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Burrowing Activity of Rodents Alter Soil Properties: A Case Study on the Short Tailed Mole Rat (*Nesokia indica*) in Pothwar Plateau, Punjab, Pakistan

Abul Hassan Faiz*, Fakhar-i-Abbas and Lariab Zahra Faiz
Women University Bagh (AJK), BRC House No. 34, Bazaar Road, Sector G-6/4, Islamabad

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Authors' Contribution
FA presented the main idea of research and provided funding for research. AHF performed the field work and collected the data. LZF manipulated the results and wrote the article.

Key words
Mound soil, Fossorial rodent, Electrical conductivity, Ecological engineer.

ABSTRACT

The present study was conducted to investigate how (*Nesokia indica*) activities impact on soil fertility. The survey was conducted from January to December, 2016 by applying line transect technique in eight types of soil (sand, loamy sand, sandy loam, sandy clay loam, loam, clay loam, silt loam, silty clay loam) to determine six soil properties (plant biomass, saturation, electrical conductivity, pH, organic matter, phosphorus and potassium) in Pothwar Plateau (250 km long and 100 km wide). We compared 216 soil samples (mound soil and undisturbed soil), to collect data on percentage water saturation, electrical conductivity (E/C), pH, organic matter content, and phosphorus and potassium contents. We found significant differences (mound soil and undisturbed soil) in % water saturation, electrical conductivity (E/C), pH, organic matter, phosphorus, potassium and biomass in all types of soil. A Chi-Square Q-Q plot was applied to test for the normality of data, and a one-way ANOVA without interaction was used for the different soil types (mound and undisturbed soil) to examine the effects of rat burrowing activity on, plant biomass, saturation, pH, electrical conductivity, organic matter, potassium and phosphorous concentration. These significant differences in soil composition have long-term effects on ecosystem sustainability and productivity of vegetation.

INTRODUCTION

Soil is the product of both biotic (flora, fauna) and abiotic components such as temperature, pH, redox potential. Soil composition is strongly influenced by burrowers, which alter both the physical and chemical soil properties (Zhang *et al*., 2003), and also soil mixing and nutrient enhancement (Clark *et al*., 2005). The short tailed mole rat (*Nesokia indica*) of the family Muridae is a digging rodent, excavating and maintaining extensive burrow systems (Hussain, 2005). Its presence becomes obvious through the deposited fresh soil mounds. *N. indica* excavates soil with its incisors and deposits the soil as mounds on the surface above the ground. There may be one to five large mounds and several smaller mounds associated with a single burrow system (Hussain, 2005). The main excavated soil mounds usually have fecal pellets and pieces of grass stems mixed with excavated soil. A number of studies have been conducted on small mammals (Faiz *et al*., 2015; Faiz and Abbas, 2016; Faiz *et al*., 2018) but the impact of rat digging on soil fertility has not been studied. In the present study we hypothesized that the mound soil of *N. indica* would have greater amounts of soil organic matter, phosphorus, potassium, electrical conductivity and saturation than soil with no mole activity.

MATERIALS AND METHODS

Study area

The study was conducted in Pothwar (32° 33' and 34° 03' N, 71° 89' and 73° 37' E), the most northern part of the Punjab province in Pakistan. Pothwar is in the north bordered by the Margalla and Kala Chitta hills and in the south of Salt Range Mountains which are separated from the main mountain ranges of the west by the Indus River. In the study area, nine tehsils (administrative division, with towns, villages) were randomly selected and in each tehsil areas around nine villages were sampled. In total, 216 soil samples were collected: 108 samples from fresh mounds and 108 samples from undisturbed soil. Undisturbed soil samples were taken 10 m away from the mound area. Soil samples were packed in plastic zipper bags and sent to the Soil and Water Testing Laboratory, Data Ganj Bakhsh Road, Rawalpindi, Pakistan, for further analyses.

* Corresponding author: sabulhussan@gmail.com
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Soil analysis

Plants biomass

All the plants above ground on mound area were removed and packed in plastic bags and similarly all plants above ground 5 meter away from mound were removed and packed. Both plants sample were heated separately in oven up till 60°C and weighed.

Determination of textural class

Jars of 600 mL were filled with air-dried, pulverized (40 g) soil samples and to the remaining third portion of water and a teaspoon of powdered, non-foaming dishwasher detergent were added. The jars were shaken for 10 to 15 min and left for two to three days and tightly sealed. The processed jar samples were then shifted to the soil texture triangle studies for further examinations based on the textural class using the USDA textural triangle of (Bouyouces, 1962).

