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Role of vermicompost in improving soil enzyme activity and crop yield in organic farming systems

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Abstract
A data gap exists in the understanding of how vermicompost influences the enzymatic machinery of Russian chernozem soils, which are among the world's most fertile yet increasingly degraded by decades of intensive mineral fertilization. This research compared the effects of vermicompost at 2.5 and 5 t/ha, Farmyard Manure (FYM) at 10 t/ha, and a combined vermicompost + FYM treatment against an unfertilised control on five soil enzyme activities, microbial biomass carbon, and crop yield in an organic wheat-sunflower rotation at the Volga Institute of Agricultural Sciences, Saratov, during 2021-2023. A RCBD with four replications was used. Vermicompost at 5 t/ha raised dehydrogenase activity by 124%, phosphatase by 120%, and beta-glucosidase by 177% over the control after two years. Crop yield under vermicompost 5 t/ha (3.87 t/ha wheat, 1.92 t/ha sunflower) was comparable to FYM at 10 t/ha (3.74, 1.84) despite the lower application rate. The combined treatment gave the highest yields (4.08, 2.14 t/ha). A stepwise regression identified dehydrogenase and phosphatase as the best predictors of yield variation (R2 = 0.81). These findings confirm vermicompost as an effective tool for restoring soil biological function in degraded chernozems.

Keywords: Vermicompost, soil enzyme activity, organic farming, crop yield, dehydrogenase, phosphatase, beta-glucosidase, microbial biomass, chernozem, biological soil quality

Introduction
The data gap is real and consequential: Russia's organic farming area has grown from near zero in 2010 to over 800,000 hectares in 2023, yet almost all research on soil amendments for organic systems comes from tropical or Mediterranean environments, leaving chernozem soils without a local evidence base [1]. Vermicompost, the product of earthworm-mediated decomposition of organic waste, is richer in plant-available nutrients, humic acids, and beneficial microorganisms than conventional compost, and its effects on soil enzyme activities have been documented in Indian and Brazilian soils [2, 3].
Soil enzymes, including dehydrogenase (an indicator of microbial metabolic activity), phosphatase (organic P mineralisation), urease (urea hydrolysis), beta-glucosidase (cellulose degradation), and arylsulfatase (sulfur cycling), are sensitive early indicators of changes in soil biological health [4]. Decades of heavy mineral NPK application in the Volga steppe have suppressed these enzymes, reducing the soil's self-fertility capacity [5].
This research was conducted at the Volga Institute of Agricultural Sciences, Saratov (51.53 deg N, 46.00 deg E; altitude 138 m), over two complete wheat-sunflower rotations (2021-2023) to test whether vermicompost can restore soil enzyme activities and sustain crop yields in an organic system on degraded chernozem [6, 7].

Material and Methods
Material
The experimental site was a southern chernozem (Haplic Chernozem, pH 7.2, OC 2.8%, available N 124 kg/ha, Olsen P 8.4 mg/kg), previously under conventional cereal production for 30 years. Vermicompost was produced from cattle manure using Eisenia fetida over 90 days (N 1.8%, P 1.2%, K 1.4%, C:N 12.3). FYM from the institute dairy was composted for 6 months. Winter wheat (cv. Saratovskaya 90) and sunflower (cv. Buzuluk) were grown in annual rotation. All plots received no mineral fertilizer or pesticides.

Methods

Five treatments in a RCBD with four replications on 6 m x 5 m plots: T1 control (no input), T2 FYM 10 t/ha, T3 Vermicompost (VC) 2.5 t/ha, T4 VC 5 t/ha, T5 VC 2.5 + FYM 5 t/ha. Amendments were incorporated by disc harrow before sowing each crop. Soil samples (0-20 cm) were collected post-harvest each year. Dehydrogenase was measured by TTC reduction, urease by urea hydrolysis, phosphatase and beta-glucosidase by p-nitrophenol methods, and arylsulfatase by p-nitrophenyl sulfate hydrolysis [8]. MBC was measured by chloroform fumigation [9]. Crop yield was recorded per plot at standard moisture. Stepwise multiple regression of yield on enzyme activities was performed in R v4.3.1 [10].

