) over conventional practice (47.61 tonnes/ha) in elephant foot yam. Organic management also produced significantly higher yield in all the three species of yams (pooled mean of 22.21, 21.96 and 16.83 tonnes/ha for white yam, greater yam and lesser yam respectively). The yield increase observed under organic management in these species was 9%, 11% and 7%, respectively over chemical based farming. Organic management lowered the bulk density by 2.3%, improved the water holding capacity by 28.4% and the porosity of soil by 16.5% in elephant foot yam. There was significant increase in pH (0.46-0.77 unit increase) apart from higher organic C (by 15-19%), available N, P and K, bacterial and fungal populations, N fixers, P solubilizers and dehydrogenase enzyme activity of soil. Organic tubers had higher dry matter, starch, crude protein, K, Ca and Mg and lower oxalate contents. Use of organically produced seed materials, seed treatment in cow-dung, neem cake, bio-inoculant slurry**,** farmyard manure incubated with bio-inoculants, green manuring, use of neem cake, biofertilizers and ash formed the strategies for organic production.

Key words: Elephant foot yam, Organic management, Soil quality, Tuber quality, Tuber yield, Yams

Worldwide awareness about food safety, anthropogenic degradation of the environment and the need to ameliorate threats to human health has stimulated interest in the development and practice of sustainable alternative agricultural systems (Carter *et al*. 1993). Chemical intensive conventional agriculture resulted in a quantum jump in food production, but led to irrevocable ecological catastrophes, viz. global warming, wide spread soil erosion, salinization, receding ground water table, deterioration of soil fertility, nutrient imbalance, damage to soil health, land degradation, desertification, loss of biodiversity and pesticide pollution besides adverse effects on human health. Organic farming is an alternate farming strategy that focuses on sustainable production, soil health, environmental protection and human health by largely excluding the use of synthetic chemicals and with maximum use of on farm generated inputs.

Tropical tuber crops, including cassava, sweet potato, yams and aroids form the most important staple or subsidiary food to about 500 million global population. Elephant foot yam (*Amorphophallus paeoniifolius* (Dennst.) Nicolson) and yams (*Dioscorea* species) are important starchy vegetables with high nutritive and medicinal values. These are food security crops in tropical countries mainly West Africa, South East Asia, Pacific Islands, Papua New Guinea Islands and the Caribbean. They respond well to organic manures and there is great scope for organic production. In addition there is a great demand for organically produced tuberous vegetables, particularly cassava, elephant foot yam and yams, among affluent Asians and Africans living in Europe, United States of America and Middle East.

Research and development on organic farming of tropical tuber crops is less focused. This paper explores the comparative advantages of organic farming over conventional practice in terms of yield, quality as well as soil physico-chemical and biological properties under elephant foot yam and yams.

MATERIALS AND METHODS

Two separate field experiments were conducted during 2004-2011 at the Central Tuber Crops Research Institute (CTCRI), Thiruvananthapuram (8° 29'N, 76°57'E, 64 m altitude), Kerala, India, in an acid Ultisol (pH: 4.3-5.0). The site experiences a typical humid tropical climate. The mean annual rainfall was 1853.89 mm and the annual means of

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Table 1 Soil fertility status prior to experimentation

Crop	pH	Organic C (%)	Available N	Available P	Available K
			kg/ha		
Elephant foot yam	4.23	1.026	255.61	79.64	253.50
Yams	5.33	0.746	159.32	216.92	337.50

daily temperature maxima and minima were 31.17°C and 24.97°C respectively. The initial soil properties are given in Table 1.

