Weed-Root Induced Release of Potassium in Tropical Soils

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Abstract

Plant nutrient release from soil minerals is reported to be speeded at lower soil pH, which is also governed by the acidifying effect of vegetation roots. This research was to investigate the effects of several tropical weeds on the exchangeable K in two tropical soils with distinct properties. Five potential weeds including *Asystacia gangetica*, *Arachis pintoi*, *Widelia* sp., *Paspalum conjugatum*, and *Pennisetum purpureum* were grown in the soil samples contained in polybags. The soil exchangeable K was depleted by weeds except that in soils planted with *A. pintoi* as indicated by the positive values of Δ Exch. K [Δ Exch. K = Final Exch. K (After Planting) – Initial Exch. K (Before Planting)], suggesting that *A. Pintoi* root was more effective than the other weed roots in stimulating the release of soil mineral K. The effectiveness of weed plants in stimulating the release of soil K were*: A. Pintoi* > *A. gangetica* > *Widelia sp*. > *P. conjugatum* > *P. purpureum.*

Keywords: *Arachis pintoi*, Root Acidifying-Effects, Tropical Weeds

Introduction

Potassium is still a problem in tropical regions. To cope with this problem, several break-throughs are being developed (Salam, 1989; Salam and Corey, 1993). The use of indigenous K by some methods is promising (Salam and Corey, 1993; Jalali and Zarabi, 2006; Jalali, 2006; Farshadirad et al., 2012; Najafi-Ghiri and Jabari, 2013). Salam and Corey (1993) show that the soil potassium uptake by Sudan Grass was well-correlated with the soil potassium-supplying capacity. Sudan Grass absorbed K mostly from the dissolved and the exchangeable forms and partially from the non-exchangeable forms. Najafi-Ghiiri and Jabari (2013) show that clay fraction releases more K than silt and sand fractions of calcareous soils. However, the use of indigenous mineral sources is rarely developed, particularly in tropical regions. Some are developed as organomineral fertilizers (Samuel & Ebenezer, 2014).

The use of indigenous soil minerals needs a speeded weathering process to release non-exchangeable K, mainly by managing one or more environmental factors. The immediate soil property that significantly affects the weathering of soil minerals is the presence of H^+ ions (Johnston and Olsen, 1972; Manley and Evals, 1986; Salam, 1989, 2012; Najafi-Ghiri and Jabari, 2013). The release of K in general increases with the increase in H^+ concentration (Salam, 1989; Calvaruso et al., 2010; Salam, 2012; Bray et al., 2015). Salam (1989; 2012) reports that some temperate soils from Wisconsin USA and tropical soils from West Java Indonesia consistently showed increasing amounts of released Ca, Mg, K, Zn, Si, and Al with decreasing pH ranging from 7 to 4. Previously, Johnston and Olsen (1972) shows that plant roots were able to extract P and other elements from apatite by dissolution process which is greatly affected by: (1) CO_2 release by roots and microorganisms, (2) chelating agents excreted by roots (Bray et al., 2015), (3) Ca adsorption and absorption by roots, and (4) acidity induced by acids excreted by roots. Manley and Evans (1986) shows that the effectiveness of organic acids to decompose soil mineral follows the order of citric > oxalic > salycylic > protocatechuic = gallic > p-hydroxybenzoic > vanilic = caffeic. Najafi-Ghiri and Jabari (2013) also show that acidic extractants released more K from soil minerals. The presence of releasing K bacteria may also increase the detachment of soil mineral K (Shang et al., 2015), probably through their acidifying properties.

This means that there must be H^+ ion sources in the soil environment. The weed plant rooting system is one of the H^+ ion and acidity sources for this purpose. Vegetation may excrete some acids that may acidify the soil environment (Song and Huang, 1988; Walker et al., 2003; Dayakar et al., 2009; Calvaruso et al., 2010). In addition, vegetation roots may also release H^+ into the soil environment. The amount of acids and H^+ may increase with the extent of vegetation root masses. Dayakar et al. (2009) also suggest that root exudates may stimulate the activities of soil microorganisms and organic matter decomposition, which may eventually lower the soil pH.

