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RESEARCH ARTICLE

SUSTAINABILITY OF SUGARCANE PRODUCTIVITY IN A LONG-TERM ORGANIC PRODUCTION SYSTEM VIS-À-VIS CONVENTIONAL SYSTEM

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Abstract

A 10-year long-term field study was initiated during 2003-04 with the objective of comparing the productivity and sustainability of organic sugarcane production system with that of conventional intensive system. In this study, two treatments, viz. organic and conventional production systems were maintained in fixed plots of 0.2 ha each accommodating 300 rows of 6m length spaced 90cm apart. The cropping programme consisted of three crop cycles each comprising a plant crop of sugarcane followed by a ratoon, green manure crop and rotational cotton; one additional plant crop was raised during 2012-13. Recommended package of practices with integrated nutrient management for conventional system and the guidelines issued by the Government of India and *Codex Alimentarius Commission* for organic production system were adopted for both plant and ratoon crops of sugarcane, and cotton. Growth parameters such as shoot/stalk population at 120,180 and 240 days after planting/ ratooning, and yield parameters like number of millable canes (NMC), cane length, cane diameter, number of internodes and single cane weight at harvest showed lower values in organic system until 2007-08 ratoon crop but started showing consistently higher values thereafter. The differences were significant between organic and conventional systems in all the years except 2007-08 ratooncrop. The lower productivity in the early years of the study was partly due to the outbreak of woolly aphid *Ceratovacunal anigera* Zehntner (Homoptera: Aphididae). Consistent and significantly higher yields (14.8,15.5 and 4.4%) obtained in the organic production system from 2009-10 could possibly be due to higher soil nutrient availability, soil organic carbon content, beneficial microorganisms and soil enzyme activities, besides lower activity of plant parasitic nematodes in the organic production system than in the conventional production system. Control of the invasive pest *C. lanigera* through biological agents was also responsible for stabilization of yields in both systems in the later years. Rotational cotton crop showed consistently higher yields of 12.2, 118.2 and 25.0% during 2005-06, 2008-09 and 2011-12, respectively under conventional production system than in organic system, the unusual difference in the second crop attributable to the invasive mealybug *Paracoccus marginatus* Williams and Granara de Willink (Homoptera: Pseudococcidae). The present long-term study indicated that yields/productivity of sugarcane could be sustained through adoption of organic production system taking care to manage the invasive pests through contingent planning.

Key words: Sugarcane, organic farming, conventional farming, productivity, sustainability, invasive pests, biological control

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Introduction

According to the *Codex Alimentarius Commission*, 'organic agriculture/farming is a holistic production management system that avoids use of synthetic fertilizers, pesticides and genetically modified organisms; minimizes pollution of air, soil and water; optimizes the health and productivity of interdependent communities of plants, animals and people (*Codex Alimentarius Commission* 2013). The organic farming system differs fundamentally in soil fertility, weed, pest and disease management, and makes higher demands on product quality and yield stability than conventional farming. Organic farming systems aim at resilience and buffering capacity in the farm ecosystem by stimulating internal self-regulation through functional agro-biodiversity in and above the soil, instead of external regulation through chemical protectants (Bueren et al. 2002), enabling agricultural systems to be productive indefinitely, without exerting negative effects on their surroundings (Raviv 2010).

Organic farming is gaining broad recognition as a system that complies well with sustainability, a far-reaching principle that will drive agriculture activities in the years to come (Knight and Newman 2013). The demand for organic products is also constantlyincreasing since they are perceived by consumers as healthier andsafer for the environment.Organic farming is a subject that triggers many different responses in people. Some are convinced that it is the way forward while others question its benefits and the wisdom of its large-scale implementation.The topic was the focus of intense debate in several fora such as Symposia (Chhonkar 2003; Magar 2004; Kirchmann and Bergström 2008) and other reports (Ramesh et al. 2005; Charyulu and Biswas 2010).

