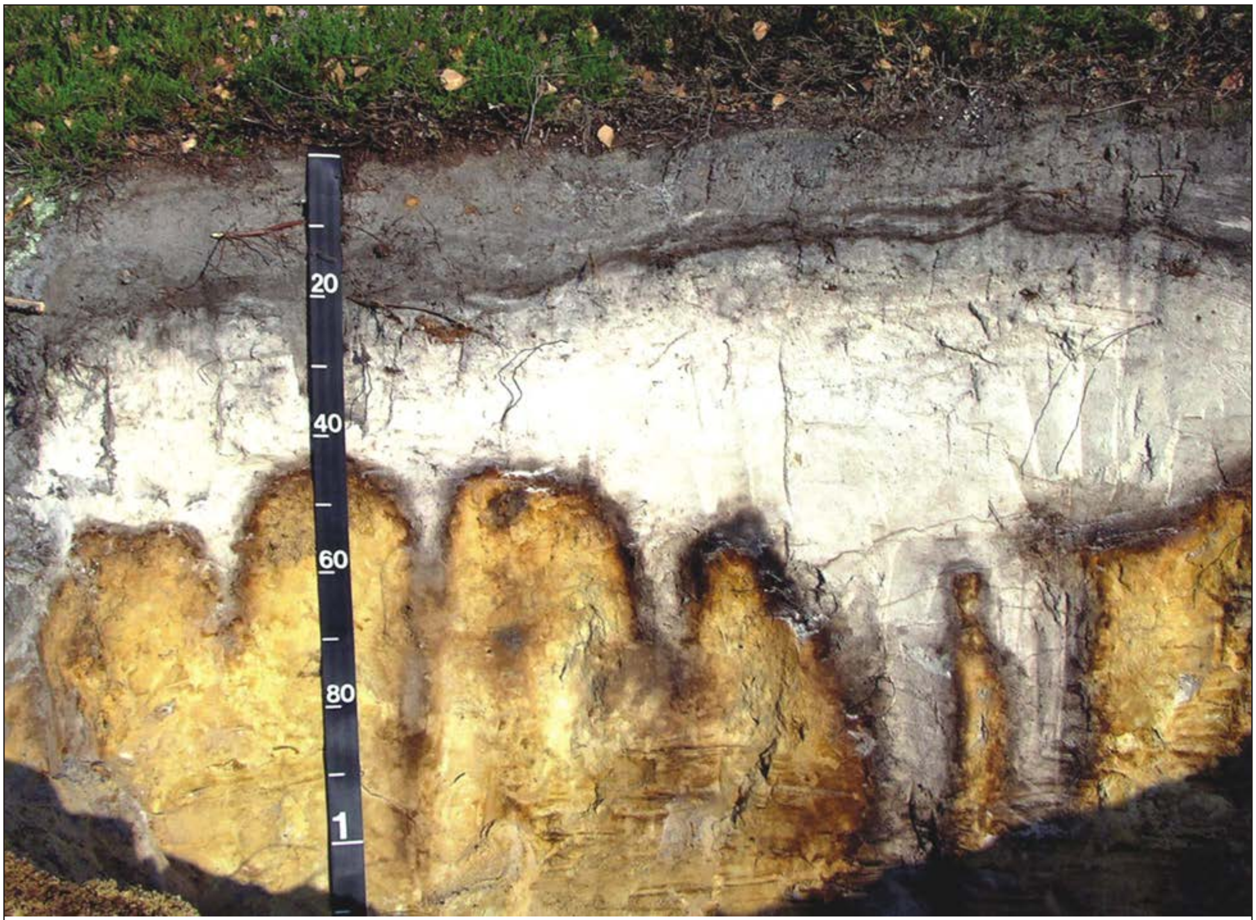

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Distribution of Potassium Forms along a Hillslope Positions of Newer Basalt on the Jos Plateau Nigeria

