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Comparative evaluation of organic and non-organic cotton (*Gossypium hirsutum*) production systems

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ABSTRACT

The sustainability of organic cotton (*Gossypium hirsutum* L.) based production system *vis-a -vis* non-organic system under low input, semi-arid pedo-climatic conditions was evaluated during 2001 through 2005 on farmers' fields in Yavatmal district, Maharashtra. Mean yield of cotton, mungbean [*Vigna radiata* (L.) R. Wilczek], soybean (*Glycine max* L. Merr.) and chickpea (*Cicer arietinum* L.) were either similar or slightly higher under the organic system than the non-organic system. The organic system also had a higher diversity index (4.3) than the non-organic system (2.9). Organic cultivation practices did not improve fibre quality parameters. Samples from 4 soil pedons and 56 surface soils were analyzed in 2001 and again in 2005. Soils from non-organic pedons had a higher *p*H and ex-Na, whereas the organic carbon content was higher under organic system. During both the sampling periods, the mean organic carbon and available Zn were significantly higher in the organic system. All the soils were calcareous but the proportion of organic to total carbon was higher in organic system and between sampling periods, this increased from 54.5 to 57.5%. Thus, adoption of organic production practices improved the biophysical sustainability of the low input systems prevailing in semi-arid pedo-climatic conditions of the region.

Key words: Diversity index, Organic cotton production, Soil quality

Repeated crop failures, decreasing marginal returns due to stagnating productivity and rising input costs, emergence of niche markets and patrons of alternate production strategies ushered the re-discovery of organic production systems in Central India. Today organic agriculture is one of the fastest growing production systems in the agricultural sector (Ramesh *et al*. 2005) and Central India is a major hub for the production and export of organic cotton. Here cotton is cultivated under sub-optimal moisture and fertility conditions. Despite the growing popularity of organic production systems, their biophysical sustainability is debated (Eyhorn *et al*. 2007). Its critics argue that annual application of 15–20 tonnes/ha of manure is needed to sustain crop yields on tropical ecosystems and such huge quantities are difficult to generate in India (Chonkar and Dwivedi 2004). On the contrary, studies suggest that yields could be sustained without increasing nutrient inputs by tightening the nutrient cycles (Stockdale *et al.* 2000) and diversification of soil biota (Ramesh and Rao 2009). More importantly, the semi-arid conditions, prevailing in large parts of Central India, cause soil degradation - depletion of organic carbon, formation of pedogenic $CaCO_3$ with concomitant development of sodicity and thus effective carbon management strategies are needed to sustain soil health (Bhattacharyya *et al*. 2006).

Crop yield and ecological aspects of organic *vis-à-vis* conventional system have been extensively researched in temperate countries (Stockdale *et al*. 2002, Lotter 2003) and in experimental research farms in tropical conditions of India (Blaise 2006). However, information on the performance of organic production systems on farmers' fields are few (Eyhorn *et al.* 2007). The present investigation therefore compares the yields, quality of fibre and soil properties under selected cotton-based organic and the prevailing conventional system (which will hereafter be referred to as non-organic production system) in a cluster of villages in Yavatmal district, Maharashtra. It also assesses the biophysical sustainability of both the production systems using some relevant soil quality indicators.

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MATERIALS AND METHODS

Yavatmal district, located in the south-east part of Maharashtra lies between 19.26–20.4° N latitute and 77.18–79.9° E longitude. The soils are generally black, shrink-swell (Vertic and their intergrades), developed in the basaltic alluvium (Pal *et al.* 2000). The region experiences a hot, moist semi-arid climate with a mean annual rainfall of 992 mm. Rainfed cotton is either monocropped or rotated with sorghum (*Sorghum bicolor* L. Moench) or soybean (*Glycine max* L. Merr.). Cotton (*Gossypium hirsutum* L.) is also intercropped with pigeonpea (*Cajanas cajan* L. Millsp). Wherever irrigation facilities are available, wheat (*Triticum aestivum* L. emend Fiori & Paol.), chickpea (*Cicer arietinum* L.), sugarcane (*Saccharum officinarum*) or horticultural crops (citrus and turmeric) are introduced. Nutrient input into the organic production systems is through farmyard manure (applied at rates varying from 3.3 to 15.0 tonnes/ha with a mean of 8.6 tonnes/ha), frequent use of vermi/tricho-compost @1–2 tonnes/ha, bio-fertilizers, inter/sequence cropping with legumes and green manuring. Pest management is through the augmentation of natural enemies and use of indigenous formulations of botanical pesticides. In the non-organic system, the mean annual application of farmyard manure was only 0.86 tonnes/ha, whereas fertilizers @ 132 kg/ha and insecticides @ 1.6 l/ha were annually applied.

