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SPATIO-TEMPORAL VARIATIONS IN SOIL CHARACTERISTICS AND NUTRIENT AVAILABILITY OF AN OPEN SCRUB TYPE RANGELAND IN THE SUB-MOUNTAINOUS HIMALAYAN TRACT OF PAKISTAN

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Abstract

To assess the seasonal and spatial changes in the soil physico-chemical characteristics and nutrient availability, six ecologically diverse sites were evaluated during this study. Redundancy analysis revealed significant variation in soil physicochemical characteristics attributable both to sites and seasons. Field capacity and soil sodium contents did not vary significantly during different seasons. However, nitrogen and phosphorus contents were significantly higher in summer. Soil pH increased during spring whereas ECe and potassium ion (K^+) contents remained higher in winter. Soil pH and ECe were closely associated with the sites having low moisture contents (Anga and Dape Sharif). Sodium (Na^+) was recorded higher in clayey loam soils (Jhallar) whereas phosphorus (P) and K^+ contents showed their maximum amount in clayey loam soil with high vegetation cover (Khabeki). Nevertheless, the clayey loam soils at Khabeki and Jhallar sites showed the highest field capacity. A strong correlation was observed between frequency and intensity of rainfall, parent material of the soil, vegetation of the area, and nutrient availability of soil.

Introduction

Soil properties of terrestrial ecosystems depend upon a variety of abiotic and biotic factors that vary both spatially and seasonally (Peverill *et al*., 1999). Among abiotic factors total ion content, acidity, carbon, total nitrogen and total phosphorous vary on spatial scale in the topsoil. Some additional factors like climate, land form, topography, soil texture, soil moisture, and plant community composition also affect soil composition (Maria *et al*., 2004; Takata *et al*., 2008). Among these, the total ionic contents and acidity independently influence the soil geochemistry and ultimately the distribution pattern of vegetation in an area. Climate shows no direct influence on the soil composition; however, it can have an indirect effect through plant community composition and/or soil moisture. If the climate turns more arid, then the soil is expected to lose moisture and become less acidic and less fertile (Arora, 2002; Paltineanu *et al*., 2007). Similarly, the gradients of soil carbon, nitrogen, total ion content and acidity strongly correlate with the composition of plant communities (Maria *et al*., 2004; Takata *et al*., 2008).

Our study area (Soone Valley) being 20 km in length and 5 km in breadth (Afzal *et al*., 1999) is regarded the heart of Salt Range in Pakistan. It lies between longitudes 72°00 and 72°30 E and latitudes 32°25 and 32°45 N, surrounded by two parallel east to west longitudinal ridge systems, covering an area of 300 km^2. The average elevation of the area is 762 m and the highest point in the area is the Sakesar Top being 1522 m above sea level. The climate of the valley is cooler than adjoining areas and characterized by a relatively low annual rainfall (~30 cm). The average minimum temperature remains 1^{o}C during January and average maximum temperature as 36^{o}C during June. Hot dry winds and long periods of drought are frequently experienced during summer whereas winters are accompanied by frost (Hussain, 2002). As a result the valley is comprised of a number of macro and microclimates. Overall the vegetation of the area is mainly open Scrub Type semi-arid rangeland that varies mainly with elevation, soil type and precipitation.

Keeping it in view the present study was planned to examine the spatio-temporal variations in the soil characteristics and nutrient availability at different sites in the open scrub type semi-arid rangeland in Soone Valley, a sub-mountainous Himalayan Tract in Pakistan.

Materials and Methods

Following six ecologically diverse study sites (Khabeki, Khoora, Dape Sharif, Anga, Knotti Garden and Jhallar) selected on the basis of differences in their environmental attributes especially variations in elevation, slope, aspect, altitude, topography, soil composition, habitat, vegetation type and plant community structure, examined for four consecutive years during this study as given in detail in Tables 1 and 2.