M.A. Samndi and Mahmud Abba Tijjani
Department of Soil Science, Faculty of Agriculture, Bayero University Kano, Nigeria

Corresponding Author: M.A. Samndi, Department of Soil Science, Faculty of Agriculture, Bayero University Kano, Nigeria

ABSTRACT

Landscape positions have always been related to erosional processes, its effects on soil chemical properties particularly the forms of potassium (K) has not well documented in the Savanna soils of Nigeria. This study was therefore conducted to accentuate the forms of potassium distribution associated with hillslope positions. A purposive stratified sampling was employed where crest, upper, middle and lower slope positions were identified, each representing changes in geomorphological position. Results showed that the forms of K varied with landscape position. The mean value of soluble K in the crest surface horizon was 14% (0.1374 cmol (+) kg^{-1}) higher than the value obtained on the lower slope position. For the underlying horizon, soluble K value was 58% (0.0187 cmol(+) kg^{-1}) lower on the crest. The exchangeable K distribution in the surface horizons were not statistically significant, though slightly higher value (0.1316 cmol (+) kg^{-1}) was obtained on the upper slope position while the lowest value (0.1086 cmol (+) kg^{-1}) was observed on middle slope. In the subsurface horizons values were in the order upper slope>crest>lower slope >middle slope. The total K values for the respective surface horizons were non significant while in the underlying horizons mean values varied between 0.6193-1.2048 cmol (+) kg^{-1}. Generally the distribution of the various forms of K did not shown a well-defined trend with respect to topographic positions. Similar profile K distributions were also not well pronounced for the respective positions.

Key words: Potassium forms, hill slope, newer basalts

INTRODUCTION

Topography directly affects soil-forming processes, as it is both an internal and external factor in pedogenesis, thus affecting soil formation (Eshett *et al*., 1989; Yamaguchi, 1992; Temgoua *et al*., 2005). Processes directly related to topography are erosion and deposition, however differences in toposequence position leads to differentiation in soil properties and hydrological conditions (Hseu and Chen, 2001; Tsubo *et al*., 2006). Krasilnikov *et al*. (2005) corroborated that soil properties on a toposequence differ due to degree of erosion, transport and deposition of chemical and particulate constituents of the soil. Singh and Mishra (1995), also confirmed that soil properties vary due to the factor of topographic influence on radiation intensity, amount of water that enters the soil, material movement and distribution and pedogenic processes. Topographic indices and soil properties were reported by Seibert *et al*. (2007) to be significantly correlated. Variations in topographic positions gave rise to sequence of soil types, each having different profile

(Amundson *et al.*, 1994). Differences in soil properties as a result of local effects of topography accounted for between 26 and 64% total variation in soil properties and moisture, respectively (Bockheim, 2005; Cox *et al.*, 2002; Wilson *et al.*, 2004).

Franzmeier *et al.* (1969) studied properties of some soils in relation to slope aspect and position and observed that particle-size distribution, base saturation and soil temperature were all related to slope position. Soils on footslope and highlands showed marked differences in Cation Exchange Capacity (CEC) and base saturation (Durak and Surucu, 2005). In Nigeria, Salako *et al.* (2006) studied soil properties on two toposequences (Ibadan and Alabata) and reported that soil pH, total N and exchangeable K differed with slope position. High exchangeable K was obtained on upper slope while total N and pH values were higher on both middle and lower slope positions. Similarly Tsui *et al.* (2004) reported high pH, available P and exchangeable Ca and Mg in surface soils at the footslope which they ascribed to slope factor involved in the transport and accumulation of soil solution.

