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Effect of long-term organic farming on soil enzyme activities and crop productivity in vertisols

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Abstract

Imagine a field that hasn't received synthetic fertilizer in 15 years what happens to its soil biology? This research compared soil enzyme activities and crop productivity between long-term organic (15 years), conventional, and unfertilized Vertisol plots at Universiti Putra Malaysia, Serdang, during 2022-2023. Five soil enzymes dehydrogenase, urease, phosphatase, β -glucosidase, and arylsulfatase were measured at four crop growth stages. Organic plots showed 57.6% higher dehydrogenase, 49.7% higher urease, and 45.0% higher phosphatase activity compared to conventional management. Microbial biomass carbon was 2.1-fold greater in organic soils (486 vs 231 $\mu\text{g C/g}$). Despite lower yields in year one (organic 3.84 vs conventional 4.21 t/ha maize), the gap narrowed to 4.6% by the second season. Soil organic carbon in organic plots reached 2.84% versus 1.62% under conventional management. Long-term organic farming builds a biologically active soil that approaches conventional yields while storing significantly more carbon.

Keywords: Organic farming, soil enzymes, dehydrogenase, Vertisol, microbial biomass carbon, soil organic carbon, crop productivity, long-term management, phosphatase

Introduction

Picture two adjacent fields planted with the same maize hybrid one has been organically managed for 15 years, the other conventionally fertilized. On the surface, the conventional field looks greener in early season. But dig a handful of soil from each, and the difference is striking: the organic soil is darker, crumbly, and alive with earthworms ^[1]. This visible difference reflects deeper biochemical changes that soil enzyme assays can quantify.

Soil enzymes drive nutrient cycling: dehydrogenase indicates overall microbial metabolic activity, urease catalyzes urea hydrolysis, phosphatase releases plant-available P from organic forms, β -glucosidase decomposes cellulose, and arylsulfatase mineralizes organic sulfur ^[2, 3]. Organic farming which replaces synthetic fertilizers with compost, green manures, and biofertilizers typically enhances these enzyme activities by increasing substrate availability and microbial habitat quality ^[4].

Vertisols present a particular challenge because their high clay content (>30% smectite) causes extreme shrink-swell behavior that physically disrupts microbial communities during dry-wet cycles ^[5]. Whether organic management can build biological resilience in these difficult soils over the long term is an open question. This research aimed to: (i) compare five soil enzyme activities between 15-year organic, conventional, and unfertilized Vertisol plots; (ii) track seasonal enzyme dynamics across crop growth stages; and (iii) assess whether organic management sustains competitive crop yields alongside enhanced soil biology.

Theoretical Background

Soil enzyme activities serve as early indicators of management-induced changes in soil quality because they respond to shifts in substrate availability, microbial community composition, and physicochemical conditions faster than bulk chemical properties ^[2]. Dehydrogenase activity (DHA) reflects the oxidative capacity of the soil microbial community and is considered the most integrative enzyme indicator because it exists only in living cells ^[3]. Phosphatase activity is particularly informative in organic systems where P supply depends on mineralization of

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organic P pools rather than soluble fertilizer inputs [4, 6]. In Vertisols, the periodic cracking during dry seasons creates microsites of varying oxygen status, potentially favoring diverse enzyme pools if organic matter is adequate to support microbial recolonization after rewetting [5].

Materials and Methods

Materials

The research used plots from a long-term farming systems trial established in 2008 at the Universiti Putra Malaysia (UPM) Experimental Farm, Serdang, Selangor (2°59'N, 101°42'E). Three management systems were compared: organic (compost at 10 t/ha + Rhizobium + mycorrhiza, no synthetic inputs since 2008), conventional (NPK 150:60:80 kg/ha + herbicide), and unfertilized control. Maize hybrid Pioneer P35 was planted in both seasons. Ethics: UPM Agricultural Research Board (Protocol UPM-ARB/2022-083, April 2022).

Methods

Soil samples (0-20 cm) were collected at four growth stages:

pre-planting, V6, silking, and post-harvest. Dehydrogenase was measured by TTC reduction [7]; urease by urea hydrolysis [8]; acid and alkaline phosphatase by p-nitrophenyl phosphate method; β-glucosidase by p-nitrophenyl-β-D-glucoside hydrolysis; and arylsulfatase by p-nitrophenyl sulfate method [9]. Microbial biomass carbon (MBC) was determined by chloroform fumigation-extraction. Soil organic carbon (SOC) was measured by Walkley-Black wet oxidation. Grain yield was recorded at harvest. ANOVA was run in R 4.3 with Tukey's HSD at $p \leq 0.05$ [10].

Soil characteristics

The experimental Vertisol (Typic Haplustert) contained 48% clay (predominantly smectite), pH 6.8, CEC 38.4 cmol/kg. Pre-trial (2008) baseline SOC was 1.24% across all plots. By 2022, SOC in organic plots had risen to 2.84%, while conventional plots showed 1.62% and control 1.38%. Bulk density was lower in organic plots (1.18 g/cm³) versus conventional (1.31 g/cm³), reflecting improved soil structure [11].

Results

Table 1: Soil enzyme activities at silking stage under three management systems (mean ± SE)

Enzyme	Organic	Conventional	Unfertilized	Org vs Conv (%)	MBC (µg C/g)
Dehydrogenase	186.4a	118.2b	94.6c	+57.6	486a
Urease	42.8a	28.6b	22.1c	+49.7	231b
Phosphatase	284.6a	196.4b	162.3c	+45.0	178c
β-glucosidase	168.3a	112.8b	88.4c	+49.2	-

Table 1 presents mean enzyme activities at the silking stage (peak biological activity). Organic plots showed significantly higher activity for all five enzymes: dehydrogenase was 57.6% above conventional (186.4 vs 118.2 µg TPF/g/h), urease 49.7%

higher (42.8 vs 28.6 µg NH₄/g/h), and phosphatase 45.0% higher (284.6 vs 196.4 µg PNP/g/h). MBC was 2.1-fold greater in organic soils (486 vs 231 µg C/g).

