Measurements of Soil Loss and Runoff from Simulated Rainstorms at Kabete, Katumani & Iiuni

R. G. Barber and D. B. Thomas

(Departments of Soil Science and Agricultural Engineering respectively, University of Nairobi)

Paper presented to the Third Annual General Meeting of the Soil Science Society of East Africa,

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ABSTRACT

A portable rainfall simulator was used to measure the runoff rates and soil losses from storms of varying intensities applied to a freshly ploughed luvisol at Katumani, a freshly ploughed nitosol at Kabete and from three soils with different grass covers on grazing land at Iiuni. The results of soil losses from similar storms showed the Katumani luvisols to be 5 to 11 times more erodible than the Kabete nitosols. Runoff losses varied from 0 to 71% at Katumani but only from 0.2 to 17% at Kabete. The much higher runoff rates from the Katumani luvisols were attributed to their rapid surface sealing. On the grazing land at Iiuni erosion rates were very high on the bare overgrazed areas but were markedly reduced to low values when the grass basal cover exceeded 15 to 20%. Runoff was high (about 63%) from the bare sites and old pasture, but ws much lower (39%) from recently reseeded pasture. The high runoff rates were attributed to surface sealing at the bare sites and to surface compaction on the old pastures; they were not influenced by the percentage grass basal cover.

INTRODUCTION

Soil erosion is a serious problem in many parts of Kenya, but data on soil erosion losses and runoff, on which the planning and design of conservation measures should be based, is very meagre. Pereira et al. (1967) measured the soil losses and runoff at Muguga from nitosols with and without terraces and with different rotation treatments. Othieno (1975) and Othieno and Laycock (1977) also worked on nitosols but at Kericho, and used permanent runoff plots to study the soil loss and runoff from under tea. The only previous known work with a rainfall simulator is that of Dunne (1977) who investigated a variety of rangeland soils in the Kajiado District.

In this study a portable rainfall simulator was used to gather additional data on soil losses and runoff. The main aims were, firstly, to measure the soil losses and runoff from storms of different intensities applied to land that had been cultivated prior to planting. Measurements under these conditions were considered to be important as Fisher (1977) and Moore (1978) had shown that it is at the beginning of the rains, before a protective crop cover has been established, that the most erosive rains are likely to occur. Two contrasting soils were selected, viz. the nitosols which have the reputation of being very resistant to erosion (Ahn, 1977) and the luvisols which are characteristic of many eroded areas in the Machakos District. The second aim was to investigate the soil losses and runoff from grazing land with varying percentage grass covers. Three sites with similar soils but different grass covers were selected in the Iiuni catchment. This location was chosen so that the results obtained would augment the hydrological data (viz.discharge rates and sediment yields) being monitored from the same catchment by the joint hydrological project of the Ministry of Water Development, Kenya and the Ministry of Overseas Development U.K.

METHODS

The rainfall simulator used in this study is of the rotating-disc type and comprises a single full-jet nozzle that had been designed to produce raindrops of a similar size to those occurring in natural rainstorms. The intensities of the simulated storms could be regulated by adjusting the size of the slit in the rotating disc, whilst keeping the pressure at which the water is pumped through the nozzle constant. The kinetic energies of the storms were found to vary from 65 to 83% of the kinetic energies that would occur in natural rainstorms of the same intensities.

The size of the plots to which the simulated rainstorms were applied and from which soil losses and runoff were measured, was 140 cm long and 108 cm wide, i.e. 1.51 m^2 in area. The runoff flowed into a trough at the lower end of the plot from which it could be collected in a series of bottles. The time taken for each bottle to be filled was recorded and the volume of runoff and weight of sediment contained in each bottle was measured in the laboratory.

Selected properties of the topsoils at Kabete, Katumani and Iiuni are given in Table 1. Detailed morphological and chemical properties of the whole profiles are given by Nyandat and Michieka (1970) for the Kabete soil, by Mbuvi and van de Weg (1975) for the Katumani soil and in Appendix I and II for the Iiuni soils. At Kabete and Katumani, plots were selected on a 6^{o} slope which had been disc ploughed a short time previously. The plots were then lightly hand-raked to bring the surface slope as near as possible to 6^{o}. Simulated rainstorm were applied at intensities of 50, 100 and 150 mm/h at Kabete and at intensities of 25, 50 and 100 mm/h at Katumani. The storm duration were adjusted to give a total of 50 mm rain for each rainstorm, except for the 150 mm/h storms to the wet plots, where only 25 mm rain was applied.