In addition to such exudates as H^+ ions and organic acids (Walker et al., 2003; Dayakar et al., 2009; Nihorimbere et al., 2011; Huang et al., 2014), weed-plant roots may also produce enzymes that may alter the unavailable structurally bonded K in the organic residues into readily available inorganic K by which K is released (Duxbury and Tate III, 1981; Bolton et al., 1985; Reddy et al., 1987; Rejsek, 1991; Sakai and Tadano, 1993; Joner et al., 1995; Salam, 2014; 2017). Some researchers report that the activities of enzymes are significantly higher in the rhizosphere than those in non-rhizosphere soils (Reddy et al., 1987; Joner et al., 1995; Bergstrom and Monreal, 1998; Fang et al., 2010). Different plants were shown to produce different activities of soil enzymes (Sakai and Tadano, 1993; Salam et al., 1997; Bergstrom and Monreal, 1998; Wu et al., 2011). Salam et al. (1997a; 1997b) report that the activities of phosphatases in the root zone of *alang-alang* (*Imperata cylindrica*) were higher than those in the root zones of green kylinga, pigweed, and amaranth. The excretion of enzymes was enhanced by root infection by mycorrihiza (Rejsex, 1991; Tarafdar and Marschner, 1994).

There are numerous weeds potential to employ in this mission (Salam et al., 1997a; 1997b; Sembodo et al., 2017). Sembodo et al. (2017) use several grass and broad-leaf weeds to improve the total soil organic matter and the related soil cation-exchange capacity (CEC) and report that *P. conjugatum, Crotalaria lappacea*, *Widelia sp.,* and *A. gangetica* were among those that significantly increased the soil organic matter content and soil CEC. They show that in the presence of these weeds the soil organic matter content significantly increased to about 200% from its initial value of 5.5 mg kg^{-1} and that of CEC increased to about 125% from its initial value of 4.45 $cmol_c$ kg^{-1}. Salam et al. (1997a) show that various weeds induced different values of soil pH; those in the root zones of pigweed (*Amaranthus spinosus L*.) and Amaranth (*Amaranthus tricolor* L.) were lower than that in the root zone of Green Kyllingia (*Cyperus kyllingia* L.) and were much lower than that in the root zone of in *alang-alang*. The changes in these soil-chemical properties may drive the release of more soil labile K. High organic matter contents and thus high soil CEC may adsorb the soluble K which may intensify the release of structural K in soil minerals (Jalali, 2006). This suggestion is in accordance with that reported by Wang and Huang (2001). The presence of weed rooting may also probably acidify the soil environment, firstly by the excretion of H^+, and secondly by the CO_2 evolution during weed root respiration.

This research was to study the influence of several potential tropical weeds in accelerating the release of non-exchangeable K in tropical soils.

Materials and Methods

To study the influence of several potential tropical weeds in accelerating the release of non-exchangeable K in tropical soils a plastic house experiment was conducted from January to June 2013 in the Faculty of Agriculture of the University of Lampung, Bandar Lampung, Indonesia. Soil samples were collected from Bandar Agung (-5,4117^o, 105,383^o) Jabung East Lampung and Serdang (-5,298^o, 105,687^o) Tanjung Bintang South Lampung Indonesia. From each location, a composite soil sample was taken from the depths of 0 – 30 cm and 30 – 60 cm. Soil samples were air-dried and sieved to pass a 2-mm sieve. Soil of Jabung was more fertile than that of Tanjung Bintang as shown by the higher soil pH, organic matter content, and exchangeable K. Several selected soil chemical properties are listed in Table 1.

(Insert Table 1)

Weeds including *Asystacia gangetica*, *Arachis pintoi*, *Widelia* sp., *Paspalum conjugatum*, and *Pennisetum purpureum* were collected from fields and initially planted and grown for several days in polybags to obtain the best weed seedlings. The visual properties of the weeds are depicted in Fig. 1. For the experiment, 10 seedlings of each weed were planted in the polybags each containing 5 kg oven-dry equivalent (24 hours 105 ^oC) air-dried soil samples which have been equilibrated for one week at the soil field moisture capacity or about 40%. The growing weeds were then let to grow for 2 months. During this experiment period, no other weeds were allowed to grow in the experimental unit.

