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Ecological Relationship of Earthworms with Soil Physicochemical Properties and Crop Yields in Conservation Agriculture

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Abstract: Earthworms are important macro-organisms in the soil as they play a vital role in improving soil properties. This paper aims to estimate the population and their relationship with crop yields and soil physicochemical properties (soil bulk density, soil organic carbon, and soil penetration resistance) in fields where long-term conservation agriculture has been practised since 2012. The study found a higher population in August (24 individuals). Earthworm populations increased in zero tillage with residue plots than without residues. ZTWR 50% BN+GS plot had a higher earthworm population, and it recorded 24, 17 and 17 individuals in August, September and October months, respectively. From the Pearson correlation analysis, it was observed that earthworm population was positively correlated with soil organic carbon and maize, wheat and mung bean crop yields; earthworm population was negatively correlated with bulk density and penetration resistance. PCA and cluster analysis revealed ZTWR 50% BN+GS as the best treatment. Hence, crop residues retention with appropriate balanced fertiliser is considered as a sustainable practice that improves the soil earthworms and increases crop yields in the North West Indo Gangetic plains.

Keywords: Soil fertility, Bulk density, Penetration resistance, Carbon, earthworm

Earthworms are called ecosystem engineers because they can change the soil environment. Because earthworms influence, many chemical and physical soil qualities and is vital to understand how soil management affects their populations (Na et al 2022). Earthworms are essential macro soil organisms crucial in soil formation (Schon and Dominati 2020). Earthworms have the ability to move 40 cm of soil every century (Sharma et al 2017). Charles Darwin calculated that around 1140 kg ha^{-1} $year^{-1}$ of earthworm cast material was eliminated from the environment. Since grazed pasture in New Zealand has been seen to produce 1120 kg ha^{-1} $year^{-1}$, (Blouin et al 2013). Biomass, such as agricultural waste, is required for soil earthworms to thrive (Joseph and Kathireswari 2020). Conservation agriculture is a method of resource-efficient practice which effectively utilises crop residues and recycles agricultural waste, which is the nutrient hub. Conservation agriculture is growing in popularity in IGP because it uses agricultural waste as mulch right in the field (Dinesh et al 2019, Dinesh et al 2021). Continuous minimal tillage, residue retention, crop diversification, and appropriate fertiliser usage are the four main principles of a no-tillage farming technique known as conservation agriculture (Vanlauwe et al 2014). Both earthworms effectively utilise organic matter produced by the crops. Primarily, it transforms complex organic materials into a very microbiologically active nutrient-rich organic matter (Andrews et al 2021). Heavy metals and inorganic fertilizers together suppress soil microbial activity, and secondary metabolites created by the breakdown of herbicides have more detrimental effects than direct ones (Sinduja et al 2022). The ploughing frequency influences the earthworm population because of the mechanical damage and habitat loss (Peigné et al 2018). The investigating earthworm populations is critical in tillage and agricultural residues studies. The earlier research has shown that earthworms offer ecosystem services in various habitats, the advantages of earthworms in conservation agriculture have remained unexplored until recently (Sharma et al 2017). Hence this study in long-term conservation agriculture provides an opportunity to study more the relationship of earthworms with crop yields and soil physicochemical properties.

MATERIAL AND METHODS

Description of the experimental site: The current study was done at ICAR-Indian Agricultural Research Institute research farm Block 9B, New Delhi (28° 40' N, 77° 12' E and 228.6 MSL). The experiment was carried out in the long-term no-tillage experimental site (since 2012). The soil type is sandy loam (Typic Haplustept), and the average precipitation of the location is 650 mm per year. Triplicate soil samples were taken from each treatment plot. They were collected before the maize sowing. First, basic soil parameters were analysed using standard (Page 1982). A core sampler was used to collect the soil samples. Then, they were dried, sieved and passed through a 2 mm sieve for soil characterisation (Ghosh et al 1983). The primary soil properties are given in Table 1.

Experimental layout and management practices: The present research includes two years and three cropping seasons: 2018-19 and 2019-20. The experiment has two main plots (MP) and four subplot treatments (SP), each with three replications. Summer mung bean (cv. Pusa Vishal), Kharif maize (cv. PMH 1) and Rabi Wheat (cv. HD 2967) were sown. The main plot treatments are Zero tillage with residue retention (ZTWR) and zero tillage without residue retention (ZTWoR). The subplot treatments are recommended dose of nitrogen (RDN), 33% basal-N followed by Green Seeker N application (33 % N +GS), 50% basal-N followed by Green Seeker N application (50% N+GS), and 70 % basal-N followed by Green Seeker N application (70% N+GS). For crops, the fertiliser rates for Maize-Wheat-Mung bean were 150:60:40, 120:60:40 and 18:46:0, respectively.

Earthworm population sampling: Soil formation is linked with earthworm activity and population (Sandhu et al 2010). Earthworm numbers and activity peaked in the rainy season. Hence samples were taken for three months, where the earthworm activity was high/highest. From each plot, 30×30×30 cm^3 soil blocks were removed using a spade. Then, earthworms were manually sorted from the soil and counted (Martin 1978).

