THE EFFECT OF LAND USES ON THE PERMEABILITY AND PHYSICAL CHARACTERISTICS OF SOIL IN DIFFERENT REGIONS OF NORTHERN WATERSHEDS

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Abstract

Results of a study on the effect of different land uses on the physical characteristics of soil are presented. Permeability, bulk density, porosity, moisture holding capacity and texture of soil were observed under forsts, agriculture and range vegetation at five sites in scrub, chirpine, kail, fir-spruce and dry temperate zones. Analysis of soil samples showed that soil under forests had higher permeability, porosity and water holding capacity as compared to soil under agriculture and pasture while the bulk density of soil under forest was lower than that of soil under agriculture and range vegetation. However, except for permeability these values were not significantly different from each other. On the other hand, in all landuses, permeability, moisture holding capacity and porosity values were higher for surface soil than those below 0.3 meter depth but these differences were only significantly less at the surface than that below 0.3 meter depth of soil.

Introduction

Permeability is the property of soil that enables it to transmit water and is independent of viscosity of water. Hydraulic conductivity is the ability of soil to let a particular fluid flow through it. It is coefficient 'k' in Darcy's equation ($v = ki$) in which 'v' is the effective flow velocity and 'i' is the hydraulic gradient (USDA, 1964). Permeability and physical characteristics of soil together govern the water intake which is the expression of several factors, including infiltration and percolation. Infiltration is the movement of surface water into the soil and the percolation is the further movement of water through the soil profile (USDA, 1964).

The relationship between soil and vegetation is very important. Initially the vegetation under a particular set of climate is dependent upon the type of soil and later on vegetation modifies the soil characteristics by the addition of organic matter and provision of favourable conditions for soil fauna and flora. Permeability and other physical properties of soil provide an understanding of watershed characteristics and suitability of sites for tree growth. In this regards, rate of infiltration and percolation, and physical characteristics of soil determine the proportion of precipitation which is converted to surface runoff. The amount of runoff determines its erosive power and sediment carrying capacity as well as intensity of floods in the streams and sedimentation in the water channels and reservoirs.

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A number of studies have been conducted to investigate the effect of different land uses on the physical charateristics of soil in different parts of the world (Berglund, *et. al.*, 1981, Mathur *et. al.*, 1982 and Bhagat 1987). It was observed that the land under coniferous forests of *Cedrus deodara, Pinus wallichiana* and *Picea smithiana* had higher infiltration rate as compared to those of adjacent agriculture field without crop because it had a thick layer of humus, higher pore space and higher water holding capacity than the latter. While comparing landuse types on sloping land, the infiltration capacity of the soil was found to be the highest under the forest and it reduced on pasture, arable land and cattle track in descending order (Kakoy and Toyoda 1981). Lee (1980) reported that infiltration under a forest vegetation is almost double than the bare soil having same soil texture. In another study Berglund (1981) had concluded that the forest vegetation in the absence of grazing improves soil properties and afforestation is the most appropriate for rehabilitation of a catchment.

Describing the physical properties of soil, Chow (1964) stated that the infiltration rate of forest floor was 6 cm/hr and that of unimproved pasture 2.4 cm/hr. While comparing the percolation rates of forested and barren land he reported that the percolation rate at 0-5.0 cm soil depth was 0.2 cm/hr for barren land and 58.9 cm/hr for lobolly pine. He also reported the porosity values of different sedimentary material such as for soil 50-60%, clay 45-55%, silt 40-50% and medium to course mixed sand 35-40%. Bhagat (1987) reported that the bulk density values of upper soil (1.04 to 1.30 gm/cm^3) were lower at all sites than those at 30-40 cm depth (1.32 to 1.46 gm/cm^3). Dunne and Leopold (1978) also reported the permeability values of geological material; clay, silt, fine sand, medium and loose sand as 0.04, 0.0004-4.0, 0.04-40 and 40-12000 cm/hr respectively. He further stated that these values are decreased with the depth of soil. Any how no work has been done on the effect of different land uses on the physical characteristics of soil in Pakistan.

Keeping in view the importance of permeability and other physical characteristics of soil on the hydrology of a watershed, a study was conducted to investigate the effect of three major land uses on the physical characteristics of soil in different zones. The soil samples and field data were collected with the help of five M.Sc. forestry students and a Research Officer. The students used some of the data collected from different localities for their individual thesis.