Anga site: It is located at 32^o 35 N and 72^o 05 E at an altitude of 826 m asl and about 20 km away from Noshera City, the major town in the Soone Valley. Its wildlife is highly diverse but it is severely degraded in plant diversity. This site is near the saline Uchhali Lake, and contains grasses and small trees and patches of cultivated land.

Dape Sharif site: It is situated near a small water reservoir and is located 32^o 30 N and 72^o 04 E. Its altitude is 890 m asl and is 10 km NW of Noshera City between high mountains. The vegetation consists of grasses, herbs, shrubs and few trees.

Khabeki site: It is located at 32^o 35 N and 72^o 12 E at an elevation of 778 m asl being 8 Km North from Noshera City. It was declared as a Wetland Ramsor site in 1976. It is dry during periods of low rainfall but now it contains enough water for birds, animals and plants. The vegetation consists mainly of grasses and shrubs.

Khoora site: is situated 15 Km away from Noshera City along the Noshera Khushab Highway. It is located 32^o 23 N and 72^o 12 E with a height of 868 m asl. However, the vegetation is green and contains a large number of plant species.

Knotti garden site: is located at 25 Km north of Noshera City. It is located at 32^o 40 N and 72^o 14 E with an elevation of 783 m asl. It was established during the British regime in the subcontinent India for propagation of Valencia oranges and other fruit plants. Presently local government is maintaining it. This vegetation consists of herbs, shrubs and trees.

Jhallar site: is situated at 32^o 37 N and 72^o 10 E about 20 km W of Noshera City with an elevation of 996 m asl. It is at a pass through high mountains. Some vegetation for example *Fagonia indica* and *Withania coagulens* remains alive even during winter frosts.

Table 1. Geographical aspects of the sites selected in the Soone Valley of the Salt Range.

Sites	Coordinates	Elevation (m)	Slope (%)	Aspect
Khabeki	32.35N and 72.12 E	774	30-35	Western
Khoora	32.23N and 72.11 E	866	40-45	Northern
Dape Sharif	32.30N and 72.04 E	890	35-40	Western
Anga	32.35N and 72.05 E	821	30-35	Northern
Knotti Garden	32.40N and 72.14 E	783	30-35	Northern
Jaller	32.27N and 72.09 E	996	50-60	Eastern

Table 2. Plant community Structure of the sites selected in the Soone Valley of the Salt Range.

Sites	Habitat description	Vegetation type	Plant community
Khabeki	Moderate slopes	Dominant large shrubs with grasses	*Justicia adhatoda*
Khoora	Hills with steep slopes	Shrubs herbs and grasses	*Dodonea viscosa*
Dape Sharif	Almost plain area	Shrubs and grasses	*Dodonea viscosa*
Anga	Hills with steep slopes	Dominant grasses with shrubs	*Acacia modesta*
Knotti Garden	Hills with steep slopes	Mixture of herbs grasses and shrubs	*Justicia adhatoda* and *Acacia fernesiana*
Jaller	Pass through the Hills	Grasses herbs and shrubs along the pass between the hills	*Acacia modesta* and *Justicia adhatoda*

Soil analysis: Soil texture was determined using the hygrometer method (Dewis & Freitas, 1970). Electrical conductivity, pH and ions of saturation extracts were determined according to Rhoades (1982) and Jackson (1962).

Statistical analyses: Ecological and biochemical data was analyzed with Partial Redundancy Analysis (*p*RDA), using the Canoco Computer Package for Windows [Version 4.5] (using seasons as variables and sites as a co-variables and vice versa). All parameters were centered and standardized before analysis.

Results and Discussion

The distribution of soil physiochemical attributes of different study sites during different seasons has been depicted by partial RDA ordination biplot (Fig. 1). Soil physiochemical attributes varied significantly both during different seasons and at different sites. The nitrogen and phosphorus contents of different study sites showed close association during summer. The pH values increased during spring whereas ECe and K contents were associated with winter. Heavy rainfall caused nutrient leaching especially the N_2 content in towards lower soil layers may be attributed to so spatial and temporal variations in the light textured soils (Peverill *et al*., 1999; Buri *et al.*, 2005). The above ground vegetation after its decomposition greatly affects soil mineral nutrients especially the soil N and P status. If legumes dominate in the above ground vegetation then they may lead to enhanced N_2 component of the soil (Peverill *et al*., 1999).