Potassium in soils exist in four forms namely solution K, exchangeable K, non exchangeable K and K in unweathered minerals (Talibudeen, 1972). Killur *et al.* (2010) studied volcanic soils and stated that water soluble K content constituted less than 1%, exchangeable K about 2.0-3.1% and non exchangeable K 2.5-4.2% of the total K. Soil mineral fraction constitute bulk of soil total K and its content depends on parent material and the degree of soil and mineral weathering (Sparks and Huang, 1985). Geologic weathering of illites and chlorites is associated with the release of soil total K according to Sharpley (1989). Variations in geomorphological condition and soil genetic processes affect the rate of depotassification process. Mineral weathering, soil formation, biocycling processes and geomormorphological conditions, according to Rezapour *et al.* (2010) resulted in significant variations in total, non-exchangeable and exchangeable K along different physiographic units. Brubaker *et al.* (1993) studied soil properties associated with landscape position and reported that available K generally decreased down slope position with the highest content occurring on the upper interfluve.

Moorman (1981) reported a strong relationship between topographic positions and soil genesis on basement complex in Southern Nigeria, however this relationship with respect to the basaltic parent materials of the Jos plateau, particularly with respect to potassium distribution has not been well documented. This study therefore looked at the various forms of K associated with slope positions along a toposequence on the newer basalts of the Jos plateau. This because K is an important nutrient element in crop production as it plays a significant role in stress resistance in crops. There is the need to study K forms and its distribution as affected by variation in landscape position.

MATERIALS AND METHODS

Environmental settings: The study area is located at Vom Jos Plateau state, in the Southern Guinea Savanna zone of Nigeria. It lies between longitudes 08°45' 01 to 8°47' 56E" and latitudes 9°43' 17 to 9°45' 15N" with an elevation of about 1270 m above sea level. The soils of Vom were formed from the newer basalts while the climate is considered as humid. The annual rainfall is about 1258 mm with a peak period between July and August. The mean temperature is about 24°C with April being the hottest, where temperature could be as high as 36°C. The soil moisture regime is considered as ustic and the temperature regime is Iso-hyperthermic (Eswaran *et al.*, 1997). Keay (1957) and Clayton (1957) described the vegetation of the area as being a transition between forest zone and the tree savanna.

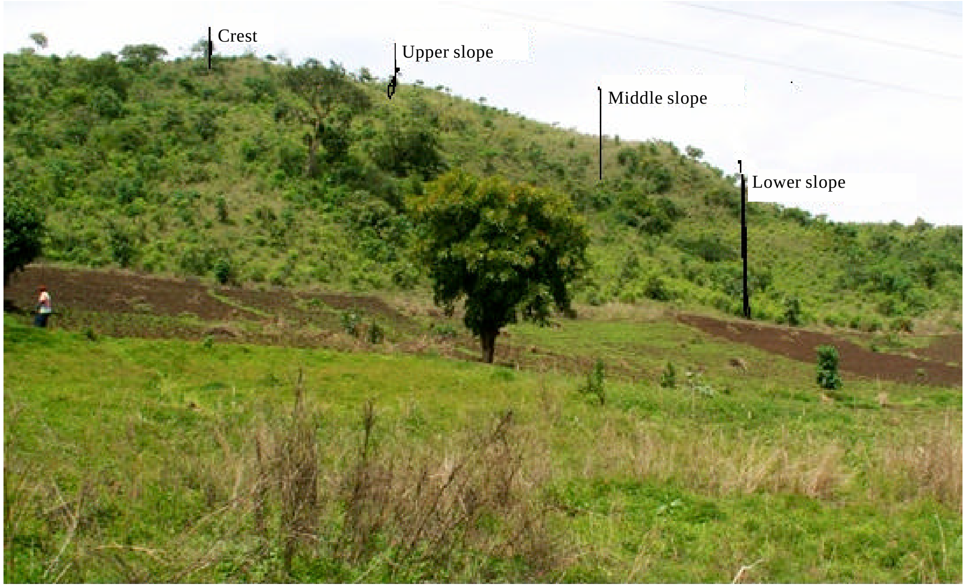

Fig. 1: Landscape positions of a Hillslope in the study area

Field sampling: A stratified purposive sampling procedure was adapted along a hillslope (Fig. 1), where four landscape positions were identified and georeferenced using Global Positioning System (GPS). The crest, upper, middle and lower slope positions were identified, each representing changes in geomorphological position. Two pedons were georeferenced at each topographic position, where they were sunk and described by genetic horizons according to Soil Survey Staff (1996). Each pedogenic horizon was sampled for laboratory analysis.