The impact of conventional, traditional, organic and biofertilizer farming was evaluated during 2004-2009 in Randomized Block Design (RBD) on growth, yield and quality of elephant foot yam (Peerumade local), physico-chemical and biological properties of soil. The gross plot size was 4.5 m × 4.5 m (accommodating a total of 25 plants and 9 net plants). All the 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 during 2006-2011 under conventional, traditional and organic farming systems in split plot design. The species were assigned to main plots and production systems to sub plots. The gross plot size was 7.2 m × 3.6 m (total 32 plants and 12 net plants). Elephant foot yam, white yam and greater yam were spaced at 90 cm × 90 cm and lesser yam at 75 cm × 75 cm. However, the effects of organic and conventional practices alone are compared in this paper.

The land for organic farming experimentation was not subjected to any chemical inputs for an year prior to the start of the investigations. In "conventional plots" the nutrient management practices as per the package of practices recommendations (farmyard manure (FYM) + NPK fertilizers) was advocated. In "organic farming plots", FYM, green manure, biofertilizers, ash and neem cake were applied to substitute chemical fertilizers. The average nutrient content of the organic manures used are given in Table 2. The treatment details are given in Table 3. Organically produced planting material of a local variety of elephant foot yam procured from Peermade Development Society, Pothupara, Idukki district, Kerala and released varieties of yams from CTCRI were used for the study.

Fresh tuber yield from the net plots was recorded. Proximate analyses of corms for dry matter, starch, total sugar, reducing sugar, crude protein, oxalates and total phenols were done using standard procedures. Dry matter, crude protein and oxalates were determined by the method of AOAC (1980). The starch content was determined by conversion to sugars by acid hydrolysis and then by the method of Dubois *et al*. (1956). Total sugars were also determined by the same method. Reducing sugars was estimated by the method of Nelson (1944) and total phenols by the method of Swain and Hillis (1955). Mineral composition of corms, viz. P, K, Ca, Mg, Cu, Zn, Mn and Fe contents were also determined by standard methods (Jackson 1973). The P content of corms was determined by the method of colorimetry, K and Ca by flame photometry, Mg, Fe, Mn, Zn and Cu by direct reading in atomic absorption spectrophotometer. The pH, organic C, available N, P and K status of the soil were estimated by standard analytical methods (Jackson 1973). Physical characters of the soil such as bulk density, particle density, water holding capacity and porosity were estimated by the methods of Gupta and Dakshinamoorthy (1980). Microbial plate count of bacteria, fungi and actinomycetes were determined by the standard procedures described by Timonin (1940).

Table 2 Average nutrient content (%) of organic manures

Organic manures	N	P_2O_5	K_2O
Farmyard manure	0.50	0.20	0.28
Green manure	3.45	0.57	2.02
Neem cake	1.50	1.00	1.20
Ash	0.6	1.60	7.11

Table 3 Production systems treatments in the field experimentation on organic farming of elephant foot yam and yams

Crop	Description of production systems	
	Conventional	Organic
Elephant foot yam	FYM @ 25 tonnes/ha+ NPK @ 100:50:150 kg/ha (POP recommendation)	*Trichoderma harzianum* inoculated FYM @ 36 tonnes/ha + green manuring to generate 20-25 tonnes/ha green matter in 45-60 days + neem cake @ 1 tonne/ha + ash @ 3 tonnes/ha
Yams	FYM @ 10 tonnes/ha + NPK @ 80:60:80 kg/ha (POP recommendation)	FYM @15 tonnes/ha + green manuring to generate 15-20 tonnes/ha of green matter in 45-60 days + neem cake @ 1 tonne/ha + ash @ 1.5 tonnes/ha + biofertilizers (*Azospirillum* @ 3 kg/ha, mycorrhiza @ 5 kg/ha and phospho-bacteria @ 3 kg/ha)

The analysis of variance of data was done using GenStat (2007) by applying analysis of variance technique (ANOVA) for randomised block design and split plot design and pooled analysis of data was done (Cochran and Cox 1992).

