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Effects of Intensive Cropping on Potassium Status of Soils in Tea Growing Areas

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ABSTRACT. Soils from 6 tea growing areas of Sri Lanka namely Hantana, Ratnapura, Talawakelle, Kottawa, Deniyaya and Passara under different agro-ecological regions were cropped with 2 sowings of perennial rye grass (Lolium perenne) adopting a greenhouse pot experiment without adding any potassium until growth virtually ceased. Potassium uptake and corresponding changes in initial soil K properties were studied in 2 stages.

The K concentrations in the soil solutions of the 6 soils had dropped to a lower range of 264–357 µmol l^{-1} after 3 months of cropping with rye grass, despite the initial higher range of 473–856 µmol l^{-1}. Intensive cropping reduced the exchangeable K of all soils to a range of 8–21 mg kg^{-1} at the 8th cut compared to the initial exchangeable K range of 60–116 mg kg^{-1} soil.

Shoot K uptake showed significant differences among all soils. The soil from Talawakelle showed the highest uptake compared to the other 5 soils throughout the cropping period. However, the differences were narrower at latter stages. Soil from Talawakelle also showed the highest root K uptake followed in the order of Hantane > Deniyaya > Kottawa > Ratnapura > Passara, at the final cuttings of 1st and 2nd stages respectively. The K uptake was clearly correlated with the initial exchangeable K and was highly correlated with the differences in soil exchangeable K between the commencement and the end of the investigation.

INTRODUCTION

The soils of different agro-ecological regions suitable for growing tea in Sri Lanka fall into 3 major soil groups (Watson, 1986). Those are Red Yellow Podzolic, Reddish Brown Latasoilc and Immature Brown Loams of which the largest extent is represented by Red Yellow Podzolic soils. The soils in the tea growing regions can also be divided into 3 groups in relation to their mineralogy (Wimaladasa, 1989). Accordingly, the 1st category of soils is in the up-country (above 1200 m amsl) which have predominantly Kaolinite, Al-chlorite, Gibbsite and Goethite with subsidiary amounts of K-feldspars, Anatase and Plagioclase feldspars. The 2nd category of soil is in the mid-country wet-zone (600–1200 m amsl) which consist of the highest Kaolinite contents with considerable amount of Mica, interstratified Mica/Vermiculite and Vermiculite. The mid-country dry-zone (600–1800

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m amsl) soils were classified similar to mid-country wet-zone soil group. The 3rd category, which is found in low-country (below 600 m amsl) has the highest amount of Kaolinite and small amounts of Gibbsite and Goethite. All these soils contain considerable quantities of Gibbsite. Goethite is found in all the acid soils under tea except for soils in Galle where Halloysites are found (Wimaladasa, 1989; Hettiarachchi, 1993). The K fixing minerals such as Smectite and Vermiculite are not generally found in the above soils. However, substantial amounts of Vermiculite are found in soils of Hantane area of mid-country wet-zone (Wimaladasa, 1989; Hettiarachchi, 1993).

The K immediately available for plant nutrition is generally present in the soil solution. The concentration of the soil solution K is very low at any given time. Thus, the replenishment of soil solution with K from other K bearing phases is of great importance in determining the K fertility status of the soils. The ability of a soil to replenish soil solution K depends on the transformations between the various labile K forms and the nature of their respective equilibrium with the soil solution, as stated below.

Mineral K ⇌ Non exchangeable K ⇌ Exchangeable K ⇌ K in soil solution

Potentially available soil K pool to plants is composed of exchangeable, non-exchangeable, and mineral K forms. The exchangeable K is readily available, since it is in direct equilibrium with soil solution. In soils containing low specifically adsorbed, or non-exchangeable K, the exchangeable K may play a predominant role in respect to K availability. The chemical equilibrium between the non-exchangeable K and exchangeable K forms is very complex and depends on the overall K status of different phase. Rapid depletion of soil solution and exchangeable K may frequently promote the release of K from non-exchangeable or fixed forms. Evidences for the utilization of fixed or non-exchangeable K by plants are ample. In many instances, the K removals by plants exceed the exchangeable K levels in soils by considerable amounts (Ayers *et al.*, 1947; Reitemeir *et al.*, 1951; Hemingway, 1963).