Laboratory analysis: Bulk soil samples were collected, air-dried, gently crushed and passed through a 2 mm sieve to remove coarse fragments. Soil pH was determined in water, using soil to solution ratio of 1:2.5 and read with a glass electrode. Organic carbon content was determined using the Walkley-Black wet oxidation method as described by Nelson and Sommers (1982). The total nitrogen content of the soil was determined using the micro-Kjeldahl technique as described by Bremner and Mulvaney (1982). Available phosphorus was extracted using the Bray No. 1 method (Bray and Kurtz, 1945), as described by Murphy and Riley (1962). Exchangeable bases (Ca, Mg, K and Na) were extracted with 1 M ammonium acetate (1 M NH_4OAc) solution buffered at pH 7.0 according to Anderson and Ingram (1998). Calcium and Mg in the leachate were determined with atomic absorption spectrophometer while K and Na were determined with flame photometer. Total Exchangeable Bases (TEB) were calculated as the sum of Ca, Mg, K and Na. The effective cation exchange capacity was calculated as the sum of the bases extracted by 1 M NH_4OAc pH 7 and exchangeable aluminium.

Water soluble K was determined by shaking soil sample with 10 mL of deionised water (1: 5 w/v) as described by Jackson (1973). Exchangeable K was obtained by leaching soil sample with 1 M NH_4OAc (buffered at pH 7). Non extractable K was determined by boiling the soil sample in 50 mL 1 M HNO_3 solution and leached with 1 M HNO_3. The difference between K extracted with HNO_3 and exchangeable K was considered as non-exchangeable K as describe by Pratt (1965).

Hydrochloric acid soluble K was extracted with 1N HCl using a soil-acid ratio of 1:10 as described by Piper (1950). Total K was estimated by digesting the soil samples with $HClO_4$-HNO_3 acid mixture and leached with HCl as described by Rayment and Lyons (2011). The various forms of K in the respective extracts were determined using the flame photometer. Mineral K was determined by subtracting total K from HNO_3 extractable.

Statistical analysis: Data generated were subjected to Analysis of Variance (ANOVA). General linear model of SAS (2002) package for statistical analysis was used for the analysis. Differences in mean values were tested at 0.05 level of significance, Duncan's multiple range test was used for mean separation as described by Snedecor and Cochram (1967). Percentage variations in mean values were also determined.

RESULTS AND DISCUSSION

Chemical properties: Soil pH values at the various topographic positions ranged between 5.2 and 7.3 (Table 1). Slightly higher mean value (7.2) was obtained on the crest position while for the other topographic positions, mean pH values varied from 6.3 to 6.9. The soil pH values at the respective topographic positions were narrow which might be associated to the moderately weathered soils. Similar narrow change in pH values with topographic position was observed by Agbenin and Tiessen (1995) and Rasmussen *et al.* (2010). Soil pH values irregularly decreased with profile depths across the respective pedons. This might be ascribed to decrease in organic matter content with soil depth.

The distribution of organic carbon content indicated higher values on the crest profiles (5.19-6.28%) which slightly deceased along the slope positions, with the lowest value (3.75%) on

Table 1: Chemical characteristics of soils on the crest, upper, middle and lower slope positions of a Hillslope in the study area