In a meta-analysis (Dobermann 2012; Reganold 2012; Seufert et al. 2012) of 316 yield comparisons in 66 studies, organic farming systems in developed countries produced yields that were 20% lower than their conventional counterparts. However, the authors also found that for certain crops under unique growing conditions and management practices, organic yields nearly matched those from conventional systems. These findings underscore the potential for organic farming to have an increasing role in a sustainable food supply. There are wide variations among yields and production costs, but either higher market price and premiums or lower production costs or the combination of these two generally result in higher relative profit in organic agriculture in developed countries. Besides, higher yields combined with high premiums are the underlying cause for higher relative profitability in developing countries (Nemes 2009).

India is gifted with the potential of producing multifarious organic products due to its diverse agro-climatic zones. In several parts of the country, the inherited tradition of organic farming is an added advantage (Ramesh et al. 2005; Prasad and Gill 2009; APEDA 2014). This holds promise for the organic producers to tap the niche market which is growing steadily both in domestic and export segments. Currently, India ranks 10th among the countries in terms of cultivable land under organic certification. India produced around 1.34 Mt of certified organic products which included all varieties of food products namely sugarcane, cotton, Basmati rice, pulses, tea, spices, coffee, oilseeds, fruits and vegetables, and their value added products. The production was not limited to the edible sector but extended to organic cotton fiber, functional food products, etc. Among the states, Madhya Pradesh has covered the largest area under organic certification followed by Rajasthan and Uttar Pradesh. Amongthe products during 2012-13, oil seeds and soybean (41%) are followed by cane sugar (26%), processed food products (14%), Basmati rice (5%), other cereals and millets (4%), tea (2%), spices (1%), dry fruits (1%) and others (APEDA 2014; FiBL and IFOAM 2014).

In sugarcane, comparative economics of the crop grown in both organic and conventionalsystems in growers’ farms led to the conclusion that a combination of fertilizers and organic manures is essential for the crop (Gawade et al. 2005). Improvement in soil physical properties, and enhancement of carbon content and available N, P, K and S were observed under organic farming (Prashanth et al. 2009). A combination of inorganic, organic and biofertilzers, biopesticides (neem cake), trash mulching and green manuring with green gramwas found suitable for sustaining productivity, maintaining soil fertility and obtaining highermonetary returns in plant and ratoon (Thakur et al. 2012). The observations of Gawade et al. (2005) and Kshirsagar (2008) indicated marginal differences in the cost ofplant protection between organic and inorganic farming systems.

In Kolhapur district of Maharashtra, organic sugarcane farming was a sustainable system due to saving in costs of human labour, seed, fertilizer, plant protection and irrigation as compared to inorganic sugarcane farming (Jadhav et al. 2013). In contrast, in Mysore, Karnataka, yields were more or less similar under both systems of production and the yield gap was highly contextual (Patil et al. 2014). Observations from our long-term study on organic farming indicated that productivity could be sustained provided the entire dose of nutrients is applied through the use of organics (Anonymous 2003) and preparedness to face invasive pests is ensured (Sivaraman et al. 2012; Srikanth et al. 2009 and 2013).

In this paper, we present results of the productivity component from a long-term (2003-13) study, conducted in the light of the preceding background with the objective of ascertaining the sustainability of organic system of sugarcane production vis-à-vis conventional system since no such long-term studies are available.

Materials and methods

Study site

The long-term study was conducted in the experimental farm of the Sugarcane Breeding Institute, Coimbatore (11^{0}00’ 30.89’’N, 76^{0}55’ 02.87’’E; 430 m above mean sea level) in the North Western region of Tamil Nadu, India, during the crop seasons of 2003-13. The soil was red sandy loam with medium available N and P, and high K.

Production systems

Organic and conventional systems were maintained in fixed plots of 0.2 ha each that accommodated 300 rows of 6m length spaced 90cm apart. The cropping programme (Fig.1) consisted of three crop cycles each comprising sugarcane plant,