Predicting available soil K is difficult, because of the complexity of the dynamic equilibrium between the various soil phases,. However, several investigators have established positive relationships between NH_4OAC extractable K or K extracted by other procedures and plant uptake (Chandler *et al.*, 1945; Pope and Chenery, 1957; Rasnake and Thomas, 1976; Von Brauschweig, 1980). Potassium concentrations measured in extracts of soils with water also show very valid relationships with plant uptake (Nemath, 1975; Sivasubramanium and Jayman, 1976). In addition, the K extracted by this method appeared to extract loosely held exchangeable K ions (Nemath, 1975; Wimaladasa, 1989). Recently, the application of centrifugation techniques has overcome many of the problems encountered with the extraction of soil solutions for K determinations (Barrachlough, 1986). There is no commonly agreed method among researchers for assessing the non-exchangeable K reserves (Mclean and Watson, 1985; Goulding, 1988).

Although K mineralogy of soils in tea growing areas of Sri Lanka is fairly understood, their release patterns and relationships between various K forms have not been adequately studied. Therefore, in this study, an attempt was made to examine the relationships between various K forms of a range of soils utilized for tea cultivation and K uptake by intensive cropping of rye grass under green house conditions.

MATERIALS AND METHODS

Soils

A pot experiment was carried out in a glasshouse using 6 top (0–15 cm) and 6 sub (15–30 cm) soils sampled from tea growing areas under different agro-ecological regions. The sampling locations were Hantane, Talawakelle, Kottawa, Ratnapura, Deniyaya and Passara. The description related to the soils are given in Table 1. The moist soils were passed through a 6.4 mm riddle prior to potting as proposed by Sinclair (1979).

Table 1. Description of soils used.

Location/ *District*	Agro-ecological region	Great soil group/ *Soil series*
Hantana/ *Kandy*	WM3	ReddishBrown Latasolic/ *Kandy Series*
Ratnapura/ *Ratnapura*	WL1	Red Yellow Podsolic/ *Malaboda Series*
Talawakelle/ *Nuwara Eliya*	WU2	Red Yellow Podsolic/ *Mattekelle Series*
Kottawa/ *Galle*	WL2	Red Yellow Podsolic/ *Mattekelle Series*
Deniyaya/ *Matara*	WM1	Red Yellow Podsolic/ *Weddagala Series*
Passara/ *Badulla*	IU3	Red Yello Podsolic/ *Not specified*

Pot experiment procedure

The experiment was set up as a Randomized Complete Block Design - factorial experiment, where destructive samples were taken periodically. Six agro-ecological regions from where soils were collected, considered as the 1st factor, and 2 sampling depths were considered as the 2nd factor, so that finally there were 12 treatment combinations. At the beginning of experiment, each treatment combination was replicated 12 times. The experiment was conducted in 2 stages of growing rye grass as the indicator plant. Four cuttings of each were taken at both stages. Soils without plants were also kept in the similar manner for comparisons with 2 replicates.

Stage 1

Soils from each location and depth (6 soils x 2 depths) were filled into 14 pots of 4.5 L capacity each holding 4.0 kg soil separately. Twelve pots were sown with 1.0 g of perennial rye grass (*Lolium perenne*). The rest 2 were kept without plants. Pots with plants were assigned to 12 blocks, so that each block had 1 pot representing each soil. All pots of each depth with plants were assigned to 2 sets comprising of 72 each, so that total

