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Research Communication

Optimizing nutrient management for sustaining sugarcane yield through integration of biochar, digested sludge, liquid slurry and ash applications with inorganic fertilizers

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ABSTRACT

A field experiment was laid out during 2023–24 at ICAR-Indian Agricultural Research Institute, New Delhi to study the effect of various nutrient management options on growth performance, yield and quality of sugarcane. The sixteen treatments comprised of organics (biochar, solid digestate, ash and liquid slurry) and inorganic (synthetic fertilizers) sources in integrated form were evaluated in randomized block design with three replications. The result revealed that a significantly higher plant height (407.8 cm), number of tillers (191 × 10^3/ha), leaf area (51,169 cm^2), leaf-area index (6.81) and cane yield (91.2 t/ha) of sugarcane were obtained with the integration of 100% synthetic along with 4 t/ha solid digest, which was at par to 100% NP + K through liquid digest, 100% synthetic + 6 t/ha biochar and 100% NP + K through Ash, while the lowest were observed under treatment receiving organic manure alone i.e. 100% N through solid digestate, might be owing to very slow mineralization process of nutrients. The former treatments (combination of organic and inorganic nutrient sources) also resulted in better sugarcane quality in terms of increased ^{0}brix reading.

Key words: Ash, Biochar, Brix, Liquid digest, Solid digestate

Sugarcane (*Saccharum officinarum* L.) is a crop of global significance, valued for its role in sugar production and increasingly recognized for its potential in bioenergy generation. In India, the area, production and productivity of sugarcane remained at 5.15 Mha, 431.81 MT and 8.31 t/ha respectively (Anonymous, 2022). There exists further scope to enhance sugarcane productivity by proper nutrient management. As sugarcane is a highly nutrient-demanding crop, therefore efficient nutrient management is crucial for maximizing yield and quality while minimizing environmental footprint. This involves the strategic application of fertilizers, recycling of nutrients through organic amendments, and the adoption of precision agriculture techniques to optimize nutrient use efficiency (NUE). Advances in understanding the complex nutrient dynamics in sugarcane systems, including the role of soil microbiota and the impact of climate variability, are critical for developing sustainable nutrient management practices that support both agricultural productivity and environmental sustainability. The application of balanced N, P and K along with other essential nutrients, is key for increasing sugarcane yield and sugar content. However, the current large-scale application of N fertilizer in sugarcane production has caused problems such as low fertilizer utilization, soil acidification, compaction, toxin accumulation, and reduced fertility (Rathore *et al.,* 2021). Integration of organic sources of the nutrients with available inorganic fertilizers in different combinations will be helpful for a balanced nutrient supply to sugarcane crop. In this regard, the secondary product of the anaerobic digestion, like the slurry, biogas digestate, or simply digestate are good options. The solid digestate contains organic compounds of both plant and microbial origin and numerous mineral elements. The N in slurry ranges from 1.2 to 9.0 kg/Mg fresh weight (FW), and phosphorus from 0.4 to 2.6 kg/Mg FW. Restoring soil fertility in Indian soils under intensive agro-ecologies is a major challenge due to limited availability of organic nutrient sources. The emerging multi-nutrient deficiencies with the use of high analysis fertilizers leads to depletion in soil organic carbon and are mainly responsible for plateauing yield (Mahapatra *et al.,* 2001). The carbon rich porous and large surface area

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characteristics of biochar aid in moisture absorption and entrapping contaminates and, as a soil, conditioner, reduce GHG emissions, and increase soil nutrient availability, which improves, plant growth and ultimately enhances farm productivity. Also, biochars and feedstock materials were chemically characterized for their nutrient content and several physico-chemical properties (Lima and White, 2017). Similarly, the biogas slurry is leftover slurry produced by anaerobic breakdown of biogas source substrates like animal manure or plant debris. Biogas slurry has attracted much interest because of its potential contribution to recovering soil characteristics and enhancing environmentally friendly agricultural productivity (Mukhtiar *et al.,* 2024). Ash, the residue from the combustion of organic materials, contains inorganic nutrients that can be beneficial to soil fertility when applied at appropriate rates. However, its impact on soil properties and crop productivity can vary widely depending on the feedstock and combustion conditions. Therefore, liquid slurry, solid digest and ash were tested in integration of inorganic fertilizers to quantify the impact on sugarcane yield, quality etc. under semi-arid conditions.