Material and Methods

Study area

The study was conducted on five sites in northern hilly areas of Pakistan which lie between 33°47′ to 35°32′ N latitude and 72°37′ to 73°25′ E longitude. Two sites are located on Murree-Islamabad road, two are on Murree-Abbottabad road and one is near Kalam, Swat. A brief description of the sites is given in Table 1.

TABLE 1

DESCRIPTION OF SAMPLING SITES

S. No.	Site	Location: Longitude (E)	Location: Latitude (N)	Elevation meters	Major Forest type and vegetation
1.	Chattar	73°14′	33°47′	615	Subtropical scrub
2.	Company Bagh	73°20′	33°52′	1228	Subtropical Chirpine
3.	Kuldana	73°24′	33°56′	1980	Moist Temperate Bluepine
4.	Dunga Gali	73°25′	34°03′	2130	Moist Temperate Fir/Spruce
5.	Kalam	72°37′	35°32′	2132	Dry Temperate Deodar

Sites are different from each other in respect of elevation, climate and vegetation type. Although first two sites are in subtropical zone, however, first site has typical scrub vegetation while the second has chir pine vegetation. The third site has blue pine vegetation while the fourth has fir/spruce vegetation; both falling in moist temperate zone. The fifth site is in dry temperate zone having deodar vegetation. Average annual precipitation and temperatures of all sites are given in Table 2.

TABLE 2

PRECIPITATION AND AIR TEMPERATURE AT SAMPLING SITES

S. No.	Site	Precipitation (mm)			An. Av. Air Temp. °C	
		July-Sep.	Oct.-June	Total	Max.	Min.
1.	Chattar*	—	—	908	28.3	14.7
2.	Ghoragali	748	724	1472	23.2	11.0
3.	Kuldana*	—	—	1509	19.1	7.3
4.	Dungagali*	—	—	1071	18.1	6.5
5.	Kalam	138	759	897	22.2	5.2

* Estimated (Khan 1988).

Collection of Soil Samples

The study was conducted during June 1989. At each site three areas were selected under three landuses: forest, agriculture and range. A line-transect was laid out on each site under each land use in a predetermined direction. On each line-transect three points were marked at 10 meters interval for collecting soil samples. Undisturbed soil samples were collected with the help of soil sampler of 8.2 cm diameter and 5.7 cm length. Two soil samples one at the surface and the other at 0.3 meter depth were collected according to the procedure described by Hoover, *et. al.*, (1954). For each landuse two additional samples, one at the surface and the other at 0.3 meter depth, were also taken without sampler to determine the texture of the soil.

Methods

The procedure adopted to determine the permeability and physical characteristics of soil has been described by Balci (1984). The procedure is briefly described below:

(i) For estimation of permeability the soil samples were saturated with water and then the rate of flow of water through this sample was observed under a constant head of 2.0 cm of water. The permeability meter apparatus prepared by Balci (1984) was used for the purpose. As mentioned earlier, the permeability or hydraulic conductivity (k) is the coeffcient in Darcy's equation ($v = ki$) in which 'v' is the effective flow velocity (cm^3/min) and 'i' is the hydraulic gradient (height of soil sample (5.7 cm)/height of soil sample + height of hydraulic head (2.3 cm). Therefore permeability was calculated by using the following equation:

$$\text{Permeability (cm/hr)} = \frac{\text{Rate of flow of water (cm}^3\text{/min)} \times 60}{\text{Cross sectional area of sampler (52.8 cm}^2\text{)}} \times \frac{5.7}{8.0}$$

(ii) Bulk density was determined by using the undisturbed soil samples which were used for permeability. It was computed by dividing the net oven dry corrected weight of undisturbed soil sample (gms) by its corrected volume (cm^3). Corrected weight of soil was calculated as the weight of oven dry soil sample minus the weight of soil particles larger than 2 mm size in that sample. The corrected volume of soil was calculated as the volume of the sampler minus the volume of soil particles of 2 mm and more size.

(iii) Moisture content by volume in percentage at saturation was determined by dividing the volume of water by corrected volume of soil and multiplied by 100. The volume of water by corrected volume of soil and multiplied by 100. The volume of water was calculated by multiplying the density of water at its temperature by difference of weight between oven dry and saturated soil sample.