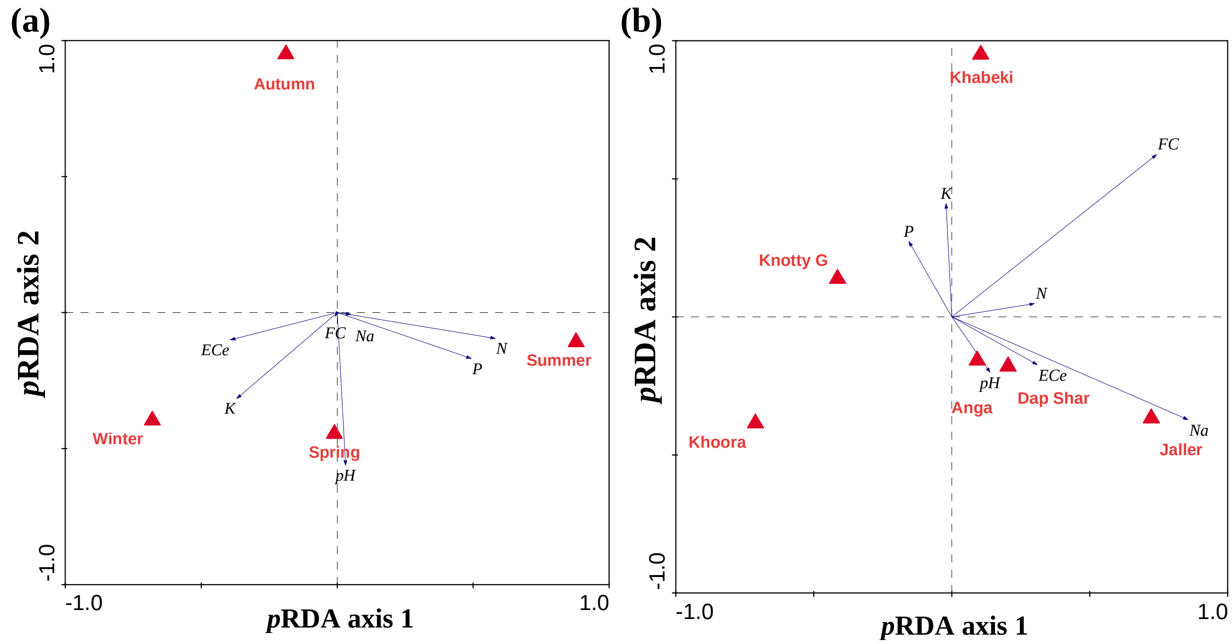

Fig. 1. Partial RDA ordination biplot showing the effect of seasons (a) and sites (b) on the distribution of soil physio-chemical attributes in Soone Valley of Salt Range.

Table 3. Meteorological data of different seasons in the Soone Valley of the Salt Range.

Season	2004 -05			2005- 06		
	Average temperature °C		Rainfall (mm)	Average temperature °C		Rainfall (mm)
	Maximum	Minimum		Maximum	Minimum	
Autumn	32.00	20.00	31.50	32.4	20.2	96.6
Winter	19.06	3.16	23.6	12.8	4.16	0.00
Spring	20.9	10.45	111.5	22.6	11.4	82.0
Summer	37.6	22.56	38.1	33.8	23.8	61.0

Table 4. Soil characteristics of the sites selected in the Soone Valley of the Salt Range.

