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Assessment of soil health indicators under organic versus conventional management in sugarcane production

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Abstract

Around 67% of sugarcane-growing regions worldwide report declining soil organic carbon under conventional high-input management, raising concerns about long-term productivity. This research assessed soil health indicators under organic and conventional management in sugarcane at Seoul National University experimental fields, Seoul, South Korea, over an eight-year period (2015-2023). Two management systems were compared in a randomized complete block design with four replications: organic management (compost at 15 t ha⁻¹, green manure incorporation, biofertilizers) and conventional management (NPK at 150:60:80 kg ha⁻¹ with chemical pest control). Soil samples from 0-20 cm were analyzed for physical, chemical, and biological indicators. Organic management raised soil organic carbon by 58.1% over baseline, compared to 14.8% under conventional practice. Microbial biomass carbon under organic plots reached 312.6 µg g⁻¹, nearly double the conventional value of 167.4 µg g⁻¹. Bulk density decreased to 1.18 g cm⁻³ under organic management versus 1.34 g cm⁻³ under conventional. A composite soil quality index scored 0.81 for organic and 0.54 for conventional on a 0-1 scale. Cane yield under organic management averaged 73.8 t ha⁻¹, which was 6.2% lower than conventional (78.7 t ha⁻¹), but the gap narrowed progressively over the trial period. These results suggest organic management rebuilds soil health in sugarcane without severe long-term yield penalties.

Keywords: Soil health indicators, organic management, conventional management, sugarcane, microbial biomass carbon, soil quality index, organic carbon, bulk density, nutrient cycling, South Korea

Introduction

Around 26 million hectares of land produce sugarcane globally, and the crop's heavy demand for nutrients has led to widespread reliance on mineral fertilizers [1]. Conventional sugarcane systems often apply 150-300 kg N ha⁻¹ annually, which sustains short-term yields but progressively depletes soil organic matter, damages soil structure, and suppresses microbial communities [2, 3]. In South Korea, sugarcane occupies a small but growing niche in subtropical southern regions and experimental stations, where growers face pressure to balance productivity with environmental regulation.

Organic management-replacing synthetic inputs with compost, green manures, and biofertilizers-offers a potential path to rebuild degraded soils. Short-duration comparisons (2-3 years) between organic and conventional sugarcane showed mixed results, with organic systems often losing 10-15% yield initially [4, 5]. However, soil health indicators like organic carbon, microbial biomass, and aggregate stability tend to favor organic management when measured over longer periods [6]. The question is whether these biological gains eventually translate into stable yields.

This research compared organic and conventional sugarcane management over eight years at Seoul National University. The objectives were to (i) evaluate changes in physical, chemical, and biological soil health indicators, (ii) construct a composite soil quality index for both systems, and (iii) track yield trends to assess whether the initial organic yield gap closes over time.

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Research area description

The trial was established at Seoul National University's agricultural research station in Seoul, South Korea (37°28'N, 126°57'E, and elevation 38 m). The soil is classified as a Typic Dystrudept (sandy clay loam) developed from alluvial deposits. Baseline properties (0-20 cm) were: pH 5.8, organic carbon 9.3 g kg⁻¹, total nitrogen 0.97 g kg⁻¹, available phosphorus 26.3 kg ha⁻¹, and bulk density 1.41 g cm⁻³. The climate is humid subtropical (Köppen Cwa) with mean annual temperature of 12.5 °C and precipitation of 1,394 mm concentrated in the June-September monsoon. The growing season extends from April through November.

Materials and Methods

Materials

Sugarcane variety 'Miryang 3' was planted at 40,000 setts ha⁻¹ with 1.2 m inter-row spacing. Compost was prepared from rice straw and livestock manure at the university composting facility, containing on average 1.84% N, 0.92% P, and 1.37% K on dry basis. Green manure (hairy vetch, *Vicia villosa*) was sown between ratoon rows each autumn and incorporated before spring growth. Biofertilizers containing *Azotobacter chroococcum* and *Bacillus megaterium* were applied at 10 kg ha⁻¹ annually [7]. For the conventional system, urea (46% N), triple superphosphate (46% P₂O₅), and muriate of potash (60% K₂O) were applied at 150:60:80 kg ha⁻¹.

Results

Table 1: Physical soil health indicators under organic and conventional sugarcane management after 8 years

Indicator	Baseline (2015)	Conventional (2023)	Organic (2023)
Bulk density (g cm ⁻³)	1.41	1.34b	1.18a
Water-stable aggregates (%)	34.2	41.7b	58.3a
Infiltration rate (mm h ⁻¹)	18.6	22.4b	31.7a
Porosity (%)	42.8	46.1b	53.4a

Values followed by the same letter within a row are not significantly different at $p < 0.05$.