An experiment was conducted during the year 2023–24 at ICAR- Indian Agricultural Research Institute, Pusa, New Delhi situated at 28°37'46.2" N latitude, 77°09'43.8" E longitude, and altitude of 228.6 m above mean sea level. The experimental soil belongs to the order *Inceptisols*, clayey loam in texture, slightly basic in reaction (7.25 to 7.65), medium in organic carbon (0.55 to 0.60%), and low in available nitrogen (112.9 to 129.6 kg/ha), medium in available phosphorus (12.6 to 15.7 kg/ha) and available potassium (187.7 to 201.4 kg/ha). The experiment was laid out in randomized block design with three replications. The study comprised of 16 treatments *i.e.,* 100% synthetic, 100% synthetic + 25% biochar (w/w), 100% synthetic + 25% solid digestate (SD) (w/w), 100% synthetic + 4 t/ha SD, 100% synthetic + 6 t/ha biochar, 100% N through SD, 75% synthetic + 25% biochar (Target N), 75% synthetic + 25% SD (Target N), 75% synthetic + 25% biochar (w/w), 75% synthetic + 25% SD (w/w), 75% synthetic + 25% SD (Target N) + 25 kg/ha S, 75% synthetic + 25% biochar (Target N) + 25 kg/ha S, 75% synthetic + 25% biochar (70% of Target N), 75% synthetic + 25% SD (70% of Target N), 100% NP + K through ash and 100% NP + K through liquid slurry. Sugarcane variety 'Co-0238' was sown manually in the first week of May, 2023, using 40 q/ha seeds in rows of 75 cm apart. A recommended dose nitrogen (180 kg/ha), phosphorus (100 kg/ha), potassium (60 kg/ha) was adopted and supplemented by the organic manures according to the treatments. Half a dose of N and a full dose of P and K were applied as basal, while half of N was given as top-dressing at 120 days after planting (DAP). The statistical analysis of the data was done according to the procedure given by Gomez and Gomez (1984).

The data regarding growth attributes *viz.,* plant height, number of tillers, leaf area and LAI (Table 1) indicate that the integration of bio-char, solid digest, liquid slurry and ash with recommended doses of fertilizers significantly influenced the growth parameters. Significantly taller plants were observed under treatment 100% synthetic + 4 t/ha SD. Data pertaining to number of tillers/ha reveal that at 120, 150 and 180 DAP, treatment, 100% synthetic + 4 t/ha SD was significantly superior over other treatments. The superior performance of treatment integrated with inorganic fertilizer and digested sludge regarding sugarcane growth can be attributed to the balanced and enhanced nutrient supply from both synthetic fertilizers and the solid digest, promoting optimal plant growth. The similar outcomes in treatments with integration of amendments like liquid slurry, biochar and ash along with synthetic fertilizers indicate that organic amendments effectively complement fertilizers by improving nutrient availability, water retention and soil health, leading to vigorous plant growth and tiller production. This result clearly corroborates the opinion of high fertilizer value of digestate, as a replacement for mineral fertilizers applied to crop (Przygocka-Cyna and Grzebisz, 2018). Previous studies have found that biochar can improve the root characteristics of the sugarcane seedlings and increase their root-shoot ratio (Liu *et al.,* 2015, Saurabh *et al.,* 2023).