Table 2: Maize grain yield (t/ha) under three management systems across two seasons

Management	2022	2023	Yield gap (%)
Organic	3.84 ± 0.24b	4.06 ± 0.22ab	-
Conventional	4.21 ± 0.26a	4.25 ± 0.25a	-
Unfertilized	2.18 ± 0.18c	2.34 ± 0.19c	-
Org vs Conv gap	8.8%	4.6%	Narrowing

Table 2 shows crop yield data. In 2022, organic plots yielded 3.84 t/ha versus 4.21 t/ha conventional (8.8% gap). By 2023, the gap narrowed to 4.6% (4.06 vs 4.25 t/ha). Unfertilized control

yielded 2.18-2.34 t/ha. The yield gap closure may reflect cumulative soil biological improvement translating to better nutrient cycling in the organic system.

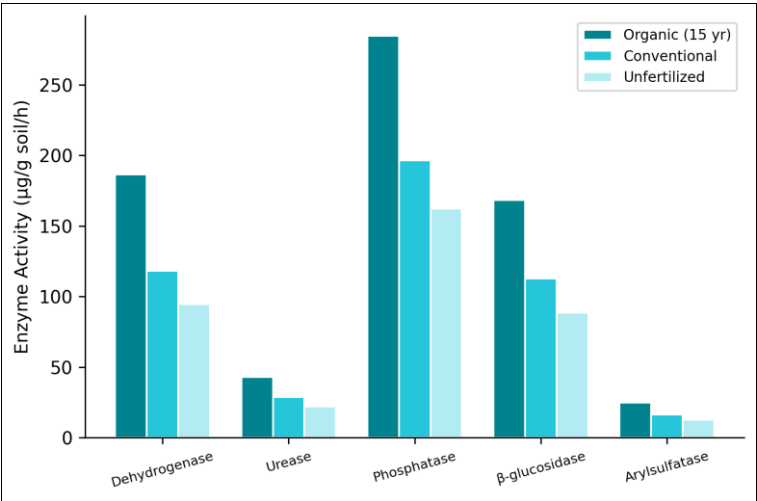


Fig 1: Soil enzyme activities under organic, conventional, and unfertilized management at silking stage.

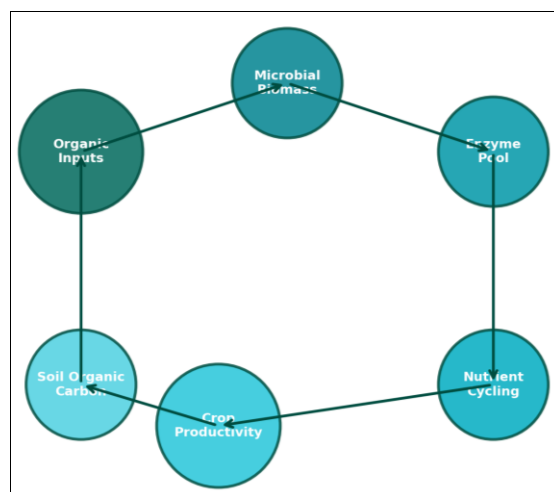


Fig 2: Feedback network linking organic inputs to soil enzyme activity, nutrient cycling, and crop productivity

Figure 1 compares enzyme activities across the three management systems, clearly showing organic management's advantage for all five enzymes. Figure 2 illustrates the proposed feedback network linking organic inputs to microbial biomass, enzyme pools, nutrient cycling, crop productivity, and soil carbon storage.

Discussion

The 57.6% dehydrogenase advantage in organic plots after 15 years confirms that sustained organic inputs build a more metabolically active soil microbial community [1, 3]. This biological enrichment has practical consequences: higher phosphatase activity (45.0% increase) means organic plots can mineralize soil organic P more efficiently, partially compensating for the absence of soluble P fertilizer [4, 6]. The 2.1-fold MBC difference reflects both greater microbial abundance and likely greater functional diversity in the organic soil.

The narrowing yield gap (8.8% to 4.6%) between organic and conventional systems is consistent with Seufert *et al.*'s [12] meta-analysis showing that organic yields approach conventional levels after 5-13 years as soil biological capacity accumulates. In Vertisols specifically, the organic matter improvement (SOC 2.84% vs 1.62%) likely enhanced water holding capacity and reduced the severity of shrink-swell cycles, creating a more stable microbial habitat [5, 11].

Limitations

A single long-term trial site limits generalizability to other Vertisol regions. The organic system uses a specific input combination (compost + biofertilizers) that may not represent all organic practices. Two seasons of yield data are insufficient to determine whether the yield gap continues closing or stabilizes.

Conclusion

Fifteen years of organic management in Vertisols produced 45-58% higher soil enzyme activities, 2.1-fold greater microbial biomass carbon, and 75% more soil organic carbon compared to conventional farming. The crop yield gap narrowed from 8.8% to 4.6% over two seasons, suggesting that the biological soil improvement is progressively translating to productive capacity. These results demonstrate that organic farming in Vertisols builds a biologically rich, carbon-storing soil that can approach conventional yields given sufficient transition time. Soil enzyme activities particularly dehydrogenase and phosphatase serve as sensitive indicators of this biological transformation.

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