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ORIGINAL ARTICLE

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Soil Fertility, Yield and Yield Attributes of Rainfed Sugarcane during Transition to Organic Production

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ABSTRACT

Field experiment was conducted consecutively for three years in the same field (2021-22 to 2023-24) at Regional Agricultural Research Station, Anakapalle to standardize the production protocols of organic farming for sugarcane under rainfed condition, with an objective to study the effect of organic farming on yield attributes, yield, quality, soil fertility and nutrient uptake of sugarcane. During the first two years, significantly superior cane and sugar yields were recorded in inorganic farming; however, on par cane yields (58.27 and 56.20 t ha^{-1} in organic and inorganic farming, respectively) were recorded during the third year. Sugar yields followed a similar trend, with higher yields recorded in inorganic farming during the first two years, whereas in the third year organic farming recorded a relatively higher sugar yield, with mean sugar yields of 7.48 and 8.03 t ha^{-1} in organic and inorganic farming, respectively. Significantly highest shoot mortality was observed in inorganic farming, whereas organic farming showed less mortality of shoots from the formative to grand growth stage. Significantly highest macronutrient uptake was observed in inorganic farming during the first two years, whereas in the third year on par results were recorded for all three macronutrients, likely reflecting the on par cane yields recorded in both treatments. Organic carbon content increased significantly under organic farming (0.56%) compared to inorganic farming (0.54%), from an initial value of 0.53%, over the three-year period. Inorganic farming recorded relatively higher available nitrogen, phosphorus and potassium status across all three years, with mean values of 242, 65 and 285 kg ha^{-1}, respectively, against 226, 61 and 276 kg ha^{-1} under organic farming. A reverse trend was observed for soil beneficial microbes, which were significantly higher in organic farming plots than in inorganic farming across all three years.

1 | INTRODUCTION

Sugarcane is one of the important commercial crops in the North Coastal Zone of Andhra Pradesh and is cultivated under both irrigated and rainfed conditions. Rainfed sugarcane occupies around 45 per cent of the total cane area in the North Coastal districts of Andhra Pradesh. Sugarcane production has tended to remain either stagnant or declining despite the application of high-cost inputs; depletion of soil quality, particularly organic carbon levels, is one of the factors responsible for yield decline in these areas. Experts attribute this stagnation to the destruction of soil health caused by application of imbalanced fertilizers without addition of organic matter. Organic farming is a holistic production system which promotes and enhances agro-ecosystem health, including biodiversity, biological cycles and soil biological activities. In the context of environmental pollution, health hazards and threats to soil sustainability, organic farming is gaining prominence, even though it has both merits and demerits in crop production. In rainfed crops, input usage has a greater effect than cultural practices. Over the last two decades, there has been significant emphasis on soil carbon build-up for sustainable soil and crop productivity. The vast majority of rainfed farmers in several areas still practise low- or no-external-input farming, well integrated with livestock, and average chemical fertilizer use in rainfed areas remains very low compared to irrigated areas. The Government of India task force on organic farming and several other reviewers have identified rainfed areas as more suitable for organic farming, given the low input use (Dwivedi, 2005; Ramesh *et al.*, 2005). Organic farming is now becoming mainstream across the country through various schemes and rising consumer demand. Extensive information is available on the yield and economics of a number of rainfed crops and cropping systems where complete organic manures, or organics as part of INM packages, have been used (Lomte and Pendke, 2004). Organic jaggery is prepared by most farmers and sold at a premium; however, crop production protocols for organic farming under rainfed conditions have not yet been standardized. Hence, the present study was conducted from 2021-22 to 2023-24 to standardize production protocols for sugarcane under rainfed conditions, with an objective to study the effect of organic farming on soil and crop productivity of sugarcane.

2 | MATERIALS AND METHODS

The field experiment was conducted from 2021-22 to 2023-24 on Inceptisols with two treatments: T1 – Organic Farming (cane trash in-situ incorporation; Farm Yard Manure @ 10 t ha^{-1}; biofertilizers, i.e. Azotobacter, PSB and KRB @ 5 kg ha^{-1} at planting; enriched compost @ 2 t ha^{-1} at 30 DAP; Panchagavya spray @ 3% at 30 and 60 DAP; biofertilizers @ 5 kg ha^{-1} at 45 DAP; and Jeevamrutham drenching @ 1000 L ha^{-1} at 45, 60, 75, 90 and 105 DAP), and T2 – Inorganic Farming (100% recommended dose of chemical fertilizers), with test variety 93A 145. An exhaust crop was sown before the main crop, and the two treatments were isolated by a 1.5 m gap. Land preparation was followed by furrow formation at 60 cm spacing, and planting was done with three-budded setts. All package-of-practice recommendations were followed as described above.