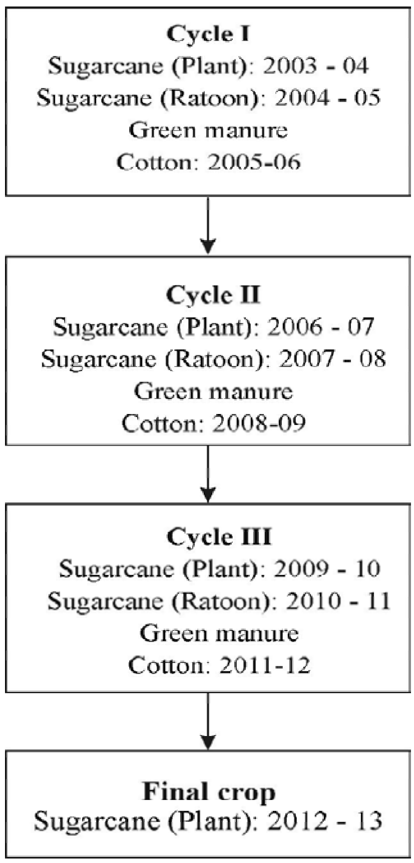

Fig.1. Cropping cycles adopted in the long-term study on organic sugarcane production

sugarcane ratoon, *daincha* (*Sesbania culeata* (Willd.) Pers.), green manure and rotational cotton crops. The sugarcane variety used in the study was the popular and widely cultivated Co 86032 which was planted or ratooned during March/April. Cotton (cv Sumangala in 2005-06; Suraj - Culture No. CCH 510 – 4 in 2008-09 and 2011-12) was sown in August at a spacing of 90 cm x 60 cm with each 6 m row accommodating 11-12 plants. The following operations were followed/practised in the experimental plots.

Management operations common to the two systems

The plot allotted to each system was kept constant until the close of the experiment**.** Cultural operations like ploughing, forming ridges and furrows were done separately to avoid any mixing of soil from organic to conventional plots and vice-versa. Field preparations common to both systems for plant crops included disc ploughing twice, ploughing with cultivator twice, running rotovator for breaking clods, use of field leveller, forming ridges and furrows at 90 cm row spacing, forming irrigation channels and rectification, application of farm yard manure (FYM) at 12 t/ha before planting two budded settsof sugarcane at 50 setts per 6 m row, and irrigation schedule. In case of ratoon crops, preparatory cultivations were replaced by stubble shaving and off-barring operations. Gap filling was done using pre-germinated setts raised in polybags to maintain population. Trash collected from both plant and ratoon crops was utilized for mulching inter-row spacings. Following the ratoon crop, a green manure crop (*S. aculeata*) was raised in both the systems and this was subsequently followed by a rotational crop of cotton.

Operations specific to organic system

Recommended dose of nitrogen (280 kg/ha) was applied through FYM (0.5% N). Phosphorus (60 kg/ha) and potassium (120 kg/ha) requirements of the crop were met from this application of manure. Bio-fertilizers were also applied as recommended. Fifty per cent of FYM was applied before planting and the rest at 90 days after planting (DAP). Cotton as rotation crop received recommended doses of N, P and K (60:30:30 kg/ha) through FYM. Weeds were managed either through hand hoeing or by mechanical means. *Sesbania culeata* was raised as intercrop green manure with plant crop and incorporated at 45 DAP. Plant protection was through biocontrol methods / biopesticides / non-chemical methods. Guidelines issued by the Government of India / *Codex Alimentarius Commission* (*Codex Alimentarius Commission* 2013) were also taken into consideration for pest and disease management under organic management. Trash collected from each plot was applied *in situ* as mulch in the furrows for recycling and adding organic matter to the soil.

Operations specific to conventional system

Nutrient requirements of the crops were met through recommended integrated nutrient supply system (Balasundaram et al. 2003). Pests, diseases and weeds were managed through conventional means i.e., mainly through application of pesticides, fungicides and herbicides.

Data collection

For data collection, each production system plot was divided in to 15 equal sized quadrats comprising 20 rows of 6m length each (Fig. 2). Observations of different growth parameters were recorded on randomly sampled plants from each of the quadrats; yield was recorded from NMC of the entire quadrat.

Growth parameters

Two rows in each quadrat were selected at random and labeled in both organic and conventional production systems for recording growth observations such as shoot population at 120 and

CONVENTIONAL PLOT	1*	2	3	4	5
	6	7	8	9	10
	11	12	13	14	15
ORGANIC PLOT	1	2	3	4	5
	6	7	8	9	10
	11	12	13	14	15

*Each quadrat with 20 rows of 6m length at 90 cm row spacing

Fig. 2. Sampling plan adopted for data collection

180 DAP or days of ratooning (DAR), stalk population at 240 DAP or DAR and NMCs at harvest. The data thus obtained were converted to plant population per ha. Five randomly cut canes were used for measuring the length of canes, number of internodes, length of internodes and single cane weight.