					Available P	^{a}TEB	^{b}ECEC
Horizon	Depth (cm)	pH (H_2O)	Org. C (%)	Total N (%)	(mg kg^{-1})	------cmol (+)kg^{-1}-------	
Crest profile 1							
A	0-14	7.0	5.19	0.560	21.00	8.18	3.61
Bt1	14-39	6.9	2.69	0.120	11.37	7.14	3.16
Bt2	39-73	7.2	1.00	0.083	6.13	7.27	3.30
Bt3	73-120	7.1	1.20	0.086	5.25	7.28	2.90
BC	120-143	6.9	0.20	0.044	6.13	7.21	2.99
Crest profile 2							
A	0-16	7.2	6.28	0.344	7.88	8.94	3.60
AB	16-59	7.1	2.69	0.127	6.13	5.86	3.60
B1	59-94	7.2	1.30	0.036	5.25	6.36	3.29
B2	94-137	6.8	0.88	0.031	6.13	10.61	2.60
BC	130-180	7.3	0.79	0.020	5.25	6.92	2.00
Upper slope profile 1							
A	0-10	6.9	3.69	0.226	23.60	7.67	3.74
AC	10-50	6.8	2.29	0.119	6.13	7.77	2.95
Cr	50-130	7.1	1.70	0.061	5.25	8.58	2.52
Upper slope profile 2							
A	0-14	6.8	4.49	0.290	11.50	8.61	1.35
AC	14-39	6.8	2.10	0.188	14.00	6.90	3.17
Cr	39-125	6.7	1.10	0.105	6.13	10.32	3.31

Table 1: Continue

					Available P	[a]TEB	Exch acid	[b]ECEC
Horizon	Depth (cm)	pH (H_2O)	Org. C (%)	Total N (%)	(mg kg^{-1})	-------------cmol(+)kg^{-1}----------		
Middle slope profile 1								
A	0-29	6.8	5.49	0.175	7.88	8.56	0.68	3.14
B	29-80	6.6	3.09	0.079	5.25	5.43	0.16	1.08
Bt1	80-122	6.5	1.40	0.088	8.75	7.50	0.56	2.52
Bt2	122-147	6.6	0.60	0.072	6.75	7.31	0.52	2.96
Cr	147-185	5.2	0.20	0.080	5.25	4.03	1.88	2.58
Middle slope profile 2								
A	0-31	7.1	4.09	0.083	6.13	8.17	0.68	3.16
AC	31-62	6.9	2.29	0.078	12.25	6.69	0.40	2.80
Cr1	62-123	6.8	1.30	0.064	13.13	8.93	0.64	1.44
Cr2	123-167	6.6	0.60	0.055	7.00	9.16	0.36	3.37
Lower slope profile 1								
A	0-28	6.9	5.19	0.075	19.25	7.61	0.16	3.21
Bt1	28-77	6.5	1.70	0.063	5.25	5.26	0.36	1.98
Bt2	77-135	5.2	0.64	0.036	7.88	6.19	0.68	3.70
Cr	135+	6.9	0.79	0.062	2.80	6.32	0.32	2.79
Lower slope profile 2								
A	0-22	6.8	3.75	0.123	5.25	6.49	0.32	2.83
B	22-64	6.8	2.29	0.095	6.13	6.36	1.16	2.07
BC	64-93	6.7	2.00	0.059	5.25	6.58	0.88	3.31
Cr	93+	6.7	0.50	0.116	5.25	8.25	0.16	1.86

[a]TEB: Total exchangeable bases, [b]ECEC: Effective cation exchange capacity

the lower slope position. Organic C decreased with soil depth irrespective of topographic position. Total nitrogen content, followed a similar pattern to that of organic C, indicating the relationship that exists between organic C and total N. Highly positive correlation coefficient value ($r = 0.8306$, $p<0.01$) between total N and organic C was reported by Samndi (2006) which was attributed to the surficial accumulation of organic material and its mineralization. The higher organic C and total N values obtained on the crest might be ascribed to the higher vegetation on the crest (Agbenin and Tiessen, 1995; Tsui *et al.*, 2004; Wezel, 2006).

