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ENVIRONMENTAL INFLUENCE ON WATER CHARACTERISTICS OF SOILS IN TWO SEMI-ARID CATCHMENTS IN LAIKIPIA, KENYA

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ABSTRACT

Influence of soil type and landuse on soil water retention and availability in the semi-arid Sirima and Mukogodo catchments in Laikipia District, were investigated. Representative soils, six in Sirima and four in Mukogodo, surveyed at a detailed level, were assessed using samples taken from 0-10, 20-30 and 40-50cm depths of bush, grass, bare ground and cultivated sites. Sirima soils retained more water than Mukogodo soils due to differences in clay type and textural composition. All Sirima layers were clay while Mukogodo topsoils were sandy loam and subsurface layers sandy clay loam. Mukogodo soils were more compact and had significantly lower carbon content than Sirima soils at all depths. For each area, only the surface layer had significant difference ($p<0.05$) in water retention among landuses, with bare ground retaining the most especially at higher pressures. However, no distinction could be made between soil types in each area based on plant water availability. Unlike the increase in clay content with depth, bulk density and carbon content were not significant in influencing plant water availability.

Key Words: **Available water, landuse, soil type, water retention**

RÉSUMÉ

L'influence de type de sol et d'utilisation de terre sur la rétention en eau du sol et sa disponibilité dans les reserves semi-arides de Sirima et Mukogodo du district de Laikipia au Kenya était étudiée. Des sols représentatifs, six à Sirima et quatre à Mukogodo, enquêtés en détails étaient évalués à partir des échantillons pris à 0-10, 20-30 et 40-50cm de profondeurs en brousse, en savanne, sur des sites non cultivés et cultivés. Les sols de Sirima avait la capacité de retenir plus d'eau que les sols de Mukogodo à cause des différences en types d'argiles et en composition texturale. Tous les strates de Sirima étaient de l'argile tandis que les sols de surface de Mukogodo étaient sablolimoneux et les strates du sous-sol sabloargilolimoneux. Les sols de Mukogodo étaient plus compact et avaient une teneur en carbone significativement bas que les sols de Sirima à toutes les profondeurs. A chaque site, seul le strate de surface avait une différence significative ($P<.05$) au point de vue retention en eau parmis les différentes utilisations de terre; le site non cultivé retenant plus d'humidité spéciallement à des pressions élevées. Cependant, on ne pourrait faire aucune distinction entre les types de sols dans chaque site se basant sur la disponibilité en eau de plantes. A part l'augmentation en teneur d'argile, la densité et la teneur du sol en carbone n'influencaient pas significativement la disponibilité d'eau de plantes.

Mots Clés: **Eau disponible, utilisation de terre, type de sol, retention d'eau, eau disponible**

INTRODUCTION

Soil water is the medium for plant nutrition. The size of its reserve and the ability of the plant to use it determine plant growth and productivity. This is even more pronouced in semi-arid environments where seasonal variation in yield is largely determined by the amount of water available for transpiration (Nix and Fitzpatrick, 1969; McCown, 1973; Kilewe and Ulsaker, 1984b).

Soil water storage and availability vary with soil type and management. Various soil properties, the most important of which include particle size distribution, clay mineralogy, organic carbon content and bulk density, influence water retention and release (Salter and William, 1965; Hill and Summer, 1967; Alexander, 1980; Sessanga, 1982; Williams *et al.*, 1983). Particle size distribution plays a major role in water holding capacity and availability as illustrated by characteristic soil moisture curves (Lal, 1979; Williams *et al.*, 1983; Gardener, 1988). Soil structure which influences pore size distribution strongly relates to soil water characteristics (Tsuji *et al.*, 1975; Lal, 1979). Available water capacity (AWC) varies among soils with wide textural ranges (Pidgeon, 1972; Maclean and Yager, 1975; Kilewe and Ulsaker, 1984a) and effects of organic carbon and bulk density on AWC for distinctly different soils are well documented (Salter and Williams, 1963; Lal, 1981; Sessanga, 1982).