Cane yield was significantly higher (91.2 t/ha) under 100% synthetic + 4 t/ha SD as compared to other treatments except treatment such as, 100% NP + K through liquid slurry, 100% synthetic + 6 t/ha biochar and 100% NP + K through ash. The lowest yield was recorded under treatment, 100% N through SD (Table 1). The solid digest might have helped in ensuring better nutrient supply to sugarcane crop in synchrony to the nutrient demand. Also, along with nutrient build up, the soil will also develop better resilience and overall better soil health will be resulted under use of these organic sources of nutrients (Przygocka-Cyna and Grzebisz, 2018, Babu *et al.,* 2023). Similarly, Gudade *et al.* (2023) and Verma *et al.* (2023) showed that various biochars significantly increased maize yields in sandy soils and partially reclaimed sodic soils, respectively. The brix reading was varied to range between 18.4 to 22.2, with non-significant variation among treatments (Table 1). However, treatment, 100% synthetic + 4 t/ha SD gave higher ^{0}brix value followed by 100% NP + K through liquid digest and 100% synthetic + 6 t/ha biochar. The higher brix value in above treatments is due to their rapid uptake and assimilation, enhancing photosynthesis and sugar synthesis. The study observed a strong positive correlation between cane yield and sugarcane leaf area (r= 0.94**) and

Table 1. Effect of biochar, solid digest, liquid slurry and ash in combination with inorganic fertilizers on sugarcane growth, yield and brix value

Treatment	Plant height (cm)				Number of tillers (× 10³/ha)			Leaf area (cm²/m row)				Leaf area index				Cane yield	⁰Brix
	120 DAP	180 DAP	240 DAP	At harvesingt	120 DAP	150 DAP	180 DAP	120 DAP	180 DAP	240 DAP	At harvesting	120 DAP	180 DAP	240 DAP	At harvesting	(t/ha)	
100% synthetic	302.2	372.3	374.4	380.2	178	191	178	32,110	56,251	49,465	30,684	4.27	7.48	6.58	4.08	84.0	21.0
100% synthetic + 25% biochar (w/w)	303.2	373.1	379.9	382.0	178	191	178	33,478	57,881	50,561	29,108	4.45	7.70	6.72	3.87	84.6	21.0
100% synthetic + 25% SD (w/w)	307.8	389.7	393.7	394.0	182	196	182	34,829	62,238	52,505	40,810	4.63	8.28	6.98	5.43	85.2	21.8
100% synthetic + 4 t/ha SD	309.6	398.7	407.8	408.9	191	209	191	42,532	67,947	64,118	51,169	5.66	9.04	8.53	6.81	91.2	22.8
100% synthetic + 6 t/ha biochar	306.7	391.7	396.2	396.0	187	204	187	36,686	65,144	55,273	48,742	4.88	8.66	7.35	6.48	87.9	22.2
100% N through SD	286.0	330.2	333.5	338.7	156	169	147	23,128	33,305	26,608	19,614	3.08	4.43	3.54	2.61	76.7	18.4
75% synthetic + 25% biochar (Target N)	291.4	342.0	345.0	346.4	164	173	156	25,157	38,655	31,118	25,470	3.35	5.14	4.14	3.39	78.3	19.6
75% synthetic + 25% SD (Target N)	293.0	342.2	347.4	349.0	164	178	160	25,934	41,885	34,399	27,616	3.45	5.57	4.58	3.67	79.2	19.8
75% synthetic + 25% biochar (w/w)	299.6	348.0	352.5	360.2	173	191	169	29,581	48,738	44,232	33,671	3.93	6.48	5.88	4.48	82.6	20.3
75% synthetic + 25% SD (w/w)	299.6	360.1	365.4	367.2	178	191	169	30,905	51,393	45,217	33,835	4.11	6.84	6.01	4.50	83.1	20.7
75% synthetic + 25% SD (Target N) + 25 kg/ha S	300.3	367.1	371.3	372.5	169	191	178	29,911	54,810	49,226	36,353	3.98	7.29	6.55	4.84	83.4	20.9
75% synthetic + 25% biochar (Target N) + 25 kg/ha S	300.3	370.2	372.5	378.4	178	191	178	31,360	56,294	49,360	37,311	4.17	7.49	6.56	4.96	83.9	20.9
75% synthetic + 25% biochar (70% of Target N)	296.2	346.1	350.4	357.2	169	182	164	28,208	45,047	35,480	30,138	3.75	5.99	4.72	4.01	79.6	20.0
75% synthetic + 25% SD (70% of Target N)	296.7	347.0	351.7	358.7	169	182	169	28,455	48,238	42,669	33,304	3.78	6.42	5.67	4.43	81.9	20.0
100% NP + K through Ash	304.9	390.1	395.5	395.6	187	200	182	36,263	62,457	53,753	42,109	4.82	8.31	7.15	5.60	86.7	22.0
100% NP + K through liquid digest	308.6	394.3	399.4	407.5	191	204	187	38,034	65,714	60,770	49,038	5.06	8.74	8.08	6.52	90.1	22.7
CD (P=0.05)	NS	23.7	27.4	27.6	13	16	13	5,709.6	5,189.1	4,563.5	2,635.5	0.76	0.69	0.67	0.35	5.5	NS

