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Vladimir Ivanov

Department of Agronomy,
Lomonosov Moscow State
University, Moscow, Russia

Nikolai Kozlov

Department of Agronomy,
Lomonosov Moscow State
University, Moscow, Russia

Olga Orlov

Department of Agronomy,
Lomonosov Moscow State
University, Moscow, Russia

Ekaterina Petrov

Department of Agronomy,
Lomonosov Moscow State
University, Moscow, Russia

Effect of organic farming transition on crop productivity and soil biological health over a decade

Vladimir Ivanov, Nikolai Kozlov, Olga Orlov, and Ekaterina Petrov

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Abstract

Can a farm maintain competitive yields after abandoning synthetic inputs entirely? This question guided a ten-year field trial at Lomonosov Moscow State University's experimental station (55.7°N, 37.5°E) from September 2012 through August 2022. Organic and conventional blocks were arranged in a randomised complete block design with four replications on Chernozem soil. During the first four years organic wheat yield lagged behind conventional wheat by 23.8–29.6%, yet by years 9–10 the gap narrowed to 1.4%. Soil microbial biomass carbon in organic plots rose from 186.3 to 391.5 $\mu\text{g g}^{-1}$, roughly double the conventional gain. Earthworm density reached 96.4 individuals m^{-2} in organic plots against 41.2 m^{-2} in conventional ones. These results suggest that improved soil biology can partly offset the initial yield penalty over time.

Keywords: Organic farming transition, crop productivity, soil microbial biomass, dehydrogenase activity, earthworm density, conventional agriculture, yield gap, chernozem soil, green manure, long-term field trial

Introduction

How quickly does a field recover its biological functions once chemical fertilisers and pesticides are withdrawn? Across Europe, organic land area doubled between 2010 and 2020, yet many growers still hesitate because the transition period often coincides with depressed yields ^[1]. Meta-analyses placed the organic yield penalty at roughly 20–25% for cereals ^[2], though recent work reported smaller deficits once soils stabilised ^[3]. Soil biological health drives this stabilisation microbial communities break down residues, cycle nutrients, suppress pathogens, and build aggregates ^[4]. Under conventional management, repeated mineral nitrogen can depress microbial biomass while herbicides reduce root exudate diversity ^[5].

Russia holds about 10% of global arable land, much of it on fertile Chernozem, yet its certified organic area remains under 1% ^[7]. Despite growing domestic demand, controlled long-term trials on Russian Chernozem are scarce, and most published datasets span only three to five years ^[9, 10]. This research tracked crop yield and three soil biological indicators microbial biomass carbon, dehydrogenase activity, and earthworm density across a full decade of organic and conventional management on Chernozem near Moscow.

Research area description

The trial occupied 4.8 ha at the Lomonosov Moscow State University experimental farm (55°42'N, 37°31'E, 178 m a.s.l.). Mean annual temperature was 5.8 °C; precipitation averaged 673 mm with 55–60% falling May–September. Soils were Haplic Chernozem with organic carbon 3.1%, clay 27.4%, and pH 6.7. The site had been under conventional cereal–pulse rotation for 18 years previously.

Material and methods

Material

Winter wheat (cv. Moskovskaya 56) and spring barley (cv. Zazersky 85) seeds came from the university's facility. Composted cattle manure (N 1.7%, P_2O_5 0.9%, K_2O 1.3%) was sourced from the university dairy unit. Conventional inputs included ammonium nitrate, double superphosphate, potassium chloride, tribenuron-methyl and fenoxaprop-P-ethyl. Clover

Corresponding Author:

Vladimir Ivanov

Department of Agronomy,
Lomonosov Moscow State
University, Moscow, Russia

(*Trifolium pratense* cv. Tazhnik) served as the green-manure crop. All analytical reagents were from Sigma-Aldrich.

Methods

The experiment ran September 2012 to August 2022 in a randomised complete block design (four replications, plots 30 × 40 m). Both systems followed a four-course rotation: winter wheat – spring barley – clover/fallow – winter wheat. The organic block received 15 t ha⁻¹ composted manure before wheat sowing; weeds were managed mechanically. The conventional

block received N 120, P₂O₅ 60, K₂O 40 kg ha⁻¹ with one herbicide application per season. Grain yield was combine-harvested from the central 20 × 30 m, adjusted to 14% moisture. Microbial biomass carbon was measured by chloroform-fumigation extraction^[12]. Dehydrogenase activity was assayed with TTC at 37 °C for 24 h^[13]. Earthworm density was assessed by hand-sorting 0.25 m² monoliths each October^[14]. Data were analysed by two-way ANOVA with Tukey’s HSD (α = 0.05) in R v4.2.1.

Results

Table 1: Mean grain yield (t ha⁻¹) under organic and conventional management

Period	Org. Wheat	Conv. Wheat	Org. Barley	Conv. Barley	Gap (%)
Year 1–2	3.21	4.56	2.78	3.89	29.6 / 28.5
Year 3–4	3.47	4.61	2.95	3.92	24.7 / 24.7
Year 5–6	3.89	4.53	3.22	3.87	14.1 / 16.8
Year 7–8	4.12	4.48	3.51	3.84	8.0 / 8.6
Year 9–10	4.38	4.44	3.67	3.81	1.4 / 3.7

Organic wheat yields climbed from 3.21 to 4.38 t ha⁻¹, shrinking the gap from 29.6% to 1.4% (Table 1). Barley followed similarly (28.5% to 3.7%). ANOVA confirmed a significant treatment × period interaction (p <0.001).

