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SOIL POTASSIUM FRACTIONS IN RICE-WHEAT CROPPING SYSTEM AFTER TWELVE YEARS OF LANTANA RESIDUE INCORPORATION IN A NORTHWEST HIMALAYAN ACID ALFISOL

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□ *A long-term field experiment with rice-wheat cropping was started in the wet season of 1988 with four levels of lantana (*Lantana camara *L.) (0, 10, 20, and 30 Mg ha*$^{-1}$ *on fresh weight basis) and three tillage practices (No puddling, puddling, and soil compaction). From wet season of 1997, however, three tillage practices were replaced with three levels of nitrogen (N) and potassium (K) to rice (33, 66, and 100% of recommended) and 66% of recommended N, phosphorus (P), and K to wheat. Phosphorus was totally omitted for the rice crop. The recommended N and K for rice was 90 and 40 kg ha*$^{-1}$*, whereas the recommendations for N, P, and K for wheat were 120, 90 and 30 kg ha*$^{-1}$*. Organic amendments are known to improve soil productivity under rice-wheat cropping by improving physical conditions and nutrient status of the soil, but their availability is restricted. There is a need to identify locally available and cost-effective organic materials that have minimal alternate uses as fodder and fuel. We evaluated* Lantana camara *L. residues, a fast-growing weed in nearby wastelands, as a potential soil organic amendment. Among the different fractions of K, nonexchangeable K was dominant followed by exchangeable and water soluble K. The incorporation of lantana (10 to 30 Mg ha*$^{-1}$*) over the last 12 years has resulted in a significant build-up of all the K fractions, the maximum being in water-soluble K (10 to 32%) followed by exchangeable K (18 to 27%) and least in nonexchangeable K (5 to 7%) over no lantana incorporation. The increasing levels of these two inputs significantly and consistently increased ammonium acetate (*NH_4OAc*)-extracted K (available K) content in soil and also resulted in significantly higher accumulation of K by the crops during the years of experimentation. Among different K fractions, exchangeable K was observed to be the most important K fraction contributing towards wheat and rice yields as well as K accumulation by wheat and rice. Stepwise multiple regression equations indicated that exchangeable K was the most important variable contributing towards total variation in grain yield and K accumulation by wheat or rice.*

Keywords: K-fractions, K-accumulation, integrated nutrient management, rice-wheat

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INTRODUCTION

Today, potassium (K) is recognized as an important limiting factor in crop production. The quantity of K absorbed by plants is as much or higher than nitrogen (N) for most cultivated crops (SOPIB, 2001). Thus, K is indeed essential in modern agriculture, horticulture, and vegetable crops as it makes plants tolerant to drought and frost and resistant to a number of diseases and pests besides its impact on yield and quality (Romheld and Kirkby, 2010). In the absence of adequate K fertilization, significant depletion of soil K reserves take place and there are yield losses and higher economic risks for farmers. Syers et al. (2001) indicated an overall annual K deficit of about 11 million tons for six Asian countries. A high deficit on a per hectare basis is expected in India, as there is no regular K fertilization program in this country. Such a deficit is creating serious nutrient imbalances with major implications for factor productivity.