(iv) Porosity of soil is the portion of soil occupied by air and water. It was calculated by the following equation:

$$\text{Porosity (\%)} = 100 - \frac{\text{Bulk density} \times 100}{\text{Particle density}}$$

Bulk density was computed as explained in (ii) above and particles density was taken as 2.65 gms/cm^3.

(v) Textural class of the soil was determined after finding the percentage of various size groups of mineral particles (sand, silt and clay) by hydrometer method and classification of textural class according to criterion specified in U.S. Department of Agriculture Hand Book No. 18 of Soil Manual 1951.

Results and Discussion

(i) Permeability

Individual observations of soil permeability at two depths of five sites under three different land uses are given in Appendix I. These observations of the soil samples taken at three points on the line transect were considered as replications. The data for each site were statistically analysed by variance analysis to compare various landuses for permeability. The significant or non-significant effect of landuses or depth of soil on permeability is indicated in Table 3.

TABLE 3

SIGNIFICANT (*) OR NON-SIGNIFICANT (NS) EFFECT OF LANDUSE OR DEPTH OF SOIL ON ITS PERMEABILITY

Comparison/sites	Chattar	Company Bagh	Kuldana	Dunga Gali	Kalam
		0-5.7 cm depth permeability			
Forest Vs Agriculture	*	*	*	NS	*
Forest Vs Range	*	*	*	NS	*
Agriculture Vs Range	NS	*	NS	*	NS
		30.0-35.7 cm depth permeability			
Forest Vs Agriculture	NS	*	NS	NS	*
Forest Vs Range	NS	*	NS	NS	NS
Agriculture Vs Range	*	NS	NS	NS	NS
		0.5.7 cm Vs 30.0-35.7 cm depth permeability			
Forest Land	*	*	*	NS	*
Agriculutre Land	NS	*	NS	*	NS
Range Land	*	NS	NS	NS	NS

The permeability of upper 5.7 cm forest soil was significantly higher than that of agriculture and rangeland soil while at 30 cm depth, the permeability values were not significantly different at four sites. Moreover the permeability of forest upper soil was also significanlty greater than that of 30 cm depth at four sites while the permeability values of agriculture and pasture land at two depth were not significantly different at most of the sites.

The average values of permeability of soil to water are given in Table 4.

TABLE 4

PERMEABILITY (CM/HR) OF SOIL UNDER THREE LANDUSES AT FIVE SITES

Depth of sample	Chattar	Company Bagh	Kuldana	Dunga Gali	Kalam
		Forest			
Surface	21.8	13.4	34.2	29.1	38.8
0.3 m	4.0	11.0	0.9	19.3	26.0
		Agriculture			
Surface	2.7	4.2	10.0	46.4	17.3
0.3 m	1.9	0.6	8.8	17.4	7.9
		Range			
Surface	2.0	1.8	2.7	19.4	24.0
0.3 m	7.6	1.2	9.2	7.9	15.4

The soil permeability of Dunga Gali and Kalam is not significantly different from each other. While the permeability of Kuldana, Chattar and Company Bagh is not significantly different from each other but significantly lower than that of Dunga Gali and Kalam.

(ii) Bulk Density

The average values of bulk density of soil at and below the surface under three landuses are presented in Table 5

TABLE 5

BULK DENSTITY (GM/CM³) OF SOIL UNDER THREE LAND USES AT FIVE SITES

Depth of sample	Chattar	Company Bagh	Kuldana	Dunga Gali	Kalam
		Forest			
Surface	1.17	1.24	0.95	1.08	1.00
0.3 m	1.38	1.26	1.68	1.17	1.14
		Agriculture			
Surface	1.44	1.35	1.16	0.80	1.30
0.3 m	1.47	1.59	1.17	1.07	1.45
		Range			
Surface	1.47	1.23	1.20	1.17	1.16
0.3 m	1.32	1.48	1.16	1.31	1.38

The bulk density values of surface and subsurface forestland were quite lower than those of surface soil under agriculture and pasture at all sites. Analysis of variance and Duncan's multiple range test show that the bulk density of upper surface is significantly different from that below 0.3 meter depth. Although the bulk density of range soil is higher than that of forest soil but the bulk density values of soil under different land uses were not significantly different from each other.