number of pots with plants was 144. The fallow pots (24) were then arranged to bare pot per block. At the time of potting, only 0.33 g of N, 0.36 g of P as $(NH_4)_2HPO_4$ and NH_4NO_3 as well as 0.12 g of Mg as $MgSO_4$ were added to each pot including the pots without grass. Twenty two mg of N pot^{-1} was added in a mixture solution of NH_4NO_3 and $Ca(NO_3)_2.2H_2O$ in a 1:1 molar ratio of N to balance the N uptake and to maintain the constant soil pH at two week intervals as suggested by Sinclair (1979). Fifteen mg Mg pot^{-1} were also added along with the N solution in form of $MgSO_4$ in order to balance Mg and S supply. Distilled water was used for the irrigation of pots at periodic intervals to maintain a soil moisture content of 60% of the field capacity. Two blocks from each depth (24 pots), were four times dismantled at 4–8 week intervals starting from 4th week after emergence where longer intervals were selected when growth was slower. After the 4th dismantling the remaining rye grass pots were emptied and stubble and roots were removed. The soils from each location and depth were composite separately for stage 2.

Stage 2

Each composite soil from the stage one was transferred into eight plastic pots (2.5 L) each holding 2.0 kg of soil. The new pots were sown with 0.50 g perennial rye grass seed per pot. There were therefore, two sets of 48 smaller pots (2 depths × 6 soil locations × 8 replicates) as well as the 12 original fallow pots from each set of stage 1. The 60 replicated pots in a set were randomized within the 12 blocks, whilst the fallow pots were retained in their original position. At the time of potting only 0.16 g N and 0.18 g P as $(NH_4)_2PO_4$ and NH_4NO_3 as well as 0.06 g of Mg as $MgSO_4$ were added to each pot including the fallow pots. A solution containing half the concentration of N, Mg and S used in stage I was added to all the pots at two week intervals after emergence of the rye grass.

Sampling procedure

Shoot samples

Rye grass was harvested from all the pots at four to eight week intervals starting from 4th week after emergence, leaving 2.5 cm of stubble. These samples were dried in an oven at 80°C and dried samples were finely (0.2 mm) ground in a Wiley mill for chemical determinations.

Soil samples

The soil with root mass from each dismantled pot was cut vertically into 2 halves. Soils of the 1st halves were separated by hand from the roots and stubble and air-dried prior to analysis. The 2nd halves were used to isolate roots by washing with distilled water. At each cutting the fallow pots were also dismantled. A sub sample was taken and air-dried and remaining soil was returned to the same pot.

Root samples

The 2nd half of the soil with root mass was cut again vertically into 2 halves. First quarter was used for determination of K in root materials. The 2nd quarter was used for determination of root fresh and dry weights.

Analytical procedure

Determination of soil solution K

Soil solutions were extracted by centrifugation of 300 g field moist soil at 2900 r.p.m. for 1 h in a 2 component perspex cell (Fig. 1). Disposable polythene bags were used to reduce the possible contamination of the soil solution. The solution collected in the lower part of the cell was separated and refiltered to separate the fine clay particles (Wimaladasa and Sinclair, 1988). When the sample was too dry to allow collection of enough solution for chemical analyses, samples were moistened by adding de-ionized water up to 90% of the field capacity. Re-moistened soil samples were stored for 3–4 days and thoroughly mixed prior to centrifugation. The concentration of K in soil solutions was determined by flame photometry.

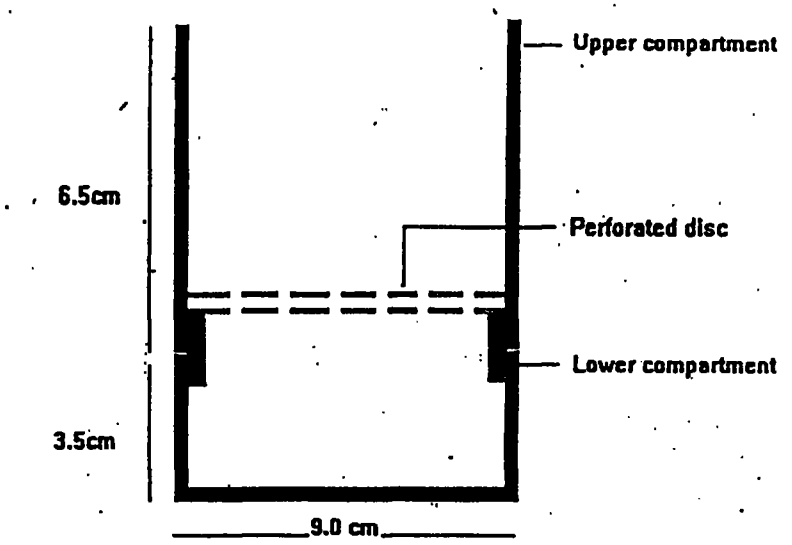

Fig. 1. Two compartment perspex cell used for the extraction of soil solution.