Determination of electrical conductivity and pH

The soil sample (10 g) was mixed with 0.01 N KCl to a paste. The paste is then passed through moist filter paper fitted inside the funnel and the resulting filtrate collected in a bottle by applying vacuum. Conductivity of the filtrate is measured with conductivity meter (MP515-01 Precision Conductivity MeterSan-Xin) in mS cm^{-1} or dS m^{-1}.

For determination the pH of each sample, saturated paste was prepared by adding deionized water to 10 gram of sample. The sample was then allowed to equilibrate for 18-24 h. Afterwards, soil pastes were rejuvenated (re shake) and their pH estimated with a pH meter (PHS-3D-02 pH Meter San-Xin).

Determination of organic matter

One gram of grounded, dried soil sample each was transferred to a 250 ml conical flask and 10 ml of 1N $K_2Cr_2O_7$ and 10 ml of concentrated H_2SO_4 (96 %, specific gravity 1.84) were added. After 30 min, 50 ml of deionized water, 3 ml of concentrated H_3PO_4 and 0.5 ml of 1% defenilamina (Barium diphenylamine sulphonate, 0.16 %) indicator were added. Then, each sample was slowly titrated with 1N $FeSO_4$ solution to a green color end point by following (Walkley, 1947).

Determination of extractable phosphorus (Olsen's Method)

The air dried sample of 2.5 g of the grounded soil was put into flask, 50 ml extracting solution (0.5 M sodium bicarbonate, 700 ml distilled water, pH 8.5) was added, the mixture shaken for 30 min and filtered with Whatman No. 42. To 5 ml aliquot, 5 ml of color developing reagent (0.528 g ascorbic acid, 4.8 % 12 g (NH_4) $6Mo7O_{24}$ $4H2O_2$, 0.291 g (KS bO.$(C_4H_4O_6)$. 1000 ml, 5 N H_2SO_4 were added and shaked to remove any gas bubbles and kept at room temperature for 15 min. A bluish color will develop whereby the concentration of phosphorus in the soil is directly proportional to the intensity of the blue color developed. The phosphorus concentration is estimated from the absorption at 880 nm wavelength in a Spectrophotometer (Digital Display Visible Spectrophotometer, Labmen) by following Olsen *et al*. (1954).

Determination of extractable potassium

The soil sample of 2.5 g was passed through a 2 mm sieve soil, collected into a 250 ml conical flask and 50 ml of extracting reagent (77.1g of CH_3COONH_4 in 800 ml H_2O, 1.907 g of KCl in 1 liter of H_2O) added. Each sample was shaken on a flatbed reciproshaker for 30 min and filtered the extract. Potassium content was determined by a flame photometer (Models PFP7) by following USDA (1954).

Statistical analyses

We used SPSS version 16 (www.ibm.com/software) to conduct all statistical analyses. A Chi-Square Q-Q plot was applied to test for the normality of data, and a one-way ANOVA without interaction was used for the different soil types (mound and undisturbed soil) to examine the effects of rat burrowing activity on saturation, pH, electrical conductivity, organic matter, potassium- and phosphorous concentration.

RESULTS

Plant biomass varied significantly between within mound soil and undisturbed soil (Table I). The maximum value of plant biomass was found in mound soil of clay loam (1870.75±13.47) and found minimum value in sandy soil type (420.5±17.93). The maximum value of plant biomass was found in control soil of clay loam (1792±16.35) and minimum value was recorded in sandy soil type (356.44±20.5).

Table I.- Plant biomass (kg).

Type soil	Plant biomass	
	Mound	Control
Sand	420.5±17.93	356.44±20.5
Loamy sand	635.56±85.3	385.19±51.7
Sandy loam	900.63±61.5	545.83±37.3
Sandy clay loam	1181.10±10.6	715.82±6.45
Loam	1343.58±8.60	1210.79±22.36
Silty clay loam	1589.12±19.6	1473.66±36.85
Clay loam	1870.75±13.47	1792±16.35

Soil water saturation % was significantly greater in the mounds compared to the undisturbed soil (Table II). The maximum value of soil water saturation % was found in mound soil of clay loam (39.63±1.21) while minimum value was found in soil type (sand) (29.44±0.50).The maximum value of saturation (%) found in control soil was clay loam (34.46±1.0) and minimum value was found in sand (20.31±1.3).