TABLE 1

Selected Properties of the top soils

Location	Soil classification	Depth (cm)	Organic carbon (%)	pH(H_2O) 1:1	CEC (me/100g)	Dominant clay Minerals	Bulk Density (g/cm^3)	Erodibility K factpr values*
KABETE Field II	Humic Nitosol	0 - 16	2.43	6.4	34.2	Kaolinite Illite	0.57	0.06
KATUMANI Field U	Ferral-chromic luvisol	0 - 15	0.99	6.0	13.0	Kaolinite Illite	1.24	0.20
IIUNI Site A	Chromic luvisol**	0 - 10	1.16	5.7	15.9	n.d.	1.22	0.19
IIUNI Site B	Orthic Ferralsol**	0 - 10	1.03	6.4	8.1	n.d.	1.60	0.22
IIUNI Site C	Orthic Ferralsol**	0 - 10	2.07	6.4	11.3	n.d.	1.55	0.20

Location	Mechanical Analysis (%) Coarse sand 2000-600μ	Medium sand 600-200μ	Fine sand 200 - 60μ	Coarse silt 60 - 20μ	Medium silt 20 - 6μ	Fine silt 6 - 2μ	Clay < 2μ
KABETE Field II	1.4	1.3	1.1	0.0	4.4	13.2	79.2
KATUMANI Field U	2.6	10.9	31.0	12.5	0.0	8.2	34.8
IIUNI Site A	1.4	11.7	29.6	4.7	2.1	2.1	48.4
IIUNI Site B	2.2	14.6	41.0	6.8	2.1	2.1	31.2
IIUNI Site C	3.4	29.2	29.0	8.9	2.1	2.1	25.3

** Provisional classification

* Calculated from the nomograph in Wischmeier *et al.*, (1971)

The recurrence intervals and erosivity R factor values for the storms are given in Table 2. The storms were initially applied to soils drier than permanent wilting point in the upper layers (dry state), and two days later the same storms were repeated on the same plots which were then approaching field capacity (wet state). Each treatment was replicated five times. Between simulated rainstorms the plots were covered with sheets of polythene to reduce surface evaporation. Further details of this study are given in Barber, et. al. (1979).

TABLE 2

Characteristics of the simulated rainstorms

Intensity (mm/h)	Duration (min)	Amount of rain applied (mm)	Rainfall erosivity 'R' factor	Recurrence interval of rainstorm (yr) (Kabete)	(Katumani, Iiuni)
25	120	50	15	5	ca.2
50	60	50	29	8.5	7
69	60	69	56	ca. [illegible]	30
100	30	50	59	ca. 160	45
150[a]	10	25	44	-	50
150[b]	20	50	88	-	100

[a] rainstorm applied to wet plots

[b] rainstorm applied to dry plots

Three sites were selected on grazing land in the Iiuni catchment, which is about 20 km south-east of Machakos. Site A was almost completely bare of vegetation, with an exposed subsoil sealed at the surface by a very thin clay layer. Site B had previously been severely eroded but was ploughed and reseeded about two years ago. Since then grazing had been restricted. The site had an average grass basal cover of 20% and the surface still retained some microtopography from the ploughing. The dominant grass species were Eragrostis superba, Harpachne schimperi, and Dichanthium insculptum. Site C was a well grassed, long established pasture, perhaps twenty years old, which had been heavily grazed and trampled so that the surface soil was very compact. The average grass basal cover was 57% and the dominant grass species were Eragrostis superba, Chloris pycnothrix, Heteropogon contortus and Dichanthium insculptum. At each site five plots were laid down and a single storm of 69 mm/h intensity and 60 min duration was applied to each plot. The runoff and soil losses were collected as before. Further details of this study are given in Moore, et. al. (1979).

RESULTS AND DISCUSSION

Cultivated land

The amount of runoff generally increased with time during the storms, until in some cases, a relatively stable, "final" runoff rate was obtained. For these cases the "final" infiltration rate could be calculated, which probably represents the soil's infiltration rate when the surface layer is saturated. The values given in Table 3 show that the nitosol gave high "final" infiltration rates of 32-100 mm/h even when the plots were initially wet. This can be attributed to the high structural stability of the nitosols. The luvisols however, gave "final" infiltration rates of 24 - 44 mm/h when the plots were initially dry, and rates of 7 - 14 mm/h when the plots were wet. The lower "final infiltration rates when the luvisols were wet is probably due to the effects of two storms, and hence a greater structural degradation of the surface layer and increased sealing of pores. This was confirmed by observation of the plots, with the luvisols giving a very smooth glossy appearance after the second storm. The Nitosols however did not develop such a pronounced surface sealing.