Available P content of the soils ranged from 5.25-23.60 mg kg^{-1}, higher values were obtained on the crest and upper slope, followed by the lower slope position with the least value obtained on the middle slope position. Similar trend was observed with mean available P distribution within the profiles, where the highest and lowest available P contents were obtained on the crest and upper slope, respectively. Wezel (2006) reported high available P contents on top and bottom slope positions. The distributions of available P within the profiles were irregular (Table 1) however, the values were slightly higher in the surface horizons, compared to the underlying horizons which might be attributed to higher surface organic matter content.

The values of Total Exchangeable Bases (TEB) at the respective topographic positions varied between 4.03 and 10.61 cmol (+) kg^{-1}, with slightly lower values on the lower slope position, compared to the crest. The TEB values slightly decreased irregularly with increase in profile depth irrespective of the topographic position. Higher surface TEB values observed might be ascribed to the recirculation of Ca, Mg and K to the surface horizons via organic matter mineralization. Samndi (2006) reported significant correlation coefficient ($r = 0.5372$, $p<0.01$) between TEB and organic C under trees on the Jos plateau Nigeria. Effective Cation Exchange Capacity (ECEC) in

Table 2: Mean forms of potassium distribution in surface and subsurface soils on Hillslope positions the study area

	Soluble K	Extractable K	HCl extractable K	Non extractable K	Total K
Variables	------cmol(+)kg^{-1}------				
Surface slope position					
Crest	0.1374	0.1156	0.3135	0.2456	0.8308
Upper slope	0.0205	0.1317	0.5023	0.7133	0.8898
Middle slope	0.1158	0.1086	0.4871	0.5441	1.0749
Lower slope	0.0187	0.1122	0.5601	0.4461	1.0325
LSD	0.2134	0.1451	0.2761	1.0130	1.5309
Subsurface					
Crest	0.0187	0.1109	0.3429^{c}	0.2136	0.7060^{b}
Upper slope	0.0241	0.1309	0.4738^{a}	0.4060	1.2048^{a}
Middle slope	0.0325	0.0867	0.4545^{ba}	0.2462	0.6193^{b}
Lower slope	0.0205	0.0986	0.3960^{bc}	0.3141	0.8746^{b}
LSD	0.0339	0.0679	0.0671	0.2865	0.2857

soils ranged between 1.08 and 3.74 cmol (+) kg^{-1}. These values were higher on the crest and slightly decreased down the slope. Similar decrease in ECEC values from upper to middle slope was reported by Owusu-Bennoah *et al.* (2000). The ECEC values decreased with soil depth irrespective of topographic position. This decrease might be ascribed to decrease in organic C with soil depth as ECEC positively and highly correlated with organic C (Samndi, 2006). Other possible reason for decreased ECEC with profile depth might be the replacement of basic cations by H^{+} as suggested by Wessel and Tietema (1995).

Distribution of potassium forms: The distribution of potassium forms along the slope positions is presented in Table 2 and 3. In the surface horizons, mean values of soluble K were not statistical significant, however values were slightly higher on the crest position. The lowest mean value (0.0187 cmol (+) kg^{-1}) was obtained on the lower slope position and was 14% lower compared to values obtained on the crest position (Table 2). Hattar *et al.* (2010) reported high available K content on a summit which showed low variability among different transects. For the underlying horizons, mean values were also not statistically significant, though slightly higher mean value (0.03245 cmol (+) kg^{-1}) was obtained on the middle slope position (Table 2). On the crest position mean value was 58% (0.0187 cmol (+) kg^{-1}) lower. Profile distribution of soluble K, indicated a slight decrease with soil depth, values were irregularly distributed for some profiles (Table 3). Pal *et al.* (1999) reported similar pattern of K distribution in some Australian soils.

