

SOME IMPORTANT PHYSICAL CHARACTERISTICS OF THE GRAVEL HORIZON IN REDDISH BROWN EARTH SOILS (ALFISOLS)

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ABSTRACT

Presence of a gravel layer is one of the main limitations of certain mapping units of Reddish Brown Earth soils (Alfisols) for agricultural use. The objective of this study was to characterize soil physical properties of the gravel layer and other soil horizons of Reddish Brown Earth (RBE) soils to assess the limitations imposed by the gravel horizon. The properties characterized were saturated hydraulic conductivity (Ks), soil texture, gravel content, bulk density and depth to the gravel layer along the soil catena. The results showed that mean Ks of the surface layer was 2.19 cm/h which decreased to 1.37 cm/h in the gravel layer showing its limitations for water flow. The bulk density increased from surface to the gravel layer which limits root penetration and aeration capacity of the soil. The depth of the surface layer increased from 40 cm to 107 cm from the top to the bottom of the valley bottom. Agroforestry systems consisting of tree species such as *Gliricidia* which are having long roots capable of penetrating the gravel layer should be used to improve the permeability to water and air in this layer.

KEY WORDS: Catena, Gravel layer, Hydraulic conductivity, Reddish Brown Earths

INTRODUCTION

Physical properties play a major role when determining the suitability of a soil for agricultural production. Among these properties, saturated hydraulic conductivity is of great importance as it will determine the amount of water entering to the soil and affect the water economy for plant growth as well as the drainage of soil profile. The manner a soil profile will respond to imposed boundary and initial conditions is determined by the water flow properties of major horizons.

The Reddish Brown Earth (RBE) soils of Sri Lanka cover an approximate area of 2.56 million hectares (Dimantha, 1992) and has the highest potential for agricultural development in the dry zone. According to Soil Taxonomy (USDA, 1975) these soils are classified as Alfisols. The well-drained, imperfectly drained and poorly drained (Low Humic Gley) great soil groups are classified as Rhodustalfs, Haplustalfs and Tropaqualfs respectively according to Soil Taxonomy (S.Somasiri, 1984, Unpubl.). The physical properties of these soils are primarily determined by the four major horizons namely surface, subsurface, gravelly and decomposing parent material (Joshua, 1988). De Alwis and Panabokke (1972) reported that the presence of a gravel

layer in these soils will interfere with most deep-rooted crops. As estimated by them, the RBE soils with moderate and high amounts of gravel in subsoils cover approximately 137,000 ha. Joshua (1988) reported that the gravelly horizon in RBE soils is of variable thickness and can range from 30 to 75 cm. The illuviated clay deposit in macro-pores in between gravel particles make it an impeding layer for water flow and root penetration. Somasiri (1981) revealed that RBE soils consist of sandy clay to sandy clay loam subsoil horizons usually with a massive and structureless gravel horizon within the solum which sometimes is thick enough to prevent effective root growth. Somapala (H.Somapala, 1983, Unpubl.) documented that in the Aluthwewa series of RBE soils the gravel layer is located at 50-60 cm depth and the change from the surface to gravel layer is very distinct. The distinct textural boundary between the surface and gravel horizons has a significant effect on moisture movement down the profile. Therefore the gravel layer plays an important role in water conservation and drainage of RBE soil profile.

The objective of this study was to characterize the soil water flow and other associated physical properties of RBE soil profile with special emphasis on the gravel layer. The physical properties characterized were saturated hydraulic conductivity, bulk density, gravel content, soil texture for the well-drained RBE and depth to the gravel layer along the RBE catena.

MATERIALS AND METHODS

This experiment was conducted at University Sub Campus in Maha Illuppallama during 1991 in the Reddish Brown Earth soils. The examination of the soil profile in the well-drained RBE (Rhodustalfs) showed four generalized soil horizons namely Ap, AB, Bt (gravel layer) and C (decomposing parent material) corresponding to 0-17, 17-37, 37-122 and >122 cm respectively. As the interest was to characterize the saturated water flow of the gravel layer with respect to surface horizons, the top two horizons (Ap and AB) were considered as one layer for hydraulic conductivity measurement.

