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POTASSIUM DYNAMICS IN IRRIGATED LOW LAND PADDY SOILS AND ITS RELATION TO PLANT K AND GRAIN YIELD OF RICE

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ABSTRACT

An experiment was conducted in irrigated low land paddy soils treated with rice straw and K fertilizer in the Low Country Intermediate Zone to identify the forms of potassium in paddy soil and its relationship to grain yield of rice and plant K contents. There were six treatments in the experiment (T1 - no K fertilizer or manure; T2 - rice straw at 5 t/ ha; T3 - rice straw at 5 t/ha with 15 kg K_2O (applied as basal); T4 - rice straw at 5 t/ha with 20 kg of K_2O applied at 6 week after planting (WAP); T5- rice straw at 5 t/ ha with 15 kg K_2O (at basal) and 20 kg K_2O applied at 6 WAP; T6 - 15 kg K_2O applied as basal and 20 Kg K_2O applied at 6 WAP. Experiment was set up in *Yala* 2011 and continued without changing plot arrangements until the 7th consecutive seasons up to *Yala* 2014. Soil samples were collected at the beginning of 7th season and analyzed for exchangeable and non- exchangeable K contents. Grain yield and plant K contents were measured at the end of the 7th season. The highest non-exchangeable K (160.2 mg /kg) and the highest exchangeable K (46.2 mg/kg) were recorded from plots treated with both rice straw at 5t /ha and K fertilizer at 35 kg k_2O/ha. These plots had the highest grain yield (5.42 t/ha) and the highest plant K content (1.02 %) as well. Significantly low non-exchangeable K (100.8 mg/kg) and the lowest level of exchangeable K (25.3 mg/kg) were recorded from control plots where neither straw nor K fertilizer was added. These plots had the lowest yield (4.78 t/ha) as well as the lowest level of plant K (0.57 %). Relationship between non-exchangeable K and exchangeable K was linear and significantly high (r^2 = 0.93). Though exchangeable K contents were significantly different among treated plots, non-exchangeable K contents and grain yield were not significantly different. Higher relationship (r^2 = 0.69) between non-exchangeable K content and plant K content was observed. Exchangeable K in all plots was below the

critical level (80 mg/kg) but no response of rice to application of K fertilizer. It is learned from this experiment that non-exchangeable K content has a positive relationship with grain yield and highly relates to plant K content and as such non-exchangeable K content should be taken as an indicator in the soil test based fertilizer recommendations to decide the K supplying capacity of paddy soils.

Key words: Exchangeable K, K fertilizer, non exchangeable K, rice, straw

INTRODUCTION

Rice occupies approximately 33 % of the total cultivated area in Sri Lanka, which accounts for 0.78 million ha (DCS, 2014). Of the above, 75 % of the rice area is in the Intermediate and Dry zones of Sri Lanka. Most of these lands in the above areas are grown with high yielding rice varieties. To get the maximum benefits from the high yielding rice varieties, application of fertilizer has become a must (Abeysiriwardena and Sandanayake 2000).

Potassium is a major nutrient which plays a critical role in regulating assimilate transportation. Short supply of potassium could affect the productivity of rice (Salisbury and Ross, 1978). Most of the paddy soils in low country of Sri Lanka is considered to be high in K and as a result, a low crop response to applied K is seen (Wickramasinghe *et al.*, 2003). In addition, with the introduction of harvesting machines to paddy sector, straw is recycled *in-situ* and provides considerable amount of K. Since large quantity of K is returned to paddy fields through straw incorporation, K level in paddy soils would be adequate to satisfy the early K needs of rice crop. Considering the above, K has been removed from the basal rice fertilizers and only top dressing was introduced in 2013 (Sirisena, 2013). The removal of K from basal fertilizer mixtures would lead to a greater risk in rice production, unless proper estimation of K contents in rice soils is adopted. Since almost all K fertilizer is imported to the country and distributed at subsidized prices, application of K fertilizer in a more judicial manner is important to relieve the burden on the Government and also to reduce cost of production.