RESULTS AND DISCUSSION

Yield

Organic management resulted in significantly higher yield than conventional practice in elephant foot yam, white yam, greater yam and lesser yam (Table 4). On an average, the yield increase observed under organic management in these crops was 20%, 9%, 11% and 7%, respectively over conventional practice. The higher productivity in organic

Table 4 Yield advantage (tonnes/ha) of organic management in tuberous vegetables

Tuber crop	Organic management	Conventional management	CD (*P*=0.05)	Percent increase (+) in organic management
Elephant foot yam	57.10	47.61	3.548	+19.99
White yam	22.21	20.31	NS	+9.35
Greater yam	21.96	19.87	NS	+10.51
Lesser yam	16.83	15.75	NS	+6.58

management may be attributed to the overall improvement in soil physico-chemical and biological properties due to addition of various organic sources of nutrients. Despite the highly nutrient exhausting nature of these crops, proper replenishment of the soil with adequate amounts of nutrients enabled getting high yield. Hence the present study indicates that satisfactory yield can be obtained in the absence of chemical fertilizers by proper supplementation of nutrients based on soil testing through cheaper and easily available organic sources.

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, Gopinath *et al*. 2008, Ponti *et al*. 2012). It is reported that yields were directly related to the intensity of farming in the prevailing conventional system (Ramesh *et al*. 2005, Ramesh *et al*. 2010). This means that in areas of intensive farming system, shifting to organic agriculture decreases yield depending on the intensity of external input use before conversion (Stanhill 1990, Offerman and Nieberg 1999). Since yams and aroids are traditionally grown with low external inputs using organic wastes and manures available in the homesteads, organic management in the present study has shown a potential to increase yields over conventional practice. This indicates that there is great scope for organic management in tropical tubers, especially elephant foot yam and yams.

Tuber quality

Bio-chemical constituents: Dry matter and starch contents of organically produced elephant foot yam corms was significantly higher than that of conventional corms (7% and 13% higher) (Table 5). Rembialkowska (2007) reported that organic crops contain more dry matter than conventional crops. Crude protein content was not significantly affected, though organic corms had 12% higher crude protein. Total sugar and total phenol content of conventional corms was significantly higher. It is worthy to note that organically produced corms had significantly lowest oxalate content. In yams, though there was not much difference in the various tuber quality parameters between organic and conventional practice, dry matter and crude protein contents were slightly higher (6-7%) under organic management. Synthetic fertilizers could enhance the total sugar, reducing sugar and total phenol contents slightly.

Mineral composition: In elephant foot yam, the content of K, Ca and Mg (3-7%) were higher under organic farming (Table 5). Pieper and Barrett (2008) also found higher levels of K in organic tomatoes. However, Mn content of conventional corms was significantly higher than organic corms. This is similar to the findings of Hargreaves *et al.* (2008), who reported that inorganic fertilizer treatment significantly enhanced the content of Mn in strawberry fruit.

Table 5 Comparison of tuber quality in organic versus conventional management in tuberous vegetables

Tuber quality	Elephant foot yam			Yams		
	Organic	Conventional	CD (P = 0.05)	Organic	Conventional	CD (P = 0.05)
Bio-chemical						
Dry matter (%)	21.41	19.93	1.061	33.56	31.36	NS
Starch (% FW basis)	16.54	14.68	0.937	26.40	26.70	NS
Crude protein (% FW basis)	2.04	1.82	NS	1.92	1.81	NS
Oxalate (% DW basis)	0.186	0.234	0.0259			
Total sugars (% FW basis)	1.98	2.38	0.257	1.88	2.52	NS
Reducing sugar (% FW basis)	0.65	0.78	NS	0.117	0.126	NS
Total phenols (mg/100g)	69.7	80.8	8.28	37.2	41.6	NS
Mineral content (mg/100g DW basis)						
K	1813	1714	207.4	998.0	948.0	NS
Ca	152.2	142.0	17.58	96.6	90.2	NS
Mg	276.5	268.1	NS	139.0	102.7	24.31
Cu	1.041	1.082	NS			
Zn	11.02	11.62	NS	1.92	1.83	NS
Mn	2.324	3.210	0.4186	0.367	0.254	NS
Fe	71.90	86.60	NS			

There was considerable improvement in the Mg and Mn contents of tubers of yams by 35% and 45%, respectively under organic farming over conventional practice. Rembialkowska (2007) also reported that organic plant products contain more minerals, especially Fe, Mg and P by 21%, 29% and 14% over conventionally produced ones. The higher mineral content in organic crops may be due to the higher abundance of micro-organisms in organically managed soil. These micro-organisms produce many compounds that help plants to combine with soil minerals and make them more available to plant roots.

