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Earthworms as an Alternative Technique for Soil Fertility Evaluation

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Abstract: Field experiments were conducted in acidic soils of Mangalpur and Fulbari VDCs in western Chitwan, Nepal to study earthworms as an alternative technique for soil fertility evaluation. Seven land use systems (cereal based lowland, cereal based upland, vegetable farm land, fruit orchard land, pasture land, forest land and farmer's field) were used and they were replicated four times in randomized complete block designs. Soil organic matter and total soil nitrogen were significantly higher from pasture land (4.69 % and 0.23 %) and the lowest were from farmer's field (2.40 % and 0.08 %). However, available soil phosphorous content was significantly higher from cereal based upland (448.3 kg ha^{-1}) and it was the lowest from forest land (13.0 kg ha^{-1}). The highest earthworm count was observed from pasture land (10.05 numbers per trap) than others but it was the lowest from farmer's field. There were significant positive correlations between soil organic matter content and the earthworm count (r= 0.957^{**}) and between total soil nitrogen content and earthworm count (r= 0.795^{**}). In contrast, a significant negative correlation was observed between earthworm count and available P (r= -0.510^{**}). Correlation between earthworm count and silt content was positive (r= 0.677^{**}) but between earthworm count and sand content was negative (r= -0.639^{**}). Soil organic matter, total soil N, available soil P and soil texture regulated earthworm dynamics in soils. Thus, earthworm population may be used as a bio-indicator of soil fertility status and it can be developed as an alternative technique for soil fertility evaluation after quantification and verification from further experiments on earthworm dynamics under different land use systems.
Keywords: land use systems, earthworm dynamics, bio-indicator, soil fertility evaluation

INTRODUCTION

Earthworms are important organisms doing a great job in the soil for mankind over thousands of year. Earthworms improve soil physical, chemical and biological properties and add nutritive value to the soil for healthy crop production due to their feeding habit [1]. Earthworms play role in nutrient cycling and dynamics along with mineralization due to their burrowing, casting and mixing actions [2]and they have been called as 'ecosystem engineers'. Earthworms stimulate soil organic matter mineralization and increase nutrient availability [3]. Diversity and density of earthworms could be indicators of soil fertility status. Abundance of earthworms could indicate fertile soil along with good soil health.However, their count differs accordingly depending upon suitability of habitat and availability of food for their growth and development. Content of soil organic matter, total soil nitrogen, available phosphorous, available potassium, soil texture and pH frequently regulated the earthworm population.Earthworm count in different land use systems differ accordingly due to variation in soil properties. Soil organic matter, NPK, bulk density, pH, sand, silt and clay contents are the mostly fluctuating soil parameters in different land use systems.

Plant behavior and expression of deficiency by phenotypic characters (deficiency symptoms), analysis of plant tissue and soil test are the major soil fertility evaluation techniques [4]. All of these techniques have their own merits and demerits but in general they are not affordable by most of the Nepalese farmers. Hence, an alternative technique of soil fertility evaluation is crucial for small and marginalized farmers. There may be an opportunity to develop an alternative technique of soil fertility evaluation by taking earthworm abundance as a bench mark. This might be the cheapest and easily accessible technique for all the farmers. Considering all these problems and factors, field experiments were conducted on earthworm dynamics under different land use systems with the following objectives:

- To quantify soil fertility status of different land use systems.

- To determine earthworm dynamics under different land use systems.
- To establish relationships between earthworm dynamics and soil properties.

METHODOLOGY

Study area and research design

Fulbari and Mangalpur village development committees (VDCs) located in the western Chitwan were purposively selected for this study since these VDCs had all the land use systems proposed for study.

Field experiments were conducted with seven land use systems as treatments.Cereal based lowland, cereal based upland, vegetable farm land, and fruit orchard lands were under the management of Institute of Agriculture and Animal Sciences (IAAS) within Mangalpur VDC and were replicated four times at different fields. Farmer's fields represented the land use managed traditionally by corresponding farmer with heavy tillage operation and application of significant amounts of chemical fertilizers and pesticides. Crops generally grown include maize, wheat and vegetables, especially carrot. In Fulbari VDC these were replicated at four different farmer's fields. Forest land and pasture lands were replicated at four different blocks as separated by the Seti Devi community Forest executive body. All together there were twenty eight study sites. The whole experiment was designed in randomized complete block design.