Soil test based fertilizer recommendation considered soil exchangeable

K level as an indicator of the K supplying capacity of paddy soils (DOA, 1997). According to soil test based fertilizer recommendation, fertilizer K application has been recommended when exchangeable soil K levels were below 80 mg/kg. In many occasions soil exchangeable K levels were below the above critical level and as such same K recommendation has been given. Contrary to the above, Sirisena and Herath (2012) have reported that there was no response of rice to application of K fertilizer even though exchangeable K levels were below 40 mg/kg. There is accumulating evidence that non exchangeable soil K also has a role to play in providing potassium to plants. A large number of exhaustive cropping experiments have demonstrated that as levels of exchangeable soil K are depleted, non-exchangeable K makes a significant contribution to plant uptake (Uddini *et al.,* 2011)

Plant K is an important parameter that protects plants form biotic and abiotic stresses (Williams and Smith, 2001, Chau and Heong, 2005). Therefore, whatever form of K in the soil should help to maintain K content in plant tissues. According to Wickramasinghe and others (2003), soil analytical data for soils from low country intermediate zone have shown that exchangeable soil K in most of these soils is low. Non-exchangeable K fraction of these soils is in sufficient range and as such no response to applied K fertilizers. In addition application of K even 150 kg K_2O/ ha has not significantly affected the grain yield of rice in any of these soils because non-exchangeable K fraction of these soils is in sufficient range. After crop harvest, the content of exchangeable K in soils was below the critical levels, showing the depletion of exchangeable K due to cropping. When amount of exchangeable potassium in soil is depleted there is a possibility to replenish non - exchangeable potassium to exchangeable potassium. So it is useful to find out the changes of non-exchangeable K and exchangeable K fraction of these soils with the application of K fertilizer and rice straw.

The objective of this study was to quantify exchangeable and non-exchangeable K in a irrigated low land paddy soils and their relation to grain yield and K content of rice plants.

MATERIALS AND METHODS

This study was conducted at Rice Research and Development Institute, Batalagoda in the Low Country Intermediate Zone. The experimental site was situated in a continuous rice producing area where two rice crops are usually grown in a year. The soils in the experimental site are sandy clay loam with 38% sand, 15% clay and 47% silt, and poorly drained. At the commencement of the study, the soil pH was 5.9, and the soil contained 0.18% total Nitrogen (N), 43 mg/ kg exchangeable K, 185 mg/kg non-exchangeable K, and 8.7 mg/kg available Phosphorus (P). This study was initiated in *Yala* 2011 and continued with same treatments for seven consecutive seasons until *Yala* 2014 without changing original plot arrangements. Treatments tested in the experiments were T1- Control – (No fertilizer and straw application), T2- straw 5t ha^{-1} , T3- straw 5t ha^{-1}+ 15 kg K_2O (basal) + 20 kg K_2O 6 weeks after establishment (6WAE), T4- straw 5 t /ha + 15 kg K_2O (basal), T5- straw 5t /ha +20 kg K_2O (6 WAE) and T6- 15 kg K_2O (basal) + 20 kg K_2O (6 WAE). Stubble of the preceding rice crop was incorporated into soil in all treatments. Treatments were arranged in a randomized complete block design and replicated four times. Rice variety Bg 352 was transplanted after raising in nursery beds for 20 days. Phosphorous was given at the rate of 45 kg P_2O_5/ ha as basal dressing. N was split applied as 5 kg, 30 kg , 55 kg and 25 kg / ha as basal, 2, 4 and 6 weeks after planting, respectively. Crop management was done uniformly across all treatments.

Crop was harvested at 3.5 months after planting and grains were sun dried after threshing and cleaning, and total grain weight was recorded in each plot at 13 % moisture. Soil samples were collected up to 15 cm depth at two weeks after incorporation of stubbles and rice straw. Samples were air dried and sieved by 2 mm sieve. Exchangeable K content in soil was determined by using 1M ammonium acetate (NH_4OAc) extractant using Atomic Absorption Spectrophotometer (AAS), (SSSSL, 2007). For determination of non-exchangeable K, 1 M Nitric solution was used. Mixture was heated gently on a hot plate until boiling and cooled. Filtrates were analyzed for non-exchangeable soil K using Atomic Absorption Spectrophotometer. Arial parts of the plant were collected as 5 plants per plot at flowering stage. Plant samples were dried at 70°C for three days until constant weight was obtained and total K content in plant tissues was determined by wet digestion method (Campbell and Plank, 1988) The analysis of variance and mean separation were performed for the experimental data using SAS statistical package.