Determination of exchangeable K

The exchangeable K was obtained by equilibrating 10.0 g of soils with 50.0 cm^3 of 1.0 N ammonium chloride (pH 7.0) in a 110 cm^3 polypropylene tube for 0.5 h in a

mechanical shaker. After equilibration, the soil suspensions were centrifuged at 1600 r.p.m. for 15 min and the supernatant was filtered. Potassium was determined as done for solution K.

Determination of K in shoots

Total potassium of rye grass was determined by digesting the ash obtained from 0.200 g of ground plant material at 475°C over night. The digestion solution (0.50 cm^3) was prepared from 25.0 cm^3 of concentrated nitric acid, mixed with 25.0 cm^3 of hydrochloric acid, and made up to 100.0 cm^3. After digestion, the tubes and contents were allowed to cool and volumes were made up to 10.0 cm^3 with 0.05 M HCl solution prior to analysis. The concentrations of potassium were determined by flame photometry.

Determination of K in roots

Roots and stubble were analyzed for K content after the each cutting. The following procedure was adopted to overcome the loss of root K in washing the roots free of soil. The fine roots, coarse roots and stubble were chopped up by hand, thoroughly mixed, and dried at 80°C for 24 h to give a uniform sample, but containing adhering particles. A sub sample was washed free of soil, then re-dried and weighed to obtain the weight of contaminating soil. The K content in this soil was assumed to be equal to the K extracted from a root-free sample (0.250 g) of the same soil (0.2 mm sieved) when shaken with 25.0 cm^3 0.5 N HCl. This concentration was subtracted from the K extracted from a 2nd sub sample (0.250 g) of soil contaminated roots after over night shaking with 25.0 cm^3 0.5 N Hcl. The resulting K value was the content in the roots (Sinclair, 1979).

Shoot and root dry matter yield

The shoots harvested at each dismantling were dried in an oven at 80°C and dry weights were taken. The roots were washed free of soil particles by using tap water. Stubble and debris were carefully separated by hand from the roots. The wet roots were transferred on to a filter paper to absorb excess water. Either the total or a suitable sub-sample of the roots (<5.0 g) was again transferred onto a 2nd filter paper to ensure that excess water was removed and the wet root weight was recorded. The wet root sample was transferred to a pre-weighed glass crucible and heated at 80°C for 48 h. Root oven-dry weight was recorded.

Data interpretation

The data were subjected to an analysis of variance for a randomized block experiment taking into account the decline in number of replicates as the experiment progressed. At each stage the data obtained form the destructive sampling were analyzed as for a randomized block design with 2 replicates. The statistical analyses were carried out with the aid of the SAS (Statistical Analysis System) package.

RESULTS AND DISCUSSION

Effect of intensive cropping on soil solution K

The Table 2 shows that, there were significant differences among 6 soils in relation to solution K at initial and final stages. However, the differences were higher at the initial stage compared to the latter stages, which may have occurred due to the uptake of K by plants. Barber (1968) has indicated that K is absorbed in larger quantities by plants than other cations even though it occurs in smaller quantities in the soil solution. This

Table 2. Effect of intensive cropping on soil solution K at different stages of cropping.

