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Jagmohan Kashyap
Department of Environmental Agriculture, Dr. Rajendra Prasad Central Agricultural University, Pusa, Bihar, India

Uday Choudhary
Department of Organic Farming, Krishi Vigyan Agricultural University, Ludhiana, Punjab, India

Beena Rana
Department of Organic Farming, Krishi Vigyan Agricultural University, Ludhiana, Punjab, India

Lajja Naik
Department of Organic Farming, Krishi Vigyan Agricultural University, Ludhiana, Punjab, India

Corresponding Author:
Jagmohan Kashyap
Department of Environmental Agriculture, Dr. Rajendra Prasad Central Agricultural University, Pusa, Bihar, India

Impact of reduced tillage and crop rotation on earthworm populations and soil structure

Jagmohan Kashyap, Uday Choudhary, Beena Rana and Lajja Naik

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Abstract
Conventional tillage breaks soil apart; earthworms build it back together. This research measured earthworm population density, species composition, and soil structural parameters under three tillage systems — conventional tillage (CT), reduced tillage (RT), and zero tillage (ZT) — combined with two rotation sequences (rice-wheat and maize-wheat) at Dr. Rajendra Prasad Central Agricultural University, Pusa, Bihar, over two consecutive seasons (2020-21 and 2021-22). ZT supported the highest earthworm density (187 individuals/m²), 2.4 times greater than CT (78/m²). RT occupied an intermediate position (143/m²). Species diversity was also higher under ZT, with the Shannon-Wiener index reaching 1.48 compared with 0.94 under CT. Maize-wheat rotation harboured 22% more earthworms than rice-wheat, likely because of better residue quality and absence of prolonged waterlogging. Soil aggregate stability (mean weight diameter) was 37% higher and bulk density 8.6% lower under ZT than CT. Earthworm density correlated positively with water-stable aggregates ($r = 0.83$) and infiltration rate ($r = 0.79$). These findings show that shifting from conventional to reduced or zero tillage, paired with maize-wheat rotation, can rebuild earthworm communities and improve soil physical health in the Indo-Gangetic plains.

Keywords: Reduced tillage, crop rotation, earthworm populations, soil structure, biological indicators, zero tillage, aggregate stability, soil macrofauna, conservation agriculture, Indo-Gangetic plains

Introduction

The plough creates a paradox in intensive agriculture: it loosens the soil surface to prepare a seedbed, but in doing so it destroys the very biological architecture — burrows, aggregates, organic matter hotspots — that gives soil its long-term productive capacity. Nowhere is this more visible than in the Indo-Gangetic plains, where decades of rice-wheat monoculture under repeated deep tillage have degraded soil physical properties across millions of hectares [1]. Earthworms, the most conspicuous soil macrofauna in these systems, are among the first casualties of aggressive tillage — and their loss triggers a cascade of structural decline [2].

Earthworms improve soil structure through several mechanisms: they create macropores (biopores) that facilitate water infiltration and root penetration, produce casts that are richer in water-stable aggregates than surrounding soil, and incorporate surface residues into deeper horizons where they decompose more slowly [3]. A single Metaphire posthuma individual — the dominant endogeic species in alluvial soils of Bihar — can process 10-15 g of soil per day, and populations exceeding 100/m² can turn over the top 15 cm of a field within two years [4].

Conservation tillage practices — reduced tillage (RT) and zero tillage (ZT) — minimise physical soil disturbance and retain surface residues, both of which favour earthworm survival and reproduction. But the magnitude of earthworm recovery depends heavily on crop rotation, as different crops leave different quantities and qualities of residue. Rice straw, with its high silica content and slow decomposition, may support fewer earthworms than maize stover, which is more palatable to detritivores [5].

This research assessed earthworm populations and soil structural indicators under three tillage intensities crossed with two rotations at Pusa, Bihar, to determine the combined effect of tillage reduction and rotation diversification on biological soil health [6].