RESULTS AND DISCUSSION

Results of this experiemnt revealed that non- exchangeable K content was significantly different between control plots and treated plots and lowest value of 100.8 mg/kg was recorded in control plots and the highest value (160.2 mg/kg) was recorded in plots treated with straw at 5 t /ha and K at 35 kg K_2O/ ha (Table 1). Soil fixed or non exchangeable K is an important reservoir of K in soil and makes an important contribution to plant K supply (Parker *et al.*, 1989). According to Uddini *et al.* (2011) soil solution and exchangeable K increased with added K. These form of K decreased with time after crop was transplanted and drastic reduction was found during one month time period. Thus split application of K gave better results instead of single application. According to Uddini *et al.*, the amount of non-exchangeable K decreased inconsistently and that helpful to provide potassium in long run. As such non exchangeable K content plays a significant role in rice production. However, research studies on effect of non exchangeable K on rice production in Sri Lanka is still at an early stage.

It has been proved form these results that potassium in rice straw is similar to K in MOP fertilizer and both K sources maintained non-exchangeable and exchangeable K content in the soil. Exchangeable K contents were significantly low at the beginning irrespective of the treatments. It was the lowest (25.3 mg/kg) in control plots while highest (46.2 mg /kg) in plots treated with straw 5 t/ ha and K at 35 kg K_2O/ ha (Table 1)

Control plots which did not receive any fertilizer or straw recorded lower levels of exchangeable and non-exchangeable K at the end of 6th seasons. These results have confirmed the findings of Dobermann and Fairhurt (2000) and Uddini *et al.* (2011) that continuous cultivation of rice without application of chemical K fertilizer or rice straw leads to deplete soil exchangeable as well as soil non-exchangeable K contents. Exchangeable K has been considered as an indicator to decide K supplying capacity of soil (DOA, 1997). Figure 1 shows the linear relationship between non-exchangeable K content and exchangeable K contents.

According to the results given in Figure 1 there is a significantly high (r^2 = 0.93) relationship between the non exchangeable K content and exchangeable K contents. As such it can be suggested that soils having higher exchangeable K content also have higher non exchangeable K content as well. Therefore, taking exchangeable K as an indicator to decide K supplying capacity of soil is justifiable. As stated by De Datta and Mikkelsen (1985), potassium from non-exchangeable soil solution provide K to rice plants when soil solution K is depleted and as such exchangeable K content is not a good indicator to decide the K requirement of rice plants. Results of the present experiments have also shown that even with continuous application of rice straw and K fertilizer, exchangeable K content of soil has not been increased above 46 mg/kg. Therefore, according to soil test based fertilizer recommendation, application of K fertilizer at full quota is recommended for all plots (DOA, 1997) even without significant yield advantage. When K nutrition is low, rice is more susceptible to many plant diseases, which can cause yield and/or quality losses beyond that caused from the physiological effects of insufficient K nutrition. High incidence of brown leaf spot (*Bipolaris oryzae*), stem rot (*Sclerotium oryzae*) and other opportunistic diseases are important signs of potential K deficiency in rice (Dobermann and Fairhurst, 2000). Therefore, consideration of critical levels of both non-exchangeable K and exchangeable K content is important before deciding the application of K fertilizer.

Table 1. Non exchangeable K contents and exchangeable K contents of the paddy soils at the beginning of 7th season.

