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CHARACTERISTICS OF SOIL CRUSTS AND THEIR INFLUENCE ON SOME SOIL PROPERTIES IN MUKOGODO CATCHMENT, KENYA

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ABSTRACT

Physical and chemical properties of soil surface crusts formed on overgrazed bare ground, in Mukogodo catchment in Kenya were investigated. These were compared with those of underlying soils and of adjacent grass and bush covered topsoils. Crusting effects on infiltration, hydraulic conductivity and water content were also investigated. The crusts were moderately strong to strong with a thickness of 1-5 mm. Crusts had higher amounts of sand, silt and clay than the underlying layer, while their total N was lower and organic C content higher than the underlying layer. On average, the contents of Ca, Mg and Na were higher in the crusts than in the underlying layers. Similarly, soil pH, EC and ESP were higher in the crusts than in the underlying layer. Cation exchange capacity and K were slightly higher in the underlying layer than in the crusts. Infiltration rate, hydraulic conductivity and soil water content in both the rainy and dry seasons in bare ground were significantly lower than those of the bush and grass covered topsoils. Bare ground surface soil bulk density was higher compared to vegetated topsoils and subsurface layers.

Key Words: Crusting, physical and chemical properties, soil cover

RÉSUMÉ

Les propriétés physiques et chimiques de la surface compacte de sol de la reserve de Mukogodo, Kenya issu d'un terrain devenu nu après avoir été excessivement brouté par les animaux ont été étudiées. Ces propriétés étaient comparées à celles des sols de profondeur et ceux couverts d'herbes et de brousses situés à proximité. L'effet de compacité de sol sur l'infiltration, la conductivité hydraulique et la teneur en eau était étudié. Les couches superficielles compactes étaient modèrement à très solide avec une épaisseur de 5mm. Les surfaces compactes avaient une plus grande quantité de sable ou de limon et d'argile que la couche de profondeur. Leur teneur en N total était faible et leur teneur en C organique élevée par rapport à la couche de profondeur. De même, le pH du sol, l'EC et l'ESP étaient plus élevées sur les surfaces compactes qu'en profondeur. La CEC et le K étaient un peu plus élevés en profondeur qu'en surface. Le taux d'infiltration, la conductivité hydraulique et la teneur en eau du sol en saisons sèche et pluvieuse en terrain nu étaient significativement plus faible que en sols couvert d'herbes ou de brousses. La densité de sol était plus élevée en sol de surface de terrain nu qu'en sol de surface de terrain couvert de plantes et couches de sol de profondeur.

Mots Clés: Surface compacte, propriétés physiques et chimiques, couverture de sol

INTRODUCTION

Formation of surface crusts or seals on bare soils is a problem in many parts of the world. Extensive areas in semi-arid regions with scarce vegetation and soils of low structural stability tend to form crusts at the surface (Hoogmoed, 1987). This is aggravated by heavy and intensive rainfall in the semi-arid tropics. By reducing infiltration, crusts increase surface runoff and erosion potential, while water availability for plant growth and seedling emergence are decreased.

Crusts form under the influence of external forces such as raindrop impact and mechanical compaction, or by slaking (Eigel and Moore, 1983). Crusting results from a combined effect of structural weakness and heavy pounding rain on unprotected bare surface soils having unfavourable size grading (Russell and Greacen, 1977). Mechanisms for the formation of surface crusts are well documented (McIntyre, 1958; Sor and Bertrand, 1967; Chen *et al.*, 1980; Eigel and Moore, 1983; Gal *et al.*, 1984; Radcliffe *et al.*, 1991). These include aggregate breakdown by rainfall impact or slaking, particle dispersion, movement and deposition into surface pores, and compaction by raindrop impact.

Valentin (1991) studied surface crusting in sandy and a clay loam soils under natural and tilled surface conditions. He found that kinetic energy of rainfall is the major crusting factor for the sandy soil and that water logging and subsequent slaking led to formation of structural and depositional crusts in the tilled clay loam plots. In both soils, infiltration was severely reduced by crusting. He also found that hydraulic conductivity measured under rainfall and ponded conditions was very low, causing intense overland flow after only 2.7 mm of applied rainfall.