Values for the total runoff as a percentage of the applied rain are given in Table 4. Considerable variation occurs within each treatment with coefficients of variation of 50% being common and sometimes up to 100% occurring. The runoff ranged from 0.2 to 17.3% for the nitosol and from 0 to 71.4% for the luvisol. For comparable storm intensities (viz. 50 and 100 mm/h), the runoff ratios for the two soils (luvisol:nitosol) were 76:1 and 26:1 for the dry soils and 5:1 and 4:1 for the wet soils. The high ratios in the dry state emphasise the speed with which surface sealing and high runoff rates will develop on the luvisols.

TABLE 3

Final infiltration and runoff rates for the Kabete nitosols and the Katumani luvisols

Soil	Rainfall intensity (mm/h)	Moisture state	Mean "final" runoff rate (mm/h)	Mean "final" infilration rate (mm/h)
Kabete nitosol	50	wet	18.0	32.0
	100	wet	48.6	51.4
	150	wet	49.8	100.2
Katumani luvisol	25	wet	4.8	20.2
	50	dry	25.8	24.2
	50	wet	43.2	6.8
	100	dry	56.4	43.6
	100	wet	86.4	13.6

The total soil eroded from the nitosols varied from means of 22.4 to 317.3 g/m^2 and for the luvisols from 19.9 to 1390.2 g/m^2. Using the bulk density values given in Table 1, this represents a surface lowering of 0.04 to 0.56 mm at Kabete and 0.02 to 1.12 mm at Katumani. For comparable storm intensities (viz. 50 and 100 mm/h), the soil loss ratios for the two soils (luvisol:nitosol) were 7.7:1 and 5.4:1 for the dry soils and 10.9:1 and 9.7:1 for the wet soils. These ratios establish

TABLE 4

Runoff and total soil eroded from the plots at Kabete and Katumani

Soil	Storm intensity (mm/hr)	Moisture state	Runoff (mm) Range	Mean	(±s.d.)	% Rain	Total soil eroded (g/m²) Range	Mean	(±s.d.)
Kabete nitosol	50	Dry	0- 0.23	0.10	(0.09)	0.2	9.3- 29.3	22.4	(11.8)
		Wet	1.69-15.76	7.45	(5.47)	14.9	34.6- 106.3	73.3	(40.3)
	100	Dry	0.03- 1.02	0.40	(0.40)	0.8	40.3- 74.9	55.9	(20.2)
		Wet	1.73-16.18	8.67	(4.73)	17.3	40.2- 267.3	142.8	(78.4)
	150	Dry	0.39- 2.80	1.49	(1.00)	3.0	59.6- 257.4	162.0	(101.5)
		Wet	1.02- 6.76	3.95	(2.64)	15.8	119.4- 715.3	317.3	(380.0)
Katumani luvisol	25	Dry	0	0	(0)	0	16.4- 26.3	19.9	(5.6)
		Wet	1.77- 9.29	4.72	(2.76)	9.4	30.8- 69.4	48.0	(27.4)
	50	Dry	1.21-10.81	7.64	(3.74)	15.3	57.8- 285.7	172.5	(124.2)
		Wet	29.26-38.76	33.66	(4.53)	67.3	467.3-1126.4	852.1	(378.4)
	100	Dry	4.24-13.70	10.34	(3.87)	20.7	136.8- 484.9	302.7	(182.5)
		Wet	31.54-38.85	35.68	(2.85)	71.4	983.1-1921.5	1390.2	(528.8)

the relative erodibility of the two soils; thus the Katumani luvisols are about 5 to 11 times more erodible than the Kabete nitosols.

The much higher runoff rates and soil losses from the luvisols suggest that the type and/or design of conservation measures appropriate to the luvisols may be very different to the conservation measures required by the nitosols.

Grazing land

The amounts of runoff and total soil loss from the Iiuni soils are given in Table 5 together with the initial moisture content, slope and percent grass basal cover for each plot. The per cent runoff and soil losses were high at the severely eroded bare plots, site A (with means of 63% and 1234 g/m^2, respectively), but much lower from the recently established pasture at site B (39% and 150 g/m^2, respectively). At the long established pasture, site C, runoff was high (64%) but soil losses were low (60 g/m^2). The per cent runoff and soil losses from all replicates at the three sites are plotted against per cent grass basal cover in Fig. 1. The grass cover clearly has little influence on runoff. At sites A and C the runoff values are very similar despite the differences in initial moisture content, slope and grass cover. This is probably due to the greater influence of the sealing and the compact nature, respectively, of the surface horizons at these two sites. The lower runoff value (39%) at the recently reseeded and largely ungrazed pasture at site B is probably because of the absence of surface compaction from grazing, and because of the persistence of microtopography from the ploughing.