Potassium availability in rice-wheat cropping system exhibits a complex behavior in acid Alfisols. Puddling and submergence in rice result in K deficiency in wheat. Thus, K deficiency may be one of the factors for poor wheat yield. Soil K exists in four forms in soils: solution, exchangeable, fixed, and structural or mineral. There are equilibrium and kinetic reactions between these four forms that affect the level of soil solution K at any particular time, and thus, the amount of readily available K for plants (Sparks, 1987). The bulk of soil K (about 98% of total K) is held in structure of the primary K bearing minerals, such as micas and feldspars being released very slowly by weathering to replenish the exchanageable and nonexchanageable pools (Syers, 2003). The readily available K constitute only 1–2% of total K and exists in soil in two form, *viz.*, solution and exchangeable K adsorbed on soil colloidal surface (Brady and Weil, 2002). Potassium removal by the crop from soil solution causes depletion of K from the solution phase, which is replenished by solid phase K (Tisdale et al., 1985). Response to K would depend upon the requirement of the plant and ability of soil to supply it form nature or added sourcing. The soil-water-fertilizer-plant system might be considered as a pool where exchange of nutrients occur leading to their uptake by crop. The incorporation of organics improves soil physical properties due to build-up of humus and releases inherent nutrients upon decomposition. In addition, the use of organics also improves the use efficiency of applied fertilizers, which in turn enhances crop yields (Clark et al., 1998; Peterson et al., 1999). Yet, the effects of organic matter addition on different crops grown during different seasons may be different owing to different functions performed by organic matter at different stages of decomposition. The organic materials most commonly used by Asian farmers are farmyard manure, compost, green manure, crop residues, and waste organic biomass, among others. But because of alternate uses as fodder and fuel, only small quantities of these materials are available to farmers for use as a soil amendment. There is need to identify locally available and cost-effective organic materials, which have minimal alternate uses as fodder and fuel. Lantana (*Lantana camara* L.) is a fast growing bush in India and was introduced as an ornamental plant. But, it is an obnoxious weed. Because of its fast growth, lantana has turned into a serious weed, with a danger of encroaching on cultivated lands. It has no value as cattle feed because it contains toxins such as 'lantidine', which causes tymphany disease if eaten by cattle. Its growth and foliage are maximum during wet season (June-September) when rice is cultivated. Owing to a nutrient-rich biomass, lantana may be used in crop production, and this use will redress the problem of containing its swift spread into productive soils (Sharma et al., 2003). Keeping in view its abundance and limited alternate use, a long-term field experiment with rice-wheat cropping system was initiated to study its utility as an alternate organic source of nutrients and to evaluate its effect on K dynamics in the soil- plant system.

MATERIALS AND METHODS

Experimental Site, Treatments and Design

A long-term field experiment was begun in June 1988 in a silty clay loam (Typic Hapludalf) at the experimental farm of the Himachal Pradesh Agricultural University, Palampur, India (32°6′N, 76°3′E,1300 m above mean sea level), with the following soil characteristics: 300 g kg^{-1} clay, 540 g kg^{-1} silt, 160 g kg^{-1} sand, pH 5.6 (1:1 w/v water), 0.88% organic carbon (OC), 12 cmol kg^{-1} cation exchange capacity, 0.12 g kg^{-1} available nitrogen (N) [potassium permanganate ($KMNO_4$)-oxidizing fraction], 8.0 mg kg^{-1} Olsen's phosphorus (P), and 0.08 g kg^{-1} ammonium acetate (NH_4OAc)-extracted K. The site lies in the Palam valley of Kangra District at foothills of Dhauladhar ranges and represents the high rainfall mid-hill wet-temperate zone of the North-West Himalayas. The mean annual rainfall around Palampur is about 2,312 ± 618 mm, with the wettest months being June to September. The annual mean maximum and mean minimum temperatures are about 23.2 ± 0.8 and 13.4 ± 0.5°C, respectively.

The 12-year field experiment was started with rice during summer season, *Kharif* (mid-June-mid-September) from 1988 to 1992–1993, with four levels of lantana incorporation (0, 10, 20 and 30 Mg ha^{-1} on fresh weight basis) and three tillage practices (no puddling, puddling, and soil campaction). The residual effect of lantana incorporation and tillage practices were evaluated on the following wheat crops every year up to *Rabi* (November–April) 1992–1993. From 1988 to 1992, the recommended N:P:K rates of 90:18:33 kg ha^{-1} were applied to rice and 120:26:25 kg ha^{-1} to wheat. However, from *Kharif* 1993 to 1997, the experiment was modified and the three tillage practices were replaced by three levels of nitrogen viz. 50, 75, and 100% of the recommended dose to rice, i.e., 90 kg N ha^{-1}. Nitrogen levels to wheat were reversed to 50, 75, and 100% of the recommended N to wheat, which was 120 kg N ha^{-1}. The four levels of lantana incorporation and three levels of fertilizer nitrogen were maintained up to *Rabi* 1996–1997. However, from *Kharif* 1997, the three nitrogen levels were further modified to 33, 66, and 100% of the recommended N and K to rice. The application of phosphorus to rice was omitted totally. The N, P, and K application to wheat was also modified to 66% of recommended levels. The recommended dose of K to rice was 40 kg ha^{-1}, and the recommended doses of N, P, and K to wheat were 120, 90 and 30 kg ha^{-1}, respectively. The total amount of K was applied at transplanting of the rice, whereas 50% of N was applied 10 days after transplanting, and the remaining 50% was applied in two splits at 20 and 40 days after transplanting. Similarly, in wheat, all of the P and K and 50% of the N was applied at sowing, and the remaining 50% of the N was top dressed in two equal splits at crown root initiation and flowering stages. The fertilizers used were urea, single super phosphate, and muriate of potash for N, P, and K, respectively. Lantana was incorporated 10–15 days before puddling/transplanting of the rice. Tender twings of lantana (on a dry weight basis) have around 403 g kg^{-1} OC, 22.3 g kg^{-1} N, 2.0 g kg^{-1} P, 14g kg^{-1} K, and a carbon (C)/N ratio of 21. Lantana twigs were chopped manually into small pieces (4–5 cm size), spread uniformly over the entire plot, and incorporated into the surface soil (0–0.15 m) with spades. Each plot was irrigated and left as such for 10–15 days, when the soil of each plot was dug again and puddled manually. The experiment was laid out in complete randomized block design with 12 treatments replicated three times.