Soil quality indicators

Physical parameters: The soil physical parameters as influenced by organic and conventional management in the test crops are given in Table 6. In elephant foot yam, organic management lowered the bulk density and particle density of the soil by 0.6-2.3% over conventional farming. Water holding capacity of the soil was found to be significantly enhanced (28.4%) and porosity appreciably (16.5%) due to organic management. Slight improvement in bulk density, water holding capacity and porosity of the soil was also observed under organic management in yams. Increased aeration, porosity and water holding capacity of soils have been observed under organic management by several earlier workers (Colla *et al*. 2000, Radhakrishnan *et al*. 2006, Ramesh *et al*. 2010). As reported by Stockdale *et al*. (2001) 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.

Chemical parameters: There was a significant improvement in pH (0.77 and 0.46 unit increase) in organic farming over conventional system in both elephant foot yam and yams (Table 7). Long term changes in soil pH occur largely as a result of displacing cations or adding sources of acidity such as H^+ and Al^{3+} on the cation exchange complex of soils (Tisdale *et al*. 1995). Organic manures help to enhance soil pH in acidic soils (Prabhakaran and Pitchai 2002, Prakash *et al*. 2002). The pH increase under organic management may be possibly due to elimination of NH_4 fertilizers and the addition of cations via manure applications. The moderating effect of organic manures like FYM, green manure, neem cake etc. on soil acidity can be attributed to decrease in the activity of exchangeable Al^{3+} ions in soil solution due to chelation by organic molecules thereby reducing Al phytotoxicity and lowering Al bioavailability. The Ca content in FYM (0.14%) and ash (20-40%) might have also contributed to a self liming effect. The addition of green manure in organic farming might have provided an additional source of cations, possibly from lower soil depths that are released at the soil surface through leaching and decomposition activities. Synthetic fertilizer application may have acidified the soil slightly in conventional systems

There was 19 % and 15% increase in organic C in organic plots over conventional plots in elephant foot yam and yams respectively. Higher organic C status of organic plots might be attributed to considerable addition of organic manures particularly green manure cowpea. In elephant foot yam, available N, P and K and in yams available N and K were higher under organic management obviously due to the direct result of inputs and constituents of various manures. Higher available N status observed in organic plots may be due to higher N content in the organic manures, especially green manure, used in the study (Table 2). Solubilization of native P by organic acids produced during decomposition of organic manures and increased mineralization of P from the added organic manures might have led to a higher available P in organic plots. Higher content of K in the organic manures, especially green manure and ash (Table 2), K mining effect from the subsurface layers by the extensive root system of green manure crop of cowpea, organic acid dissolution of the rather inaccessible K minerals in the soil during green manure decomposition all might have contributed to higher content of available K in organic plots.

In summary organic farming resulted in higher pH, soil organic C, available N, P and K. The study indicates that the use of organic manures especially green manure and the elimination of chemical fertilizers results in increased soil

Table 6 Comparison of soil physical parameters in organic versus conventional management in tuberous vegetables

Physical parameters	Elephant foot yam				Yams			
	Organic	Conventional	CD (P=0.05)	Percent increase (+) or decrease (-) in organic management	Organic	Conven-tional	CD (P=0.05)	Percent increase (+) or decrease (–) in organic management
Bulk density (g/cm^3)	1.544	1.580	NS	-2.28	1.72	1.74	NS	-1.15
Particle density (g/cm^3)	2.287	2.301	NS	-0.61	2.63	2.63	NS	0
Water holding capacity (%)	14.11	10.99	2.442	+28.38	11.73	9.84	NS	+19.2
Porosity (%)	36.51	31.35	NS	+16.45	34.64	33.65	NS	+2.94