Some tropical soils are naturally compacted and have low total porosity (Lal, 1979), and others are easily compacted by vegetation removal (Lal and Cummings, 1979; Alegre *et al.*, 1986). Soil water management and conservation practices require data on water storage and availability to plants. In Kenya, especially in the semi-arid areas, literature is very scarse on soil water characteristics under prevailing soil properties and transient conditions. More than 80% of Kenya's land is semi to very arid (GOK, 1986). Therefore, information on how soils store the scanty rains and avail water for plant growth is paramount. Most of Laikipia district is semi-arid and water is the most limiting factor for the overall district development. Yet, since 1969 the population has been growing due to immigration and naturaly at 7.3% annually (Kohler, 1987). Formerly large scale farms or ranches have been sub-divided since the 1970s (Jaetzold and Schmidt, 1983) and people practice farming systems developed for high potential areas but inapproapriate for their new settlements (Liniger, 1988). At Sirima, newly settled farmers are attempting arable agriculture but face acute water constraints. The problem of recurrent crop failure is prevalent. In Mukogodo, a pastoral grazing area, the problem of overgrazing is crucial. Overstocking has depleted vegetation cover and the resultant soil erosion has destroyed the natural conditions of the soils (Jaetzold and Schmidt, 1983; Kironchi, 1992). It was thus found necessary to investigate the soils of two catchments with the objective of determining the influence of soil type, landuse and vegetation cover on soil water retention and availability to plants.

MATERIALS AND METHODS

Study area. Sirima catchment covers an area of 365 ha and is located approximately 30 km S.W. of Nanyuki town at an elevation of 1,910 to 2,100 m. Rainfall is bimodal with an annual mean of 753 mm and mean temperatures of 17°C. The soils are developed from intermediate igneous rocks and are dark, clayey with vertic properties (except on hills and footslopes). Vegetation comprises of bush grassland and bushland. Recent (6-7 years) sub-division of land into plots of 1-2 hectares has resulted in subsistence cultivation attempts in this formerly ranching area. However, due to low and unreliable rainfall, most of the land is still under natural vegetation, unfenced and communally used for grazing.

Mukogodo catchment covers an area of 252 ha and is located approximately 40 km N of Nanyuki town at an elevation of 1,730 to 1,880 m. Rainfall is bimodal with an annual mean of 563 mm and mean temperatures of 19 °C. The soils developed from metamorphic basement rocks are red, sandy and gravelly. Vegetation comprises of dense to open dry thorn-bushland which has been under heavy grazing by pastoralists for more than 50 years.

Sirima and Mukogodo belong to agro-climatic zones IV and V, respectively (Sombroek *et al.*, 1982). Agro-climatic zone IV and V have a ratio of average annual rainfall to average annual potential evaporation (r/Eo) of 40-50% and 25-40%, respectively.

Representative soils, six in Sirima and four in Mukogodo, surveyed at detailed level (Njoroge, 1992) were assessed. Within soil types, four site conditions with respect to vegetation cover and landuse were investigated. These were:

Bush (TB). Sites under bush or small tree canopy within 1-2 metres from stem crown; having fair to good herbaceous ground cover due to partial inaccessibility by grazing livestock.

Grass (OG). Grass interspace sites with at least 50% basal grass cover.

Bare ground (BG). Site vegetation depleted due to excessive livestock grazing, less than 5% basal cover and most of the top soil eroded.

Cultivated surface (CS). Conventionally tilled and weeded with a hand-hoe, maize intercropped with beans. Sampled between rows 5-6 weeks from sowing, 1-2 weeks after weeding. Cultivation treatment was only applicable in Sirima.

From three representative profiles for each treatment, undisturbed samples were taken from 0-10, 20-30 and 40-50 cm layers in triplicate using aluminium core rings, 5 cm both in height and inner diameter. Disturbed samples were also taken from the same depths for particle-size analysis (Gee and Bauder, 1986) and organic carbon content (Nelson and Sommers, 1982) analysis. The pressure chamber method (Klute, 1986) was used for soil water characterisation at 0.1. 0.3., 0.5. 1, 3, 5, 7, 10, 15 bars. After the 15 bar equilibrium, cores were oven-dried at 105 °C for 24 hr for determination of bulk density (Blake and Hartge, 1986). Pressure values were converted to pF for ease of presentation. Njoroge (1992) determined the clay mineralogy of both areas soils. Data analysis was by ANOVA and means separation accomplished with least significant difference (LSD) test as described by Steel and Torrie (1980).

RESULTS AND DISCUSSION

Water retention. Sirima soils retained water more consistently than Mukogodo soils at any particular pressure (Figs. 1 and 2). Total water storage capacity (Saturation water content) was 60-67% and 36%-46% of the soil volume for Sirima and Mukogodo, respectively. At 15 bars Sirima soils retained more than two thirds while Mukogodo soils retained only about one third of the water at saturation. This trend in water release may be attributed to differences in the soils' clay mineralogy. Sirima soils have predominantly 2:1 clays (montmorillonitic) while Mukogodo's are dominantly kaolinitic (Njoroge, 1992). Warkentin (1974) and Sessanga (1982) have also reported such significant influence of clay type on moisture retention.