Soil Sampling and Analysis

Soil samples were taken from 0–0.15 m depth from each treatment after twelve cycle of rice-wheat cropping system. The soil samples collected after harvest of wheat were mixed thoroughly, air dried in shade, crushed to pass through 2-mm sieve, and store in sealed plastic jars for total K (Jackson, 1967) and available K by neutral NH_4OAC method (AOAC, 1970). They also were fractioned *Viz.* water-soluble K (WSK), exchangeable K (EK), and nonexchangeable K (NEK) by the method described by Black (1965). The exchangeable K was calculated by subtracting water-soluble K from available-K, and nonexchangeable K was calculated by subtracting exchangeable K from nitric acid (HNO_3)-K. The rice and wheat yields and K uptake data were recorded and correlated with different forms of K and interdependency among different forms of K also was worked out.

Statistical Analysis

The data were subjected to standard ANOVA of completely randomized block design (Gomez and Gomez, 1984) and the means of the treatments were tested using least significant differences at 5% level probability of using the IRRISTAT data analysis package (International Rice Research Institute, 2000).

RESULTS AND DISCUSSION

Potassium Fractions

Increasing levels of either fertilizers or lantana incorporation increased the available K content significantly and consistently (Table 1). The increase in available K content with 10, 20, and 30 Mg ha^{-1} lantana was about 15, 22, and 28%, respectively, over no lantana incorporation. The increased in available-K with the incorporation of lantana is understandable as water-soluble and exchangeable K, which accounts for a major portion of available K in the soil, increased significantly. The build-up in available K content in soil due to the addition of organic material also has been reported by many researchers (Sharma et al., 2001; Singh and Chauhan, 2002). The percent increase due to fertilizer application under 66 and 100% of recommended dose amounted to 16.5 and 32.6, respectively, over 33% of the recommended dose. Possibly, fertilizer application increased the productivity and root growth parameters and the root remained in the soil after crop harvest and on decomposition contributed in the build-up of available K.

Among the different fractions of K, nonexchangeable K (424 mg kg^{-1} soil) was the dominant one followed by exchangeable K (106 mg kg^{-1} soil) and water-soluble K (38 mg kg^{-1} soil). The dominance of nonexchangeable K in the present soils can be ascribed to abundance of K-fixing minerals such as illite and chlorite in the present soils (Verma et al., 1994). Since water-soluble K is subjected to removal by crops as well as prone to leaching under the influence of high rainfall intensity, its contents in present soil were the lowest among all the three fractions. The relative per cent contribution of water- soluble, exchangeable and nonexchangeable K towards total K was 1.9, 5.4 and 21.7%, respectively; whereas the rest was residual K. Incorporation of lantana over the last 12 years has resulted in significant build-up of all the fractions of K. Increasing lantana incorporation from 10 to 30 Mg ha^{-1} increased water-soluble K by 10 to 32%, exchangeable K by 18 to 27% and nonexchangeable K by 5 to 7% over no lantana incorporation. In comparison, fertilizer application at 66 and 100% of recommended dose to 33% of its dose increased the respective K-Pools by 31–50%, 12–27%, and 6–5%.