Soil sample collection and laboratory analysis

Composite soil samples were collected from each study site from 20 cm depth of land use systems.Soil samples were prepared and stored for laboratory analysis.Air-dried samples were ground, sieved through 2.0 mm sieve and stored for physical and chemical analyses. For SOM analysis samples were sieved through a 0.2 mm sieve.

Soil texture, pH, organic matter, total nitrogen, available phosphorus and available potassium contents were analyzed at the Central Soil and Plant Analysis Laboratory of the Institute of Agriculture and Animal Sciences, Tribhuvan University. However, total nitrogen, available phosphorous and available potassium were analyzed in the Soil Science Division, NARC, Khumaltar. Standard laboratory procedures were followed for the analysis of the soil physicochemical properties.

Method of earthworm collection

Earthworm traps were used for the collection and study of earthworm abundance. Each plastic bucket having 18 cm upper and 20.5 cm lower periphery in diameter and 22 cm in height was used for preparing earthworm traps. Since there were all together 28 study sites, 28 buckets with above mentioned dimension were selected and perforated to facilitate free entry and exit of earthworms from the buckets. Each bucket was filled with one kg of cow dung and 300 g of poultry pellet (Broiler ration, B_2) as attractants for earthworms. The buckets were installed in the study sites in such a way that bucket top was three cm below the soil surface. Earthworms were attracted towards the bucket and they were collected and counted with hand sorting method at 30 days intervals, five times during the experimental period (Feb, March, April, May and June, 2013) as shown in Appendix 6. After each count the attractant materials were replaced by new in the buckets.

Statistical analysis and data presentation

Data were analyzed using MSTAT-C. Different descriptive techniques such as average and standard error were used for computing results. Duncan's Multiple Range Test and correlation as a measure of inferential statistics were also used for data analysis. Calculation of correlation coefficients and multiple regression analysis were performed using SPSS. XLSTAT package was used for principal component analysis.

RESULT AND DISCUSSIONS

Effect of land use systems on soil physicochemical properties

Table-1: Soil physical properties under different land use systems of western Chitwan, Nepal, 2013

Land use systems	Sand (%)	Silt (%)	Clay (%)	Bulk Density (g cm^{-3})	Soil Textural Class
Cereal based lowland	59.70^{b}	25.38^{bc}	14.93^{ab}	1.30	Sandy loam
Cereal based upland	69.36^{a}	20.53^{d}	10.10^{c}	1.41	Sandy loam
Vegetable farm land	67.49^{a}	22.36^{cd}	10.15^{c}	1.34	Sandy loam
Fruit orchard land	58.78^{b}	27.67^{b}	13.55^{bc}	1.23	Sandy loam
Pasture land	35.95^{c}	46.92^{a}	17.13^{ab}	0.99	Loam
Forest land	34.38^{c}	47.33^{a}	18.30^{a}	1.18	Loam
Farmer's field	57.70^{b}	26.85^{b}	15.45^{ab}	1.39	Sandy loam
LSD (0.05)	5.296**	4.279**	3.768**	NS	
SEM (±)	1.782	1.440	1.268	0.1414	
Grand Mean	54.765	31.006	14.229	1.267	
CV (%)	6.51	9.29	17.83	22.32	

Means followed by the same letter in a column are not significantly different at 5% level of significance as determined by DMRT

Soil texture was affected by land use and land management. Significantly higher silt (47.33 %) and clay (18.30 %) contents were observed from the forest soils than other land use systems. Cereal based upland soils had higher sand content (69.36 %) than other land use systems. However, there was not significant effect of land use systems on bulk density of the soil.

The highest amount of soil organic matter (4.69 %) was recorded from the pasture land whereas the lowest (2.40 %) was from the farmer's field (Table 2). The lower levels of SOM from farmer's field, cereal based upland, cereal based lowland and vegetable farm land could be the result of high OM decomposition, insufficient organic materials inputs in the systems, residue removal and lack of crop rotation [5]. Clay particles adsorbed and stabilized more OM and other nutrients [6]in pasture and forest lands.