TABLE 5

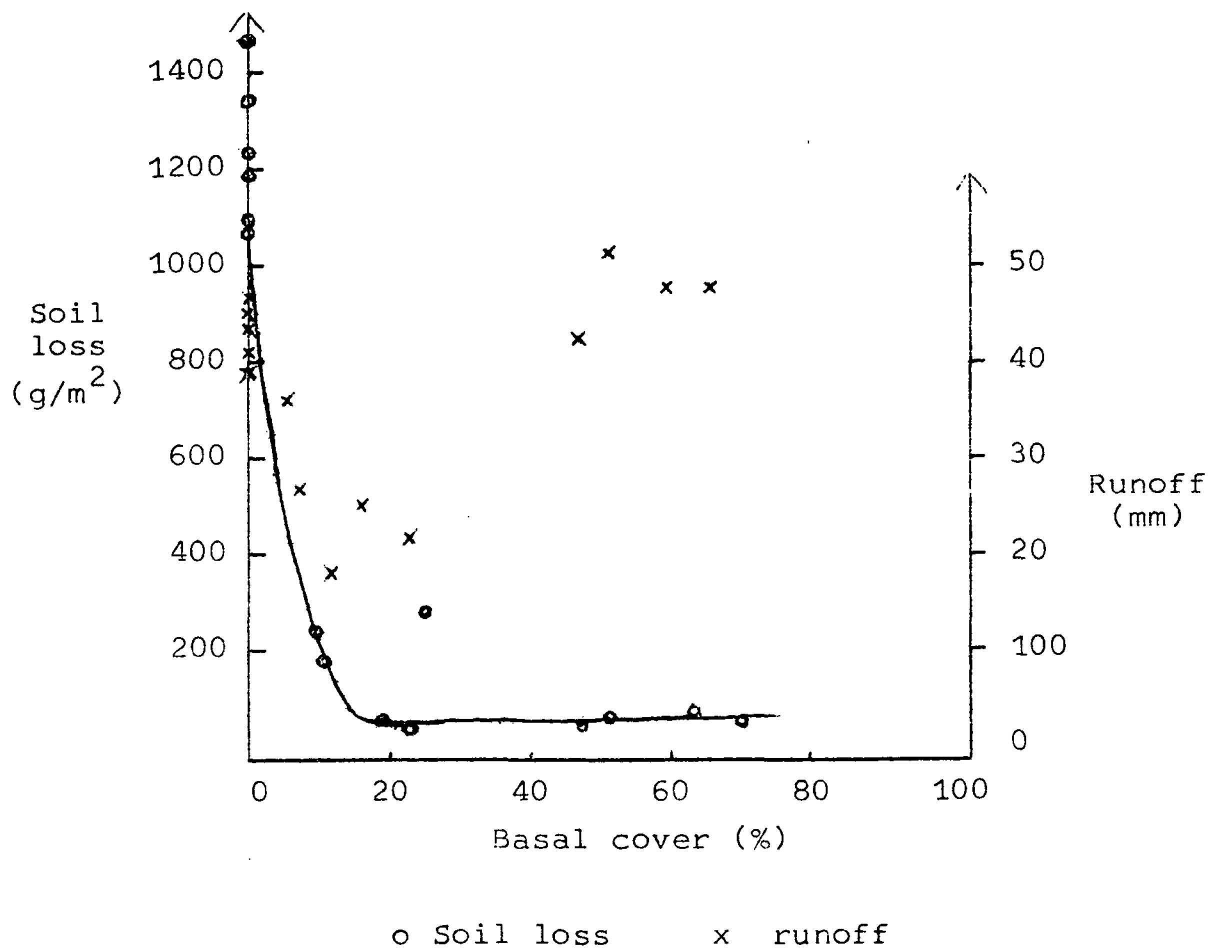
Plot characteristics, runoff and soil loss from the Iiuni sites