Treatment	Cutting								
	Initial	1st	2nd	3rd	4th	5th	6th	7th	8th
	μ.mol l^{-1}								
Hantana	856	1177	674	1113	1072	3168	398	428	290
Ratnapura	486	319	220	466	192	604	239	354	310
Talawakele	844	1036	673	457	463	455	281	280	264
Kottawa	500	563	384	417	225	632	214	572	269
Deniyaya	473	660	384	218	153	845	194	522	357
Passara	486	357	379	303	235	397	192	439	530
LSD P=0.05	-	291	N.S	537	418	1151	105	226	214
0–15 cm	673	619	401	412	299	952	217	410	231
15–30 cm	541	749	503	594	481	921	269	441	442
LSD P=0.05	-	N.S	N.S	N.S	N.S	N.S	N.S	N.S	123

1st–4th = Stage 1 5th–8th = Stage 2

considerable capacity for K absorption is certainly true for grasses as well. Numerous reports have emphasized the significance of large root surface areas in increasing K diffusion to the plant roots (Barber, 1968 and 1985; Baldwin, 1974; Nye, 1977). Uptake of K was favoured largely by the supply of K to the dense, fibrous root system of grasses that thoroughly penetrates the soil. This undoubtedly was a major factor to deplete soil solution K to extremely low levels observed. The K concentrations in the soil solutions of all soils have dropped to a range of 264–357 μmol l^{-1} after the cropping except for the increase up to 530 μmol l^{-1} in the soil from Passara, despite the wide range of 473–856 μmol l^{-1} in the initial soil solutions. The soil solution K concentrations in 2 depths were not significantly different throughout the cropping period indicating an almost similar behaviour. When the initial soil solution K concentrations are concerned, soil from Hantana showed the highest value followed in the order of Talawakelle > Kottawa > Ratnapura = Passara > Deniyaya. However, after the resowing, soil from Hantana showed high levels of soil solution K in both depths. Such a rapid increase could be considered as

a result of release of non-exchangeable K from micaceous minerals which are available more in the soil from Hantana as described by Wimaladasa (1989).

Sivasubramanium and Jayman (1976) showed that water soluble soil K was better correlated with K requirements of the tea plant than either exchangeable or total K from a field trial in Talawakelle and leaf K reached to a maximum value when the water soluble K content was about 12 mg kg^{-1} soil. They have reported that, when water soluble K level in zero K plot is around 2.4 mg kg^{-1} soil, deficiency symptoms may occur in tea plants even though the exchangeable K remains around 49 mg kg^{-1} soil. None of the soils under investigation have shown such low levels of solution K at any given stage of the experimental period indicating an acceptable availability.

Effect of intensive cropping on soil exchangeable K

Significant differences in exchangeable K were observed among all soils due to the soil variability in different agro-ecological regions. The highest exchangeable K level was observed in soil from Talawakelle followed in the order of Hantana > Deniyaya > Passara > Ratnapura > Kottawa (Table 3). The exhaustive cropping reduced exchangeable K in all soils to a narrower range of 8–21 mg kg^{-1} soil at the 8th cut, compared to the initial

Table 3. Effect of intensive cropping on soil exchangeable K at different stages of cropping.

Treatment	Cutting								
	Initial	1st	2nd	3rd	4th	5th	6th	7th	8th
	(mg kg^{-1})								
Hantana	88	74	34	36	18	16	12	12	16
Ratnapura	62	47	14	12	10	7	9	9	8
Talawakele	116	100	47	40	30	19	20	21	21
Kottawa	60	54	18	15	11	9	10	11	11
Deniyaya	68	50	13	8	10	9	9	10	10
Passara	65	52	16	10	11	9	9	13	12
0–15 cm	85	68	24	20	16	12	13	13	13
15–30 cm	68	57	23	20	14	11	10	12	12
LSD P=0.05	2	N.S	N.S	5	2	0	2	N.S	N.S

1st–4th = Stage 1 5th–8th = Stage 2

range of 60–116 mg kg^{-1} soil. The greatest reduction in exchangeable K was observed over the 1st 4 cuts within a 5 months period. This initial rapid decrease in exchangeable K corresponds to vigorous uptake of K by rye grass. A slight reduction of exchangeable K was observed in fallow soils which could be attributed to the possible substitution occurred as a result of addition of other cationic nutrients in form of a fertilizer solution. At the 8th cut soil from Talawakelle had the highest value whereas other remained more or less

similar.. Numerous researchers have cropped soils intensively, usually with grasses, to estimate soil K supplying capacities (Abruna, 1980; Baldwin, 1974). Results have consistently shown high K supplying capacities for 1 or 2 cropping periods followed by drastic declines to some relatively uniform level for subsequent periods. This pattern is most apparent for highly weathered soils. Abruna (1980) also showed that the decline occurred more rapidly and reached a lower level in Oxisols and Ultisols than in Inceptisols and Mollisols.