The increase in water-soluble K due to lantana incorporation can be explained on the basis of direct contribution of K from lantana biomass being added for the last 12 years. Such an increase in the content of water-soluble K due to addition of organic material also has been reported by Verma and Ram (1994) and Sood et al. (2008). The increase in exchangeable K can be explained on the basis of the fact that decomposition of lantana might have

TABLE 1 Effect of long-term lantana and fertilizer application on various forms of soil K

	Fertilizer applications (% of the recommended dose)			
Lantana addition (Mg ha^{-1})	33	66	100	Mean
		Available K (mg kg^{-1})		
0	110	117	145	124
10	122	143	164	143
20	125	157	173	152
30	139	161	177	159
Mean	124	145	165	
LSD (P = 0.05)	F = 5	L = 6	L × F = NS	
		Water-soluble K (mg kg^{-1})		
0	26	33	42	34
10	29	39	43	37
20	32	40	47	40
30	35	47	51	44
Mean	30	40	46	
LSD (P = 0.05)	F = 2.7	L = 3.1	L × F = NS	
		Exchangeable K (mg kg^{-1})		
0	85	84	103	90
10	93	104	121	106
20	93	117	126	112
30	103	114	126	115
Mean	94	105	119	
LSD (P = 0.05)	F = 6	L = 7	L × F = NS	
		HNO_3-K (mg kg^{-1})		
0	455	568	581	534
10	555	575	586	572
20	572	576	595	581
30	573	593	598	588
Mean	538	578	590	
LSD (P = 0.05)	F = 19	L = 21	L × F = 37	
		Nonexchangeable K (mg kg^{-1})		
0	370	484	479	444
10	461	471	465	466
20	478	459	469	469
30	470	479	471	473
Mean	445	473	471	
LSD (P = 0.05)	F = 13	L = 16	L × F = 27	
		Total K (mg kg^{-1})		
0	1664	1906	2078	1883
10	1781	2006	2106	1964
20	1949	2074	2172	2065
30	2054	2154	2249	2153
Mean	1862	2035	2151	
LSD (P = 0.05)	F = 49	L = 56	L × F = NS	

F-fertilizer application; L- lantana application.

resulted in an increase in organic colloids, which in turn, enhance the cation exchange capacity of the soil, thereby giving a strong sink for K$^+$ (Kher and Minhas 1992; Navneet and Benipal, 2006).

The minimum increase in nonexchangeable K might be due to release of K from K bearing primary minerals (biotite, muscovite) due to dissolution with organic acids produced because of decomposition of lantana (Song and Huang, 1988). Anaerobic conditions are particularly favorable for the microbial synthesis of organic acids (Bhat, 1988), and alternate wetting and drying coupled with high content of exchangeable K might have resulted in conversion of exchangeable K into nonexchangeable K with the passage of time (Dhanorkar et al., 1994). Since in the present study, lantana was incorporated before the transplanting of rice every year, a major portion of lantana has been decomposed under anaerobic conditions. These results are corroborated with the findings of Santhy et al. (1998), Sharma and Verma (2000), and Pannu et al. (2001).

Increase in fertilizer doses increased the HNO_3-K, but the effect was significant only at the 66% dose, whereas 100% dose was equal in effect with that of 66%. Similarly, lantana incorporation also increased the content of HNO_3-K. Here again the effect of 10 Mg ha^{-1} lantana was significant over the control whereas 20 or 30 Mg ha^{-1} lantana was not significant over 10 Mg ha^{-1}. The interaction effect between fertilizer application and lantana incorporation was significant. The incorporation of lantana at 10 Mg ha^{-1} under 33% of recommended fertilizers increased the HNO_3-K content, whereas further increase in its levels did not raise HNO_3-K content significantly. By contrast, under 66 and 100% of recommended fertilizer doses, lantana incorporation at any rate did not show any significant effect on the buildup of HNO_3-K content. Similarly, fertilizers dose of 66% increased the HNO_3-K only under no lantana incorporation. Fertilizer dose at 66 or 100% did not influence HNO_3-K at any level of lantana incorporation.

Total K in present soil varied from 1664 to 2250 mg kg^{-1} soil with an average value of 1957 mg kg^{-1} soil. The content of total K increased significantly with twelve annual lantana incorporation at 10, 20, or 30 Mg ha^{-1} over no lantana incorporation. The percent increase as a consequence of incorporation of 10, 20, and 30 Mg ha^{-1} lantana amounted to 4.3, 9.7, and 14.3, respectively, over no lantana incorporation. Similarly, increased levels of fertilizers also brought about significant increase in total K content. As lantana twigs contain on an average 1.4% K, annual applications over the last twelve years might have resulted in buildup of total K in soils. The lantana incorporation at 10 Mg ha^{-1} actually added 840 mg K kg^{-1} soil, whereas at 20 Mg ha^{-1} it added 1680 mg K kg^{-1} soil and at 30 Mg ha^{-1} it added 2520 mg K kg^{-1} soil.