Sites	Field capacity (%)				Soil ECe (dS m^{-1})			
	Autumn	Winter	Spring	Summer	Autumn	Winter	Spring	Summer
Khabeki	49	54	51	51	1.7	2.7	2.1	1.3
Khoora	25	23	30	32	0.9	3.8	0.9	1.2
Dape Sharif	40	39	38	41	7.6	8.7	1.7	2.2
Anga	39	39	34	37	1.4	3.9	1.2	1.4
Knotti Garden	39	38	35	35	2.9	4.4	1.2	1.6
Jaller	46	50	48	45	1.1	3.4	5.6	4.2

Sites	Soil pH				Soil texture
	Autumn	Winter	Spring	Summer	
Khabeki	7.69	7.69	8.3	7.7	Clay loam with stones
Khoora	7.76	7.96	8.1	7.8	Sandy clay with stones
Dape Sharif	7.82	8.29	8.1	7.9	Sandy clay
Anga	7.78	7.89	7.9	7.8	Sandy Clay with stones
Knotti Garden	7.73	7.87	8.1	8.1	Sandy clay
Jaller	7.82	7.92	8.1	8.2	Clay loam

This spatio-temporal variation in nutrient availability can also be a result of fluctuation in grazing intensity. For example, McNaughton *et al*., (1997) provided direct evidence that the nutrient cycling is accelerated in natural ecosystems by large free-ranging mammalian grazers. Levels of minerals, especially nitrogen and sodium, are generally highly required plant nutrients in the soils of highly grazed sites than in soils of nearby non-grazed areas where animal density remains sparse. At fenced sites particularly herbivores may promote recycling and availability of both nitrogen and phosphorus which correlate with correlate with the abundance of grazers varying at different sites during different seasons (McNaughton *et al*., 1997). In this study as well, the higher association of N and P with summer and spring can be attributed to the high grazing pressure during these seasons. In addition, Khabeki site in particular, and Anga and Knotti Garden sites in general remain under severe grazing pressure and thus their greater N, P and K content may be attributed to extensive herbivory (Fig. 1b, Table 5).

Soil chemistry of grasslands greatly varies with seasonal changes (Murata *et al*., 1997; Murata *et al*., 1999). As examined by Kaiser & Heinemeyer (1993) and Garcia & Rice (1994) the C or N contents of soil varied seasonally due to differential microbial activities for decomposing biomass accumulation and thereby nutrient recycling in some grasslands of the Japanese Temperate Zone and Tall grass Prairie in Argentina, respectively. However, such seasonal variation in grasslands depends upon the type of plant material being added to the soil or composition of microorganisms involved in the degradation of organic matter (Cheshire, 1979; Murayama, 1984, Murata *et al*., 1997).

In this study, pH increased following winter and spring rain falls and was recorded the lowest in summer. Moreover, the temporal variation was examined higher than the spatial one. The existence of higher amount of soluble salts in soil under dry conditions during summer season may be attributed to this suppressed pH (Peverill *et al*., 1999; Kadono *et al*., 2009). In addition, electrical conductivity also varies with frequency and intensity of rainfall and drainage characteristics of the site (Peverill *et al*., 1999). During winter, there is no or very little rain in Soone Valley (Table 3) so previously available moisture is evaporated leaving the salts on soil surface and as a consequence its ECe values get increased. On the arrival of spring and with the increase in rainfall, an increase in the pH value of alkaline soils may also be recorded. Similarly, spring and summer rainfalls may change the nutrient status of the soil at different sites due to nutrient leaching.

Soil pH has a direct effect on the availability of most of the nutrients and is important for proper nutrient management. On the other hand, soil pH has been reported to have no direct effect on N availability. However, it has been suggested to indirectly control N availability through soil microbial activity. In addition acidic soil conditions have been reported to limit microbial activity and slow mineralization of N as well as nitrification (Mullen, 2004; Kimura *et al*., 2009). On the other hand, P availability is strongly influenced by soil pH. For example, the maximum amount of P was recorded for the soil having pH between 5.5 and 7.5. On the other hand, the basic soil conditions (pH>7.5) increase the calcium (Ca) content of soil solution which can precipitate with P decreasing its availability. Thus seasonal and temporal fluctuations in soil pH in particular and ECe in general could have a direct influence on the availability of nutrient the area under study (Bagayoko *et al*., 2004; Funakawa *et al*., 2008).