Wimaladasa (1989) reported that intensive cropping reduced the exchangeable K of all soils to a narrower range of 19–31 mg kg^{-1} soils. The greatest reduction in exchangeable K was found over the 1st 4 cuts. The intensive initial K uptake was due to the release of substantial amounts of available K from the other K sources.

Effect of intensive cropping on shoot K uptake

Shoot K uptake showed significant differences among all soils. The soil from Talawakelle showed a greater uptake compared to other 5 soils throughout the cropping period. However, the difference were narrower at latter stages. The soil from Hantana occupied 2nd place throughout the cropping period (Table 4). The higher K uptake by soils

Table 4. Effect of intensive cropping on shoot K uptake at different stages of cropping.

Treatment	Cutting							
	1st	2nd	3rd	4th	5th	6th	7th	8th
	(mg kg^{-1})							
Hantana	10.86	8.99	13.64	8.01	10.11	5.48	0.77	0.86
Ratnapura	10.57	6.61	4.95	3.65	4.26	1.50	0.35	0.24
Talawakele	9.80	23.96	39.97	10.94	9.18	3.90	0.82	1.25
Kottawa	8.50	6.12	6.50	2.65	5.77	1.73	0.56	0.00
Deniyaya	9.78	6.83	9.62	2.83	3.46	2.72	0.86	0.78
Passara	10.40	7.48	3.55	2.57	4.12	1.09	0.63	0.00
LSD P=0.05	N.S	4.26	6.34	2.77	1.54	0.81	N.S	N.S
0–15 cm	13.84	15.32	20.86	7.31	5.31	3.07	0.59	1.08
15–30 cm	6.19	5.14	6.22	2.91	6.99	2.40	0.48	0.37
LSD P=0.05	1.61	2.46	3.66	1.60	0.89	0.47	N.S	N.S

1st–4th = Stage 1 5th–8th = Stage 2

from Talawakelle and Hantane could be attributed to greater initial levels of exchangeable K observed. Significant differences were also found among 2 depths, where 0–15 cm depth showed higher uptake values compared to 15–30 cm depth. After the 4th cut, K uptake has been drastically reduced. It could be attributed to low growth and exchangeable K content in soil after the 4th cut.

Effect of intensive cropping on root K uptake

Soil from Talawakelle showed the highest root K uptake followed in the order of Hantane > Deniyaya > Kottawa > Ratnapura > Passara, at the 4th cut and 8th cut at termination of 1st and 2nd stages respectively (Table 5).

Table 5. Effect of intensive cropping on root K uptake at different stages of cropping.

Treatment	Cutting							
	1st	2nd	3rd	4th	5th	6th	7th	8th
	(mg kg^{-1})							
Hantana	0.54	0.49	5.85	9.58	0.19	0.75	1.24	0.94
Ratnapura	4.29	5.34	2.62	5.58	1.25	2.09	1.27	1.01
Talawakele	0.40	1.52	2.20	14.28	0.88	2.57	6.29	3.98
Kottawa	9.99	1.22	7.15	4.43	1.15	2.65	1.48	0.00
Deniyaya	1.18	6.17	5.83	3.48	0.54	1.25	3.44	3.36
Passara	2.24	1.71	2.51	2.11	1.15	0.92	0.30	0.00
LSD P=0.05	4.00	1.83	N.S	5.68	0.63	0.92	1.50	N.S
0–15 cm	3.85	3.74	7.75	10.43	1.11	1.49	3.38	2.77
15–30 cm	2.36	1.75	0.97	2.72	0.61	1.92	1.29	1.60
LSD P=0.05	N.S	1.06	4.20	3.28	0.36	N.S	0.87	N.S

1st–4th = Stage 1 5th–8th = Stage 2

Table 6. Potassium balance sheet.

