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Decomposition and nutrient release rates of selected legume residues in a cold semiarid environment of Kenya

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Abstract

Incorporation of legume residues in soil is a low cost option for improving soil fertility, but its effectiveness depends on residue quality. A study was conducted for two seasons (2007 and 2008) to determine the decomposition and nutrient release rates of butter bean, grasspea, common bean and chickpea residues. Chopped legume residues were placed in 2 mm nylon mesh bags and incubated in the soil at a depth of 15 cm. Dry matter weights and composition of residues were determined before incubation and thereafter fortnightly until the 14^{th} week after incubation. Chickpea residues had significantly higher initial % lignin and lignin/nitrogen ratio than butter bean, grasspea and common bean residues. All studied legume residues had similar levels of cellulose, C/N ratio, N, C, P, K, and Ca. Nitrogen concentrations were above the critical values (18-22 g/kg) for net N mineralization in all the legumes whereas P concentrations were below the critical value (2.5 g/kg) for net P mineralization in chickpea and common bean. Dry matter and nutrient (N, P, K, Mg and Ca) disappearance rates of chickpea residues were significantly lower than for grasspea, butter bean and common bean. Grasspea residues had higher dry matter disappearance rates than other legumes' residues. Grasspea and butter bean residues had significantly higher nutrient disappearance rates than common bean residues. Nutrient loss from all the residues was in the order K > P > N > Mg > Ca. Butter bean and grasspea crop residues have potential of providing soil N, P, K and Mg in the cold semi-arid region within a growing season.

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Introduction

One of the factors limiting food production in the cold semi-arid plateau of laikipia district of Kenya is low soil fertility. Nitrogen and phosphorus are identified as the major limiting nutrients for many cropping systems in Kenya (Kwambiah *et al.,* 2003) and their application from organic and inorganic sources is essential to maximize and sustain crop yield potentials (Hartermink *et al.,* 2000). Inorganic sources of N and P are however not readily available to small scale farmers (Smestad *et al.,* 2002). It is therefore important that other sustainable alternatives of soil fertility management are sought to ensure improved crop yields. Promising low input soil nutrient management practices include use of farm yard manure and incorporation of legume residues (Place *et al.,* 2003) and improved legume fallows (Nelson and Sommers, 2010). Legume fallows are not feasible in the cold semi-arid region of laikipia due to labour and land constraints while farm yard manure is not available in the required quality and quantity.

The role and usefulness of recycling legume residue in maintaining or building up soil fertility has long been recognized (Stevenson and Van Kessel, 1996). Upon mineralization, legume residues release plant nutrients that become available for uptake by other plants (Giller, 2001).

Many of the soil and crop benefits of legume residues are realized upon decomposition of the residues. The rates of decomposition and nutrient release from crop residues are influenced by residue quality parameters such as N concentration (Haynes, 1986), C/N (Mubarak *et al.,* 2002; Nicorlardot, 2001) and lignin content (Fosu, 2003). The critical levels for N concentration, lignin content and carbon/nitrogen ratio are established to be 2.5%, 15% and 30, respectively (Haynes, 1986). Other factors reported to influence decomposition and nutrient release rates from residues include soil moisture (Insam, 1990), soil aeration and drainage (Lunar-Orea, 1996).

Various studies have shown that the quantity of biomass produced by a legume is not necessary indicative of its effectiveness in improving soil fertility (Fosu, 2003; Fosu *et al.,* 2004). The quality of residues as sources of plant nutrients depend on the amount of nutrients released upon their decomposition. These in turn depend on nutrient concentrations in the residues. Consequently residue quality, decomposition and mineralization rate need to be evaluated.

Whereas Giller (2001) indicates that residues from grain legumes can contribute nitrogen to the soil if their residue is not removed, in the cold semi-arid region of laikipia, crop residues are burnt or removed from the fields and fed to livestock. Little information exists on the value of grain legume residues as sources of soil nutrients for the cold semi-arid areas.

A study was therefore conducted to determine decomposition and nutrient release rates of butter bean, grass pea, chickpea and common bean crop residues in the cold semi-arid region of laikipia.

Materials and methods

Study site

The study was conducted at Matanya location, in Lamuria Division of Laikipia District, Kenya. Rainfall and temperatures at the trial site during the experimental period are summarized in Table 1.

Composition and nutrient release from of legume crop residues

Treatments were crop residues of butter bean, grass pea, common bean and chickpea. The experiment was arranged in a randomized complete block design and replicated three times. Fifty grams of each crop residue was weighed, chopped and placed inside 2 mm nylon mesh bag (20 cm x 20 cm). The bags were incubated in the soil at a depth of 15 cm in the field. A total of 21 bags of each crop residue were incubated.