(iii) Moisture Contents at Saturation

Average values of moisture contents of saturated surface and subsurface soil under three landuses at five sites are summarized in Table 6.

TABLE 6

MOISTURE CONTENTS (% BY VOLUME) AT SATURATION OF SOIL UNDER THREE LAND USES AT FIVE SITES

Depth of sample	Chattar	Company Bagh	Kuldana	Dunga Gali	Kalam
		Forest			
Surface	55.7	54.6	51.5	64.6	58.7
0.3 m	26.6	35.8	46.3	58.8	47.3
		Agriculture			
Surface	28.0	35.2	54.3	67.4	42.3
0.3 m	35.7	43.9	52.1	50.7	28.0
		Range			
Surface	12.5	39.8	51.2	36.6	46.2
0.3 m	42.3	40.7	51.4	43.2	32.6

Analysis of variance and Duncan's multiple range test show that the minimum water holding capacity and the moisture contents at saturation at the surface or below 0.3 meter depth is not significantly different under different land uses. However, the amount of moisture contents at saturation of the surface soil under forests were higher than the sub-surface layers at all sites and these values were also higher than the surface soil under agriculture and range at most of the sites.

(iv) Porosity of Soil

Average values of porosity at the surface and 0.3 meter below the surface under three landuses at five sites are given in Table 7.

TABLE 7

POROSITY (%) OF SOIL UNDER THREE LAND USES AT FIVE SITES

Depth of sample	Chattar	Company Bagh	Kuldana	Dunga Gali	Kalam
		Forest			
Surface	55.6	53.2	64.1	59.4	62.0
0.3 m	48.2	48.7	36.8	55.9	56.0
		Agriculture			
Surface	45.4	49.1	56.3	69.6	30.0
0.3 m	44.7	40.0	55.9	59.6	45.0
		Range			
Surface	44.4	53.0	54.6	55.9	55.0
0.3 m	50.1	44.2	56.2	50.6	47.0

Analysis of variance and Duncan's multiple range test show that under different land uses there is no significant difference in soil porosity. However porosity of surface soil under forest was higher than that of range and agriculture land. The values of porosity at the surface soil were also significantly higher than at 0.3 meter depth.

(v) Soil Texture

Percentage of sand, silt and clay and the textural classes of soil under three landuses at five sites is given in Table 8. There is more than 80% sand in the soils at all sites under different land uses. In most of the cases the soil is loamy sand.

TABLE 8

TEXTURE OF SOIL UNDER THREE LANDUSES AT FIVE SITES

Texture of soil	Chattar	Company Bagh	Kuldana	Dunga Gali	Kalam
		Forest			
Sand (%)	83.1	85.0	84.7	80.3	83.1
Silt (%)	11.9	0.8	1.4	3.9	2.0
Clay (%)	5.0	14.2	13.9	15.8	13.9
Textural class	Loamy sand	Loamy sand	Sandy loam	Sandy loam	Loamy sand
		Agriculture			
Sand (%)	85.2	85.2	84.9	83.8	82.6
Silt (%)	12.8	0.8	1.1	4.4	2.8
Clay (%)	2.0	14.0	14.0	11.8	14.6
Textural class	Loamy sand	Loamy sand	Loamy sand	Loamy sand	Loamy sand
		Range			
Sand (%)	82.6	84.2	81.7	81.1	83.0
Silt (%)	15.2	1.8	2.8	4.4	3.8
Clay (%)	2.2	14.0	15.5	14.5	13.2
Textural class	Loamy sand	Loamy sand	Loamy sand	Loamy sand	Loamy sand

Permeability and physical characteristics data of soil were grouped according to localities, landuses or depths of soil and subjected to variance analysis and Duncan's multiple range test. Those are not significantly different from each other are presented in Table 9.

TABLE 9

GROUPING OF LOCALITIES, LANDUSES AND DEPTH OF SOIL WHICH ARE NOT SIGNIFICANTLY DIFFERENT FROM EACH OTHER ACCORDING TO DUNCAN'S MULTIPLE RANGE TEST

Localities are: Chattar (Ch), Company Bagh (Cb), Kuldana (Kd), Dunga Gali (Dg), Kalam (Km).

Landuses of soil are: Forest (F), Agriculture (A), Range (R).