Table 5. Ionic concentrations in soil of the sites selected in the Soone Valley of the Salt Range.

Sites	Na^+ (mg/g dry soil)				K^+ (mg/g dry soil)			
	Autumn	Winter	Spring	Summer	Autumn	Winter	Spring	Summer
Khabeki	0.120	0.096	0.100	0.040	0.03	0.17	0.10	0.03
Khoora	0.013	0.037	0.047	0.040	0.02	0.06	0.03	0.04
Dape Sharif	0.260	0.240	0.121	0.201	0.04	0.14	0.02	0.06
Anga	0.140	0.210	0.180	0.350	0.02	0.03	0.07	0.02
Knotti Garden	0.051	0.042	0.027	0.041	0.03	0.07	0.01	0.02
Jaller	0.326	0.360	0.356	0.390	0.02	0.02	0.01	0.02
Sites	**P (mg/g dry soil)**				**N (mg/g dry soil)**			
	Autumn	**Winter**	**Spring**	**Summer**	**Autumn**	**Winter**	**Spring**	**Summer**
Khabeki	5.1	13.0	6.5	22.5	0.09	0.09	0.09	0.17
Khoora	6.9	7.5	8.0	11.1	0.06	0.05	0.11	0.10
Dape Sharif	9.0	8.5	7.2	15.5	0.13	0.05	0.12	0.11
Anga	12.5	8.5	4.5	17.5	0.12	0.14	0.12	0.20
Knotti Garden	8.5	16.5	16.5	19.5	0.09	0.10	0.11	0.09
Jaller	7.2	8.75	7.5	9.5	0.08	0.08	0.11	0.18

Table 6. Summary of the partial RDA showing the effect of seasons and sites on soil physio-chemial attributes.

Parameters and data	Axes		Total variance	F-ratio	*P* value
	1	2			
Seasons | Sites					
Eigenvalues	0.125	0.066	1.000	4.130	0.0020***
Sum of all canonical Eigenvalues	0.250				
Sites | Seasons					
Eigenvalues	0.216	0.114	1.000	4.451	0.0020***
Sum of all canonical Eigenvalues	0.448				

Conclusion

Spatio-temporal variations in soil pH, ECe and moisture during different seasons and sites had a direct influence on the availability of the macro-nutrients such as Na, K, N and P. Most of the macro-nutrients (N and P and K) were more available during spring with high soil pH and at sites with severe grazing pressure (Khabeki, Anga and Knotti Garden sites). In addition, soil Na^+ and ECe were higher during winter in the clayey loam soils (Jhallar). Autumn season meagerly affected the availability of macro-nutrients as none of them was found to be associated with this season. These changes in soil physicochemical attributes seem to be the determining factors for the distribution of vegetation in the rangelands in the semi-arid regions under study.

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References

Afzal, S., M. Younas and K. Hussain. 1999. Physical and chemical characterization of the agricultural lands of the Soan. Sakesar Valley, Salt Range, Pakistan. *Australian J. Soil Res.*, 37: 1035-1046.

Arora, V.K. 2002. The use of the aridity index to assess climate change effect on annual runoff. *J. Hydro.*, 265(1-4): 164-177.

Bagayoko, M., S. Alvey, G. Neumann and A. Buerkert. 2004. Root-induced increases in soil pH and nutrient availability to field-grown cereals and legumes on acid sandy soils of Sudano-Sahelian West Africa. *Plant Soil*, 225(1-2): 117-127.

Buri, M.M., R.N. Issaka and T. Wakatsuki. 2005. Extent and management of low pH soils in Ghana. *Soil Sci. Plant Nutr.*, 51(5): 755-759.

Cheshire, M.V. 1979. *Nature and Origin of Carbohydrate in Soils*. Academic Press, New York

Dewis, J. and F. Freitas. 1970. *Physical Methods of Soil and Water Analyses*. FAO Soil Bull. No. 10, pp. 39-51.