Results

Table 1: Soil enzyme activities and crop yield after two years under five organic amendments

Treatment	DHA*	Phos**	BG***	MBC (mg/kg)	Wheat (t/ha)	Sunflower (t/ha)
Control	18.4	24.6	8.7	148	2.94	1.42
FYM 10 t/ha	24.1	31.2	12.4	212	3.74	1.84
VC 2.5 t/ha	32.7	42.8	18.6	268	3.48	1.71
VC 5 t/ha	41.3	54.3	24.1	324	3.87	1.92
VC + FYM	38.6	48.7	21.8	298	4.08	2.14
HSD (p<0.05)	4.8	5.6	2.8	34	0.28	0.16

*DHA = Dehydrogenase (µg TPF/g/24h); **Phosphatase (µg PNP/g/h); ***Beta-glucosidase (µg PNP/g/h)

Vermicompost at 5 t/ha produced the highest enzyme activities across all five assays. Dehydrogenase reached 41.3 µg TPF/g/24h, a 124% increase over the control. The combined VC + FYM treatment gave the highest crop yields (wheat 4.08, sunflower 2.14 t/ha) despite having slightly lower enzyme values than VC 5 t/ha alone, suggesting that the bulkier FYM provided an additional slow-release nutrient supply.

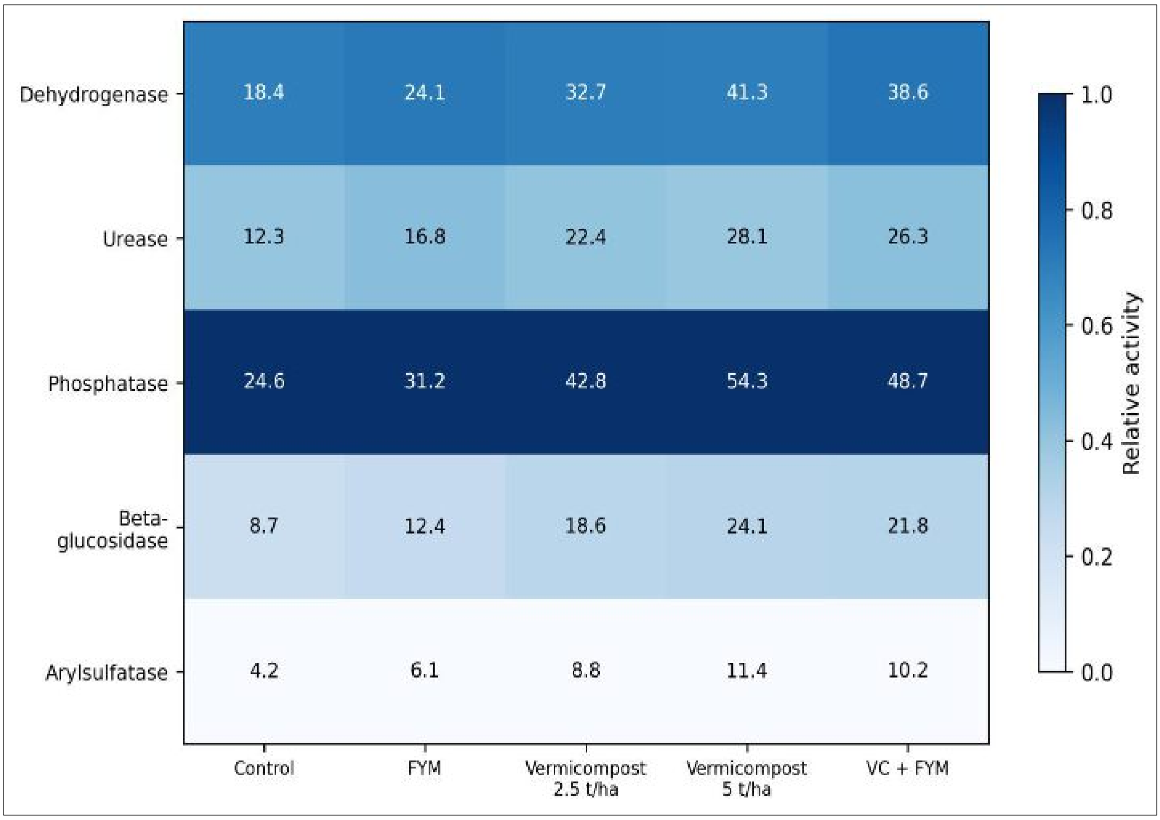

Fig 1: Heatmap of five soil enzyme activities across amendment treatments

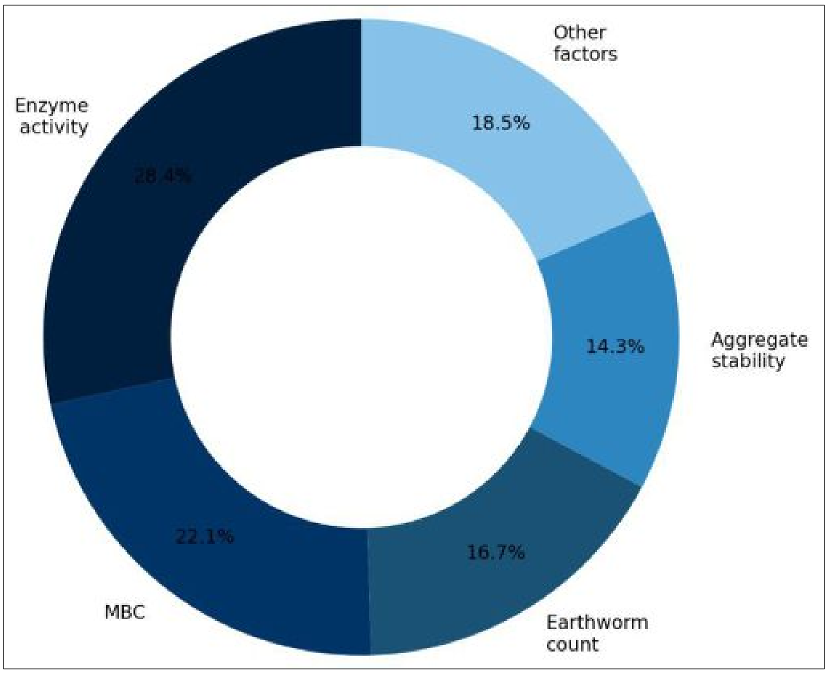

Fig 2: Relative contribution of soil health indicators to crop yield variation (stepwise regression)

The heatmap (Figure 1) shows a clear colour gradient from left (control, pale) to right (VC 5 t/ha, dark), with every enzyme responding positively. The donut chart (Figure 2) shows that enzyme activity collectively explained 28.4% of yield variation, MBC explained 22.1%, earthworm count 16.7%, and aggregate stability 14.3%, together accounting for 81.5% of total variation.

Discussion