Insert Figure 1

To evaluate the effect of weeds statistically, a split-split plot design was employed with three factors that include weeds as the main plot, soil samples as sub-plot, and soil layers as sub-sub plots. The experiment was conducted with three replications. A polybag containing 5 kg of oven-dry equivalent air-dried soil sample was used as an experimental unit.

Weeds and soil samples were harvested at the end of the experimental time. The weeds were cut at the soil surface to obtain shoot fresh-weight and shoot dry-weight. The bottom parts of weeds were also carefully harvested to obtain root fresh-weight and root dry-weight with minimum loss of root parts during the soil mass removal from the root mass using water. Dry weight was obtained after putting the fresh weed materials in an oven of 60^{o}c for 3 x 24 hours. Soil samples were also taken from each experimental unit to determine the soil pH, soil total C, and exchangeable K. Soil pH was determined using pH-electrode, Total C using the Method of Walkey and Black, and the soil exchangeable K was extracted using 1 N NH_4OAc pH 7.0 and determined using a flame photometer.

Results and Discussion

As shown by the results of analysis of variance (Anova), the presence of weeds significantly affected the soil pH and exchangeable K (Table 2). Unlike those reported by Sembodo et al. (2015), the presence of weeds did not affect the soil organic C content (Table 2). Therefore, there must be a dynamic interrelationship between the changes in soil pH and the changes in the soil exchangeable K. However, this experiment cannot explain this phenomenon because the soil pH data indicate only the observation at the end of the experiment. However, it is obviously shown by the changes in the exchangeable K that K was released during the weed growing time (Table 3).

Insert Table 2

The data in Table 3 clearly shows that weeds absorb K from soils and deplete the soil exchangeable K during the growing time. The effectiveness of various weeds in absorbing K and causing the exchangeable K depletion is various. *Penisetum purpureum* is the most effective in depleting the soil exchangeable K. The order of their effectiveness in depleting the soil exchangeable K is *P. purpureum* > *P. conjugatum* > *Widelia sp.* > *A. gangetica* > *A. Pintoi*. However, the fact that the soil exchangeable K in soils under *A. pintoi* increased to about 114.0% in soil of Jabung and to about 145.0% in soil of Tanjung Bintang (Table 3), particularly in topsoils, suggests that the presence of weeds also stimulate the release of K from soil mineral stuctures through weathering processes. The release was at least 14% of the initial exchangeable K in soil of Jabung and 45% of the initial exchangeable K in soil of Tanjung Bintang, assuming that the *A. pintoi* did not absorb K from the soil exchangeable K. The soil exchangeable K of these soils might have increased more than 14% and 45%, respectively, if weeds did not absorb soil K. This suggests that the weeds in fact stimulated the release of soil mineral structural K. The effectiveness of weeds in stimulating the release of soil K or in increasing the soil exchangeable K follows the order of: *A. Pintoi* > *A. gangetica* > *Widelia sp*. > *P. conjugatum* > *P. purpureum*.

Insert Table 3

The conceptual model depicted in Fig. 2 may explain the weed-root induced release of soil mineral K. Weed roots may release the H^+ ions in exchange of the absorption of cations including K^+. The root respiration might have also released CO_2, that upon reaction with water molecules produced H^+ ion. The processes might have increased the concentration of H^+ ion, which then attacked the K position in the soil minerals. As reported, the released K^+ is intensified by the presence of more H^+ ions (Johnston and Olsen, 1972; Manley and Evals, 1986; Salam, 1989; Najafi-Ghiri and Jabari, 2013). Part of the released K was absorbed by weed plant roots and some other part was adsorbed by soil colloids increasing the soil exchangeable K. The increase in soil exchangeable K is obviously shown in soils under the influence of *A. pintoi* (Table 3). Other weeds might have, of course, increased the soil exchangeable K. However, the absorption of K by these weeds was more intensive than was *by A. pintoi*.