Treatments	Non-exchangeable K (mg/kg)	Exchangeable K (mg/kg)
No K	100.8b	25.3d
Straw 5t ha^{-1}	131.0ab	33.4 c
Straw 5t ha^{-1}+ 15 kg K_2O ha^{-1} (Basal) + 20 kg K_2O ha^{-1} (6 WAP)	160.2a	46.2a
Straw 5t ha^{-1}+ 15 kg K_2O ha^{-1} (Basal)	158.7ab	42.9ab
Straw 5t ha^{-1}+ 20 kg K_2O ha^{-1} (6 WAP)	132.4ab	38.7abc
15 kg K_2O ha^{-1} (Basal) + 20 kg K_2O ha^{-1} (6 WAP)	126.7ab	35.3bc

* Mean values within a column with different letters are significantly different at $p<0.05$.

Results presented in Table 2 revealed that application of rice straw and chemical K fertilizer increased grain yield and plant K contents. Accordingly, in comparison to treated plots significantly lower yield of 4.78 t/ha has been recorded from control plots where rice straw or chemical K fertilizer has not been added for the last 7 seasons. Grain yields were non-significant among the treated plots revealing that rice straw can provide considerable amount of K to paddy fields. This is an agreement with the findings of Senaratne *et al.* (2006) that K provided by rice straw is similar to K supplied by the MOP fertilizer. As such, application of rice straw and chemical K fertilizer increased grain yield significantly over control.

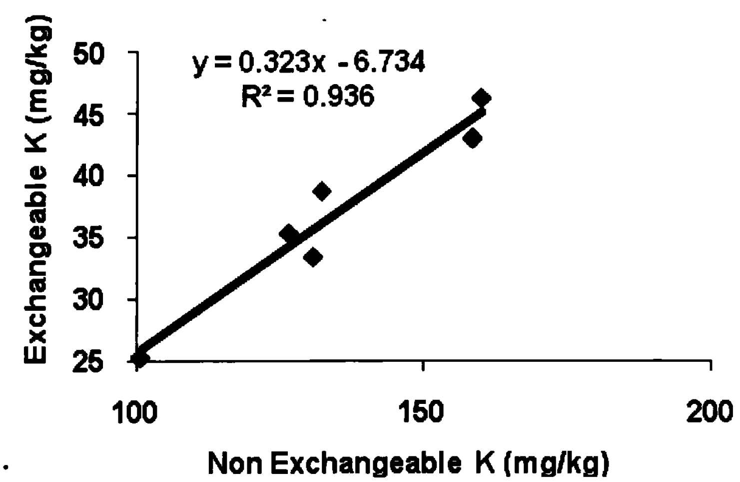

Figure 1. Relationship between non exchangeable K content and exchangeable K content.

Table 2. Grain yield and plant K content of the plots treated with rice straw and different rates of chemical K fertilizer.

Treatments	Grain yield (t/ha)*		Plant K contents (%)*
	Average of the past 6 seasons*	7th season*	
No K	4.25c	4.78 b	0.57d
Straw 5t ha^{-1}	4.49bc	4.90 ab	0.74c
Straw 5t ha^{-1}+ 15 kg K_2O ha^{-1} (Basal) + 20 kg K2O (6 WAP) ha^{-1}	4.78 a	5.07 ab	1.02a
Straw 5t ha^{-1}+ 15 kg K_2O ha^{-1} (Basal)	4.90a	5.30 ab	0.81bc
Straw 5t ha-1+ 20 kg K_2O ha^{-1} (6 WAP)	4.90 a	5.42 a	0.80bc
15 kg K_2O ha^{-1} (Basal) + 20 kg K_2O ha^{-1} (6 WAP)	4.72ab	5.19 ab	0.86ab

*Note : Mean values within a column with different letters are significantly different at p<0.05.

Plant K is an important parameter that protects plants from pests and diseases. Higher levels of plant K help plants to withstand biotic and abiotic stress conditions (Williams and Smith, 2001; Chau and Heong, 2005). Application of straw and MOP at the rate of 35 kg k_2O/ha significantly increased plant K content. Results shown in Figures 2 and 3 revealed that there is good relationships (r^2 = 0.66 and 0.77) between non-exchangeable K and exchangeable K content with plant K content. Therefore, instead of exchangeable K contents non-exchangeable content can be measured to decide the ability of soil to provide K to plants