Mukogodo catchment of Kenya is a semi-arid area where intense livestock grazing has greately reduced the natural soil cover. A large proportion of the land is currently bare. The present study was aimed at determining the physical and chemical properties of soil surface crusts of bare soils compared with properties of the underlying soil layer, and with surface soils from sites under grass or bush cover. Also, the effect of these properties on infiltration rate, hydraulic conductivity, bulk density and soil water content were examined.

MATERIALS AND METHODS

The study area covers 252 hectares and is situated in Laikipia District. The area is bound by longitudes 37° and 37° 04'E and latitudes 0° 22' and 0° 24'N.

The catchment is found in a semi-arid region in agro-climatic zone V, with a ratio of mean annual precipitation to mean annual potential evaporation (r/Eo) of 25-40%. The average annual rainfall ranges from 450-900 mm with a medium to low potential for plant growth when soil conditions are not limiting (Sombroek *et al.*, 1982). The major soils in the catchment are classified chromic Lixisols (FAO/UNESCO, 1990) or Alfisols (Njoroge, 1992).

From eight locations within the catchment, surface crusts were carefully removed from the bare soil surface using a sharp field knife. The thickness was measured using a metallic measuring tape graduated in milimetres, while their strength was determined qualitatively by pressing between the thumb and fourth finger and noting the ease of breaking. Crusts were sampled during the rainy season of April, 1992. This timing was necessary as from experience crusts peel off well without crumbling during a rainy season. The soil below the crust (up to 10 cm) on bare ground and the topsoils (0-10 cm) under bush and grass covers were also sampled. Thus, eight samples for each treatment were taken for mechanical and chemical analysis.

Soil samples were air dried, ground and seived through a 2-mm sieve. Those for organic C and total N determination were further ground to pass a 0.5-mm sieve. Texture was determined by the hydrometer method (Gee and Bauder, 1986). Soil pH and EC (electrical conductivity) were measured in a 1:2.5 soil-water suspension using a pH meter (McLean, 1982) and EC meter (Rhoades, 1982), respectively. Organic C was determined by the Walkley-Black method (Nelson and Sommers, 1982) and organic N by the Kjeldahl method (Bremner and Mulvaney, 1982). Exchangeable bases (Ca^{2+}, Mg^{2+}, K^+ and Na^+) were extracted with 1N NH_4OAc at pH 7.0.

Subsequently, K and Na^+ were determined using a flame photometer, and Ca^{2+} and Mg^{2+} by atomic absorption spectrophotometry (Thomas, 1982).

Infiltration rates on bare ground, grass and bush cover were determined using a double ring infiltrometer of 30 and 60 cm diameters for inner and outer ring, respectively (Kironchi, 1992). For each surface condition, 12 replicates were run. Saturated hydraulic conductivity and bulk density were determined on soil cores of 5 cm both height and diameter. For each surface condition, 2 profile pits were opened and from each, 4 cores taken from every layer. Samples for water content were taken from every site where infiltration tests were run during the dry and rainy seasons. Water content was determined using the gravimetric method.

RESULTS AND DISCUSSION

Table 1 shows textural and chemical properties of the surface soil crusts, the underlying soil layer and the topsoil under bush cover. Grass sites had results similar to those of the bush. The sand, silt and clay contents varied irregularly in the crust, the underlying horizon and the topsoils under bush. There was no significant difference ($P<0.05$) among the treatments in sand, silt and clay contents. The nitrogen, carbon and CEC values were generally higher in the topsoils under the bush cover than in the crusts and their underlying horizons. Calcium and Mg^{2+} were higher, in the crusts, than in the layer below or bush surface soils. Potassium was slightly higher in the topsoils under bush and the crust underlying layer, whereas sodium was higher in the crusts than in the adjacent horizons. Soil pH was slightly higher in the crusts than the other horizons, but the difference between the crusts and the topsoils under bush cover, was not significant.