All Sirima soils were classified as clay in all depths while Mukogodo soils varied from sandy loam at the surface to sandy clay or sandy clay loam in the subsurface layers (Table 1). Sirima soils had similar amount of clay content in all depths, however, Mukogodo soils had significantly more ($p<.05$) in the subsurface layers. Table 2

TABLE 1. Textural composition of Sirima and Mukogodo soils at three depths

Area	Depth (cm)	Particle size (%) Sand	Silt	Clay	Textural class
SIRIMA	0-10	18[a]*	17[a]	65[a]	Clay
	20-30	14[a]	19[a]	67[a]	Clay
	40-50	16[a]	13[a]	71[a]	Clay
MUKOGODO	0-10	74[a]	15[a]	11[a]	Sandy loam
	20-30	63[b]	14[a]	23[b]	Sandy clay loam
	40-50	65[b]	11[a]	24[b]	Sandy clay loam

*Each value is a mean of 6 measurements. Means in a given column within each area with the same letter superscript are not significantly different.

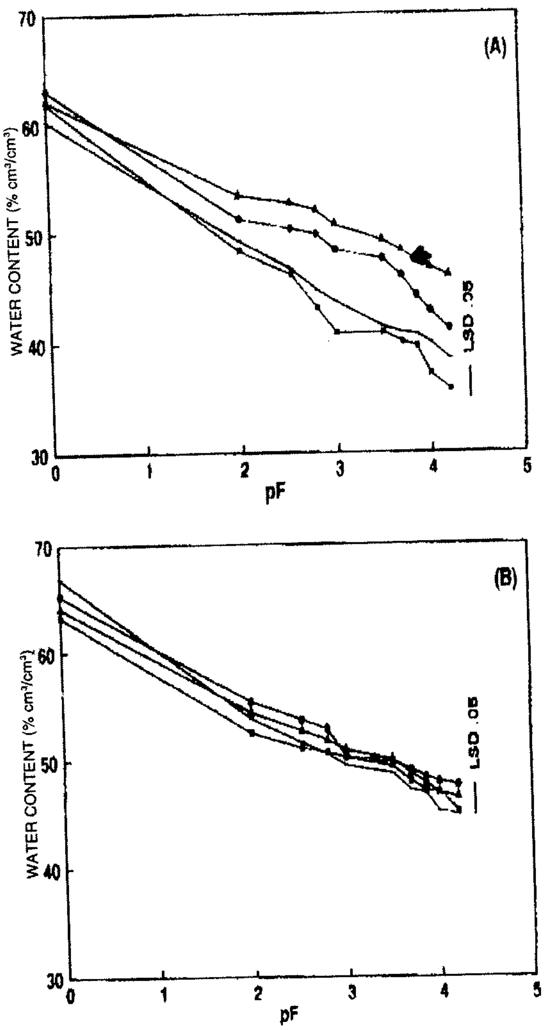

Figure 1. Sirima soils (A) surface layer (0-10cm) and (B) subsurface layer (20-30cm) water retention under various soil surface conditions.