The change in the soil exchangeable K (Δ Exch. K), assumed to be part of K that was absorbed by weeds, was found to be well-correlated with the weed shoot dry-weight with relatively high correlation coefficients, ranging from 0.58 to 0.89 (Table 4), and except in the subsoils of Tanjung Bintang, was also well-correlated with the weed root dry-weight also with relatively high correlation coefficients, ranging from 0.60 to 0.87 (Table 5). Δ Exch. K was calculated as follows:

$$\Delta \text{ Exch. K} = \text{Final Exch. K (After Planting)} - \text{Initial Exch K (Before Planting)}$$

Insert Figure 2

The correlation coefficients were in general higher in soil of Jabung which was more fertile than that in soil of Tanjung Bintang (Table 4 and Tale 5). These data suggest that the release of soil mineral K induced by weed roots was indeed related to weed absorption. This means that the released K was available for plant absorption. These phenomena are also shown by Anova that shows the influence of weeds on shoot and root dry-weights (Table 6).

Insert Table 4

Insert Table 5

Insert Table 6

The ability of weed roots to explore the soil mineral K is related to the values of root-to-shoot ratios (RSR) listed in Table 7. *A. pintoi*, that was shown to induce the highest Δ Exch. K (Table 3), was found to have the highest RSR among the weeds employed in this research. The RSR of *A pintoi* in topsoil of Jabung was more than twice compared to those of *A. gangetica* and *Widelia sp.* and almost 1.5 times those of *P. conjugatum* and *P. purpureum*. A similar pattern was observed in soil of Tanjung Bintang. The higher portion of *A. pintoi* biomass as roots might have enabled this weed to explore more soil minerals and induced the release of more soil mineral K. The RSR values of weeds are also shown to be higher in the subsoils than those in the topsoils since weed plant roots must work harder in less fertile condition.

Insert Table 7

The effectiveness of *A. pintoi* in inducing the release of K is also shown by the values of Sk, that indicates the production of weed shoot per unit lost exchangeable K calculated as follows:

$$S_K = \text{Shoot Dry-Weight}/\Delta \text{ Exch. K}$$

where S_K is expressed in g dry-weight per $cmol_c\ kg^{-1}$. The S_K of *A. pintoi* in topsoils is highest among the five weeds both in soil of Jabung and in soil of Tanjung Bintang (Table 8). Minus values indicate that there was no exchangeable K used but there was an increase instead. The increase is obviously originated from the release of soil mineral structural K.

Insert Table 8

Conclusions

The soil exchangeable K was depleted by weeds except that in soils planted with *A. pintoi* as indicated by the positive ∆ Exch. K [∆ Exch. K = Final Exch. K (After Planting) – Initial Exch. K (Before Planting)], suggesting that *A. Pintoi* root was more effective in stimulating the release of soil mineral K. The effectiveness of weeds is: *A. Pintoi* > *A. gangetica*, *Widelia sp*. > *P. conjugatum* > *P. purpureum.*

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Figure 1. Several weeds employed in the experiment.