SD, solid digestate, w/w, weight wise; N, nitrogen; P, phosphorus, K, potassium, 100% synthetic, 180 : 100 : 60 kg N : P_2O_5 : K_2O/ha

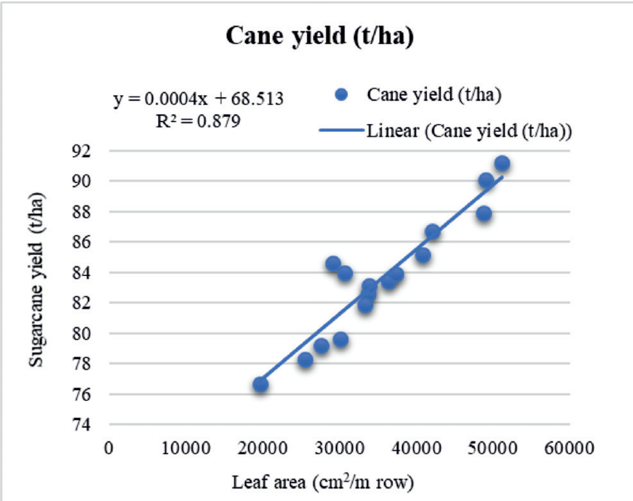

Fig. 1. Correlation between leaf area and cane yield

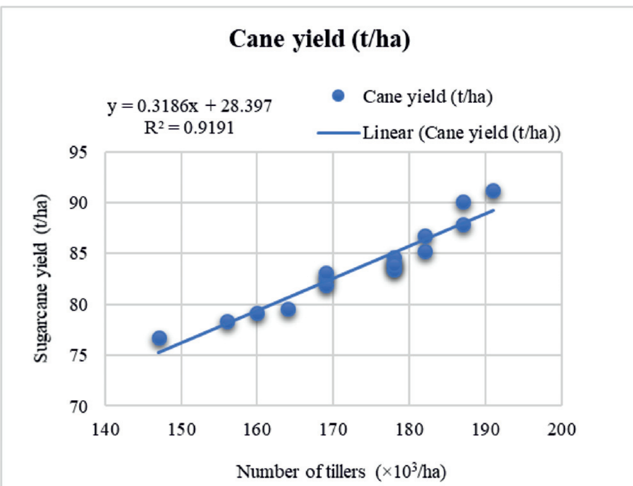

Fig. 2. Correlation between tiller production and cane yield

cane yield and sugarcane tiller count (r= 0.96**) (Fig. 1 and Fig. 2), which suggests that higher leaf area enhances photosynthesis, providing more energy for growth, while a higher tiller count increases the number of stalks, directly boosting cane yield.

Hence, from the above study, it can be concluded that the integrated application of synthetic fertilizers along with organic amendments such as solid digest, biochar and liquid slurry was found to be most effective in enhancing growth, cane yield and quality of sugarcane.

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