Table 1. Soil physicochemical properties

Parameter	Value	Reference
Soil pH	7.8	Nayak et al 2016
Electrical conductivity	0.42 dS m^{-1}	Nayak et al 2016
Soil organic carbon	4.69 mg kg^{-1}	Walkley and Black 1934
Soil bulk density	1.38	Blake et al 1986
Soil penetration resistance	452.19 kpa	Anderson et al 1980
Soil nitrogen	162.8 kg ha^{-1}	Subbaiah and Asija 1956
Soil phosphorous	15.2 kg ha^{-1}	Olsen et al 1954
Soil potassium	152.2 kg ha^{-1}	Prasad 1998

Statistical analysis: The split-plot design using Microsoft Excel 2016 was used to test the significance (Rangaswamy 2018). Pearson correlation analysis was done using the R programme. The p-values and correlations were obtained using the R-program 1.4.1103 (R Core Team 2013). Finally, principal component analysis and relationship analysis was done using standard procedures (Shankar et al 2019).

RESULTS AND DISCUSSION

Earthworm population: The earthworm population was higher in August, and it gradually decreased in October (Table 2). This is due to rainfall, New Delhi receives good precipitation in August, and starts to decrease in November later winter onsets (Zodinpuii and Lalthanzara 2019). In August, a maximum earthworm population was observed in the ZTWR 50%BN+GS treatment. Overall, the earthworm population was higher in ZTWR plots as the residue was retained in these plots (Dekemati et al 2020). On the contrary, the lowest earthworm population was observed in August under ZTWoR 70% BN+GS treatment. The main plot and subplot treatments are statistically significant in both years. The pooled analysis also reveals a significant difference between the years. The two-way interaction analysis between the main plot (RM) and subplot (PNM) is non-significant; hence there is no interaction between residue management and precision nitrogen management. However, there was a significant difference between a year and residue management and year and precision nitrogen management. The three-way interaction analysis between year × residue management × precision nitrogen management shows non-significant interaction.

Relationship analysis: From the cluster analysis, maize and wheat crop yields are closely related to each other in a single cluster. Soil parameters such as soil bulk density, soil organic carbon and soil penetration resistance are classified into a single cluster. However, the mung bean yields are unclustered. The treatments ZTWoR RDN, WoR 50%BN+GS, and WR 70%BN+GS are classified into a single cluster (Fig. 2). Earthworm, soil bulk density, organic and penetration resistance are closely related to each other, and influenced maize and wheat yields but not mungbean grain yield. Among the treatments, ZTWoR 70%BN+GS are underperformed, and it is reflected in the earthworm population as well.

Correlation analysis: Earthworm population is negatively correlated with soil penetration resistance, soil bulk density and is positively correlated with maize, wheat yield, and mungbean. This has a strong positive correlation with soil organic carbon (soil penetration resistance is soil organic carbon earthworm population, maize yields and wheat yields), mungbean yields and positively correlated with soil bulk density (Fig. 3).

Principal component analysis: All the observed data from the PCA analysis were consolidated into 7 Principal components. Among that, PC 1 and 2 has a variance of 99.04% (Table 3). Hence these two PC were taken for further analysis. Biplot analysis, revealed that the ZTWR 33%BN+GS was considered the best treatment. Mung bean and wheat yields are towards the positive dispersions (Fig. 4). Hence, it is concluded that the earthworm populations positively influence the mung bean and wheat yields with a high confidence level.

Earthworm population was lowest in ZTWoR 70%BN+GS treatment may be due to more nitrogenous fertiliser application in a single dose in the field. However, urea and urea with nitrification inhibitors negatively impact earthworms (Yahyaabadi et al 2018, Zisi et al 2020). Therefore, while applying chemical fertilisers, it is recommended that organic fertilisers be used in conjunction with chemical fertilisers to minimise the detrimental effects on organisms (Dinesh 2017, Dinesh et al 2018). Soil bulk density was positively correlated with soil penetration resistance (Fig. 3). Similar results were reported by Li et al (2020). Mung bean and wheat yields negatively correlate with soil bulk density and penetration resistance and is due to the negative effect of soil bulk density. When soil bulk density is higher, it is difficult for the root to penetrate deeper layers, ultimately affecting crop yields (Diatta et al 2020). Earthworm population is negatively correlated with soil bulk density and soil penetration resistance, but it has a positive relationship with wheat, mung bean yields and soil organic carbon. When the earthworms' population and activity are high, soil compaction, soil bulk density, and soil penetration resistance decrease (Sohrabi et al 2021). Soil organic carbon and crop yields a positive relationship with earthworm populations. Therefore, when