Nitrogen content of soil was significantly affected by the land use systems. Total soil nitrogen content was the highest (0.23 %) from pasture land and the lowest (0.08 %) was from farmer's field (Table 2). A land use change from natural forest to cultivated land aggravates land degradation and reduces the quantity of soil N content over the long run. Runquan [7] also reported a decrease in soil organic matter and total nitrogen due to deforestation. Fu *et al.*[8]also found 18% increment in total soil N when farm lands were converted back to forest land.

Table-2: Soil chemical properties under different land use systems of western Chitwan, Nepal, 2013

Land use systems	SOM (%)	N (%)	P_2O_5 (kg ha^{-1})	K_2O (kg ha^{-1})	pH
Cereal based lowland	3.01^{cd}	0.13^{c}	17.00^{c}	27.25	5.49
Cereal based upland	2.79^{cd}	0.09^{d}	448.3^{a}	90.00	5.63
Vegetable farm land	2.58^{d}	0.15^{c}	375.3^{a}	86.50	5.41
Fruit orchard land	3.75^{b}	0.18^{b}	83.75^{bc}	120.5	5.68
Pasture land	4.69^{a}	0.23^{a}	15.25^{c}	72.75	5.74
Forest land	3.42^{bc}	0.19^{b}	13.00^{c}	79.50	5.36
Farmer's field	2.40^{d}	0.08^{d}	119.3^{b}	88.25	5.20
LSD (0.05)	0.6441**	0.01914**	83.54**	NS	NS
SEM (±)	0.2168	0.006442	28.12	26.23	0.2382
Grand Mean	3.236	0.153	153.107	80.679	5.505
CV (%)	13.39	8.70	36.73	65.01	8.66

Means followed by the same letter in a column are not significantly different at 5% level of significance as determined by DMRT

The highest available phosphorous (448.25 kg ha^{-1}) was recorded from the cereal based upland and that of the lowest (13 kg ha^{-1}) was observed from the forest land. P fixation is greater in soil having higher clay content [9] and this might be the reason for low level of available P from the pasture land, forest land and cereal based lowland. Low levels of available P from the forest soil might also be due to the forest vegetation itself with large biomass and thus more P uptake and immobilization in plant biomass. Phosphorous shows a tendency to build up in soil with subsequent addition of phosphatic fertilizers from external sources. The residual effect of added phosphatic fertilizers might have caused a high level of phosphorous from the cereal based upland and vegetable farm, but such an effect in the cereal based lowland may have been overridden by the higher clay content.

There were no significant effects of land use systems on the potassium content of the soil. Soils of all the land use systems were acidic in nature (pH below 6).

Land use systems effects on earthworms dynamics

Earthworms dynamic in terms of their abundance were significantly affected by the land use systems. The highest earthworm count (10.05 per trap) in terms of average of the five sampled dates was recorded from the pasture land and the lowest (3.30) from the farmer's field (Table 3). Highest soil organic matter in the pasture land might contribute to supply more feed stuffs to the earthworms and made environment favorable for their multiplication. Lavelle *et al.*[10] and Lee [11] reported that soil organic matter was an important factor governing earthworm variations in different land use systems because soil organic matter was a major food resource for earthworms. Yusnaini *et al.*[12]also reported a positive effect on activity and existence of soil organisms with the increase of soil organic matter content. Abundance of earthworm from the pasture and forest soils was also depicted by Edwards and Bohlen [13]. Baker *et al.* [14] found a positive correlation between earthworm abundance and clay content. Positive correlation between earthworm abundance and silt content of soil was reported by Hendrix *et al.*[15]. Thus, the highest amount of clay and silt particles from pasture land (Table 1) might have attributed to the highest earthworm count. Agricultural practices like plowing, multiple tillage, application of chemical fertilizer and pesticides could have reduced the earthworm members in farmer's field besides lower content of soil organic matter.