On average, the electrical conductivity (EC) of the crusts was higher than the underlying horizon and the topsoil under bush cover. The exchangeable sodium percentage (ESP) was highest in the crusts, being almost double that in the underlying layer or in topsoils under bush.

Infiltration was more than ten times higher under bush cover than the bare ground in both seasons (Figs. 1A and B, Table 2). Plant cover

TABLE 1. Some properties of crusts, the underlying layer and topsoils under bush cover in Mukogodo, Kenya

Soil samples	S^*	Si	C	t/cl	N	C	Ca^{2+}	Mg^{2+}	K^+	Na^+	CEC	pH(H_2O)	EC	ESP
	—(%wt—		—(%wt—				—(cmol kg^{-1})—							
Crust	67	10	24	SCL	0.05	0.30	17.40	2.44	8.05	1.65	10.30	7.1	0.17	16.5
Below crust	65	12	23	SCL	0.08	0.46	3.40	1.68	8.15	1.01	10.66	6.6	0.07	10.1
Bush topsoils	69	10	21	SCL	0.10	0.80	5.45	1.93	8.25	1.10	14.30	6.9	0.11	7.9

*Means from eight samples. S: sand, Si: silt, C: clay, T/cl: tectural class, SL: sandy loam, SCL: sandy clay loam, EC: electrical conductivity; and ESP: exchangeable sodium percentage

TABLE 2. Some physical properties of Mukogodo topsoils (0-10 cm) under difference cover conditions

Surface conditon	Bulk density	Hydraulic conductivity (Mg/m^3)	Infiltration rate ($cm\ hr^{-1}$)	Dry season water content ($cm\ hr^{-1}$)	Rainy season water content (%v/v)
Bush	1.25(.14)	14.0(6.5)	31.6(8.7)	9..7(3.1)	19.7(3.3)
Grass	1.40(.11)	8.2(6.1)	18.4(11.3)	7.4(3.7)	16.3(3.8)
Bare	1.62(.07)	1.2(1.0)	6.7(4.9)	6.2(2.6)	11.5(2.9)

Means from eight samples for bulk density and hydraulic conductivity; and twelve samples for infiltration and water content. Items in brackets are the standard deviations.