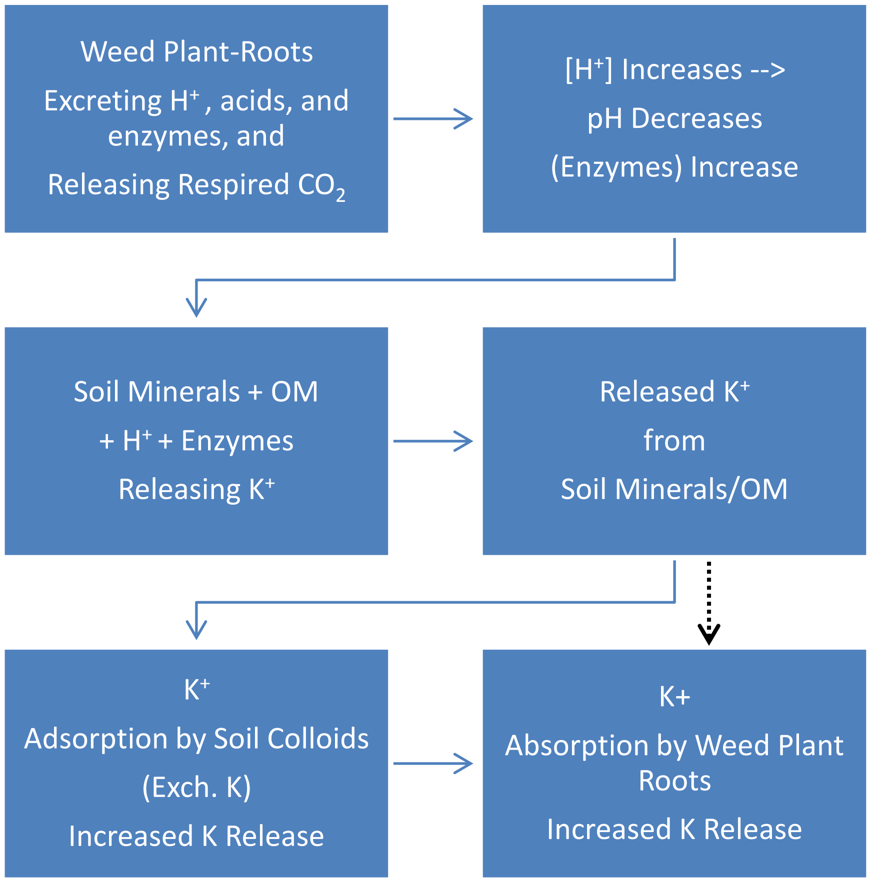

Figure 2. Conceptual relationship between excreted H^+ and respired CO_2 by plant roots, released K^+ from soil minerals and organic matter, and improvement of plant growth.

Table 1. Selected properties of soil samples for the experiment.

Soil Propertiies	Methods	Soil of Jabung		Soil of Tanjung Bintang	
		Topsoil	Subsoil	Topsoil	Subsoil
pH	Electrometry	5.81	4.87	5.32	5.67
Organic C (g kg^{-1})	Walkey and Black	6.00	3.10	1.00	1.50
Exchangeable K (cmol$_c$ kg^{-1})	NH_4OAc N pH 7.0	0.36	0.29	0.09	0.07

Table 2. Variance analysis on the effect of weed roots on tropical soil properties.

Treatment Factors	Soil Properties		
	pH	Organic C	Exchangeable K
Main Plot:			
Weed Plant Roots (A)	**	ns	**
Sub-Plot			
Soil Type (B)	**	*	**
AB	**	ns	**
Sub Sub-Plot:			
Soil Layers (C)	ns	**	**
AC	**	ns	**
BC	**	ns	**
ABC	ns	ns	ns

ns = not significant, * significantly different, ** very significantly different

Table 3. Relative changes in soil exchangeable K as affected by weed roots.

Soils	Layers	Weeds[1)]				
		Ag	Ap	W	Pc	Pp
		% of initial contents[2)]				
Jabung	Topsoil	72.2	**114.0**	75.0	83.3	44.4
	Subsoil	65.5	93.1	58.6	69.0	38.0
Tanjung Bintang	Topsoil	88.9	**145.0**	66.7	55.6	33.3
	Subsoil	85.7	85.7	42.9	28.6	28.6
Average		78.1	110.0	60.8	59.1	36.1

1) Ag *Asystacia gangetica*, Ap *Arachis pintoi*, W *Widelia* sp., Pc *Paspalum conjugatum*, and Pp *Pennisetum purpureum*
2) Initial topsoil and subsoil exchangeable K were 0.36 and 0.29 cmol$_c$ kg^{-1}, respectively, for soil of Jabung and 0.09 and 0.07 cmol$_c$ kg^{-1}, respectively, for soil of Tanjung Bintang

Table 4. The relationships between shoot dry-weight and changes in the soil exchangeable K.

Soils	Layers	Weeds[1]	Shoot Dry Weight	Δ Exch. K[1]	Correlation Coefficient
			(g pot^{-1})	(cmol$_c$ kg^{-1})	(r)
Jabung	Topsoil	Ag	6.69	- 0.10	
		Ap	4.13	+ 0.05	
		W	13.2	- 0.09	0.84
		Pc	13.8	- 0.06	
		Pp	36.5	- 0.20	
	Subsoil	Ag	5.78	- 0.10	
		Ap	3.59	- 0.02	
		W	9.55	- 0.12	0.89
		Pc	9.30	- 0.09	
		Pp	32.5	- 0.20	
Tanjung Bintang	Topsoil	Ag	4.16	- 0.01	
		Ap	2.47	+ 0.04	
		W	10.5	- 0.03	0.63
		Pc	7.38	- 0.04	
		Pp	128	- 0.06	
	Subsoil	Ag	3.45	- 0.03	
		Ap	1.85	- 0.03	
		W	8.67	- 0.04	0.58
		Pc	4.97	- 0.05	
		Pp	126	- 0.05	