Soil samples were collected from farms located in Pahur, Loni, Akolabazar, Borgaon, Uttarwadh, Madni, Krishnapur, Vyahali, Borgaon and Hatgaon villages belonging to Babulgaon, Ner, Akolabazar and Yavatmal tehsils. Fifty-six surface (0–25 cm) samples encompassing, shallow, moderately deep and deep soils (41 organic and rest non-organic) were collected from farmers' fields in 2001. The same fields were re-sampled in 2005. Majority of the sampled farms were converted into the organic production system between 1986 and 1995, although a few farms were practising it since 1979. In addition, 4 profiles of deep soils were examined in representative locations for morphometric properties and horizon-wise soil samples were analyzed for chemical properties. Data on input use, crop yields (2000–04) and returns from organic farms were collected from the records maintained by the agency (ECO farms Ltd, Yavatmal) which organizes certification. The same for non-organic farms were collected though personal interview. Fibre length (2.5 span length), bundle strength and micronaire were determined from samples collected from organic farms and compared with the data provided in the varietal release proposals (CIRCOT 1999). Strout's Diversity index was calculated as the reciprocal of sum of squares of the share of gross income from each individual crop enterprise in a single year (Strout 1975).

Soil organic carbon content was determined by Walkley and Black procedure, *p*H, EC, $CaCO_3$ and $CO_3^{—}$, HCO_3^{-}, $Cl^{—}$ and $SO_4^{—}$ in saturated extract was determined by Richards (1954) and available Zn in DTPA extract by Lindsey and Norvel (1978). The means of surface samples from unpaired (organic and non-organic) data were compared using Student's t test.

RESULTS AND DISCUSSION

Crop yield and diversity index

The yields of component crops except sorghum were similar or slightly higher under the organic production systems than the non-organic production systems (Table 1). However, the yields of all the crops were far below their genetic potential owing to the unfavourable pedo-climatic environment. Sorghum being more exhaustive, responded better to inorganic nutrient inputs and hence its yield was higher in the non-organic system. The diversity index was higher (4.30) in the organic farms compared to the non-organic farms (2.9). Recently, Eyhorn *et al.* (2007) also

Table 1 Yield (kg/ha) of crops in farms under organic and non-organic production systems (mean 2000–04)

	Crop	Organic		Non-organic	
		Range	Mean (±SD)	Range	Mean (±SD)
Pure crop	Cotton	580–1 750	1 230 (169)**	560–1 500	11.8 (142)
	Sorghum	750–2 000	1 180 (304)	670–2 630	14.7 (551)
	Mungbean	250–820	490 (229)	NA	NA
	Soybean	830–2 080	1 570 (399)	720–2 820	1620 (426)
	Pigeonpea	250–1 000	670 (231)	NA	NA
	Chickpea	600–1 090	740 (320)	580–1 220	700 (355)
	Sugarcane	NA	NA	875	875
Intercropping combination*	Cotton (base crop)	200–1 530	890 (320)	240–1 270	750 (305)
	Sorghum (base crop)	630–1 000	770 (164)	NA	NA
	Mungbean (intercrop)	80–1 690	440 (229)	NA	NA
	Urdbean (intercrop)	130–4 30	220 (101)	100–540	280
	Soybean (intercrop)	340–1 130	710 (290)	NA	NA
	Pigeonpea (intercrop)	50–1 250	510 (307)	50–1 040	450 (422)
Strout's Diversity index		4.3		2.9	