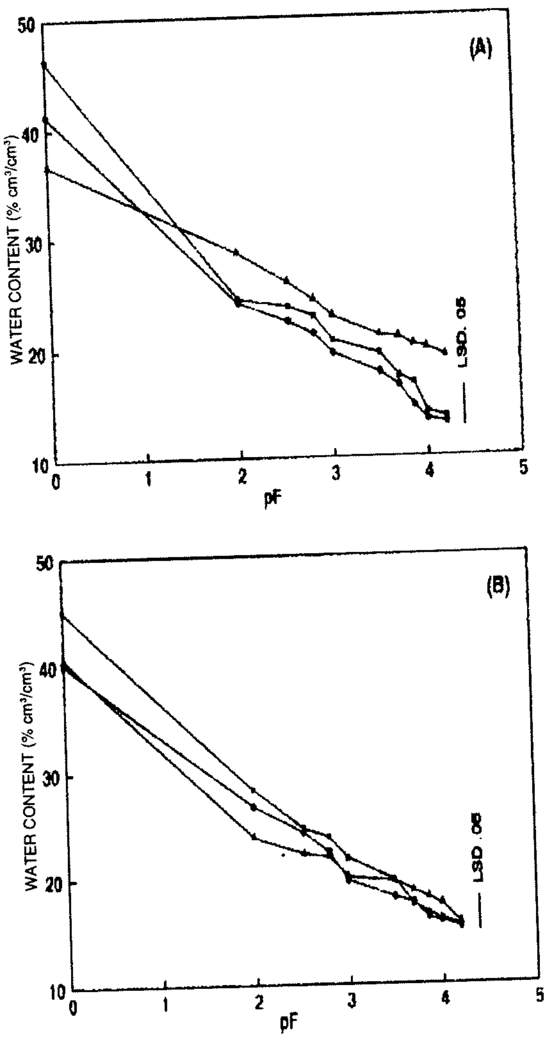

Figure 2. Mukogodo soils (A) surface layer (0-10cm) and (B) subsurface layer (20-30cm) water retention under various soil surface conditions.

indicates that Mukogodo soils are definitely more compact and have significantly lower carbon content than Sirima soils at all depths.

Soil water characteristics at 0-10 and 20-30 cm depths are presented in Figures 1 and 2. The third layer (40-50 cm) in both areas behaved similar to the second (20-30 cm), therefore, the graphs are not presented. It can be noted that all the soil layers from both areas produced similar moisture characteristic curves. Topsoils retained less water compared to subsurface layers for all landuses except BG. For each area, only the surface layer had significant difference ($p<.05$) in water retention among landuses, with BG retaining the most at higher pressures.

The water retention pattern among landuses in each area may be explained as being due to organic matter and texture. However, the effect of carbon content is unlikely considering the variation shown in Table 2. Therefore, the increase in clay content with depth could be the most likely explanation. Texture, rather than structure (largely influenced by carbon content and bulk density), becomes the dominant factor determining the amount of water retained at higher pressures. Gardner (1988) suggests this to be the reason why, at 15 bar, the amount of water retained is well related to the soil's clay content, after allowance is made for clay type. Our data for topsoils seem not to conform to this rule.

Cultivated topsoils in Sirima have a water retention curve similar to that of bush sites (Fig. 1A). Short term cultivation has not affected soils' water retention. Alegre *et al.* (1986) report quick response when a tropical forest is removed for cultivation. The likely reason is because the latter has a thicker surface layer or organic matter that cultivation mixing effects are pronounced right from the first season of ploughing.

Available water capacity (AWC). The amount of water held between 0.3 and 15 bars (pF of 2.5 and 4.2, respectively) was considered to approximate the plant available water; though

TABLE 2. Bulk density and organic carbon content for Sirima and Mukogodo soils at three depths under various landuses

Landuse	Bulk density at depth (cm)			Organic carbon at depth (cm)		
	0-10	20-30	40-50	0-10	20-30	40-50
	gcm^3			%wt		
SIRIMA						
Bush	0.98^{a1*}	1.13^{a2}	1.20^{a2}	4.09^{a1}	2.14^{a2}	1.19^{a3}
Grass	1.10^{b1}	1.15^{a1}	1.18^{a1}	2.38^{b1}	1.40^{b2}	0.84^{b3}
Bare	1.23^{b1}	1.29^{b1}	1.25^{a1}	0.93^{c1}	0.71^{c2}	0.59^{c3}
Cultivated	1.01^{a1}	1.16^{a2}	1.21^{a2}	2.86^{b1}	1.56^{b2}	1.08^{a3}
MUKOGODO						
Bush	1.32^{a1}	1.53^{a2}	1.58^{a2}	1.61^{a1}	0.78^{a2}	0.53^{a3}
Grass	1.46^{b1}	1.55^{a2}	1.57^{a2}	0.88^{b1}	0.47^{b2}	0.39^{b2}
Bare	1.64^{c1}	1.58^{b1}	1.61^{b1}	0.41^{c1}	0.38^{b1}	0.28^{b2}

*Each value is a mean of 9 measurements. Means within each area in a given column with the same letter superscript or in a given row (for each parameter) with the same digit superscript are not significantly different at the 5% level by LSD.