The texture of the fine earth fraction (< 2 mm size particles) was characterized using the pipette method (Gee and Bauder, 1986). The gravel content was measured by wet-sieving and oven drying. Four replicates were used for these determinations. The bulk density was determined using undisturbed soil core samples with a diameter and height of 5.2 cm and 6 cm respectively. Four soil bulk density samples were obtained for each horizon. Saturated hydraulic conductivity was obtained *in situ* using double ring infiltrometers and mercury manometer tensiometers installed at the surface and gravel layers. Infiltration runs were conducted with a 3 cm constant head until steady state was achieved. The flux obtained at steady state was divided by hydraulic gradient prevailing to obtain Ks as proposed by Green *et al.* (1986). This was characterized for the surface and gravel layers at 16 locations in 50 x 50 m area according

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to a predetermined sampling grid. Depth to the gravel layer was determined using auger holes along the catena from the irrigation channel to the drainage channel at 25 m intervals which included RBE well-drained (Rhodustalfs), imperfectly drained (Haplustalfs) and Low Humic Gley (Tropaqualfs) great soil groups.

RESULTS AND DISCUSSION

Saturated hydraulic conductivity

Mean saturated hydraulic conductivities (K_s) for the surface soil and gravel layer are given in Table 1. To facilitate measurements of saturated hydraulic conductivities, Ap and AB horizons were combined and named as surface layer (surface to 37 cm). The gravel layer occurred from 37 to 122 cm. These values show that the average saturated hydraulic conductivity of the gravel layer is lower than that of the surface layer. According to the FAO classification (Baver *et al.*, 1972) the surface and gravel layers belong to the moderate and slow permeability classes, respectively. As the horizon boundary between the surface and gravel layer is very sharp, this decrease affect the water flow in the profile considerably.

Table 1. Mean *in situ* K_s values for surface and gravel layers of RBE soils

K_s (cm/h)	Surface layer	Gravel layer
Mean	2.19	1.73
CI (95% p level)	0.93 - 3.47	0.66 - 2.09

CI = Confidence limit

The confidence interval shows that even though there was a 21% decrease in K_s , this difference was not significant at 95% probability level. Landon (1984) documented that K_s is a highly variable soil property with coefficient of variation ranging from 86 to 190%. According to Warrick and Nielsen (1980) an estimation of mean K_s within 10% accuracy at 0.05 significance level needs approximately 1300 measurements. Only 16 successful measurements of K_s were conducted in this study from the limited resources available. Therefore chances of getting significant differences are less at 95% probability level.

Joshua (1988) showed that in RBE soils the proportion of macro-pores which are more efficient in conducting water at saturation is lower in gravel layer than in the surface layer. The macro-pore spaces formed among gravel particles are occupied by illuviated clay making the gravel layer hard and compact. These factors contribute to the reduction of K_s of the gravel layer in comparison to the surface horizon. The K_s values are also used as input parameters in drainage design equations to calculate the depth and spacing of drains to lower the water table (Hillel, 1980).

Bulk density

Bulk density and porosity values for Ap, AB, Bt and C horizons of well-drained RBE soils are given in Table 2. As for any typical soil profile the bulk density increased with depth as effects of cultivation and organic matter contents decreased. The highest bulk density was for the Bt (gravel) horizon. The increase in bulk density is mainly due to the presence of gravel and illuviated clay particles deposited in macro-pores among the gravel particles. High bulk density

Table 2. Bulk density and porosity of major horizons in RBE soil profile

Horizon	Bulk density (g/cm ³)	Porosity (cm ³ /cm ³)
Ap	1.60 a	0.40 a
AB	1.68 a	0.37 a
Bt	1.82 b	0.31 b
C	1.56 ac	0.41 ac
LSD (p < 0.05)	0.12	0.04

Means followed by the same letter in each column are not significantly different at $p < 0.05$ according to Duncan Multiple Range Test

and less porosity can impede root growth in this horizon. As quoted by Taylor and Gardner (1963), a bulk density value higher than 1.63 g/cm³ for a sandy loam soil can cause hindrance to root penetration. It has been documented that high bulk density and soil strength combined with the unique water retentivity of the gravelly horizon of Alfisols were considered to affect root development (H.Somapala, 1983, Unpubl.). Anaerobic conditions may also easily occur in the gravel layer if the moisture content increases even slightly above the field capacity. The combination of high bulk density and low aeration porosity make it impossible for normal roots to penetrate and thrive in the gravel layer. It has been shown that roots of trees such as *Gliricidia* used in agroforestry systems could penetrate the gravel layer facilitating air and water movement into this horizon (W.L.Weerakoon, 1983, Personnel communication).