NA, Not adopted; *, in various row proportions; *, figures in parentheses denote standard deviation (SD) recorded more diverse cropping systems in the organic farms of Madhya Pradesh. Greater crop diversity in organic farms improved soil quality, besides minimizing risk of crop loss due to biotic and abiotic stresses. Thus, in the traditional rainfed cotton belt, organic production systems have the potential to maintain or improve productivity, provided the crop combinations are selected judiciously. Ramesh and Rao (2009) also reported that the productivity of the organic systems can be improved through the selection of appropriate crop combinations.

Quality of cotton lint

Under organic system the fibre quality parameters, viz micronaire and bundle strength matched the genetic potential of the respective cultivars (Table 2). The fibre length (2.5 span length) was slightly higher under the organic production system. Earlier, Blaise (2006) opined that a better soil moisture regime and improved nutrient availability in the organic system enabled cotton to produce lint with longer and stronger fibres.

Soil properties

Properties of soil pedons: Out of the 4 soil pedons examined, 2 (designated as Loni and Akolabazar) were organic and the other 2 (designated as Pahur and Borgaon) were non-organic. All the profiles belonged to order Vertisols

Table 2 Fibre properties of cotton cultivars

Parameter	System	Cultivar						
		'NHH 44'	'Anjali'	'LRA 5166'	'PKV 081'	'Rajat'	'AKA 8401'	Mean
Micronaire	Organic	4.1	3.9	3.7	4.2	4.0	4.4	4.05
	Conventional*	3.8	3.4	3.8	4.2	4.5	4.8	4.08
2.5 span length (mm)	Organic	27.6	26.5	27.1	25.5	25.8	25.9	26.4
	Conventional*	28.0	27.0	26.0	25.0	24.0	26.0	26.0
Bundle strength (g/tex)	Organic	23.0	24.2	24.0	24.6	22.8	20.7	23.2
	Conventional*	24.0	23.0	25.0	24.0	22.0	21.0	23.1

* From release proposal (CIRCOT 1999)

Table 3 Chemical characteristics of soil pedons under (a) organic- Loni and Akolabazar, and (b) non-organic (Pahur and Borgoan) systems

Depth (cm)	Horizon	EC (dS/m)	Sum of exchangeable bases mole c mole (p^+)/kg	Saturation extract of soils (me/l)			Available Zn (mg/kg)
				HCO_3^-	Cl^-	SO_4^{-}	
			Loni (organic)				
0–14	Ap	0.28	40.4	1.26	1.30	0.21	1.71
14–65	Bw1	0.30	41.6	1.50	1.25	0.55	0.90
65–99	Bss1	0.29	62.4	2.0	1.00	0.16	0.55
99–144	Bss2	0.46	75.6	1.5	1.00	0.26	0.44
144–160	Bss3	0.42	74.6	2.0	1.25	0.60	0.44
Weighed mean		0.35	58.8	1.64	1.13	0.36	0.72
			Akolabazar (organic)				
0.15	Ap	0.18	58.5	1.0	1.00	0.26	0.64
15–38	Bw1	0.28	56.4	1.0	1.00	0.63	0.41
38–66	Bss1	0.15	54.8	1.0	1.00	0.10	0.40
66–107	Bss2	0.16	52.6	1.5	1.00	Tr	0.51
107–150	Bss3	0.21	47.8	1.0	1.25	0.10	0.44
Weighed mean		0.19	54.8	1.36	1.07	0.17	0.47
			Pahur (non-organic)				
0–19	Ap	0.20	45.1	2.0	2.66	0.65	0.7
19–40	Bw1	0.17	49.2	1.25	1.25	0.23	0.51
40–78	Bss1	0.27	44.1	2.00	10.50	0.40	0.50
78–122	Bss2	0.28	42.0	2.00	3.75	0.98	0.42
122–150	Bss3	0.38	68.1	1.00	2.25	0.96	0.41
Weighed mean		0.27	48.8	1.71	4.69	0.68	0.48
			Borgaon (non-organic)				
0–13	Ap	0.40	52.0	1.00	2.00	0.38	0.60
13–35	Bw1	0.16	59.2	1.50	0.50	Tr	0.30
35–58	Bss1	0.27	56.8	1.00	3.00	0.20	0.40
58–96	Bss2	0.40	55.5	1.00	4.50	1.35	0.30
96–138	Bss3	0.35	43.2	2.00	2.25	1.68	0.50
Weighed mean		0.32	52.2	1.38	2.69	0.95	0.40