2.1 | Data on yield and yield attributes

Juice analysis was carried out prior to harvest; juice quality observations, i.e. sucrose percentage, commercial cane sugar (CCS) and purity percentage, were estimated as per the method suggested by Meade and Chen (1977). Shoot population was recorded at the formative and grand growth stages, and the number of millable canes (NMC) was recorded at harvest along with cane yield data. Sugar yield was computed as cane yield multiplied by % CCS.

2.2 | Chemical analysis of soil and plant samples

Soil samples were collected before initiation of the experiment to establish initial soil status, and again from post-harvest soils after each harvest. Initial and final soil samples were air-dried and sieved to pass a 2 mm mesh for determination of soil physico-chemical properties (pH, electrical conductivity and organic carbon) and available nitrogen, phosphorus, potassium, zinc and iron, following standard procedures (Jackson, 1967). Soil pH and EC were measured using a digital pH meter and EC bridge, respectively. Soil organic carbon content was determined using the Walkley and Black wet-digestion method. Available nitrogen was estimated by the alkaline permanganate method (Subbiah and Asija, 1956); available phosphorus by the Olsen extraction method (Olsen *et al*., 1954); and available potassium by flame photometry. Available zinc and iron were estimated in the DTPA extract following Lindsay and Norvell (1978). Plant samples were collected at the grand growth stage for nutrient uptake studies, and macro- and micronutrient analysis was carried out as per Jackson (1967). Rhizosphere soil samples were collected and assayed for soil microbial population. Data on yield and soil fertility parameters were subjected to analysis of variance using standard statistical software (Chandel, 2002).

HIGHLIGHTS

- Organic farming matched inorganic cane yield by the third year of transition.
- Organic carbon and beneficial soil microbes increased significantly under organic management.
- Available nitrogen, phosphorus and potassium remained higher under inorganic farming throughout.

3 | RESULTS AND DISCUSSION

3.1 | Shoot population and number of millable canes at different growth stages

The three-year mean shoot population counts at the formative and grand growth stages were 99303 and 92053 No. ha^{-1} under organic farming, and 100060 and 89175 No. ha^{-1} under inorganic farming, respectively (Table 1). Mean NMC of 83933 No. ha^{-1} was recorded under organic farming, compared with 82362 No. ha^{-1} under inorganic farming. Percent mortality of shoots from formative to maturity was 18.31 under organic farming, compared with 21.62 under inorganic farming. During the first year, shoot population at the formative and grand growth stages was relatively higher under inorganic farming (92200 and 101560 No. ha^{-1}, respectively) than under organic farming (91650 and 99860 No. ha^{-1}, respectively), whereas in the third year it was slightly higher under organic farming, a trend also reflected in the percent mortality of shoots.

Regarding millable canes, on par results were observed during the first two years, whereas in the third year significantly higher millable cane counts were observed under organic farming than under inorganic farming. Shoot mortality from formative stage to harvest was slightly higher under inorganic farming during the first two years, and significantly higher under inorganic farming during the third year, likely due to continuous availability of nutrients through organic inputs under organic farming. Gayatri Verma and Vikrant Singh (2023) reported that nutrients such as nitrogen, phosphorus, potassium and various micronutrients are necessary for plant metabolism, photosynthesis, root development and sugar accumulation, and that adequate nutrient availability contributes to better tillering, higher NMC and increased biomass production, all of which positively affect cane productivity.

3.2 | Juice quality

Juice quality with reference to juice sucrose, for the mean of three years, showed slightly higher sucrose under organic farming (18.98%) than under inorganic farming (18.63%) (Table 2).

3.3 | Cane yield and sugar yield

During the first two years, significantly superior cane and sugar yields were recorded under inorganic farming compared with organic farming; however, on par cane yields (58.27 and 56.20 t ha^{-1} in organic and inorganic farming, respectively) were recorded during the third year (Table 2).