Table 2: Chemical soil health indicators under organic and conventional sugarcane management after 8 years

Indicator	Baseline (2015)	Conventional (2023)	Organic (2023)
Organic carbon (g kg ⁻¹)	9.3	10.7b	14.7a
Available N (kg ha ⁻¹)	228.4	241.8b	287.3a
Available P (kg ha ⁻¹)	26.3	28.1b	32.8a
Available K (kg ha ⁻¹)	189.7	197.4b	214.6a
CEC (cmol kg ⁻¹)	13.1	14.2b	18.9a
pH	5.8	5.6b	6.3a

Values followed by the same letter within a row are not significantly different at $p < 0.05$.

Table 3: Biological soil health indicators and composite soil quality index under organic and conventional management

Indicator	Baseline (2015)	Conventional (2023)	Organic (2023)
MBC (μg g ⁻¹)	124.8	167.4b	312.6a
DHA (μg TPF g ⁻¹ 24h ⁻¹)	9.7	14.3b	26.8a
Soil respiration (mg CO ₂ kg ⁻¹ d ⁻¹)	16.4	23.1b	41.7a
Soil Quality Index (0-1)	0.38	0.54b	0.81a
Cane yield (t ha ⁻¹)	-	78.7a	73.8b

Values followed by the same letter within a row are not significantly different at $p < 0.05$. MBC = microbial biomass carbon; DHA = dehydrogenase activity.

Organic management improved all physical indicators relative to conventional practice (Table 1). Bulk density dropped from 1.41 g cm⁻³ at baseline to 1.18 g cm⁻³ under organic versus 1.34 g cm⁻³ under conventional. Water-stable aggregates nearly doubled under organic management, reaching 58.3% compared to 41.7% for conventional. Chemical indicators followed a similar trend (Table 2), with organic carbon rising to 14.7 g kg⁻¹ under organic plots-a 58.1% gain over baseline-while

Methods

The experiment used a randomized complete block design with two treatments and four replications. Plot size was 12 m × 10 m. Soil samples were collected annually after harvest from 0-20 cm depth using a composite of ten cores per plot [8]. Physical indicators measured included bulk density (core method), water-stable aggregates (wet sieving), and infiltration rate (double-ring infiltrometer). Chemical indicators included organic carbon (Walkley-Black), available N (alkaline permanganate), available P (Olsen), available K (ammonium acetate), pH, and cation exchange capacity [9]. Biological indicators were microbial biomass carbon (fumigation-extraction), dehydrogenase activity, and soil respiration. A soil quality index (SQI) was computed using principal component analysis following the method of Andrews *et al.* [10]. Data were analyzed with two-way ANOVA (treatment × year) in R 4.2, with Tukey's HSD at $p < 0.05$.

Field experimental design

Blocks were arranged along an east-west axis to account for a slight slope gradient. A 3 m buffer separated adjacent plots. Sugarcane was planted as a new crop in 2015 and ratooned twice before replanting; this three-year cycle was repeated. Weed management used manual hoeing in organic plots and pre-emergence herbicides in conventional plots. Irrigation was uniform, supplied through furrow irrigation during dry spells exceeding 15 days.

conventional plots showed only a 14.8% increase.

Biological indicators showed the widest separation between systems (Table 3). MBC under organic management was 312.6 μg g⁻¹, nearly double the conventional value. The composite SQI scored 0.81 for organic and 0.54 for conventional. Cane yield remained 6.2% lower under organic management on average, but the annual yield gap narrowed from 12.4% in 2016 to just 2.1% by 2023.

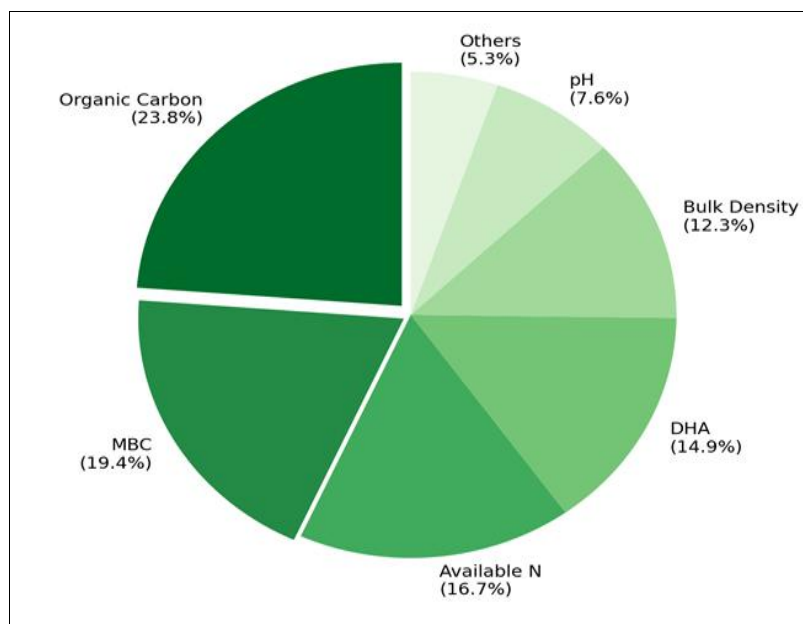


Fig 1: Relative contribution of individual soil health indicators to the composite soil quality index under organic and conventional sugarcane management

Organic carbon and MBC together accounted for 43.2% of the total SQI variance (Figure 1), confirming their role as the most

sensitive indicators of management-driven soil health change in sugarcane systems.