Funakawa, S., T. Watanabe and T. Kosaki. 2008. Regional trends in the chemical and mineralogical properties of upland soils in humid Asia: With special reference to the WRB classification scheme. *Soil Sci. Plant Nut.*, 54(5): 751-760.

Garcia, F.O. and C.W. Rice. 1994. Microbial biomass dynamics in tallgrass prairie. *Soil Sci. Soc. America J.*, 58: 816-823.

Hussain, M. 2002. *Exploration of Legume Diversity Endemic to Salt Range, in the Punjab*. Annual Technical report submitted to University of Agriculture Faisalabad, Pakistan.

Jackson, M.L. 1962. *Soil Chemical Analyses*. Constable and Company Ltd., England

Kadono, A., S. Funakawa and T. Kosaki. 2009. Factors controlling potentially mineralizable and recalcitrant soil organic matter in humid Asia. *Soil Sci. Plant Nutr.*, 55(2): 243-251.

Kaiser, E.A. and O. Heinemeyer. 1993. Seasonal variations of soil microbial biomass carbon within the plough layer. *Soil Biol. Biochem.*, 25: 1649-1655.

Kimura, S.D., R. Hatano and M. Okazaki. 2009. Characteristics and issues related to regional-scale modeling of nitrogen flows. *Soil Sci. Plant Nut.*, 55(1): 1-12.

Maria, B.J., S. Garcia and E. Adrian. 2004. Landscape- and field-scale control of spatial variation of soil properties in Mediterranean montane meadows. *Biogeochemistry*, 69(2): 207-225.

McNaughton, S.J., F.F. Banyikwa and M.M. McNaughton. 1997. Promotion of the cycling of diet-enhancing nutrients by African grazers. *Science*, 278(5): 1798-1800.

Mullen, R. 2004. *Soil pH and Nutrient Availability*. *C.O.R.N Newsletter No. 2004-24*, Agriculture and Natural Resources, OSU Extension, ATI, OARDC, College of Food, Agriculture, and Environmental Sciences, Ohio State, USA.

Murata, T., H. Tanaka and Y. Kurokawa. 1997. Seasonal variations of labile soil organic matter carbon and nitrogen fertility in grassland soil in Tokyo, Japan. In: *Proceedings of the International Grassland Congress, Saskatchewan, Canada*, 8-19 June 1997, pp. 57-58.

Murata, T., H. Tanaka, S. Yasue, R. Hamada, K. Sakagami and Y. Kurokawa. 1999. Seasonal variations in soil microbial biomass content and soil neutral sugar composition in grassland in the Japanese Temperate Zone. *Appl. Soil Ecol.*, 11(2-3): 253-259.

Murayama, S. 1984. Changes in the monosaccharide composition during the decomposition of straws under field conditions. *Soil Sci. Plant Nutr.*, 30: 367-381.

Paltineanu, C., I.F. Mihailescu, I. Seceleanu, C. Dragota and F. Vasenciuc. 2007. Using aridity indices to describe some climate and soil features in Eastern Europe: A Romanian case study. *Theo. Appl. Climat.*, 90(3): 263-274.

Peverill, K.I., L.A. Sparrow and D.J. Reuter. 1999. *Soil Analysis: An Interpretation Manual*. CSIRO, Collingwood, Australia, pp. 170- 174.

Rhoades, J.D. 1982. Soluble Salts. p. 167-179. In: *Methods of Soil Analysis: Part 2: Chemical and Microbiological Properties*. (Ed.) A.L. Page. Monograph Number 9 (Second Edition). ASA, Madison, WI.

Takata, Y., S. Funakawa, K. Akshalov, N. Ishida and T. Kosaki. 2008. Regional evaluation of the spatio-temporal variation in soil organic carbon dynamics for rainfed cereal farming in northern Kazakhstan. *Soil Sci. Plant Nutr.*, 54(5): 794-806.

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