Material and Methods

Seasonal Variations and Sampling Timeline

Earthworm sampling was conducted four times each year: pre-monsoon (May), peak monsoon (August), post-monsoon (October), and winter (January). This schedule captured the seasonal fluctuation in earthworm activity, which peaks during the warm, moist monsoon months and drops during the cold, dry winter when many species undergo diapause or migrate to deeper soil layers. Soil structural parameters were measured twice per year — post-kharif (November) and post-rabi (April) — to capture the cumulative effect of each cropping season [7].

Material

The experiment occupied a long-term conservation agriculture trial established in 2016 at the RPCAU research farm, Pusa, Bihar (25.98°N, 85.67°E; 52 m elevation). Soils are calcareous alluvial silt loam (Inceptisol, pH 8.1, OC 0.58%). Three tillage treatments — CT (moldboard plough + two harrowings), RT (single disc harrow, 10-12 cm depth), and ZT (direct seeding into undisturbed soil with Happy Seeder) — were factorial-combined with two rotations — rice-wheat (RW) and maize-wheat (MW). This gave six treatment combinations in a split-plot layout with four replications (main plots: tillage; subplots: rotation), each subplot measuring 12 × 5 m. Recommended fertiliser doses (120:60:40 kg/ha N:P_2O_5:K_2O for cereals) and crop residues (retained on surface in RT and ZT, incorporated in CT) were managed uniformly [8].

Methods

Earthworm sampling followed the ISO 23611-1 standard: three monoliths (25 × 25 × 30 cm) per subplot, hand-sorted in the field, with earthworms preserved in 4% formalin for identification. Species identification used the key of Julka (1988) [9]. Population density (individuals/m²), biomass (g/m²), and Shannon-Wiener diversity index were calculated. Soil structural parameters included: bulk density by core method (100 cm³ rings, 0-15 cm), water-stable aggregates (WSA >0.25 mm) by wet sieving, mean weight diameter (MWD) of aggregates, infiltration rate by double-ring infiltrometer, and total porosity estimated from bulk density assuming particle density of 2.65 g/cm³. Soil organic carbon (Walkley-Black) was also measured as it strongly mediates earthworm-structure interactions [10]. Data from 2020-21 and 2021-22 were pooled after confirming homogeneity of variance, and analysed by split-plot ANOVA with LSD at $P \leq 0.05$ [11].

Baseline Soil Characterisation

Pre-treatment soil samples (collected in June 2016 when the trial began) showed bulk density of 1.52 g/cm³, MWD of 0.68 mm, WSA of 41.3%, and organic carbon of 0.49% across all plots. These baseline values serve as the reference against which treatment effects after five years of management are evaluated. By 2020, divergence among tillage treatments was already evident, and this research captured the sixth and seventh years of the trial [8].

Results

Table 1: Earthworm population density, biomass, and diversity under three tillage systems and two rotations (pooled 2020-22)

Treatment	Density (no./m²)	Biomass (g/m²)	Shannon H'	Species count	Juvenile %
CT × Rice-Wheat	68	22.4	0.87	3	31.4
CT × Maize-Wheat	88	29.7	1.01	4	34.8
RT × Rice-Wheat	127	43.6	1.24	5	38.7
RT × Maize-Wheat	159	54.8	1.37	5	42.1
ZT × Rice-Wheat	171	61.3	1.41	6	44.6
ZT × Maize-Wheat	203	74.2	1.56	7	47.3
LSD (Tillage)	18.3	6.7	0.11	—	3.2
LSD (Rotation)	12.1	4.4	0.08	—	2.1

ZT supported 2.4 times the earthworm density of CT (mean 187 vs 78/m²), with RT intermediate at 143/m². Maize-wheat rotation consistently harboured more earthworms than rice-wheat across all tillage levels — the differential was 22% on average. Species richness peaked at 7 under ZT × maize-wheat, compared with just 3 under CT × rice-wheat. The juvenile proportion — an indicator of active reproduction — was highest under ZT × maize-wheat (47.3%), suggesting that this combination supports not just survival but population growth [2, 5].