Table-3: Earthworms abundance under different land use systems in western Chitwan, Nepal, 2013

Land use systems	Earthworms count per trap
Cereal based lowland	5.15^{cd}
Cereal based upland	4.25^{d}
Vegetable farm land	3.50^{d}
Fruit orchard land	7.80^{b}
Pasture land	10.05^{a}
Forest land	6.50^{bc}
Farmer's field	3.30^{d}
LSD (0.05)	1.730^{**}
SEM (±)	0.5822
Grand Mean	5.793
CV (%)	20.10

Means followed by the same letter in a column are not significantly different at 5% level of significance as determined by DMRT

Relationship between soil properties and earthworm dynamics

Soil properties frequently regulate earthworm abundance and distribution in different land use systems. Earthworm dynamic was significantly regulated by SOM, total soil nitrogen, available P, sand and silt contents.

A significant positive correlation (r= 0.957^{**}) was recorded between soil organic matter and earthworm count (Table 4). This result was in accordance with the findings of Hendrix *et al.*[15] that a strong positive correlation between earthworm population density and soil organic matter content across 10 sites they studied. Schmidt *et al.*[16]also recorded an increased earthworm number with the increase in organic carbon content in the Egyptian soil. Soil with low organic matter content cannot support food for higher numbers of earthworms and resulted in their lower count as described by Edwards and Bohlen [13].

Table-4: Simple correlation coefficients between soil properties and earthworm counts in western Chitwan, Nepal, 2013

	pH	SOM	N	P_2O_5	K_2O	BD	Clay	Sand	Silt
Earthworms count	0.234	0.957^{**}	0.795^{**}	-0.510^{**}	0.050	-0.167	0.351	-0.639^{**}	0.677^{**}

There was a positive correlation (r= 0.795^{**}) between total soil nitrogen and earthworm count, supporting the argument that higher amounts of total nitrogen favored increment in earthworm numbers (Table 4). Application of a large amount of nitro chalk to pastures for grass production increased earthworm numbers [17]. The increment in earthworm count with increased total nitrogen might be due to increased vegetative production which in turn increases the amount of residues returned to the soil. The same phenomenon of increment in earthworm number with the addition of chemical nitrogenous fertilizer was reported by Duiker and Stehouwer [18].Thus, the higher number of earthworm in an ecosystem can be taken as an indicator of higher total nitrogen content in that ecosystem.

Available soil P and earthworm count showed a negative correlation (r = -0.510^{**}) as shown in Table 4. Gerard and Hay [19]also reported a decrease in number of earthworms from grass plots with the application of superphosphate fertilizers. The decreased count of earthworms from soils having higher content of available P might not be the result of available P rather it might be due to other soil parameters such as lower amount of soil organic matter, total nitrogen and higher fraction of sands than silt and clay in soils.

A negative correlation (r = -0.639^{**}) was observed between sand content and the earthworm count whereas, silt content and the earthworm count were found to have a positive correlation (r = 0.677^{**}). Soil texture modifies other soil characteristics like water holding capacity and nutrient status [13]. 1996). Higher silt content was responsible for a higher earthworm count. Hendrix *et al.*[15]also reported higher earthworm abundance from soils having higher silt contents.

Table-5: Factors contributing in the earthworms count in different land use systems in western Chitwan, Nepal, 2013

Particulars	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
	B	Std. Error	Beta		
(Constant)	-1.483	2.093		-.707	.488
SOM	2.565	.275	.849**	9.338	.000
N	2.224	5.354	.046	.415	.682
P_2O_5	-.003	.001	-.188*	-2.135	.046
K_2O	.007	.003	.128	2.084	.051
pH	-.241	.361	-.040	-.667	.513
Bulk density	.218	.592	.024	.368	.717
Sand	-.121	.029	-.639**	-4.232	.000
Silt	.014	.025	.060	.576	.571
Clay	-.061	.060	-.087	-1.023	.319

Dependent Variable: Earthworms count (per trap)
R^2 = 94.9%, Adjusted R^2= 92.7%, Standard error of the estimate = 0.70075, F-ratio = 43.902
*.Significant at 0.05 level
**.Significant at 0.01 level