Gravel content

The gravel, sand, silt and clay contents for Ap, AB, and Bt horizons of a well-drained RBE soil are given in Fig.1. Gravel, which consists of particles higher than 2 mm (Anonymous, 1978) were classified into two classes, fine gravel (2 to 3 mm in diameter) and medium gravel (3 to 5 mm in diameter). The amount of gravel larger than 5 mm was insignificant. It should be noted that the gravel includes particles higher than 2 mm and therefore should not be confused with standard textural data. When fractions higher than 2 mm (gravel) is considered, the Bt horizon

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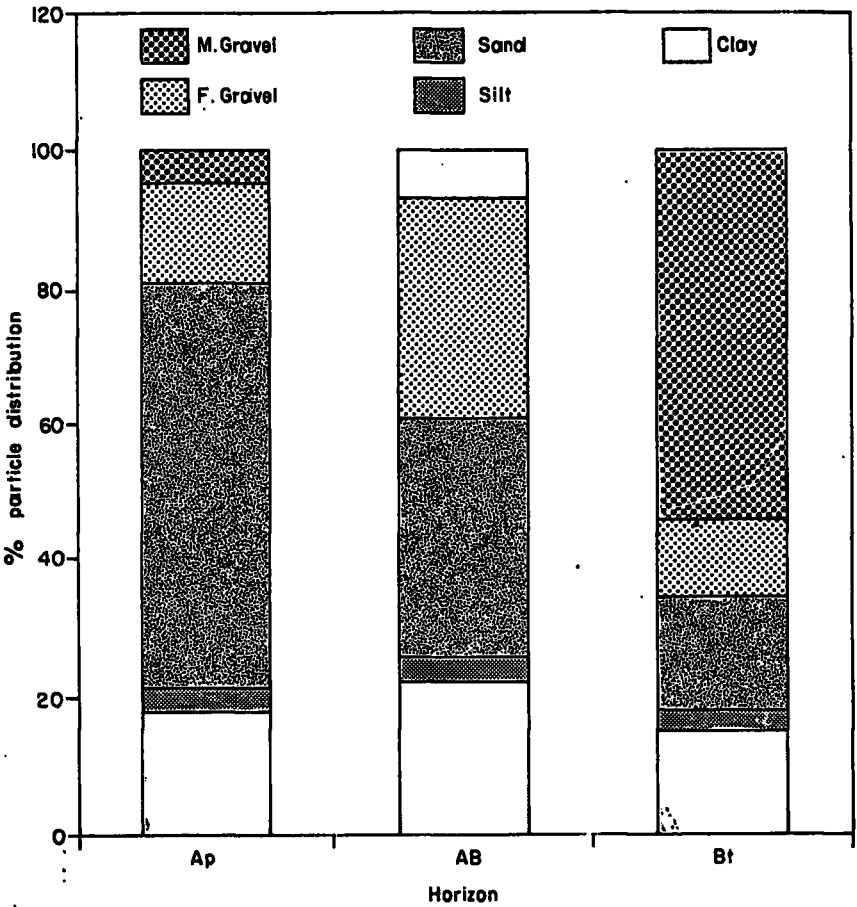


FIG. 1 : GRAVEL , SAND, SILT AND CLAY CONTENT FOR THE MAJOR HORIZONS OF RBE SOIL .

consists of more than 65% gravel which supports the nomenclature of it as a gravel layer. De Alwis and Panabokke (1972) documented that this gravel consists of mostly ironstone and quartz. The gravel layer (Bt) consists of 55% of medium gravel in contrast to 5% and 7% in Ap and AB horizons respectively. The increase of gravel content in the gravel layer is mostly at the expense of sand content. There is also a significant amount of clay deposited in the gravel layer which makes it a dense impermeable horizon. When only particles less than 2 mm are considered the clay content in the gravel layer was 44.7% compared with 36.6% and 21.9% of over lying AB and Ap horizons respectively. The increase in clay content and coatings of clay on surface of gravel qualifies this horizon to be classified as an argillic layer. Presence of an argillic layer is one of the major factors considered when placing RBE soil in Alfisol order according to Soil Taxonomy (USDA, 1975).