Yield

Quadrats with 20 rows constituted a sample unit for cane yield. Each quadrat was harvested separately, the weight of canes recorded and weights these were converted to values per ha. A similar sampling procedure was followed for recording the yield of cotton *kapas*.

Data analysis

The data recorded under various parameters were subjected to two sample *t* test for significant differences between organic and conventional sugarcane production systems.

Results and discussion

Growth and yield parameters

Growth parameters of sugarcane such as shoot/stalk population at 120,180 and 240 DAP/DAR, and NMC at harvest (Fig.3) showed considerable variation among years, including plant and ratoon, and organic and conventional systems. Shoot population at 120 DAP/DAR (Fig. 3a) varied the most amongst the growth parameters. The population which was the highest in cycle I decreased considerably in cycle II but increased marginally in cycle III. In general, ratoon showed higher population than plant crop in all the three cycles. Organic and conventional systems differed only during 2007-08 ratoon and 2012-13 plant and in both crops organic had higher population than conventional. Shoot population at 180 DAP/DAR did not vary considerably among different years but showed slightly lower values in ratoon than in plant crop (Fig. 3b). However, between the two systems, organic showed higher values than conventional in three out of four years. Stalk population at 240 DAP/DAR showed a slight decline in cycle II but appeared to recover in cycle III with no discernible differences between plant and ratoon (Fig. 3c). In continuation of the trend shown by shoot population at 180 DAP/DAR, stalk population at 240 DAP/DAR too showed higher values in organic than in conventional in four out of five years that showed significant differences. NMCs followed a trend similar to that of stalk population at 240 DAP/DAR with no difference between plant and ratoon crops (Fig. 3d). Organic and conventional systems differed significantly only in two years both of which showed higher values in the former.

Yield parameters of sugarcane did not vary as much as growth parameters (Fig. 4). Cane length was uniform among years, crops and systems except in one year when organic showed higher cane length (Fig. 4a). With minimal variation, cane diameter was significantly higher in organic than conventional system in four years (Fig. 4b). Number of internodes too showed uniformity across all variables and was higher in organic in two years (Fig. 4c). Single cane weight, which effectively contributes to the yield just as NMCs, surprisingly showed very little variation except being higher in one year (Fig. 4d).

Sugarcane yield

The yields of sugarcane (Table 1) over the study period showed interesting trends, apparently governed by various causes including the crucial NMC and single cane weight. The differences were significant between organic and conventional systems in almost all years except 2007-08 ratoon crop. In the 2003-04 plant crop, the yield was significantly higher in the organic system that received high volume low-content organic nutrient supply, possibly due to the ability of the crop to utilize the resident nutrient matrix. The chronic effect of withdrawal of rich inorganic nutrient supply began showing its effect in the subsequent years beginning 2004-05 ratoon crop. The impact of depleting nutrient supply on the organic crop was compounded by the