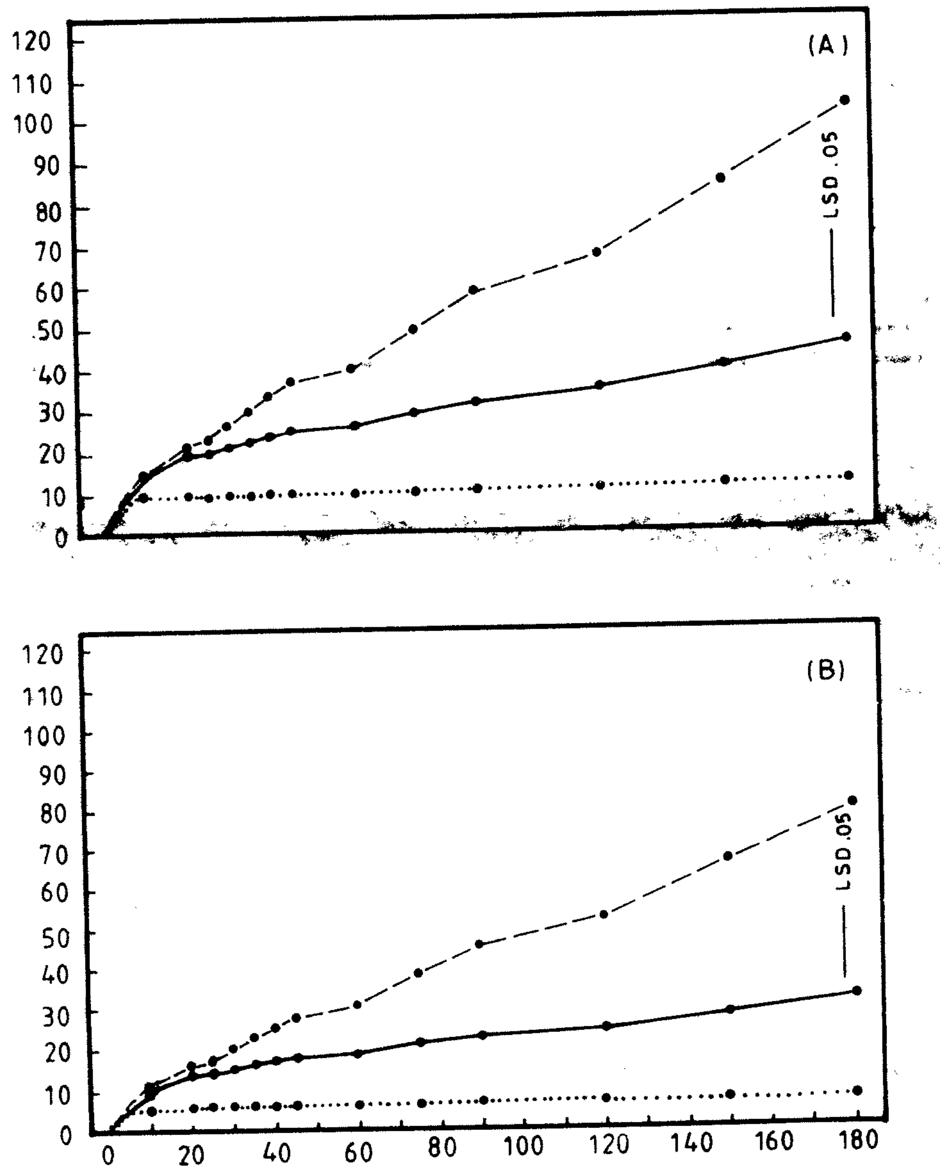

Figure 1. Cumulative infiltration (cm) of Mukogodo soils under bush, grass and bare ground during the (A) dry season and (B) rainy season

protection, accumulation of organic matter and fauna activity under bush and grass covers, lead to low bulk density, high infiltration, water conductivity and moisture content (Table 2). Higher organic matter content under bush and grass covers increases cation exchange capacity and, hence, higher cation values in the topsoils under plant cover than on crusted bare ground. The higher ESP values in the crusts than in the underlying layer are due to accumulation of Na^+ on the soil surface from the underlying horizons, as evaporation and drying occurs. Gal *et al.* (1984) state that chemical dispersion and formation of a washed-in layer is the dominant process responsible for the reduction in crust conductivity in soils with ESP>1.5. Also, Shainberg (1986) suggests that soils with ESP values greater than 1% have a high susceptibility to dispersion. This, together with low organic matter and high silt contents makes the soils on bare ground susceptible to dispersion by raindrops and, hence, higher susceptibility to crust formation.

The high bulk density of bare ground soils indicate compaction. The bare soils are exposed to raindrop impact unlike the case of bush covered sites. Bare soils resulting from overgrazing in this study, gave similar observations to those obtained when some Alfisols in Nigeria, with sandy topsoil textures, were cleared for cultivation and severe surface crusting took place resulting in high water losses and erosion (Wilkinson and Aina, 1976). These results show that a bush cover, just like a crop or grass cover as reported by Kandiah (1979), decreases bulk density and increases organic matter content and infiltration rates.