It has been reported that root growth of soybean was reduced when the gravel content of soil was above 30% by volume (H.Somapala, 1991, Unpubl.). Nayakekorala (1991) using radioisotope tracer techniques showed that a gravel content of 21% did not cause considerable impedance to cowpea, mungbean and chilli root growth in RBE soils. These evidences show the importance of gravel content in limiting root growth in certain mapping units of RBE.

Depth to the gravel layer

Depth to the gravel layer from the crest of the catena to the lowest point was measured relative to the soil surface and is shown in Fig.2. This gives an indication of the limitation of surface soil along the catena which is exploited by roots of most annual crops. At the crest, the depth of the surface horizon was about 40 cm but increased considerably along the catena towards the drainage channel to a uniform depth of about 107 mm (Fig.2). This may be due to erosion from the crest and deposition of soil particles in the lower elevations over the years. If this trend continues the effective rooting depth at the crest will reduce further limiting crop production. One of the major concerns of soil conservationists is to reduce surface runoff to more subsurface flow. With the development of agrowell-based farming systems the replenishment of the groundwater is a major concern. According to Somapala (H.Somapala, 1983, Unpubl.) an attempt was made to infiltrate more water into the gravel layer in farmers' fields in Yoda Ela by installing perforated tubes. These tubes filled with gravel and opened to the soil surface were used as a erosion control cum water harvesting technique successfully. Weerakoon (W.L.Weerakoon, 1983, Personal communication) showed that tree species such as *Gliricidia sepium* used in conservation farming systems have the capability of penetrating to the gravel layer thereby increasing water and air movement to deeper horizons.

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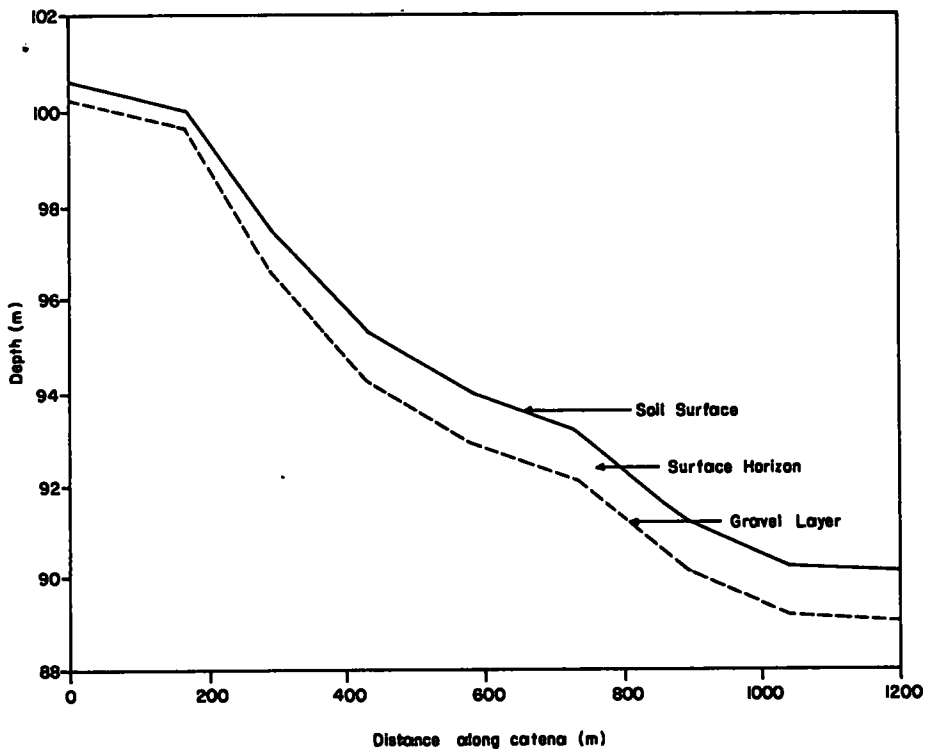


FIG. 2 : DEPTH OF THE SOIL SURFACE HORIZON ALONG A RBE SOIL CATENA .