Three-year mean cane yields of 55.51 and 59.65 t ha^{-1} were recorded under organic and inorganic farming, respectively, representing a yield reduction of 13.18% under organic farming relative to inorganic farming. Sugar yield followed the same trend, with higher yields under inorganic farming during the first two years and a relatively higher yield under organic farming in the third year, with mean sugar yields of 7.48 and 8.03 t ha^{-1} under organic and inorganic farming, respectively. Ramalakshmi *et al.*, (2020) reported that inclusion of different organic sources in the sugarcane ecosystem not only enhanced soil organic carbon (SOC) but also adequately met nitrogen requirements, leading to on par yield relative to recommended fertilizer application. Ramya *et al*., (2022) reported increased productivity levels of commercial crops like cotton and chillies due to tank silt application in Warangal and Khammam districts of Telangana state in southern India

Based on research data generated under the All India Coordinated Research Project on Dryland Agriculture and related projects over the last 25 years, it is evident that chemical fertilizers have significantly contributed to improved productivity in rainfed crops, even where legumes form part of the cropping system. However, long-term data suggest that sustainability of higher yields over time, even in drylands, is possible only when optimum nutrients are supplied through organics, or a combination of organics and chemical fertilizers, rather than chemical fertilizers alone (Hegde *et al*., 1988). Ravisankar *et al*., (2017) noted that the Government of India task force on organic farming and several other reviewers have identified rainfed areas as more suitable for organic farming given the low input use. Few well-replicated field trials have been conducted on organic farming in major rainfed crops, with the exception of a six-year cotton trial in Maharashtra that showed reduced cost of cultivation and increased gross and net returns compared with conventional cultivation (Rajendran *et al*., 2000). However, extensive information is available on yield and economics for a number of rainfed crops and cropping systems using complete organic manures, or organics as part of INM packages (Lomte and Pendke, 2004).

TABLE 1 Effect of organic farming on cane population and percent mortality of shoots under rainfed sugarcane.

Year	Shoot population at formative (No. ha^{-1})		Shoot population at grand growth (No. ha^{-1})		NMC at harvest (No. ha^{-1})		% mortality of shoots (formative to maturity)	
	OF	IF	OF	IF	OF	IF	OF	IF
2021-22	99860	101560*	91650	92200	85462	85960	16.84	18.14*
2022-23	101600	102600	93530	92600	84835	84495	19.76	21.42*
2023-24	96450	96019	90980	82725	81503	76632	18.34	25.30*
Mean	99303	100060	92053	89175	83933	82362	18.31	21.62

OF = Organic Farming; IF = Inorganic Farming *Significant at 0.05

TABLE 2 Effect of organic on juice sucrose (%), cane and sugar yields (t ha^{-1}) under rainfed sugarcane (pooled data).

Year	Sucrose (%)		Cane yield (t ha^{-1})		% yield reduction	Sugar yield (t ha^{-1})	
	OF	IF	OF	IF		OF	IF
2021-22	18.85	18.60	55.75	64.58*	15.86	7.51	8.57
2022-23	19.68	19.10	52.50	63.10*	20.19	7.37	8.32
2023-24	18.42	18.18	58.27	56.20	3.50	7.56	7.19
Mean	18.98	18.63	55.51	59.65	13.18	7.48	8.03

*Significant at 0.05

3.4 | Soil physico-chemical properties

Soil physico-chemical properties after three years of experimentation revealed no significant effect of treatment on soil pH or EC, relative to either the other treatment or the initial status (Table 3). Organic carbon content, however, increased significantly under organic farming (0.56%) compared with inorganic farming (0.54%), from an initial value of 0.53%, over the three-year period. Inorganic farming recorded relatively higher available nitrogen, phosphorus and potassium status across all three years, with mean values of 242, 65 and 285 kg ha^{-1}, respectively, compared with 226, 61 and 276 kg ha^{-1} under organic farming. In both treatments, available nitrogen declined over the three years relative to its initial value (244 kg ha^{-1}), with greater depletion under organic farming (to 231 kg ha^{-1}) than under inorganic farming (to 240 kg ha^{-1}). Available phosphorus was maintained under inorganic farming (65 kg ha^{-1}) relative to its initial value (64.50 kg ha^{-1}), whereas it declined slightly under organic farming (to 60.9 kg ha^{-1}). A similar trend was observed for potassium, which was recorded at 276 and 285 kg ha^{-1} under organic and inorganic farming, respectively, relative to an initial value of 286 kg ha^{-1}.Sharma *et al.*, (2023) reported that, application of solid and liquid organic manures could be used to sustain productivity and soil health in mustard grown soils of Sadopur in Ambala of Haryana.