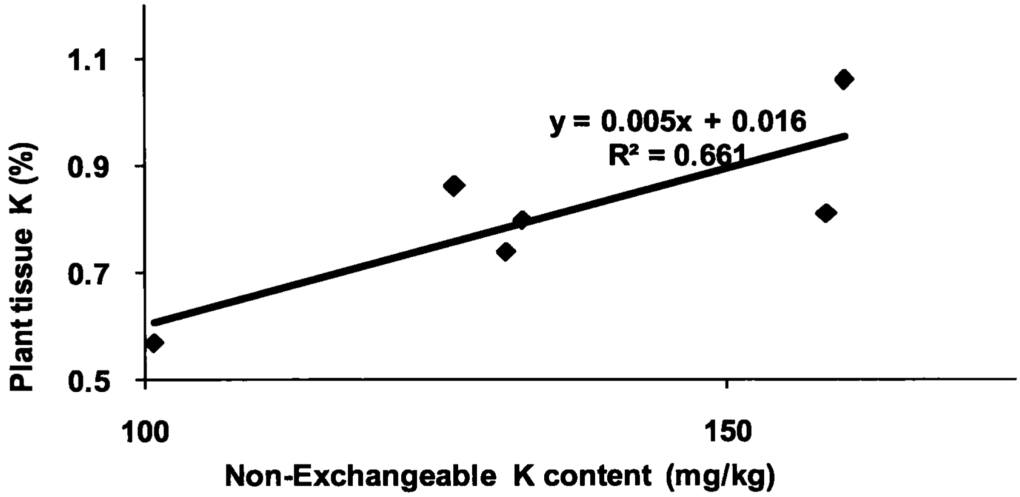

Figure 2. Relationship between non exchageable K contnet and plant K content

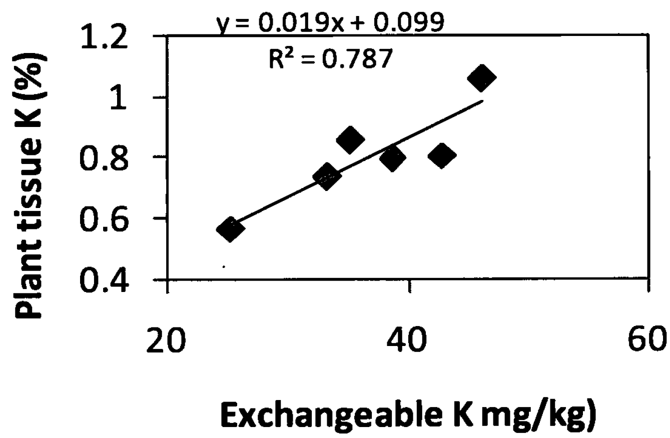

Figure 3. Relationship between exchangeble K contnet and plant K content

According to the above results application of chemical K fertilizer is necessary to maintain exchangeable K and non exchangeable K in soil. Similarly it is observed in this experiment that application of chemical fertilizer enhanced the plant K contents as well (Table 2). Therefore, even with the application of rice straw application with K fertilizer is important not only to get higher grain yield but also to get higher K content in plant tissues for protecting plants from pest and diseases (Williams and Smith, 2001; Chau and Heong, 2005).

Senaratne *et al.* (2006) indicated the potential contribution by K fertilizers, and increased yield benefits in the application of K towards flowering instead of at the basal dressing stage, when the initial K needs are satisfied by decaying stubble and straw. Since there is no significant difference between treatments (split vs basal) (Table 2) split application of K fertilizer at growth stage would be better than basal only, apart from time involved and cost of application.

CONCLUSIONS

The removal of K from basal fertilizer mixtures, promotion of straw recycling to return K removed by the rice crop and maintenance of high soil K content in rice soils are logically related to each other. Application of rice straw along with chemical K fertilizer in long run significantly increases exchangeable as well as non exchangeable K content in paddy fields. It also increases grain yield of rice as well as plant K contents. Non-exchangeable K content has a positive relationship with grain yield and highly relates to plant K content and as such non-exchangeable K content is a better indicator in the soil test based fertilizer recommendations to decide the K supplying capacity of paddy soils.

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Table 2. Grain yield and plant K content of the plots treated with rice straw and different rates of chemical K fertilizer.

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