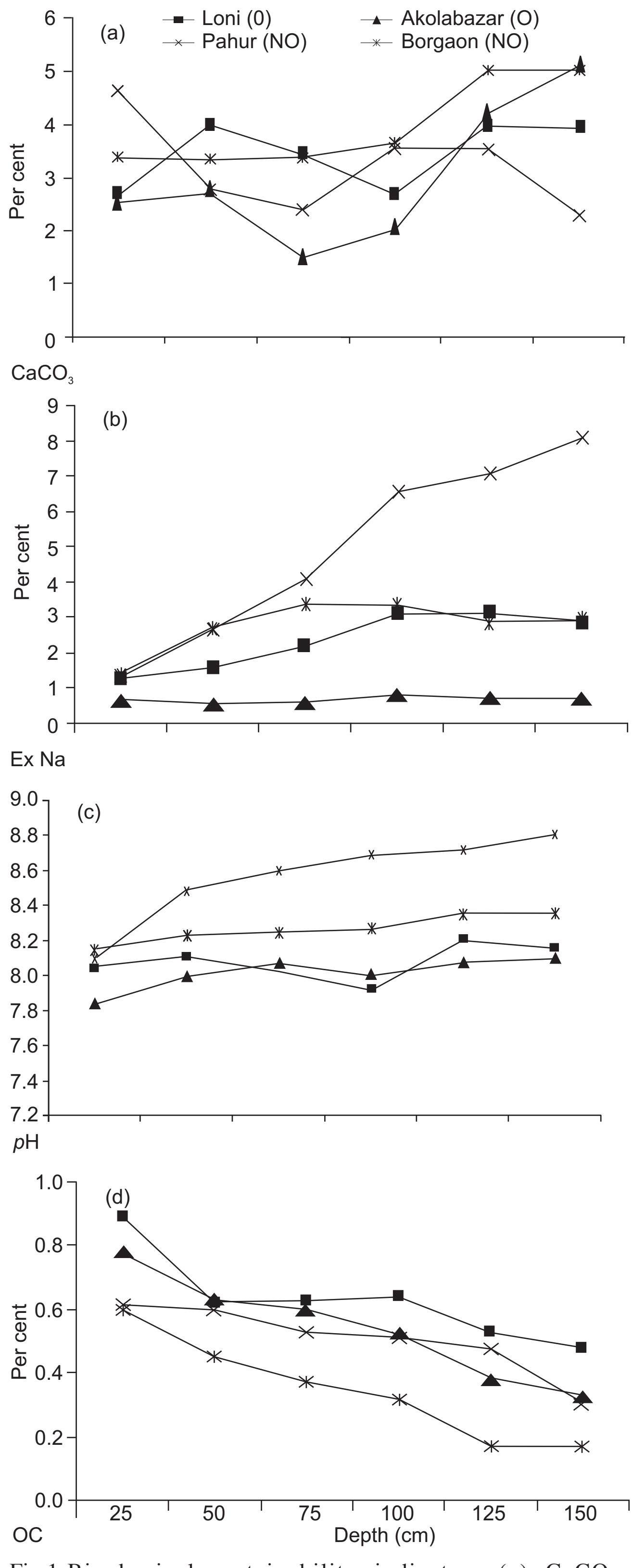

Fig 1 Biophysical sustainability indicators (a) $CaCO_3$, (b) exchangeable Na content in organic (Loni and Akolabazar) and non-organic (Pahur and Borgaon) pedons, (c) *p*H, and (d) organic carbon

(Typic Haplusterts). Their morphometric and physical properties were similar because they were developed in the alluvium of the weathering of a common parent material, basalt, under identical physiographic and climatic environment and were not readily influenced by the production system adopted.