Location	Depth	Exch. K (Initial)	Exch. K (Final)	Exch. K	Total Uptake	Difference
		a	b	a-b		
		(mg/kg)				
Hantane	0-15 cm	96	13	83	100	-17
	15-30 cm	80	19	61	39	22
Ratnapura	0-15 cm	66	10	56	44	12
	15-30 cm	57	7	50	28	22
Talawakele	0-15 cm	136	18	118	175	-63
	15-30 cm	96	23	73	67	6
Kottawa	0-15 cm	65	11	54	48	6
	15-30 cm	55	11	44	28	16
Deniyaya	0-15 cm	76	10	66	69	-3
	15-30 cm	59	10	49	19	30
Passara	0-15 cm	71	13	58	41	17
	15-30 cm	58	12	46	24	22

Total K uptake and K balance sheet

Soil from Talawakelle showed the highest total K uptake followed in the order of Hantana > Deniyaya > Kottawa > Ratnapura > Passara (Table 6). These total K uptake values are reflected by the initial K status of the soils. The K removed during the early stages, which was the relatively rapid uptake phase, comprised initial exchangeable K followed by removal of loosely held non-exchangeable K in soils from Hantana, Talawakelle and Deniyaya where the total uptake values were higher than initial exchangeable K in the soils.

The K uptake was correlated with the initial exchangeable K (Fig. 2a) and highly correlated with the exchangeable $K_{difference}$ (exchangeable $K_{initial}$ - exchangeable K_{final}) as well (Fig. 2b).

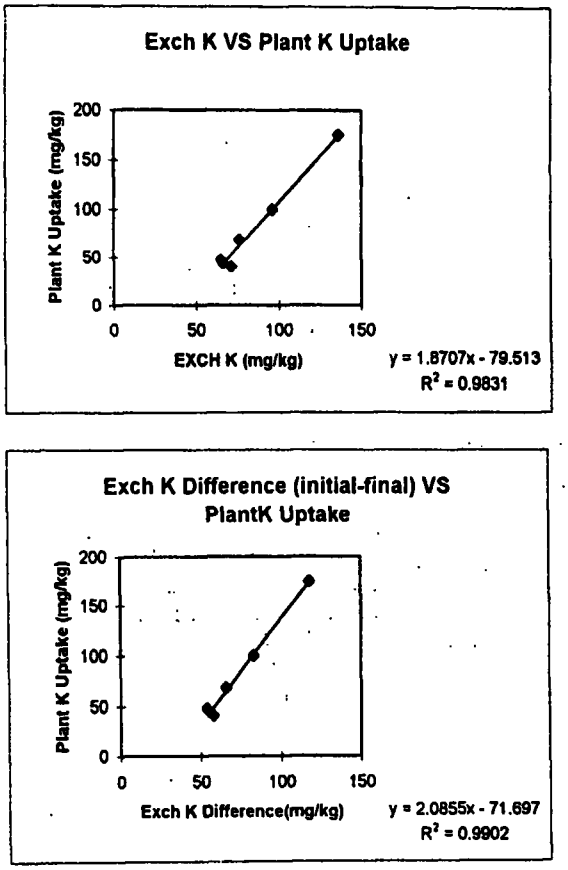

Fig. 2. Linear regression: exch. K, exch. K difference and plant K uptake by rye grass (0-15 cm soil).

CONCLUSIONS

This study revealed that there are either secondary and/or primary K releasing minerals in soils of tea growing areas of Sri Lanka at varying levels. It was evident that considerable contents of such were present in soils from Talawakelle and Hantana whereas only a relatively small content was present in the soil from Deniyaya. The K contents of other soils seemed extremely low. Presence of K releasing minerals in tested soils appeared to be site specific. Hence, in the tea fertilisation practices, it is worthwhile to consider the presence of K releasing minerals in well-defined soil units, probably at series level, along with their buffering capacities to optimise K fertiliser application rates.

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