TABLE 3. Available water ($\%cm^3/cm^3$) between 0.3 and 15 bars for Sirima and Mukogodo soils at three depths under grass cover

Soil type	Soil depth (cm)		
	0-10	20-30	40-50
	$\%cm^3/cm^3$		
SIRIMA			
Eutric Vertisols	8.72^{a1*}	5.36^{a2}	6.73^{a2}
Rudi-Vertic Luvisols	8.47^{a1}	6.22^{a1}	6.09^{a2}
Verti-Calcic Luvisols	9.11^{a1}	5.74^{a2}	6.78^{a2}
Chromic Luvisols	9.80^{a1}	6.59^{a2}	6.41^{a2}
Chromic Cambisols	8.50^{a1}	6.61^{a2}	5.84^{a2}
Rudi-Eutric Cambisols	10.42^{a1}	5.54^{a2}	5.35^{a2}
MUKOGODO			
Chromo-Ferric Lixisols	10.85^{a1}	8.68^{a1}	9.84^{a1}
Ferri-Chromic Lixisols	9.65^{a1}	9.06^{a1}	9.63^{a1}
Rudi-Chromic Lixisols	9.11^{a1}	9.59^{a1}	9.45^{a1}
Eutric Fluviols	8.15^{a1}	8.43^{a1}	7.92^{a1}

*Each value is a mean of 9 measurements. Means within each area in a given column with the same letter superscript or in a given row with the same digit superscript are not significantly different at the 5% level by LSD.

under the study area conditions, for the bushes, 15 bar pressure may not be the real upper point for water availability. The grass treatment was used to assess the influence of soil type on water availability. Surprisingly, the topsoil of both areas stored similar amounts of available water (Table 3). Sirima subsurface layers had similar amounts of plant available water which was significantly less than that of the topsoils (Table 4). However, there was no significant difference in AWC among layers for Mukogodo soils. It is probable that the positive influence of organic carbon in the topsoils was evened out in subsurface layers by the slight increase in clay content therein. Despite the difference in soil types in each area, no distinction could be made among them based on water availability. Williams (1983) observed that differences in soils do not necessarily lead to variation in AWC. Gardner (1988), argues that there can be almost as much variation in AWC for a given soil textural class (reflecting structural differences) as there is between textural classes.

Available water obtained in this study was less than the values reported by Kilewe and Ulsaker (1984a) for Humic Nitisols (clay) from Muguga, and Ferric-Chromic Luvisols (sandy clay to sandy clay loam) from Katumani, Kenya. Probable explanations are that Sirima soils are heavy clays with vertic properties while Mukogodo soils are more sandy than the Katumani soils.

CONCLUSION

Sirima soils retained more water than Mukogodo soils due to differences in clay type and textural composition. Topsoils retained less water than the subsurface layers for all landuses except BG. For each area, only the surface layers varied in water retention among landuses, with BG retaining the most especially at higher pressures. No distinction could be made between soil types in each area based on plant water availability. Unlike clay content which increased with depth, bulk density and carbon content did not influence plant water availability in this study. Soil cover, by influencing surface soil conditons and degree of soil removal by erosion, also influenced surface soils' water characteristics.

Cultivation effect seems to be gradual in Sirima, and, most organic matter may disappear leading to surface soils degradation, unless crop residues are returned to the soil after harvesting. However, very often, crop residues are fed to livestock. In both catchments, grazing pressure should be eased by reducing the number of livestock per unit area. This will reverse the current trend of rapid vegetation cover removal and lead to re-establishment of soil cover on bare ground. Not only will the soils be protected from further direct rain drops impact and subsequent erosion, but also biological activity will reappear and organic matter regenerated. This will enhance

TABLE 4. Available water (%cm³/cm³) between 0.3 and 15 bars for Sirima and Mukogodo soils at three depths for various landuses

Treatment	Soil depth (cm)		
	0-10	20-30	40-50
	%cm³/cm³		
SIRIMA			
Tree/Bush	10.58^{a1*}	5.88^{a2}	6.37^{a2}
Open Grass	9.17^{ab1}	6.01^{a2}	6.20^{a2}
Bare Ground	6.66^{c1}	6.14^{a1}	6.85^{a1}
Cultivated	8.25^{b1}	6.78^{a2}	6.96^{a2}
MUKOGODO			
Tree/Bush	10.26^{11}	9.13^{a2}	7.48^{b3}
Open Grass	9.44^{a1}	8.94^{a1}	9.21^{a1}
Bare Ground	6.89^{b1}	6.56^{b1}	5.77^{ac}

*Each value is a mean of 9 measurements. Means within each area in a given column with the same letter superscript or in a given row with the same digit superscript are not significantly different.

infiltration and water storage, thus further plant growth, when the scarse rains come in these semi-arid areas. Therefore, there is need to retain and maintain adequate ground cover in order to ensure optimum soil water storage and availability to plants.

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