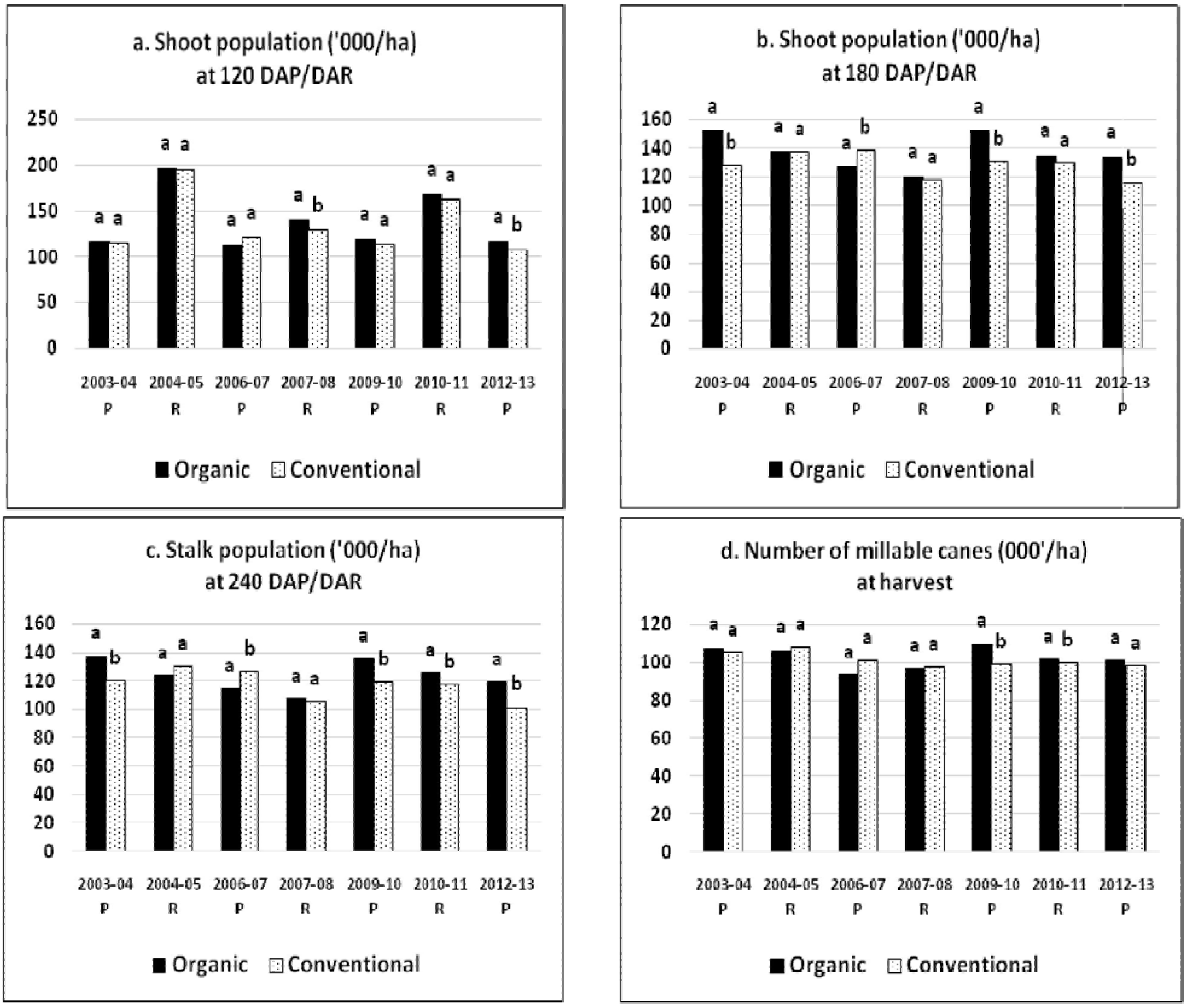

Fig.3. Growth parameters of sugarcane under organic and conventional production systems (2003-13). DAP - days after planting; DAR-days after ratooning; P-Plant; R-ratoon; bars with the same letter for any year are not significantly different (*P*>0.05) by Student's test

severe outbreak of the woolly aphid *Ceratovacuna lanigera* Zehntner (Homoptera: Aphididae) during September-January when the plant crop was six months old and its delayed control through augmentative releases of the predator *Dipha aphidivora* (Meyrick) (Lepidoptera: Pyralidae). The slightly higher, i.e. normal yield in conventional system was due to the control of the aphid through constant monitoring and spot application of insecticides (Srikanth et al. 2009). Although the aphid attack in the current season is often known to reduce sprouting and growth in the ratoon, the non-significant difference between organic and conventional systems in 2007-08 ratoon indicated no such negative effect of the aphid but, on the other hand, indicated a slight recovery by the organic crop. Consistently and significantly higher yields (14.8,15.5 and 4.4%) obtained in the organic production system from 2009-10 could possibly be due to higher soil nutrient availability, soil organic carbon content, beneficial microorganisms and soil enzyme activities, besides lower activity of plant parasitic nematodes in the organic production system than in the conventional production system