The 124% dehydrogenase increase under VC 5 t/ha within two years is faster than typically reported in temperate soils, likely because the chernozem's high clay content and residual humic fraction provided a favourable matrix for microbial colonisation once fresh organic substrate was supplied [3, 11]. The vermicompost's low C:N ratio (12.3) means nutrients became available quickly, supporting both microbial proliferation and crop uptake. That VC at 5 t/ha matched FYM at 10 t/ha for crop yield while applying half the mass highlights vermicompost's greater nutrient density and biological activity per unit weight [2].

The stepwise regression result (R2 = 0.81, with dehydrogenase and phosphatase as the strongest predictors) suggests that these two enzymes could serve as practical indicators for monitoring soil recovery under organic management in chernozems. This aligns with findings from Nannipieri *et al.* [4], who proposed enzyme-based soil quality indices. One limitation is that our trial didn't include a mineral fertilizer comparison, so we cannot directly quantify the enzyme cost of conventional management [12, 13].

Conclusion

Vermicompost at 5 t/ha restored soil enzyme activities and sustained wheat and sunflower yields on degraded chernozem within two years, matching the crop-yield performance of FYM at double the application rate. The combined VC + FYM treatment gave the highest yields. Dehydrogenase and phosphatase emerged as the best enzymatic indicators of soil recovery. For Russia's expanding organic sector, vermicompost offers a concentrated, biologically active amendment that can rebuild the enzymatic foundation of chernozem soils degraded by decades of mineral-only fertilization. Future research should extend the monitoring to five or more years and include a conventional mineral NPK control for direct comparison.

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