3.5 | Soil beneficial microbes

Across all three years, significantly higher populations of Azospirillum, Azotobacter and phosphorus-solubilizing bacteria (PSB) were recorded under organic farming, with mean values of 6.10 × 10^5, 5.60 × 10^5 and 2 × 10^3 c.f.u./g soil, respectively, compared with 4.05 × 10^5, 3.52 × 10^5 and 0.67 × 10^3 c.f.u./g soil under inorganic farming (Table 4). Ramalakshmi *et al*., (2019) similarly reported that Azospirillum and Azotobacter populations were highest in the sugarcane rhizosphere, with the lowest population counts recorded for phosphorus-solubilizing bacteria. Recently published work from Australia indicates that part of the yield response in sugarcane following rotation breaks with pasture, bare fallow or green manure crops can be linked to soil microbial properties, including the amount and composition of microbial biomass and a reduction in some detrimental soil organisms (Pankhurst *et al*., 2000).

3.6 | Nutrient uptake by sugarcane whole plant

Significantly higher macronutrient uptake was observed under inorganic farming during the first two years, whereas in the third year on par results were recorded for all three macronutrients in both treatments, likely reflecting the on par cane yields recorded that year (Table 5). During the first year, N, P and K uptake by the sugarcane whole plant under organic farming was 181, 82 and 210 kg ha^{-1}, respectively, compared with 219, 117 and 251 kg ha^{-1} under inorganic farming. During the third year, NPK uptake under organic farming was 202, 90 and 231 kg ha^{-1}, respectively, compared with 198, 97 and 236 kg ha^{-1} under inorganic farming.

TABLE 3 Effect of organic farming on soil properties under rainfed sugarcane.

Year	pH		EC (dS m^{-1})		OC (%)		Avail. N (kg ha^{-1})		Avail. P_2O_5 (kg ha^{-1})		Avail. K_2O (kg ha^{-1})	
	OF	IF	OF	IF	OF	IF	OF	IF	OF	IF	OF	IF
Initial	7.26	-	0.268	-	0.53	-	244	-	64.50	-	286	-
2021-22	7.18	7.20	0.225	0.240	0.56	0.54	228	240*	58.4	60.90	280	288
2022-23	7.16	7.21	0.189	0.234	0.55	0.54	220	246*	60.8	67.4	277	285
2023-24	7.20	7.22	0.202	0.215	0.56	0.54	231	240	63.5	67.0	270	282
Mean	7.16-7.20	7.20-7.22	0.21	0.23	056*	0.54	226	242*	60.9	65	276	285*

*Significant at 0.05

TABLE 4 Effect of organic farming on soil microbial population under rainfed sugarcane.

Year	Azospirillum (×10^5 c.f.u./g soil)		Azotobacter (×10^5 c.f.u./g soil)		PSB (×10^3 c.f.u./g soil)	
	OF	IF	OF	IF	OF	IF
Initial	5.78	5.78	3.45	3.45	1	1
2021-22 (Plant)	6.80	5.25	7.80	4.56	1	-
2022-23 (Ratoon)	5.50	3.40	7.00	5.00	4	2
2023-24 (Plant)	6.00	3.50	2.00	1.00	1	-
Mean	6.10*	4.05	5.6*	3.52	2*	0.67

*Significant at 0.05

TABLE 5 Effect of organic farming on macronutrient uptake (kg ha^{-1}) by sugarcane whole plant under rainfed sugarcane.

Year	N (kg ha^{-1})		P (kg ha^{-1})		K (kg ha^{-1})	
	OF	IF	OF	IF	OF	IF
2021-22 (Plant)	181	219*	82	117	210	251
2022-23 (Ratoon)	168	208*	84	109	195	244
2023-24 (Plant)	202	198	90	97	231	236
Mean	184	208	85	108	212	244

*Significant at 0.05

4 | CONCLUSIONS

Over the three-year transition period, organic farming progressively closed the yield gap with inorganic farming, reaching on par cane and millable-cane counts by the third year, alongside higher juice sucrose, greater soil organic carbon build-up and significantly higher populations of beneficial soil microbes. Available nitrogen, phosphorus and potassium status, however, remained consistently higher under inorganic farming throughout the study, indicating that nutrient supply through organic sources alone may need supplementation during the transition period to fully sustain macronutrient status. These findings support rainfed sugarcane as a suitable candidate for transition to organic production, provided nutrient management is carefully calibrated during the early transition years.

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CONFLICT OF INTEREST

The manuscript has no conflict of interest, and the authors confirm the article has not been submitted or considered for publication elsewhere.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

AUTHOR'S CONTRIBUTION

Ch.S. Ramalakshmi: Conceptualization, Investigation, Methodology, Data curation, Writing – original draft. A. Sireesha: Investigation, Formal analysis, Writing – review & editing.

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