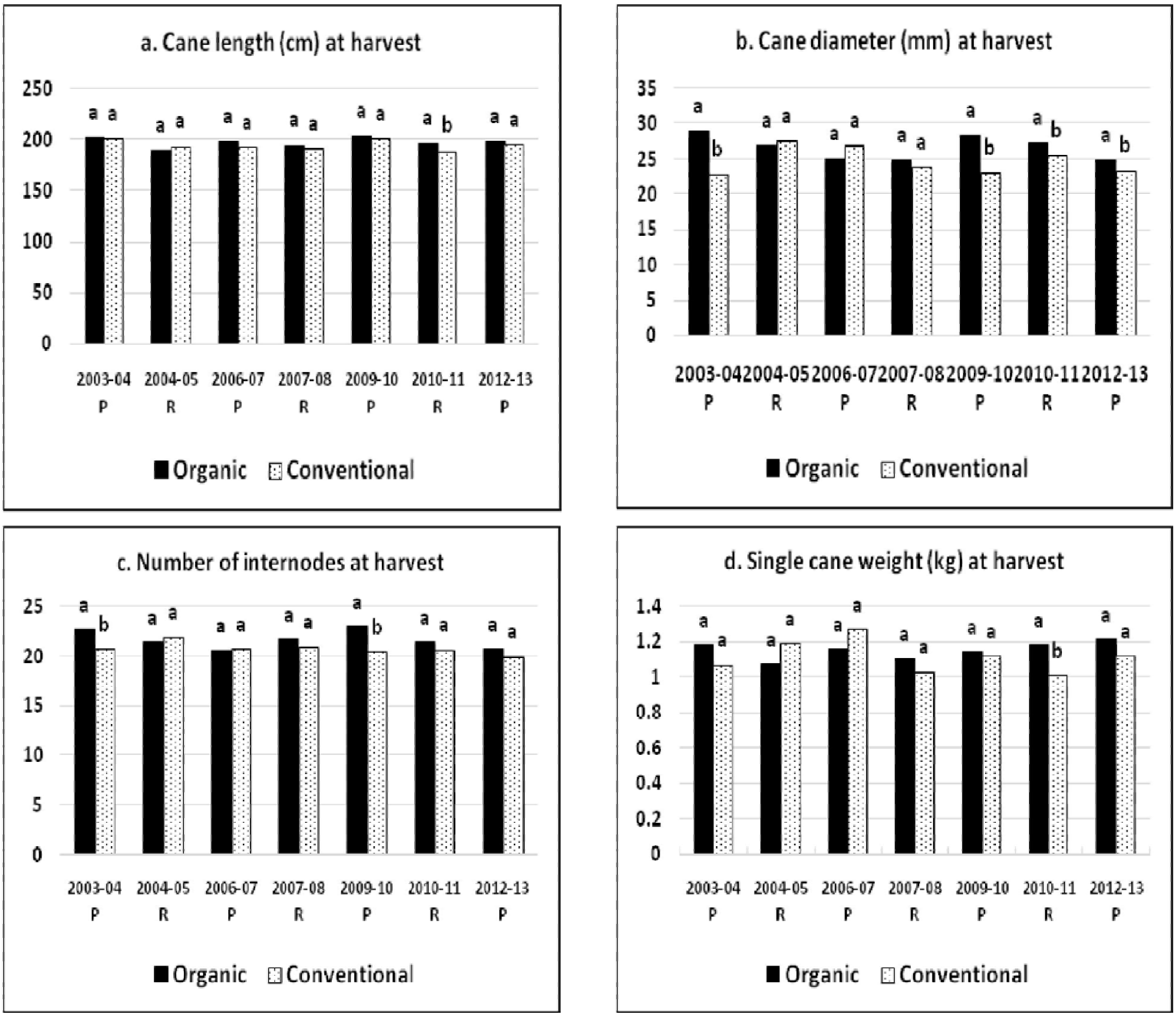

Fig.4. Yield parameters of sugarcane under organic and conventional production systems (2003-13). DAR-days after ratooning; P-Plant; R-ratoon; bars with the same letter for any year are not significantly different (*P*>0.05) by Student's test

Table 1. Productivity of sugarcane (t/ha) and cotton (q/ha) under organic and conventional production systems during 2003-13