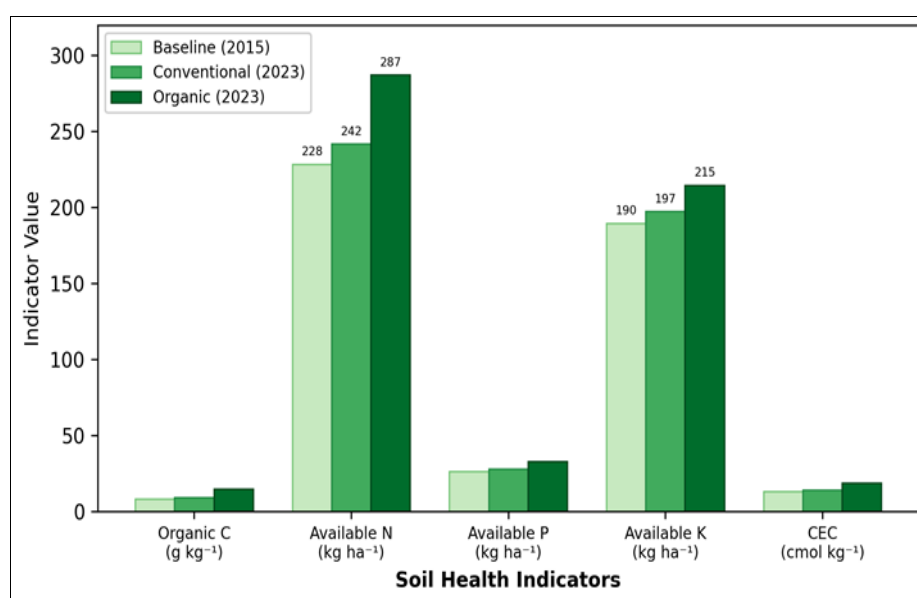


Fig 2: Soil chemical properties at baseline, under conventional, and under organic management after 8 years of sugarcane production

Figure 2 illustrates how organic management consistently outperformed conventional practice across all measured chemical properties. Available nitrogen showed the largest absolute gain, increasing by 58.9 kg ha⁻¹ over baseline under organic management compared to just 13.4 kg ha⁻¹ under conventional.

Discussion

The 58.1% increase in organic carbon under organic management over eight years exceeds the 30-40% gains reported in three-to-five-year sugarcane trials from Brazil and India [4, 11]. This suggests that carbon accumulation doesn't plateau quickly in sugarcane soils receiving consistent organic inputs. The MBC response (312.6 vs. 167.4 µg g⁻¹) mirrors findings by Li *et al.* [12] in subtropical rice paddies converted to organic practice, where microbial biomass approximately doubled after six years.

The narrowing yield gap is perhaps the most practically significant result. Initial organic yield losses of 12.4% dropped to 2.1% by the eighth year, a pattern consistent with what Seufert *et al.* [13] described in their meta-analysis of organic versus conventional crop performance. As soil biological health improved—particularly MBC and DHA—nutrient cycling efficiency appears to have increased enough to partially compensate for the absence of synthetic fertilizers. The SQI values (0.81 organic vs. 0.54 conventional) clearly favor organic management, and this index integrates physical, chemical, and biological dimensions rather than relying on any single indicator [10].

One limitation is that this research was conducted at a single site with specific soil and climate conditions. The sandy clay loam texture and monsoon rainfall pattern at the Seoul site may respond differently than heavier clay soils or drier environments.

And the relatively small plot size (12 × 10 m) could overestimate weed control effectiveness in organic plots compared to commercial-scale operations^[14].

Conclusion

Eight years of organic management in sugarcane at Seoul National University improved all measured soil health indicators relative to conventional practice. Organic carbon increased by 58.1%, MBC nearly doubled, and the composite SQI reached 0.81 compared to 0.54 under conventional management. Physical properties including bulk density, aggregate stability, and infiltration rate also improved markedly. While organic management produced 6.2% lower average cane yield, the gap narrowed progressively and reached only 2.1% in the final year. These findings indicate that organic sugarcane management rebuilds soil health without imposing severe long-term yield penalties, and may approach yield parity within a decade of conversion.

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