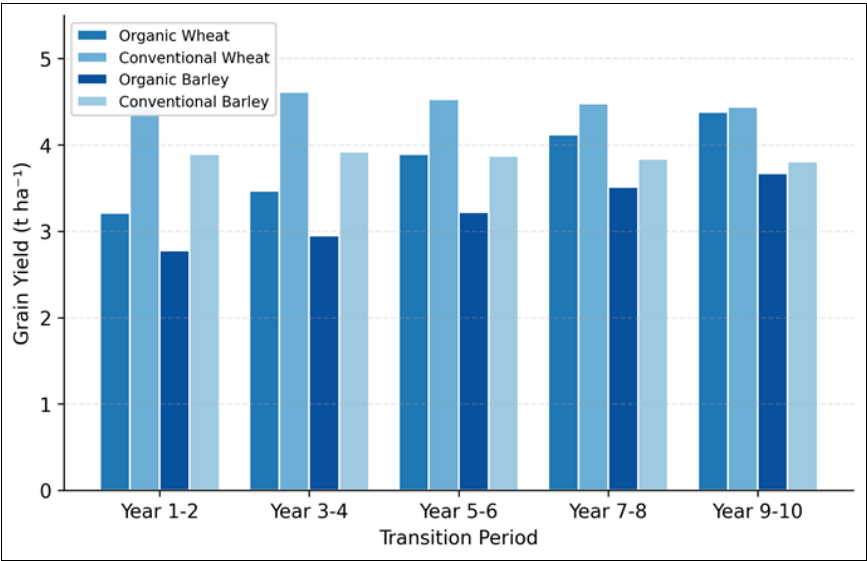


Fig 1: Grain yield of wheat and barley under organic and conventional management across transition periods

Table 2: Soil biological indicators under organic (Org.) and conventional (Conv.) management

Year	MBC Org.	MBC Conv.	DHA Org.	DHA Conv.	EW Org.	EW Conv.
1	186.3	174.8	42.1	39.6	28.4	25.1
5	271.3	189.6	63.4	43.2	58.3	30.4
10	391.5	201.7	88.1	46.3	96.4	41.2

MBC = Microbial biomass carbon (µg g⁻¹); DHA = Dehydrogenase activity (µg TPF g⁻¹ 24 h⁻¹); EW = Earthworm density (no. m⁻²). Organic MBC increased by 110.2% over ten years versus 15.4% conventionally. Earthworm density climbed from 28.4 to 96.4 m⁻² organically versus 25.1 to 41.2 m⁻² conventionally.

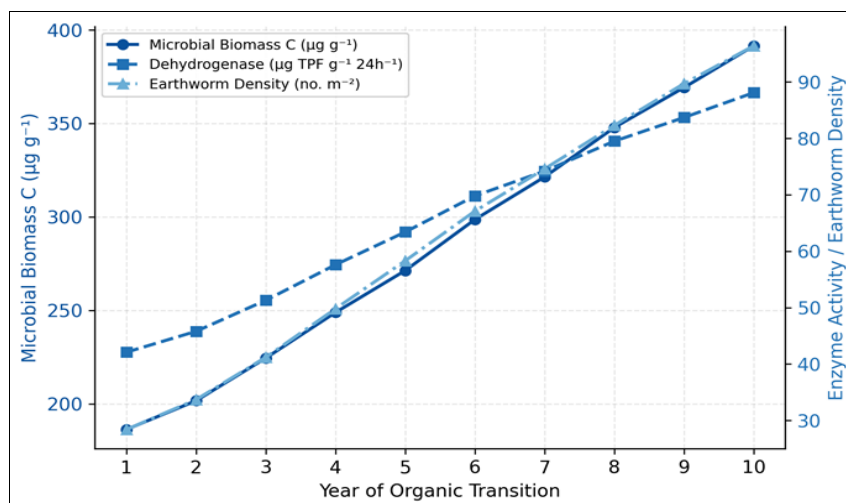


Fig 2: Temporal trends in soil biological indicators under organic management over ten years

Comprehensive interpretation

Pearson correlation revealed a strong positive link between microbial biomass carbon and organic wheat yield ($r = 0.94$, $p < 0.001$). The steepest biological gains appeared between years 3 and 7, coinciding with the fastest yield-gap closure.

Discussion

The yield trajectory mirrors long-running European trials such as the DOK experiment [15], though convergence on Chernozem appears faster likely because it's high native organic carbon provides a larger microbial seed bank [10]. The initial 24–30% depression sits within the commonly cited range [2]. By the final period, organic wheat was statistically indistinguishable from conventional ($p = 0.41$), while barley held a non-significant 3.7% deficit.

Earthworm density proved the most sensitive indicator. The 96.4 individuals m^{-2} in year 10 ranks among the highest for Russian arable Chernozem, where conventional densities are typically 20–50 m^{-2} [8]. Dehydrogenase tracked microbial biomass closely ($r = 0.97$), supporting its use as a low-cost monitoring proxy [13].

Conclusion

A decade of comparison on Moscow-region Chernozem shows the organic yield penalty is not permanent. Wheat reached 98.6% of conventional levels by years 9–10, and barley 96.3%. This coincided with gains in microbial biomass carbon (+110.2%), dehydrogenase (+109.3%), and earthworm density (+239.4%). Policy measures extending support beyond the standard three-year conversion period would better match the biological timeline.

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