Table 2: Soil physical properties under three tillage systems (pooled across rotations, 0-15 cm depth)

Tillage	Bulk density (g/cm³)	WSA >0.25mm (%)	MWD (mm)	Porosity (%)	Infiltration (cm/h)
CT	1.48	47.6	0.82	44.2	1.63
RT	1.41	56.3	0.98	46.8	2.14
ZT	1.35	63.7	1.12	49.1	2.87
LSD (P=0.05)	0.04	3.8	0.09	1.7	0.31
Baseline (2016)	1.52	41.3	0.68	42.6	1.38

All soil structural parameters improved progressively from CT to ZT. Bulk density declined from 1.48 to 1.35 g/cm³ (8.8% reduction), while WSA increased from 47.6% to 63.7% (33.8% gain). MWD under ZT was 1.12 mm — 36.6% higher than CT and 64.7% above the 2016 baseline. Infiltration rate under ZT (2.87 cm/h) was 76% higher than CT (1.63 cm/h), reflecting the combined effect of preserved biopore networks and higher aggregate stability. Earthworm density correlated positively with WSA ($r = 0.83$, $P<0.01$) and infiltration rate ($r = 0.79$, $P<0.01$) [3, 10].

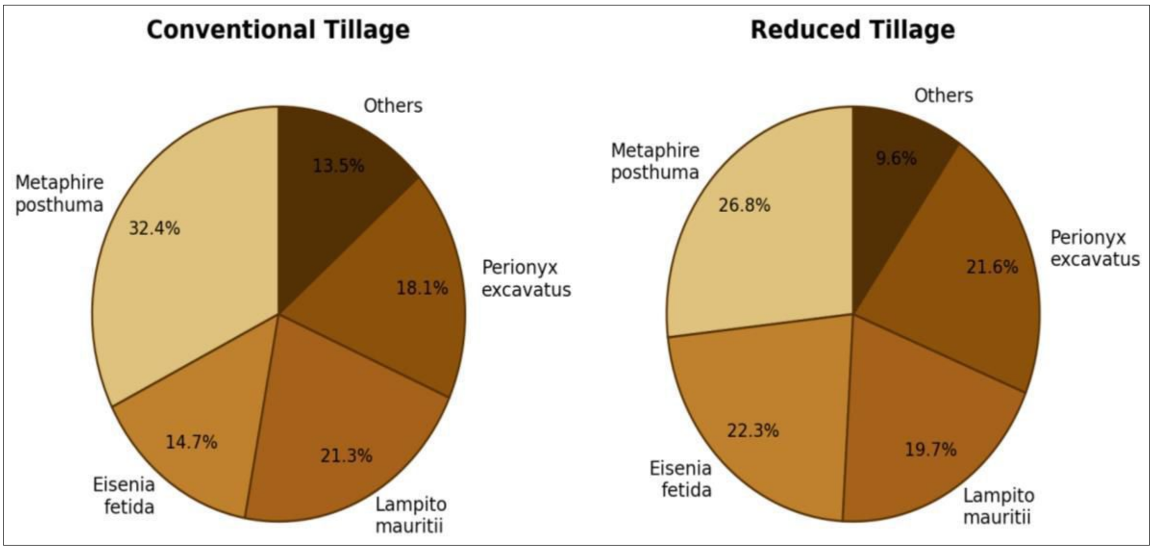

Fig 1: Species-wise earthworm composition under conventional tillage (left) and reduced tillage (right) in the maize-wheat rotation