The chemical properties being more dynamic, were influenced by the production system adopted (Table 3). The electrical conductivity (EC) did not differ in the organic and non-organic production system. Ca^{++} and Mg^{++} were the dominant exchangeable bases but the sum of exchangeable bases were slightly higher (58.8 and 54.8 (cmole (p+)/kg) in the organic pedons than the non-organic pedons (48.8 and 52.2 (cmole (p+)/kg). The Cl^{-} and SO_4^{-} contents of the saturated extract were lower in the organic pedons (weighted means of 1.07–1.13 and 0.17–0.36 me/litre, respectively) than the non-organic pedons (weighed means of 2.69–4.69 and 0.68–0.95 me/litre, respectively). The higher exchangeable Na, accompanied by high concentration of Cl^{-} and SO_4^{-} in the saturated extracts indicate the inherent potential to develop sub-soil sodicity (Pal *et al.* 2000) and this tendency was reduced in the organic production system. The available Zn content was higher in the organic (0.4–1.71 mg/kg) than the non-organic pedons (0.3–0.7 mg/kg).

The biophysical sustainability of the production systems was assessed using 4 soil quality parameters, viz *p*H, exchangeable Na, organic carbon and $CaCO_3$ relevant to the semi-arid pedo-climatic regime (Fig 1). Compared to organic pedons, the soil *p*H was higher in the non-organic pedons and *p*H increased with depth. The exchangeable Na content increased with depth and the soils-surface horizons of non-organic pedons had a higher exchangeable Na. The pedon from the non-organic (Pahur) site which had a sub-soil *p*H 8.6 to 8.8 and exchangeable Na between 4.1 and 8.1 mole (p+)/kg was under sugarcane. The organic carbon content which declined with depth was consistently higher in the organic pedons compared to the non-organic ones. Blaise *et al*. (2004) also observed a higher organic carbon content up to 0.9 m depth in organically maintained cotton plots. All the soils were calcareous and $CaCO_3$ was irregularly distributed in the profile. However, the $CaCO_3$ content in the surface layer was lower in the organic pedons.

Properties of surface samples: The mean *p*H and $CaCO_3$ contents were high in the soils under non-organic compared to the organic production systems (Table 4). In the non-organic soils, there was a further increase in the sodicity as well as $CaCO_3$ content between the sampling periods (2001 and 2005). The proportion of non-organic soil samples with *p*H above 7.8 increased from 53 to 87% (Table 5). The proportion of samples with more than 7% $CaCO_3$ increased from 33% in 2001 to 47% in 2005. The mean organic carbon content was 31% higher in the organic production system than the non-organic one in 2001 which further increased to 41% in 2005. Although all the soils were calcareous, the

Table 4 Properties of surface soils under organic and non-organic systems

Property	Organic				Non-organic			
	Year	Range	Mean	SEm	Range	Mean	SEm	t test
*p*H	2001	7.1-8.10	7.73	0.05	7.7-8.40	8.01	0.07	**
	2005	7.27-8.1	7.79	0.03	7.66-8.38	8.05	0.04	**
$CaCO_3$ (%)	2001	1.1-12.5	5.3	0.32	2.4-12.2	6.2	0.77	NS
	2005	2.4-11.8	5.4	0.27	3.1-12.9	6.9	0.75	*
Av. Zn (mg/kg)	2001	0.39-2.14	0.88	0.08	0.38-1.07	0.66	0.05	*
	2005	0.46-2.28	0.90	0.03	0.30-1.12	0.57	0.06	**
Org. carbon (%)	2001	0.31-1.70	0.76	0.04	0.32-0.86	0.58	0.05	*
	2005	0.52-1.68	0.86	0.03	0.35-0.87	0.61	0.04	**
Organic carbon as	2001	51.0-69.4	54.5		37.0-53.7	45.5		
per cent of total carbon	2005	54.2-64.4	57.7		35.0-48.5	43.3		