Table 7 Comparison of soil chemical parameters in organic versus conventional management in tuberous vegetables

Physical parameters	Elephant foot yam				Yams			
	Organic	Conventional	CD (*P*=0.05)	Percent increase (+) in organic management	Organic	Conventional	CD (*P*=0.05)	Percent increase (+) or decrease (–) in organic management
pH	5.32	4.55	0.285	+0.77 unit	5.47	5.01	0.212	+ 0.46 unit
Organic C (%)	1.402	1.178	NS	+19.02	0.86	0.75	NS	+14.66
Available N (kg/ha)	125.6	103.3	NS	+21.59	193	162	NS	+19.14
Available P (kg/ha)	185.2	163.7	NS	+13.13	270	289	NS	-6.574
Available K (kg/ha)	362.0	340.9	NS	+6.19	343.5	256.4	40.21	+33.97

Table 8 Comparison of soil biological parameters in organic versus conventional management in tuberous vegetables

Soil biological parameters	Elephant foot yam				Yams			
	Organic	Conventional	CD (*P*=0.05)	Percent increase (+) or decrease (–) in organic management	Organic	Conventional	CD (*P* = 0.05)	Percent increase (+) or decrease (–) in organic management
Bacteria (cfu/g soil)	31×10^7	22×10^5	NS	+40.90	118×10^3	96×10^3	NS	+22.91
Fungi (cfu/g soil)	6×10^6	5×10^6	NS	+20.00	7×10^2	6×10^2	NS	+16.66
Actinomycetes (cfu/g soil)	22×10^5	24×10^5	NS	–8.33	11×10^3	12×10^3	4.682	–8.33
N fixers (cfu/g soil)	182×10^5	165×10^5	NS	+10.30	7×10^3	11×10^3	NS	–36.36
P solubilizers (cfu/g soil)	5×10^6	5×10^6	NS	–	11×10^3	9×10^3	NS	+22.22
Dehydrogenase enzyme (µg TPF formed/g soil/ h)	1.625	1.323	NS	+22.82	1.174	0.079	NS	

organic matter and storage of nutrients, which can provide long term fertility benefits.

Biological parameters: The population of bacteria was considerably higher in organic plots than in conventional plots; 41% and 23% higher in elephant foot yam and yams, respectively. Organic farming also favoured the fungal population by 17-20% (Table 8). However, the actinomycetes count was higher under conventional management. While the N fixers showed an upper hand in organically managed soils by 10% over conventional management under elephant foot yam, P solubilizers remained more conspicuous under organic management of yams (22% higher than conventional management). The dehydrogenase enzyme activity was higher in organic plots in both the crops tested. Dehydrogenase enzymes, respiratory enzymes and integral part of all soil organisms, are the most commonly used indicator of biological activity in soils. The higher dehydrogenase enzyme activity in organic plots may be due to higher oxidation or decomposition of organic matter due to addition of large quantities of organic sources of nutrients (FYM, green manure, neem cake etc.) to replace the chemical fertilizers. Thus, higher microbial activity in organically managed soils enabled nutrient transformations and increased availability of nutrients to the plants. However, acid phosphatase activity was more under conventional farming in both cases which may be due to the addition of synthetic fertilizers. Urease enzyme activity remained unaffected due to management.

On the whole, organic farming is a feasible management strategy in elephant foot yam and yams for getting high yield of quality tubers and safe food besides maintaining soil fertility and soil health. Use of organically produced seed materials, seed treatment in cow-dung, neem cake, bio-inoculant slurry**,** farmyard manure incubated with bio-inoculants, green manuring, use of neem cake, bio-fertilizers and ash formed the strategies for organic production

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