Cycle	Crop@	Year	Production system		*t* test
			Organic	Conventional	
I	Sugarcane (P)	2003-04	125.7	117.7	4.798***
	Sugarcane (R)	2004-05	117.7	123.1	3.322**
	Cotton	2005-06	21.28	23.88	3.298**
II	Sugarcane (P)	2006-07	106.7	125.6	9.288***
	Sugarcane (R)	2007-08	105.0	103.0	0.714ns
	Cotton	2008-09	8.97	19.57	24.122***
III	Sugarcane (P)	2009-10	124.0	108.0	8.105***
	Sugarcane (R)	2010-11	119.0	103.0	7.446***
	Cotton	2011-12	18.74	23.43	7.588***
Final crop	Sugarcane (P)	2012-13	119.0	114.0	2.322*

@P- plant; R - ratoon
$^{*}P<0.05$; $^{**}P<0.01$; $^{***}P<0.001$; $^{ns}P>0.05$

(Sivaraman et al. 2012).The inconsistent difference between plant and ratoon crop yields in a given cycle, except under the influence of external stress like woolly aphid, indicated that the type of planting had no serious effect on yield. Invasive pests such as woolly aphid appeared to pose a threat to organic production system since emergency insecticidal control could not be used against it. However, the subsequent identification and field establishment of potential natural enemies such as *Encarsia flavoscutellum* Zehntner (Hymenoptera: Aphelinidae) led to stabilization of the aphid in a short span of 2-3 years not only in organic system but also under conventional cultivation, as was observed in the 2007-08 ratoon (Srikanth et al. 2009) and 2012-13 plant (Srikanth et al. 2013) crops. Such contingencies hinder the progress of organic farming temporarily but need not undermine its prospects and practice. The overall stability of the crop naturally favors organic cultivation with least interference from resident borer pests whose populations generally remain under equilibrium (Srikanth et al. 2013). By virtue of its geographical location, historically Coimbatore is relatively free from most of the sugarcane diseases. Under natural conditions, no disease incidence was observed during the study period and hence the comparison between conventional and organic plots could not be made.

Cotton yields

The yields of rotational cotton crop during 2005-06, 2008-09 and 2011-12 were consistently higher (12.2, 118.2 and 25.0%) under conventional production systemthan in organic system (Table 1). In the 2005-06 crop, sprays of neem oil with Teepol at 30, 60 and 90 DAP, and Neemazal, an azadirachtin compound, at 100 and 120 DAP in organic plot gave relief against sucking pests; methyl demeton at 30 DAP, dicofol at 90 DAP, and imidachloprid and dicofol at 120 DAP were effective in the conventional plot. In 2008-09 crop, the invasive papaya mealybug *Paracoccus marginatus* Williams and Granara de

Willink (Homoptera: Pseudococcidae) in the conventional plot was controlled with recommended insecticides. However, application of Neemazal in the organic plot gave only minimal control of the pest. The severe infestation of mealybug devastated the organic crop which recorded significantly lower *kapas* yield of 8.97 q/ha as against 19.57 q/ha in conventional plot. In the 2011-12 crop, papaya mealybug incidence was not observed, apparently due to the introduction and establishment of specific and efficient natural enemies in the intervening two years by cotton entomologists (Dharajothi et al. 2011). Spray applications of imidacloprid and acephate in the conventional plot, and neem oil and Neemazal in the organic plot were adopted to bring down the populations of sucking pests.

In earlier short-term studies in subtropical India, highest cane yields were obtained through combined use of sulfitation pressmud and FYM for the supply of nutrients (Srivastava et al. 2009) and productivity could be sustained through the integrated supply of nutrients with greater share of inorganic than organic source (Thakur et al. 2012). It was observed in Karnataka that sugarcane yields stabilized by the end of the third year and became higher with organic sugarcane farming than inorganic farming from the fourth year (IFAD 2005). However, there was no significant difference in yield between inorganic and organic sugarcane farming treatments in an experiment conducted in Iran (Soraghi et al. 2013). Resultsof our earlier preliminary studies (Anonymous 2003) and the present elaborate study established that productivity can be sustained through adoption of an organic production system comprising only organic sources of nutrients, notwithstanding the transition period and management of unanticipated biotic stresses.

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