	Plot	Initial soil moisture content w/w	Slope %	Basal cover %	Runoff mm	"Final" infiltration rates mm/h	Runoff as % rain applied	Soil loss g/m^2
Site A (bare)	1		12	0	46	12.0	66	1099
	2		11	0	46	10.8	66	1075
	3		13	0	46	18.0	66	1193
	4		15	0	39	19.8	57	1357
	5		11	0	41	12.0	60	1447
	mean	10.1	12.4	0	43.6	14.5	63.0	1234.2
		(n.d.)	(1.7)		(3.4)	(4.1)	(4.2)	(162.5)
Site B (new grass)	6		17	12	28	30.0	41	229
	7		19	30	24	33.0	35	246
	8		22	12	36	17.4	53	191
	9		21	20	18	40.2	26	50
	10		16	25	27	30.0	40	34
	mean	5.7	19.0	19.8	26.6	30.1	39.0	150.0
		(1.3)	(2.5)	(7.9)	(6.5)	(8.2)	(9.8)	(100.7)
Site C (old grass)	11		16	62	46	12.0	67	76
	12		20	69	46	16.8	67	64
	13		n.d.	n.d.	38	22.2	55	40
	14		18	47	42	18.6	61	59
	15		20	51	48	16,8	69	62
	mean	17.3	18.5	57.3	44.0	17.3	63.8	60.2
		(2.6)	(1.9)	(10.1)	(4.0)	(3.7)	(5.8)	(13.0)

Standard deviations in parentheses

FIGURE 1

Relationship between percentage grass basal cover and soil loss and runoff at Iiuni



Soil erosion rates, on the other hand, are reduced by an increase in grass cover as shown in Figure 1. Erosion losses were not related to percent runoff, or factors such as slope or moisture content which affect runoff, since site C which gave the lowest erosion losses had a similar per cent runoff to site A. Erosion losses were also unrelated to inherent soil erodibility differences between the three sites, since the soil at site A with the highest soil loss had the lowest erodibility K factor value (see Table 1).

The relationship between erosion losses and per cent grass basal cover in Figure 1 suggests that a critical value of 15 to 20% is important. At values less than this, erosion is intense, whereas at values above 15 to 20% there is little further reduction in soil loss. A similar relationship has been found by Dunne (1977) in the rangeland areas of Kajiado district, where erosion losses were greatly reduced with an increase in grass basal cover from 0 to 20%. At high basal covers there was little further reduction in soil loss. The influence of grass cover in reducing soil loss can be explained by a reduction in raindrop detachment of soil particles and a reduction in the velocity of runoff.

CONCLUSIONS

The data obtained for the cultivated nitosols and luvisols showed that the luvisols were about 5 to 11 times more erodible than the nitosols and gave much higher runoff rates. This suggests that the type and/or design of conservation measures required by the luvisols may be very different to what is required by the nitosols.

On the grazing land at Iiuni the per cent runoff was high from both overgrazed bare land and from long established, well grassed pastures when subjected to high intensity rainstorms. This appeared to be caused by surface compaction from grazing on the long established pastures and to the development of very thin clay seals at the soil surface of the bare plots. Where pastures had been established only two years previously and grazing had been restricted the per cent runoff was much less. This was attributed to the lack of compaction from grazing and to the remains of a microtopography from the ploughing. The soil losses from grazing land were very high from overgrazed, bare areas but were greatly reduced when the grass basal cover exceeded 15 to 20%.

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APPENDIX I

Morphological Soil Profile Descriptions of the Iiuni Soils

Site A

0 - 0.1 cm	Sandy wash layer
0.1 - 0.2 cm	Yellowish red clay? seal
0.2 - 2 cm	Yellowish red 5YR4/6; clay; weak coarse subangular blocky structure; friable to firm; few coarse and medium pores; few roots; merging smooth and clear to..
2 - 24 cm	Reddish brown 5YR4/4 mottled 5% brown to dark - brown 75YR4/2; clay; weak coarse sub-angular blocky structure; friable-; patchy thin cutans; many coarse and medium pores; few roots; marging smooth and gradual to ...
24 - 49 cm	Reddish-brown 5YR4/4 mottled 1% dark grey 7.5YR4/0; clay, weak coarse subangular blocky structure; friable; patchy thin cutans; many coarse and medium pores; very few roots; merging smooth and diffuse to ...
49 - 109 cm+	Yellowish-red 5YR4/6 mottled 5% dark reddish brown 5YR3/3; clay; massive structure; firm; patchy thin cutans; many coarse and medium pores; very few roots.