While using multiple regression model, the value of R^2, Adjusted R^2, Standard error of the estimate and F-ratio were found to be 94.9%, 92.7%, 0.70075 and 43.902 respectively. Contribution of SOM, total N, available K, bulk density and silt content showed the positive relation with the earthworms count in western Chitwan whereas available P, soil pH, sand and clay contents showed the negative relationship for the same. Soil organic matter and sand contents were found significant at 1% level of significance whereas available P was found significant at 5% level of significance in the regression model. If the SOM contents increased by 1%, the earthworms count increased by 2.565 numbers. If the sand contents increased by 1%, the earthworms count decreased by 0.121 numbers. Similarly, if available P increased by 1 kg ha^{-1}, the earthworms count decreased by 0.003 numbers. The equation is given below:

$$Y = -1.483 + 2.565 X_1 + 2.224 X_2 - 0.003 X_3 + 0.007 X_4 - 0.241 X_5 + 0.218 X_6 - 0.121 X_7 + 0.014 X_8 - 0.061 X_9$$

Y = Earthworms count, X_1 = Soil organic matter, X_2 = Total soil nitrogen, X_3 = Available soil P, X_4 = Available soil K, X_5 = Soil pH, X_6 = Soil bulk density, X_7 = Sand content, X_8 = Silt content and X_9 = Clay content.

Principal component analysis (PCA) of earthworm dynamics

The principal component analysis was made by using the mean values of nine variables of earthworm dynamics. The variables used for PCA analysis were soil organic matter, total soil nitrogen, available phosphorus, available potassium, soil bulk density, soil pH, sand, silt and clay contents. The first four components were better to explain variability in earthworm dynamics in different land use systems as variance for four components were above more than 80%. All together four components contributed 85.71% divergence among earthworm dynamics in different land use systems. First component contributed 48.445%, second component contributed 16.925%, third component contributed 12.479%, and fourth component contributed 7.862% respectively.

Table-6: Principal components and proportion of variation generated by them in earthworms count of western Chitwan, Nepal, 2013

Variables	**Eigen value**	**Percentage variance**	**Cumulative percentage**
PC 1	4.360	48.445	48.445
PC 2	1.523	16.925	65.370
PC 3	1.123	12.479	77.849
PC 4	0.708	7.862	85.710
PC 5	0.640	7.109	92.819
PC 6	0.312	3.461	96.280
PC 7	0.188	2.091	98.372
PC 8	0.147	1.628	100.000

Table-7: Loading values and contribution of variables (%) to principal components

Variables	PC 1		PC 2		PC 3		PC 4	
	Lv	Ct	Lv	Ct	Lv	Ct	Lv	Ct
SOM	-0.721	11.915	0.378	9.371	-0.230	4.723	0.433	26.543
Total soil nitrogen	-0.826	15.638	0.303	6.020	-0.259	5.982	0.071	0.722
Available P	0.798	14.594	0.338	7.520	-0.078	0.535	0.021	0.061
Available K	0.103	0.241	0.705	32.627	0.462	18.978	-0.395	22.054
Soil BD	0.426	4.158	0.263	4.551	0.640	36.444	0.559	44.192
Soil pH	-0.085	0.164	0.766	38.477	-0.297	7.831	-0.115	1.854
Sand	0.950	20.715	0.034	0.075	-0.218	4.226	0.034	0.168
Silt	-0.935	20.047	0.006	0.002	0.111	1.105	0.016	0.037
Clay	-0.739	12.529	-0.144	1.357	0.476	20.175	-0.176	4.369

Lv= Loading value; Ct= Contribution; PC= Principal Component

Sand contributed the highest and soil pH contributed the lowest variation in the total variation caused by PC 1. Soil pH contributed the highest and silt content contributed the lowest amount of variation in the total variation brought about by PC 2. Similarly, Soil bulk density was the major variable responsible for the highest amount of variation caused by PC 3 and PC 4. Whereas, available P contributed the lowest amount to the variation caused by PC 3 and silt content contributed the same for PC 4 as shown in Table 7.

CONCLUSIONS

Soil properties and earthworm dynamics were significantly affected by the land use systems. Earthworms may be used as bio-indicators to evaluate soil fertility status. Earthworm abundance can be used as an alternative technique for soil fertility evaluation. However, for quantification and verification, both phytotron and field experiments are required for detailed study on earthworm dynamics.

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