[1] Ag *Asystacia gangetica*, Ap *Arachis pintoi*, W *Widelia* sp., Pc *Paspalum conjugatum*, and Pp *Pennisetum purpureum*
[2] Δ Exch. K = Final Exch. K (After Planting) – Initial Exch. K (Before Planting)

Table 5. The relationships between root dry-weight and changes in the soil exchangeable K.

Soils	Layers	Weeds[1]	Root Dry Weight	Δ Exch. K[1]	Correlation Coefficient
			(g pot^{-1})	(cmol$_c$ kg^{-1})	(r)
Jabung	Topsoil	Ag	1.36	- 0.10	
		Ap	2.15	+ 0.05	
		W	2.97	- 0.09	0.87
		Pc	5.46	- 0.06	
		Pp	12.1	- 0.20	
	Subsoil	Ag	2.42	- 0.10	
		Ap	4.40	- 0.02	
		W	2.72	- 0.12	0.71
		Pc	3.46	- 0.09	
		Pp	13.3	- 0.20	
Tanjung Bintang	Topsoil	Ag	1.14	- 0.01	
		Ap	1.31	+ 0.04	
		W	1.32	- 0.03	0.60
		Pc	1.49	- 0.04	
		Pp	7.55	- 0.06	
	Subsoil	Ag	2.38	- 0.03	
		Ap	1.34	- 0.03	
		W	2.17	- 0.04	0.03
		Pc	1.69	- 0.05	
		Pp	2.01	- 0.05	

[1] Ag *Asystacia gangetica*, Ap *Arachis pintoi*, W *Widelia* sp., Pc *Paspalum conjugatum*, and Pp *Pennisetum purpureum*
[2] Δ Exch. K = Final Exch. K (After Planting) – Initial Exch. K (Before Planting)

Table 6. Variance analysis of the effects of weeds on dry-shoot and root weights.

Treatment Factors	Dry Weight	
	Shoots	Roots
Main Plot:		
Weed Roots (A)	**	**
Sub-Plot		
Soil Type (B)	**	**
AB	**	*
Sub Sub-Plot:		
Soil Layers (C)	**	**
AC	Ns	Ns
BC	Ns	*
ABC	ns	ns

ns = not significant, * significantly different, ** very significantly different

Table 7. The root-to-shoot ratio (RSR) of weeds grown in tropical top and subsoils.

Soils	Layers	Weed Plants[1)]				
		Ag	Ap	W	Pc	Pp
Jabung	Topsoil	0.203	0.521	0.225	0.395	0.342
	Subsoil	0.418	1.220	0.285	0.372	0.410
Tanjung Bintang	Topsoil	0.274	0.529	0.125	0.202	0.059
	Subsoil	0.690	0.725	0.250	0.340	0.016

[1)] Ag *Asystacia gangetica*, Ap *Arachis pintoi*, W *Widelia* sp., Pc *Paspalum conjugatum*, and Pp *Pennisetum purpureum*

Table 8. The production of weed shoot per unit lost exchangeable K (S_K).

Soils	Layers	S_K of Weeds[1)] (g dry-weight per $cmol_c\ kg^{-1}$)				
		Ag	Ap	W	Pc	Pp
Jabung	Topsoil	66.9	-82.6	147	230	183
	Subsoil	57.8	180	80.0	103	163
Tanjung Bintang	Topsoil	416	-62.0	351	185	2130
	Subsoil	115	62.0	217	99.0	2520

[1)] Ag *Asystacia gangetica*, Ap *Arachis pintoi*, W *Widelia* sp., Pc *Paspalum conjugatum*, and Pp *Pennisetum purpureum*

[2)] S_K = Shoot Dry-Weight/Δ Exch. K; Δ Exch. K = Final Exch. K (After Planting) – Initial Exch. K (Before Planting)