SITE B

0 - 15 cm	Brown to dark brown 7.5YR4/2 mottled 25% reddish brown 5YR4/4 sandy clay loam; moderate medium to coarse subangular blocky structure; friable; common coarse and medium pores; abundant roots; merging smooth and gradual to ...
15 - 49 cm	Brown to dark brown 7.5YR4/4; sandy clay; weak coarse subangular blocky structure; friable to firm; common coarse and medium pores; common roots; merging smooth and clear to ....
49 - 72 cm	Brown to dark-brown 7.5YR4/4; sandy clay; weak coarse subangular blocky structure; friable to firm; many coarse and medium pores; common roots; merging smooth and gradual to ...

72 - 102 cm+	Yellowish red 5YR4/8 mottled 1%, grey 10YR5/1; sandy clay; moderate coarse subangular blocky structure; very friable; many coarse and medium pores; few roots.

SITE C

0 - 6 cm	Dark brown 10YR3/3 mottled 1%, very dark grey 7.5YR3/0; sandy clay loam; weak medium subangular blocky structure; firm; compact with few coarse or medium pores; frequent roots; merging smooth and clear to ...
6 - 16 cm	Dark brown 10YR3/3; sandy clay loam; moderate medium subangular blocky structure; very friable; common coarse and medium pores; frequent roots; merging smooth and clear to...
16 - 36 cm	Dark brown 7.5YR 3.5/2 mottled 5% reddish brown 5YR4/4; sandy clay; moderate to strong medium subangular blocky structure; very friable; many coarse and medium pores; common roots; merging smooth and clear to...
36 - 63 cm	Brown to dark brown 7.5YR4/4 mottled 10% brown to dark brown 7.5 YR4/2; sandy clay; massive structure; firm; many coarse and medium pores; few roots; merging smooth and gradual to ...
63 -96 cm	Brown to dark brown 7.5YR4/4 mottled 10% brown to dark brown 7.5YR4/2; sandy clay; moderate coarse subangular blocky structure friable to firm; common coarse and medium pores; common roots; merging smooth and gradual to ...
96 - 120 cm+	Strong brown 7.5YR5/6 mottled 7% brown to dark brown 7.5YR4/4 and 1% olive 5YR5/3; sandy clay; weak coarse subangular blocky structure; friable to firm; may coarse and medium pores; common roots.

APPENDIX II

Soil Profile Analyses of the Iiuni Soils

	Site A			Site B				Site C					
Depth (cm)	0-24	24-49	49-109	0-15	15-49	49-72	72-102	0-6	6-16	16-36	36-63	63-96	96-120
Sand (%)	32	38	27	60	56	48	46	68	64	60	nd	52	54
Silt (%)	9	6	16	6	4	4	8	8	6	4	nd	8	6
Clay (%)	59	56	57	34	40	48	46	24	30	36	nd	40	40
Texture class	c	c	c	scl	sc	sc	sc	scl	scl	sc	nd	sc	sc
pH-H_2O 1:2½ suspension	5.6	5.8	nd	6.4	6.2	6.3	6.3	6.3	5.9	5.9	5.9	6.0	5.6
pH-KCl 1:2½ suspension	4.8	5.0	nd	5.2	4.9	4.9	5.1	5.2	4.7	4.6	4.6	4.8	4.5
EC 1:2½ (mmhos/cm)	0.19	0.15	nd	0.07	0.05	0.04	0.03	0.08	0.07	0.05	0.04	0.04	0.04
C (%)	0.59	nd	nd	0.94	nd	nd	nd	1.41	0.68	nd	nd	nd	nd
CEC (me/100g)	12.9	10.7	nd	9.3	7.5	7.5	4.9	9.3	8.1	8.9	7.1	6.1	6.5
Exchangeable Ca(me/100g)	5.4	5.2	nd	4.5	2.9	2.5	2.5	4.5	3.1	3.5	3.3	3.3	2.5
" Mg "	2.2	2.25	nd	1.4	0.95	1.25	1.4	1.50	1.05	0.8	1.10	1.65	1.40
" K "	1.37	1.11	nd	0.80	0.50	0.58	0.47	0.63	0.58	0.41	0.17	Trace	Trace
" Na "	Trace	Trace	nd	0.30	Trace	Trace	0.12	0.12	Trace	0.04	0.22	Trace	0.04
Sum of exchangeable bases (me/100g)	8.97	8.56	nd	7.00	4.35	4.33	4.49	6.75	4.73	4.75	4.79	4.95	3.94
Base saturation (%)	70	80	nd	75	58	58	92	73	58	53	67	81	61