There were also significant differences in E/C in the mound soil compared to the undisturbed soil. The maximum value of electrical conductivity (E/C) was found in mound soil of loam (1.91±0.08) and minimum value was found in soil type (clay loam) (0.62±0.10) (Table II). The maximum value of saturation (%) found in control soil was loam (1.46±0.06) and sandy loam (0.31±0.03) (Table II).

There were also no significant differences in pH in the mound soil compared to the undisturbed soil. The maximum value of pH was found in mound soil of clay loam (7.67±0.07) while minimum value was found in soil type (loam) (7.46±0.05). The maximum value of pH found in control soil was sandy clay loam (7.01±0.0) and minimum value was found in soil type (sand) (5.50±0.31) (Table II).

There were significant differences in organic matter % in the mound soil compared to the undisturbed soil. The maximum value of organic matter % was found in clay loam mound soil (0.83±0.06) and minimum value was found in sandy loam soil type (0.16±0.03) (Table III). The maximum value of organic matter % was found in clay loam control soil (0.59±0.04) and minimum value was observed in sandy loam soil type (0.11±0.01) (Table III).

There were significant differences in phosphorus contents in the mound soil compared to the undisturbed soil (Table III). The maximum value of phosphorus contents was found in mound soil of type sandy loam (6.14±0.4), and minimum value was found in sandy soil type (4.47±0.2) (Table II). The maximum value of phosphorus contents was found in clay loam control soil (5.37±0.1) and minimum value was found in sandy soil type (3.0±0.0.2) (Table III).

There were significant differences in potassium contents in the mound soil compared to the undisturbed soil (Table III). The maximum value of potassium contents was found in mound soil of sandy clay loam (165.25±8.31), and minimum value was recorded in soil type (loamy sand) (45.78±9.4). The maximum value of potassium contents was found in clay loam control soil (136.88±6.94) and minimum value was recorded in sandy loam soil type (31.97±15.70).

Table II.- Saturation, electrical conductivity and soil pH.

Type soil	Saturation%		Electrical conductivity (dSm^{-1}) E/C		Soil pH	
	Mound	Control	Mound	Control	Mound	Control
Sand	29.44±0.50	20.31±1.3	1.20±0.06	0.63±0.04	7.53±0.10	5.50±0.31
Loamy sand	31.33± 2.1	27.14±1.5	0.71±0.14	0.39±0.07	7.66±0.44	7.02±0.0
Sandy loam	32.25±1.7	28.04±1.5	0.62±0.11	0.31±0.03	7.58±0.37	7.02±0.0
Sandy clay loam	34.0±0.87	29.57±0.7	0.69±0.02	0.37±0.01	7.46±0.05	7.01±0.0
Loam	38.06±0.49	32.50±0.4	1.91±0.08	1.46±0.06	7.46±0.05	6.97±0.06
Silty clay loam	33.82± 0.5	29.41±0.4	0.72±0.03	0.40±0.02	7.64±0.09	7.03±0.01
Clay loam	39.63±1.21	34.46±1.0	0.62±0.10	0.51±0.10	7.67±0.07	7.06±0.01

Table III.- Organic matter, phosphorus and potassium.

Type soil	Organic matter %		Phosphorus (mg kg^{-1})		Potassium (mg kg^{-1})	
	Mound	Control	Mound	Control	Mound	Control
Sand	0.78±0.05	0.43±0.02	4.47±0.2	3.0±0.0.2	57.7±3.73	34.49±2.05
Loamy sand	0.79±0.15	0.45±0.09	5.66±0.9	3.28±0.6	45.78±9.4	34±6.06
SANDY loam	0.16±0.03	0.11±0.01	6.14±0.4	3.51±0.3	51.25±15.91	31.97±15.70
Sandy clay loam	0.50±0.05	0.27±0.02	5.61±0.1	3.90±0.1	56.86±1.97	45.92±1.59
Loam	0.56±0.02	0.46±0.02	5.4±0.2	3.04±0.1	102.1±3.53	84.75±3.02
Silty clay loam	0.77±0.04	0.50±0.02	5.77±0.1	3.21±0.0	129.41 ±5.6	104±4.66
Clay loam	0.83±0.06	0.59±0.04	6.03±0.2	5.37±0.1	165.25±8.31	136.88±6.94

Table IV.- Results of one-way ANOVAs of the effects intermediate and control soil properties.

S No.	Soil properties	F	Significant
1	Saturation	435.261	0.000
2	Potassium	323.091	0.000
3	Phosphorus	182.068	0.000
4	Organic matter	590.851	0.000
5	Electrical conductivity	685.379	0.000
6	Soil pH	182.068	0.000
7	Plant biomass	690.98	0.0000

The results of (ANOVA) are given in Table IV and Figure 1 which present trended chi square Q-Q plots for normal distribution of data.