Depths of soil are: 0-5.7 cm (S) and 30.0-35.7 cm (0.3 m).

Physical	Attributes of grouping					
Characteristics	Localities			Landuses		Depths
	Group (1)	Group (2)	Group (3)	Group (1)	Group (2)	
Permeability	Dg, Km	Km, Kd	Kd, Ch Cb	FA	AR	O*
Bulk Density	Ch, Cb Km, Kd	Km, Kd Dg	—	RAF	—	O*
M.C. at Sat**	Dg, Kd Cb	Cb, Km Ch	—	FAR	—	S, 0.3 m
Porocity	Dg, Kd Km, Kd	Km, Ch Cb	—	FAR	—	O*
Texture	Not different in localities, landuses or depths.					

* Zero (o) in the colum show that the values are significantly different from each other and do not make a group of insignificant difference.

** M.C. at Sat. = Moisture content of soil at saturation.

The soil permeability, its moisture content at saturation point and porosity values are high and bulk density is less when the land is under forest cover as compared to agriculture land and range land. However, these values are not significantly different from each other except for permeability. Permeability, moisture content at saturation and porosity values are significantly higher for surface soil than those below 0.3 meter depth. Bulk density is also significantly less at the surface than that at 0.3 meter depth. Permeability, moisture content at saturation are significantly higher and bulk density is significantly lower in soil at Dunga Gali than those of Chattar. The soil texture is almost similar (loamy sand) irrespective of site or land use.

The results of this study show that soil under forest have higher permeability, porosity and water holding capacity as compared to soil under agriculture and range vegetation at both surface as well as subsurface level. There was exception at Dunga Gali where surface layer soil had higher permeability under agriculture which may be due to ploughing of the field at the time of study. At 0.3 m depth the permeability of soil was higher under forest at all the sites. In fact the infiltration is controlled by the permeability rate of any layer under the surface. It was interesting to note that soil texture was almost the same at all the sites of the study but even then there was difference of permeability, bulk density, porosity and water holding capacity of soils under different land uses. The results of the study have proved that the physical characteristics of the soil are modified by the land use and the type of vegetation cover.

Conclusion

The results of the study have confirmed the results of the earlier studies conducted in different parts of the world.

Therefore, it can be concluded that forests play an important role in increasing the permeability as well as infiltration capacity of soil which in turn decrease the surface runoff and increase the baseflow. Reduction in surface runoff is beneficial for mitigating soil erosion, siltation of reservoirs and flood hazards. The current afforestation programme through the watershed development projects will certainly help in reducing the siltation rate of reserviors and regulating the stream flow which is the main objective of their management of these areas in Pakistan.

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APPENDIX I

PERMEABILITY OF SOIL UNDER DIFFERENT LANDUSES AT VARIOUS ZONES

(R = Replication number)

Landuse	Water intake (cm/hr) at Depths					
	0.0-5.7 cm			30.0-35.7 cm		
	R1	R2	R3	R1	R2	R3
1. Chattar (Subtropical scrub zone)						
Forest	19.6	17.2	28.6	4.7	3.3	4.2
Agriculture	2.5	3.6	1.9	1.8	1.9	2.1
Range	2.3	1.5	2.2	8.6	6.4	7.8
2. Company Bagh (Subtropical Chirpine zone)						
Forest	13.2	13.8	13.2	9.6	11.4	12.0
Agriculture	4.2	4.2	4.2	0.6	0.6	0.6
Range	1.8	1.8	1.8	1.2	1.2	1.2
3. Kuldana (Moist Temperate Blue-pine zone)						
Forest	35.6	38.0	29.0	1.5	0.7	0.5
Agriculture	9.1	9.7	11.2	8.5	8.8	9.1
Range	3.6	3.5	1.0	11.1	10.9	5.6
4. Dunga Gali (Moist Temperate Fir/Spruce zone)						
Forest	14.9	31.0	41.6	27.2	10.2	20.4
Agriculture	58.8	50.0	30.4	16.3	15.4	20.5
Range	16.6	15.5	26.3	9.4	7.0	7.4
5. Kalam (Dry Temperate Deodar zone)						
Forest	44.9	27.6	43.8	32.2	21.1	24.6
Agriculture	21.7	18.6	11.5	9.1	12.2	2.4
Range	17.6	26.5	27.9	10.9	19.8	15.6