* and ** indicate significant at 5 and 1% respectively

$CaCO_3$ in the surface soil, the HCO_3^- content in the saturated extract and *p*H in the surface as well as profile samples were lower under the organic production system. Besides the native $CaCO_3$ present in these soils, the semi-arid climate favours the formation of pedogenic $CaCO_3$ and concomitant increase in ESP (Pal *et al.* 2000). This is a natural degradation process which must be arrested to maintain soil quality. Conversion to organic production system reverted this natural degradation by improving the organic C content. Further, the organic acids released during the decomposition of organic matter decreased the *p*H, solubilized $CaCO_3$ and releases Ca^{++} (Bhattacharyya *et al.* 2001). This in-turn improves porosity, water infiltration and permeability. This cyclic effect of improvement in organic carbon content and a concomitant decline in $CaCO_3$ content arrested further rise in soil *p*H, development of sub-soil sodicity and decline in hydraulic conductivity. Thus adoption of organic production systems may be an alternative to the application of gypsum (chemical amendment) for these soils as suggested by Pal *et al.* (2000).

The organic carbon was above a minimum threshold of 0.63% (Bhattacharyya *et al.* 2006) in 71 and 90% of the soils sampled from organic farms in 2001 and 2005, respectively (Table 4). Contrarily, in 60–66% of the soils from non-organic farms the organic carbon was below this threshold level. The proportion of organic carbon as a percentage of total carbon was also higher in the organic than non-organic production system and this increased from 54.5 to 57.5% between the sampling periods, indicating a decrease in the formation of pedogenic carbonates. Despite a hot, semi-arid tropical climate, higher values of organic carbon (above the threshold level of 0.63%), indicates sequestration of carbon due to the adoption of organic production system. Venugopalan and Tarhalkar (2003) also observed that continuous application of farmyard manure and other organic materials to rainfed cotton-based systems in Vertisols improved the organic C in the surface and sub-surface soils.

The mean available Zn content was 0.22 mg/kg higher in soils under the organic system compared to non-organic system in 2001 and this difference increased to 0.31 mg/kg by 2005. Majority (73%) of the soils from non-organic farms (Table 4) had available Zn content below the critical level of 0.7 mg/kg (Lindsay and Norvel 1978). However, adoption of the organic production system improved the availability of Zn to levels above this critical limit in 64 and 76% of the samples in 2001 and 2005, respectively. Blaise *et al*. (2004) also observed a significant build-up in available Zn in rainfed cotton on Vertisols which were continuously maintained under organic condition.

Table 5 Frequency distribution (%) of surface soils for different properties under organic and non-organic system

Class interval	2001		2005	
	Organic	Non-organic	Organic	Non-organic
*p*H				
7.01–7.40	19	0	6	0
7.41–7.80	32	47	46	13
7.81–8.20	49	33	48	60
8.21–8.60	0	20	0	27
Organic carbon (%)				
0.231–0.630	29	66	10	60
0.631–1.030	64	34	73	40
1.031–1.430	5	0	15	0
1.431–1.830	2	0	2	0
Calcium carbonate (%)				
1.01–4.00	22	27	17	13
4.01–7.00	66	40	70	40
7.01–10.00	10	20	11	33
10.01–13.00	2	13	2	14
Available zinc (mg/kg)				
0.20–0.70	36	73	24	73
0.71–1.20	51	27	61	27
1.21–1.70	8	0	10	0
1.71–2.20	5	0	5	0

Despite similar substrate quality and identical climatic influence, the cotton-growing Vertisols and their intergrades of Yavatmal district have the ability to sequester more organic carbon by adoption of organic production systems. This system appears to be a sustainable management option to enhance the organic carbon status, which in turn improves many physical and chemical properties, besides arresting the natural degradation of these soils through the formation of pedogenic $CaCO_3$ and sodicity. Thus, organic production system would help in sustaining the productivity of cotton grown under low input, sub-optimal pedo-climatic conditions not only in Yavatmal district but also in similar soils and climatic environment elsewhere in the Indian sub-continent.

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