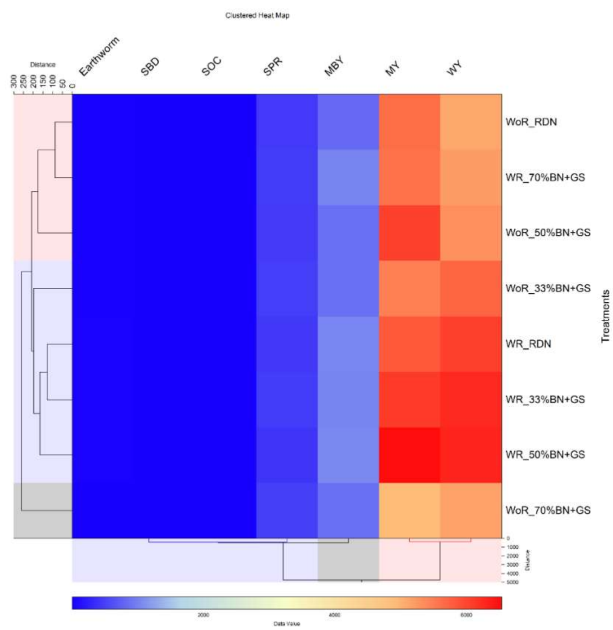

Fig. 1. Relationship between earthworm population with various soil parameters and crop yields

Table 2. Effect of conservation agriculture practices on earthworm population (Nos. ft^{-1})

CRM	PNM	August	September	October	SE	SD
ZTWoR	RDN	5	8	6	0.67	1.17
	33+GS	6	9	5	1.11	1.93
	50+GS	7	14	12	2.16	3.75
	70+GS	3	7	2	1.44	2.50
ZTWR	RDN	16	12	13	1.40	2.42
	33+GS	18	12	14	1.79	3.10
	50+GS	24	17	17	2.51	4.34
	70+GS	14	8	11	1.49	2.59
Treatment		2018-19		2019-20		Pooled
MP: Residue Management (RM)						
CD (p=0.05)		11.03		13.39		1.14
SP: Precision Nutrient management (PNM)						
CD(p=0.05)		1.76		2.06		4.44
Int. RM×PNM		NS		NS		*
Y x RM						1.71
Y×PNM						2.96
Y×RM×PNM						NS

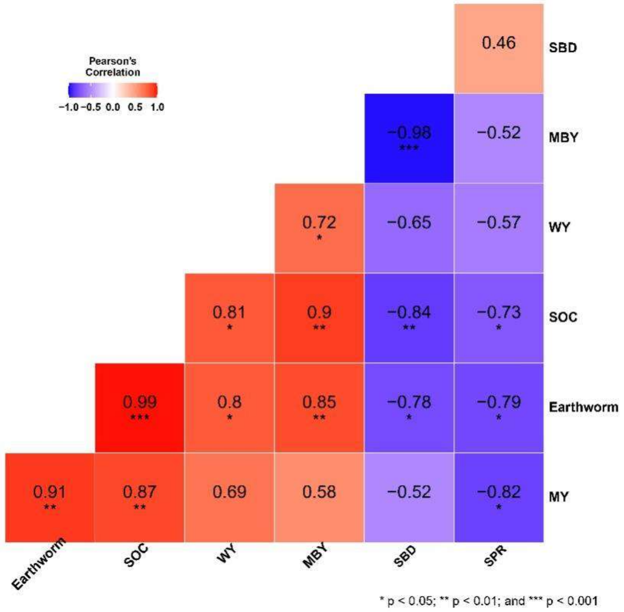

Fig. 2. Relationship between earthworm population and soil physicochemical properties

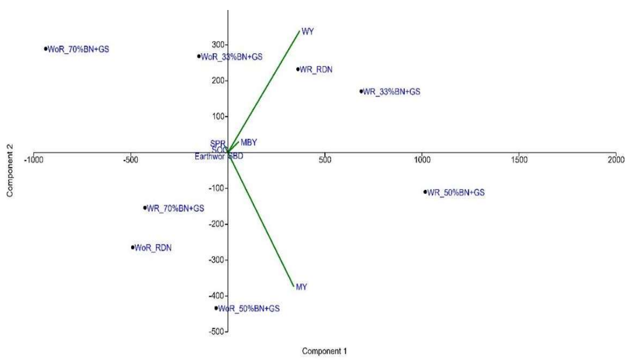

Fig. 3. Effect of conservation agriculture on earthworm population and soil physicochemical properties by Biplot analysis

earthworm populations are high, it will positively influence the crop yields (Johnston et al 2018) and more earthworm activity decomposes the crop residues and converts them into organic carbon-rich humus (Kumar et al 2020, Treder et al 2020). Hence, it can be concluded that SOC improves the earthworm population and eventually increase crop yields.

CONCLUSION

Earthworm populations increased in zero tillage with residue plots than without residues. Earthworm activity peaked in the rainfall season and positively influenced by soil organic carbon. Hence, earthworms improve the maize, wheat and mung bean yields, and are negatively influenced by penetration resistance and bulk density. PCA analysis showed that ZTWR RDN and ZTWR 33%BN+GS were the best treatments for the earthworm. Hence, crop residues retention with appropriate balanced fertiliser is considered as a sustainable practice that improves the soil earthworms and crop yields in the North West Indo Gangetic plains.

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