The mean values of exchangeable K in the surface horizons were not statistically significant, however values were slightly higher (0.1316 cmol (+) kg^{-1}) on the upper slope position (Table 2), followed by the crest and lower slope positions. The lowest mean value (0.1086 cmol (+) kg^{-1}) was obtained on the middle slope and was 83% lower than the values obtained on the upper slope position. Similar pattern in exchangeable K distribution was observed in the underlying horizons, where mean values were statistically non significant with respect to the various slope positions. On the other hand, the exchangeable K distribution were in the order upper slope>crest>lower slope >middle slope. The mean value obtained on the middle slope was 66% (0.0867 cmol (+) kg^{-1}) lower than the value on the upper slope position (0.1309 cmol (+) kg^{-1}). Rezapour *et al.* (2010) reported lower exchangeable K value on lower plains which was attributed greater soil forming processes on the plains. The exchangeable K values were slightly higher in the underlying B and C horizons and were irregularly distributed within the profiles irrespective of topographic position.

Table 3: Forms of potassium distribution in soil profiles on the crest, upper, middle and lower slope positions in the study area

			Exchangeble K	Non exchangeble K	HCl soluble K	Total K
Horizon	Depth (cm)	Water sol. K	-----cmol (+) kg^{-1}-----			
Crest profile 1						
A	0-14	0.0605	0.0997	0.3526	0.3101	1.2581
Bt1	14-39	0.0305	0.0641	0.2403	0.3541	0.5453
Bt2	39-73	0.0303	0.0713	0.5040	0.3471	0.4034
Bt3	73-120	0.0232	0.0749	0.2009	0.3219	0.9966
BC	120-143	0.0142	0.0677	0.1673	0.3242	0.7590
Crest profile 2						
A	0-16	0.2140	0.1318	0.1385	0.3169	0.4034
AB	16-59	0.0160	0.2352	0.0621	0.2688	0.7368
Bt1	59-94	0.0142	0.0818	0.2317	0.2173	0.8068
Bt2	94-137	0.0214	0.0749	0.2223	0.6442	0.7829
BC	137-180	0.0305	0.2172	0.0800	0.2651	0.6171
Upper slope profile 1						
A	0-10	0.0232	0.1815	0.4579	0.3794	0.5932
AC	10-50	0.0214	0.0818	0.4240	0.4240	1.0923
Cr	50-130	0.0303	0.1282	0.2118	0.5041	1.2342
Upper slope profile 2						
A	0-14	0.0178	0.0818	0.9686	0.6342	1.1863
AC	14-39	0.0285	0.0749	0.3453	0.5022	1.4239
Cr	39-125	0.0160	0.2387	0.6427	0.4648	1.0684
Middle slope profile 1						
A	0-29	0.0356	0.0926	0.4487	0.4133	1.4947
B	29-80	0.0249	0.0713	0.1746	0.4166	0.9504
Bt1	80-122	0.0303	0.0356	0.3828	0.5608	0.1658
Bt2	122-147	0.1060	0.0641	0.1835	0.3973	0.9265
Cr	147-185	0.0249	0.1567	0.1389	0.3169	0.4752
Middle slope profile 2						
A	0-31	0.0196	0.1246	0.6394	0.5609	0.6550
AC	31-62	0.0178	0.0749	0.3135	0.5483	0.8068
Cr1	62-123	0.0106	0.0785	0.2812	0.5519	0.4752
Cr2	123-167	0.0267	0.1210	0.2226	0.3579	0.5453
Lower slope profile 1						
A	0-28	0.0232	0.1354	0.7035	0.5537	1.2581
Bt1	28-77	0.0160	0.0641	0.4537	0.4040	0.7128
Bt2	77-135	0.0142	0.0785	0.3063	0.3986	1.2103
Cr	135+	0.0196	0.0713	0.0660	0.2794	0.9966
Lower slope profile 2						
A	0-22	0.0142	0.0890	0.1886	0.5665	0.8068
B	22-64	0.0214	0.0641	0.2848	0.6124	1.0923
BC	64-93	0.0305	0.0785	0.2541	0.4325	0.7366
Cr	93+	0.0214	0.2352	0.5198	0.2490	0.4991