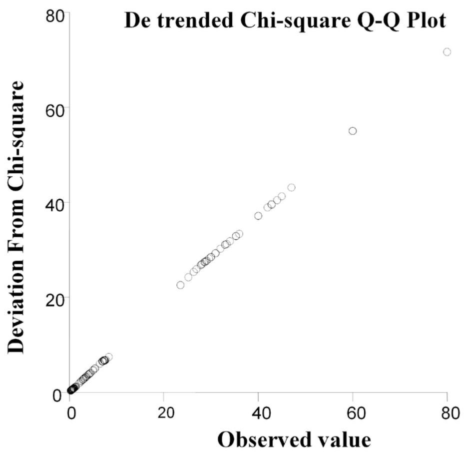

Fig. 1. The trended chi square Q-Q plots.

DISCUSSION

The results of this study indicate that burrowing of rodents alter the soil properties around their burrows which improves its aeration, infiltration and water-holding capacity. These properties are beneficial for the soil because they affect absorption of phosphorus, absorption zinc, copper, other nutrients and the uptake of water (Plaster, 2009).

The burrowing of rodents cause lowering of plant biomass above the ground, by burying vegetation under the excavated soil, and by reducing above ground vegetation (Williams and Cameron, 1986). The species (*N. indica*) also invades areas of dense vegetation , disrupts the existing vegetation matrix by strong burrowing and intensive foraging, hence lower plant biomass and, thereafter, subordinate plant species invade the area which otherwise would be ousted by competitively superior species (Jones *et al*., 2008).

The significant increase in water saturation % of the mound soil suggests that the water holding capacity of soil in the mounds increased and in turn enhances infiltration (Doran and Zeiss, 2000) which increases the water holding capacity and thus encourages plant growth according to the findings of Plaster (2009). The increase in % water saturation helps reduces nutrients loss, up to 60% through water drainage (Lalonde *et al*., 1996).

Electrical conductivity of soil is a predictor of plant response and it differs according to their critical electrical conductivity range (Rhoades and Loveday, 1990). The increased in electrical conductivity range of mound soil than undisturbed soil, indicated that rat burrowing has positive impact on soil electrical conductivity. The increased in electrical conductivity has positive impact on plants which causes improvement in ecosystem functioning (Richards, 1954).

The results of our study indicated that soil pH increased by urination of *N. indica* and the soil pH is of much importance for plant -soil chemical relations which regulate the availability of essential micronutrients (Fe, Mn, Cu and Zn) and toxic ions (Holste *et al*., 2011). The significant increase in organic matter in mound soil indicated impact of rat activity due to foraging underground stem, roots of plants and excavated soil which buries vegetation resulting in increase in organic matter (Sherrod and Seastedt, 2001). The addition of organic matter indicates improvement in quality of soil because soil organic matter determines quality of soil (Carter, 2002). The cultivated soil is deficient in organic matter due to crop production (Janzen, 2006). The burrowing activities can be used in reversing land degradation and increased soil fertility and crop production (Weil and Magdoff, 2004).

The results of this study indicated significant difference of phosphorus between mound soils and undisturbed soils. A significant increase of phosphorus can thus possibly also be considered as a positive effect on phosphorous soil resources. Phosphorus is important nutrient for ecosystem structure, processes and function. Their availability limits the production of plant biomass (increases in root surface area, branching) and growth (Hu and Schmidhalter, 2005). Phosphorus is essential primary nutrient for plant growth (cell division, reproduction), production and quality (Zapata and Zaharah, 2002).

The study results indicated significant difference of potassium between mound soils and undisturbed soils. A significant increase of potassium can thus possibly also be considered as a positive effect on potassium soil resources. Major cultivated lands of the world are deficient in available K and K-bearing minerals and thus rocks are used in soil as an alternative potassium source (Römheld and Kirkby, 2010). The potassium contents in soil which provide appropriate ionic environment for metabolic and regulatory processes of plants (Leigh and Wyn Jones, 1984).

CONCLUSION

Our findings suggest that *N. indica* positively alters chemical and physical soil characteristics and improves quality and health of soil and serves as an ecosystem engineer like other subterranean rodents of North and South America, Europe or Asia (Reichman and Seabloom, 2002).

Statement of conflict of interest

Authors have declared no conflict of interest.

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