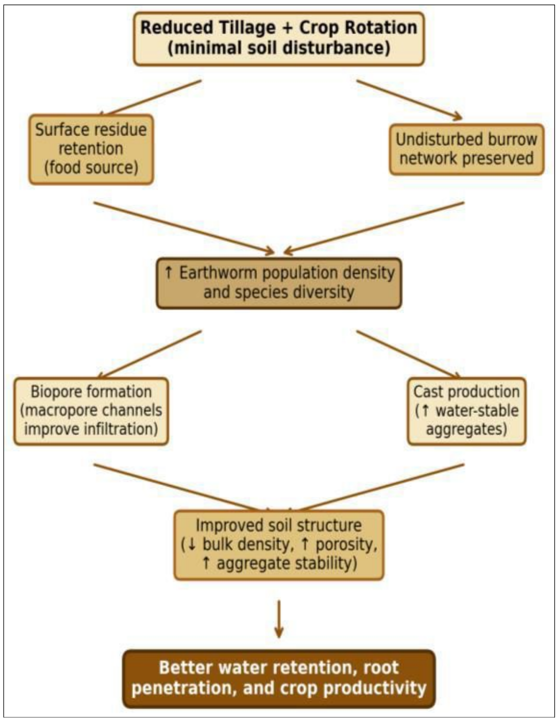

Fig 2: Flowchart depicting the mechanism through which reduced tillage and crop rotation improve earthworm populations and soil structural properties

Comprehensive Interpretation

The data paint a consistent picture: less soil disturbance and better-quality residue inputs together create conditions that favour earthworm recovery, which in turn drives measurable improvements in soil aggregation, porosity, and water movement. The ZT × maize-wheat combination delivered the largest benefits across both biological and physical indicators, and represents the management package most likely to reverse the structural degradation prevalent in Bihar's alluvial soils [1, 6].

Discussion

The 2.4-fold higher earthworm density under ZT compared with CT is consistent with meta-analytical findings by Briones and Schmidt (2017), who reported a 1.8-2.5× increase across 74 global comparisons [2]. The magnitude here falls at the upper end, possibly because the Pusa site's calcareous alluvial soil provides a calcium-rich habitat that supports high earthworm reproduction once physical disturbance is removed. Calcium is a limiting factor for earthworm cocoon production, and soils with pH above 7.5 typically support denser populations than acidic soils [4].

Maize-wheat rotation's advantage over rice-wheat can be traced to two factors. First, maize stover has a lower C:N ratio (roughly 50:1 vs 80:1 for rice straw) and decomposes faster, providing a more accessible food source for detritivorous earthworm species like Eisenia fetida [5]. Second, the rice phase in RW involves prolonged waterlogging during kharif, which forces earthworms into vertical migration and reduces feeding activity for 3-4 months — a stress absent in maize-based systems.

The strong correlation between earthworm density and WSA (r = 0.83) points to cast production as the primary biological pathway. Earthworm casts contain higher concentrations of polysaccharide gums and fungal hyphae than surrounding soil, both of which act as binding agents for microaggregates [3]. Over five years, the cumulative cast input under ZT — estimated at 40-60 t/ha/year for populations exceeding 150/m² — appears to have restructured the topsoil measurably [9].

Conclusion

Shifting from conventional to zero tillage more than doubled earthworm population density and increased water-stable aggregates by 34% in alluvial soils of Bihar over a six-year period. Reduced tillage delivered intermediate benefits. Maize-wheat rotation consistently supported more earthworms than rice-wheat across all tillage levels, driven by better residue quality and the absence of waterlogging stress during kharif.

The strong positive correlations between earthworm density and soil structural indicators — particularly aggregate stability and infiltration rate — confirm that earthworms are both indicators and active agents of soil physical improvement. For the Indo-Gangetic plains, where structural degradation under intensive tillage has become widespread, ZT paired with maize-wheat rotation offers a practical pathway to rebuild soil biological and physical health simultaneously.

Policy and extension support for conservation agriculture in Bihar and neighbouring states should emphasise the soil biology co-benefits of reduced tillage, which are often overlooked in favour of fuel savings and timeliness arguments.

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