Interdependency among Various Soil Potassium Fractions

The values of various organic and inorganic soil K factions were corelated to known their interdependency (Table 2). The most important variable contributing to the total variation in the regression of water-soluble

TABLE 2 Matrix of correlation coefficients relating different fractions of soil K

	Ws-K	Ex-K	Non-ex K	HNO_3-K
Ex-K	0.961**			
Non-ex K	0.936**	0.831**		
HNO_3-K	0.917**	0.802**	0.998**	
Total K	0.876**	0.775**	0.992**	0.984**

**significant at 1 percent.

Ws-K: water-soluble K; Ex-K: exchangeable K; Non-ex K: nonexchangeable K.

K was exchangeable K, of exchangeable K it was water-soluble K, of nonexchangeable K it was HNO_3-K, of HNO_3-K it was nonexchangeable K and of Total K it was HNO_3-K.

The most important variable contributing to the total variation in the regression of water-soluble K was exchangeable K (Table 3). About 93% of the total variation in water-soluble K was explained by exchangeable K and nonexchangeable K alone. Similarly, the most important variable contributing to the total variation in the regression of exchangeable K was water-soluble K followed by nonexchangeable K. Both these fraction of K accounted to about 82% of total variation in exchangeable K. The most important variable contributing to the total variation in nonexchangeable K was HNO_3- K, explaining about 86% variation in nonexchangeable K. The second most important variable contributing to the total variation was exchangeable K, which accounted or about 14% of the total variation in

TABLE 3 Stepwise regression data indicating interrelationship among different potassium fractions

Y	Stepwise variables	R^2	ΔR^2
Water-soluble K	1. Ex-K	0.912**	—
	2. Ex-K, Non Ex-K	0.927**	0.0156
	3. Ex-K, Non Ex-K, HNO_3-K	0.930**	0.0030
Exchangeable K	1. Ws-K	0.799**	—
	2. Ws-K, Non Ex-K	0.825**	0.026
	3. Ws-K, Non Ex-K, HNO_3-K	1.000	0.175
	4. Ws-K, Non Ex-K, HNO_3-K, Total K	1.000	0.0000
Nonexchangeable K	1. HNO_3-K	0.858**	—
	2. HNO_3-K,Ex-k	1.000	0.142
	3. HNO_3-K, Ex-k, Total K	1.000	0.000
	4. HNO_3-K, Ex-k, Total K, Ws-K	1.000	0.000
HNO_3-K	1. Non Ex-K	0.858**	—
	2. Non Ex-K, Ex-K	1.000	0.142
	3. Non Ex-K, Ex-k, Total K	1.000	0.000
	4. Non Ex-K, Ex-k, Total K, Ws-K	1.000	0.000
Total K	1. HNO_3-K	0.912**	—
	2. HNO_3-K, Ex-k	0.959**	0.049
	3. HNO_3-K, Ex-k, Non-Ex-K	0.955**	0.006

Ws-K: water-soluble K; Ex-K: exchangeable K; Non-ex K: nonexchangeable K.

nonexchangeable K. About 100% of the total variation in the regression of nonexchangeable K was explained by HNO_3-K and exchangeable K. As far as HNO_3-K was concerned, the most important variable contributing to the total variation in HNO_3-K was nonexchangeable K followed by exchangeable K. About 100% of the total variation in the regression of HNO_3-K was explained by nonexchangeable K and exchangeable K alone. The most important K fraction contributing to the total variation in Total K was HNO_3-K followed in decreasing order by exchangeable K and nonexchangeable K. About 96% of the total variation in Total K was explained by these three fractions of K alone.