In this study, organic matter was more than double under the bush covered topsoils than in the surface crusts, and about twice the content in the layer underlying the crusts (Fig. 2B). Organic matter content governs resistance to structural breakdown as it determines, to a great extent, soil wettability. Aggregates with low organic matter are weakly bound together and drying leads to development of incipient fracture faults which, upon contact with water, quickly rewet owing to rapid rehydration of particle surfaces resulting in rapid release of energy which causes considerable aggregate breakdown (Haynes and Swift, 1990). Therefore, higher

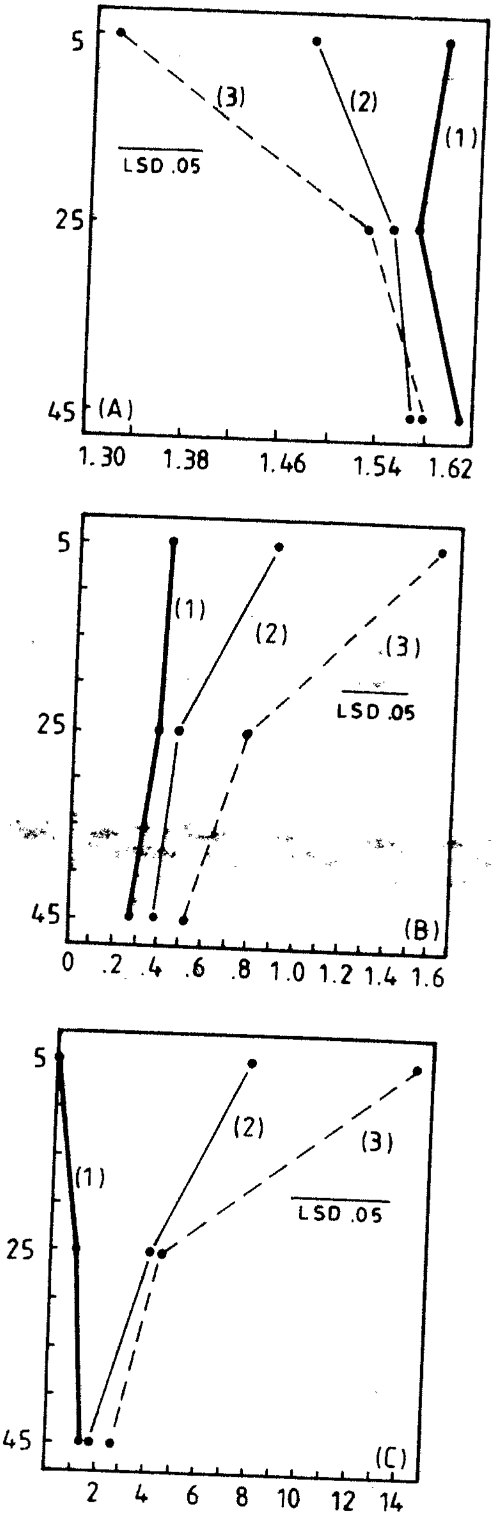

Figure 2. Effect of soil surface condition and depth on (A) bulk density (Mg/m^3), (B) organic carbon (% wt), and (C) saturated hydraulic conductivity (cm/h) on Mukogodo soils. Bush (1), Grass (2), and Bare (3).

organic matter in the topsoils under bush and grass cover renders them less susceptible to collapsing and formation of crusts, than the bare soils. Small reductions in soil organic matter content can remarkably increase soil erodibility and erosion rate (Fullen, 1991). This may explain the observed surface soil removal from the bare sites in the study area.

CONCLUSIONS

In this study, clay, silt and sand contents of the soil surface crusts did not differ significantly from those of the underlying layer or that of topsoils under bush or grass cover. However, there were significant differences in total nitrogen, carbon content, CEC, Ca^{2+}, Mg^{2+}, Na^{+}, EC and ESP.

The high ESP of the crusts makes them very dispersive and, hence, they collapse upon wetting resulting in clogging of soil pores and, therefore, reducing water infiltration and hydraulic conductivity on bare ground. Consequently, there is a reduction in organic matter and ensuence of compaction of surface soils. The magnitude of the effect of soil plant cover depletion in terms of changed soil properties has been documented by this study. In the study area, overgrazing is the major cause of reduced vegetation cover which exposes the soils to rainfall impact, soil removal and direct evaporation. Reduction of livestock grazing pressure in order to reverse the adverse trend of increasing bare ground is urgently required in Mukogodo. This will lead to gradual cover re-establishment and, ultimately, reduced surface soil crusting.

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