The distribution of non exchangeable K for both surface and subsurface horizons was statistically non significant (Table 2). The lowest surface and subsurface mean values (0.2456 and 0.2136 cmol (+) kg^{-1}) were observed on the crest position, the decrease were 34 and 53%, respectively compared with the highest mean values of 0.7133 and 0.4060 cmol (+) kg^{-1} obtained on the upper slope position. The non exchangeable K distributions were slightly higher in the surface horizons and decreased with profile depth across the various slope positions. The mean values of exchangeable K extracted with 1 M HNO_3 in the surface horizons along topographic positions were not statistically different. The lowest mean value of 0.3135 cmol (+) kg^{-1} was observed on the crest position. The crest mean value was 56% lower than the value (0.5601 cmol (+) kg^{-1}) recorded on the lower and upper slope positions. In the subsurface horizons, significantly higher mean value of 0.4738 cmol (+) kg^{-1} was obtained on the upper slope position, followed the middle and lower slope positions. The least mean value (0.3429 cmol (+) kg^{-1}) was obtained on the crest position and was 72% lower than value obtained on the upper slope position. The profile distribution of HCl extractable K decreased with increased profile depth, though the pattern of distribution was irregular across the respective slope positions. Similar irregular pattern of forms of K distribution in some virgin soils of Australia was also reported by Pal *et al.* (1999).

The surface distribution of total K did not show any significant difference with respect to slope position. Mean values varied between 0.8308 and 1.0749 cmol (+) kg^{-1}, with the lowest value of 0.8308 cmol (+) kg^{-1} obtained on the crest. For the subsurface horizon, values were statistically significant ($p<0.05$), with the highest mean value (1.2048 cmol (+) kg^{-1}) obtained on the upper slope while for other slope positions, values were statistically at par. The middle slope position recorded the lowest (0.6193 cmol (+) kg^{-1}) total K content which was 51% lower than value obtained at the upper slope position. Except for profiles 1 on the crest, middle and lower slopes, total K contents generally increased with increased soil depths (Table 3).

CONCLUSION

Soil chemical properties indicated that the soils were slightly acid to neutral (5.2 and 7.3). There was a narrow pH variation with respect to slope position, however slightly higher value was obtained on the crest. The pH, organic C and total N values slightly decreased with increased profile depth. Available P content for the soils ranged from 5.25-23.61 mg kg^{-1}, with slightly higher mean values (22.90 and 20.48 mg kg^{-1}) on the crest and generally decreased with increased profile depth. The TEB and ECEC values were slightly higher in the surface horizons and decreased with profiles depth irrespective of topography position.

The surface distribution of soluble K values were slightly higher on the crest position and was 14% (0.1374 cmol (+) kg^{-1}) higher than the value obtained on the lower slope position. For the underlying horizons, soluble K value was 58% (0.0187 cmol (+) kg^{-1}) lower on the crest position. The mean values of exchangeable along the respective topographic positions were not statistically significant, however values were slightly higher on the upper slope position. The lowest mean value of 0.1086 cmol (+) kg^{-1} was obtained on the lower slope position and was 83% lower than value obtained on the upper slope position. In the underlying horizons, values were in the order upper slope>crest>lower slope>middle slope. Then non exchangeable K values for both horizons were non significant, however the lowest mean values of 0.2456 and 0.2136 cmol (+) kg^{-1} were obtained on the crest position. The distribution non exchangeable K values were slightly higher for the surface horizons and decreased with profile depth irrespective of topographic position. The total K distribution in the surface horizons were not statistically influenced by topographic positions, however the lowest content (0.8308 cmol (+) kg^{-1}) was obtained on the crest position. The effect of topography on the total K distribution in the subsurface horizon was statistically significant ($p<0.05$), with 1.2048 cmol (+) kg^{-1} being the highest mean value obtained on the upper slope position.

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