Potassium Accumulation

The interaction effect of lantana addition and fertilizer application was not significant on K accumulation by rice or wheat; hence, their individual effects are given in Table 4. Like rice and wheat yields which were given elsewhere (Sharma et al., 2008), the accumulation of K also increased significantly with twelve annual additions of lantana as well as with increased levels of fertilizers. The increase in K accumulation by rice with 10, 20, and 30 t ha^{-1} lantana addition was 17.7, 25.0, and 32.8 during Season-1 and 12.6, 28.1, and 49.4% during Season-2 over no lantana. The corresponding values in case of K accumulation by wheat were 9.3, 20.5, and 31.5% during Season-1 and 17.3, 29.1, and 46.9% during Season-2 over no lantana addition. Such increase in K accumulation by rice and wheat due to the incorporation of lantana may be attributed to better proliferation of roots under the influence of lantana incorporation might have resulted in the increased absorption of

TABLE 4 Effect of long term lantana and fertilizer application on total K accumulation by rice and wheat

	Rice (kg ha^{-1})		Wheat (kg ha^{-1})	
Treatment	After eleven years	After twelve years	After eleven years	After twelve years
Fertilizer level (% of recommended dose)				
33	80	84	27	23
66	93	109	35	30
100	95	111	37	30
LSD ($P = 0.05$)	3	4	2	1
Lantana levels (Mg ha^{-1})				
0	75	83	29	22
10	88	93	32	26
20	94	114	35	28
30	99	117	38	32
LSD ($P = 0.05$)	4	5	2.4	1.5

TABLE 5 Coefficient of correlation between different yield parameters and K fractions

		Wheat		Rice	
S. No.	K fractions	Grain yield	Total K Uptake	Grain yield	Total K uptake
1.	Water-soluble K	0.973**	0.975**	0.947**	0.930**
2.	Exchangeable K	0.980**	0.978**	0.949**	0.968**
3.	Nonexchangeable K	0.952**	0.961**	0.938**	0.911**
4.	HNO_3-K	0.967**	0.949**	0.934**	0.945**
5.	Total K	0.844**	0.831**	0.837**	0.844**

**significant at 1 percent.

water and availability of nutrients in the soil from larger areas and greater depths (Sharma et al., 2005). This increase in K accumulation either with lantana addition or with fertilizer application was mainly because of increase in rice or wheat yields under these treatments.

Relationship between Soil Potassium Fractions and Crop Growth Parameters

To assess the relative contribution of various organic and inorganic K fractions to different plant growth parameters, linear stepwise regression equations were computed between the values of various organic and inorganic K fractions and plant growth parameters and given in Table 5. Among different K fractions, exchangeable K was the most important K fraction contributing towards grain yield by wheat (0.98**) or rice (0.95**). Similarly, in the case of K accumulation by wheat and rice, exchangeable K (0.98** and 0.97**, respectively) was the most important K fraction. A critical examination of these equations indicates that exchangeable-K was the most important variable computed to the total variation in the regression of wheat grain yield and K accumulation by wheat. The R^2 value indicates that about 96% variation in grain yield and 95% variation in K accumulation were attributed only to this fraction of K. The second most important variable was water-soluble K in case of wheat grain yield and nonexchangeable K in case of K accumulation by wheat. The second most important variable was water-soluble-K in case of rice grain yield and HNO_3-K in case of K uptake by rice. The R^2 values indicates that about 98 and 97% of the total variation in grain yield and K accumulation by wheat could be explained only on the basis of exchangeable K in soils. The corresponding values in rice were 94 and 97%, respectively.

CONCLUSION

Incorporation of lantana residues increased yields of rice and wheat and at the same time saved chemical fertilizers by improving physical properties and nutrient status of the soil. Among different K fractions determined during the present investigation, nonexchangeable K was the most dominant and water-soluble, the least one. In general, the incorporation of lantana over the last 12 years has resulted in significant build-up of all the fractions of K. On an average, the maximum build-up was water-soluble K (10 to 32%) followed by exchangeable K (18 to 27%) and minimum in nonexchangeable K (5 to 7%). Similarly, the maximum increase was observed in water soluble K (31 to 50%) followed by exchangeable K (12 to 27.0%) and minimum in nonexchangeable K (6 to 5%) due to fertilizer application at 66 and 100% of recommended dose in comparison to 33% of its dose. Exchangeable K was the most important K fraction contributing to K nutrition of rice and wheat grown in sequence. The cost-effectiveness of the lantana treatment, however, is an important issue and needs to be considered. Nevertheless, these studies show the potential of waste organic residue in nutrient substitution and in sustaining rice-wheat productivity.

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