Penetration of the gravel layer was listed as an advantage in using seedlings in contrast to vegetatively propagated materials as the tree component in such farming systems. Further research is needed on the use of deep-rooted multipurpose tree species in the crest of a catena to break the gravel layer by root action thereby increasing organic matter content and permeability to water and air, and enhancing soil forming processes.

CONCLUSIONS

The study clearly demonstrated the restrictive nature of the gravel layer in RBE soils for agricultural purposes which can result in decreasing permeability to air and water, and root penetration. The gravel content was more than 65% by weight consisting of 54.6% of 3-5 mm particles and 11% of 2-3 mm particles. Ks decreased by more than 20% from the surface horizon to the gravel layer. As the horizon differentiation from surface to gravel layer is sharp and distinct, this reduction of Ks restricts vertical water flow in the profile significantly. The bulk density of the gravel layer was as high as 1.72 g/cm³. All these factors contribute to the impermeable and compact nature of the gravelly horizon. The depth of the surface layer increased from 40 cm to 107 cm along the catena from the crest to the valley showing the limitation of rooting depth for annual highland crops in the well-drained area. Other than breaking the gravel layer by mechanical methods, practical options such as growing of deep-rooted multipurpose tree species capable of penetrating this impermeable layer should be given consideration. Multipurpose trees which can fix nitrogen and add considerable organic matter to the soil with deep rooting characteristics combined with any agroforestry system will help in making the gravel layer of RBE more permeable to air and water. Percolating more water into the soil profile to increase subsurface water flow will show beneficial effects on tank-based as well as agrowell-based agriculture in the dry zone.

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REFERENCES

- Anonymous. 1978. Glossary of soil science terms. The Soil Science Society of America, Madison, Wisconsin, USA. 52p.
- Baver, L.D., W.H.Gardner and W.R. Gardner. 1972. Soil Physics. John Wiley & Sons, New York, USA. 493p.
- De Alwis, K.A. and C.R.Panabokke. 1972. Handbook of the Soils of Sri Lanka. J.Soil Sci. Soc. Sri Lanka 2:1-97.
- Dimantha, S. 1992. Soil scientists should lead in scientific land use planning in Sri Lanka. J.Soil Sci. Soc. Sri Lanka 8:1-27.
- Gee, G.W. and J.W.Bauder. 1986. Particle size analysis. In Methods of Soils Analysis. Part I. Physical and mineralogical properties. Ed. A.Klute. pp 383-409. American Society of Agronomy, 2nd edition, Madison, Wisconsin, USA.
- Green, R.E., L.R.Ahuja, S.K.Chong and L.S.Lau. 1986. Water conduction of Hawaii's oxic soils. Technical Report No.143. Water Resources Research Centre, University of Hawaii, Honolulu, Hawaii.
- Hillel, D. 1980. Applications of Soil Physics. Academic Press, New York. USA. 377 p.
- Joshua, W.D. 1988. Physical properties of RBE soils and their relationships to agriculture. J.Soil Sci. Soc. Sri Lanka 5:1-42.
- Landon, J.R. 1984. Booker Tropical Soil Manual. Booker Agricultural International Limited, Pitman Press, Bath, England. 450 p.
- Nayakekorala, H.B. 1991. Root penetration and activity patterns of some upland crops of Sri Lanka. A research report submitted to the Mahaweli Research Committee, Land and Water Use Division, Department of Agriculture, Peradeniya.
- Taylor, H.M. and W.Gardner. 1963. Penetration of cotton seedling tap roots as influenced by bulk density, moisture content and strength of soil. Soil Sci. 96:153-156.
- USDA. 1975. Soil Taxonomy. A system of soil classification for making and interpreting soil surveys. Agric. Handbook No. 436. US Government Printing Office, Washington, D. C., USA. 753 p.
- Warrick, A.W. and D.R.Nielson. 1980. Spatial variability of soil physical properties in the field. In Application of Soil Physics. Ed. D.Hillel. pp. 319-343. Academic Press, New York, USA.