Before incubation, residue samples were analyzed for lignin, cellulose, hemicellulose, nutrient content (nitrogen, phosphorus, potassium, carbon, calcium and magnesium) and dry matter. Three bags of each residue type were retrieved after 2, 4, 6, 8, 10, 12 and

14 weeks and the decomposed residue analyzed for remaining dry matter and nutrients.

Table 1. Mean monthly rainfall (mm) and temperature (°C) at Matanya in 2007 short rains and 2008 long rains seasons.

2007 Short rains season					2008 Long rains season				
	Temperature (°C)		Rainfall (mm)			Temperature (oC)		Rainfall (mm)	
Month	Max.	Min.	Total	Rainy days	Month	Max.	Min.	Total	Rainy days
October	24.5	13.5	109.0	9	March	26.5	15.8	22.2	3
November	22.7	13.8	114.0	9	April	24.3	14.5	69.7	8
December	25.8	14.4	127.0	5	May	26.8	16.1	53..6	3
January	26.1	14.7	117.0	7	June	28.4	14.8	0.0	
February	28.6	12.6	36.0	3	July	22.6	13.8	18.8	1
March	27.9	12.9	45.0	5	August	24.1	14.9	29.4	2
Mean	25.9	13.7			September	26.9	15.1	16.1	2
Total			548.0	38	Mean	25.7	15.0		
					Total			209.8	19

Nitrogen content was determined by Kjeldahl method as described by Nelson and Sommers (2010), while Ca, Mg, K and P were determined by the dry ashing method (Mubarak *et al*., 2002). Total P, K, Ca and Mg were determined from the $HClO_4$-HNO_3 digest by the molybdo-phosphoric blue colour method for P (Nelson and Sommers, 2010), flame emission for K, and EDTA titration for Ca and Mg. The Walkley-black was adapted for carbon (Nelson and Sommers, 2010).

Percent of dry matter and nutrient remaining at each stage of incubation was determined as the ratio of dry matter or nutrient at the stage of incubation to the initial content. Dry matter and nutrient disappearance rate constants were calculated, respectively, as the difference of percent dry matter and nutrient remaining between two consecutive sampling periods over time (Njunie et al., 2004).

Data analysis

Collected data were subjected to analysis of variance using SAS statistical package (SAS, 1993). Where the ANOVA gave significant F values, means were compared using the least significant difference (LSD) tests at p = 0.05.

Regression analysis was used to determine the relationship between decomposition rates of residues and carbon/nitrogen and lignin/nitrogen ratios.

Results

Nutrient composition of legume residues

Legume residues significantly differed in % hemicellulose, % lignin and lignin/nitrogen ratio but not in % cellulose and carbon/nitrogen ratio (Table 2). In both seasons, chickpea residue had significantly higher % hemicellulose and % lignin than butter bean residue. It also had significantly higher initial % lignin and lignin/nitrogen ratio than grass pea and common bean residues. Butter bean residue was comparable to grass pea residue in % hemicellulose, % lignin and lignin/nitrogen ratio and had significantly lower values of these parameters than common bean.

Legume residues significantly differed in magnesium content in both seasons and at all sampling periods but not in other nutrients (Table 3). Butter bean residue had significantly higher magnesium content than the other crop residues at all sampling periods in both seasons.

Decomposition and nutrient release of legume residues

Residue types significantly differed in dry matter disappearance rate at 0-2, 2-4, 10-12 and 12-14 weeks after incubation in 2007 SR season and at 0-2, 4-6, 10-12 and 12-14 weeks after incubation in 2008 LR season (Table 4).

Table 2. Initial % hemicellulose, % cellulose, % lignin, lignin/nitrogen ratio and carbon/nitrogen ratio of grass pea, butter bean, common bean and chickpea residues before incubation in 2007 short rains and 2008 long rains seasons.

Season	Crop residue	% hemicellulose	% Lignin	Lignin /N	Cellulose	C/N
2007 short rains season	Grass pea	19.58bc	4.50c	1.17c	33.93	13.02
	Butter bean	12.88c	4.05c	1.08c	25.51	11.46
	Common bean	27.01ab	6.83b	2.03b	36.91	15.62
	Chickpea	30.19a	10.26a	2.96a	37.38	16.69
	Mean	22.42	6.41	1.81	33.43	14.20
	LSD(p=0.05)	8.30	2.10	0.73	Ns	Ns
2008 long rains season	Grass pea	19.30ab	4.41bc	1.19bc	25.26	11.85
	Butter bean	12.75b	4.01c	1.11c	30.58	13.00
	Common bean	25.33a	6.27b	1.90b	33.35	15.45
	Chickpea	26.79a	9.13a	2.79a	33.55	16.99
	Mean	21.04	5.95	1.75	30.69	14.32
	LSD(p=0.05)	8.63	1.93	0.72	Ns	Ns

For each column, figures followed by the same letters are not significantly different using LSD p=0.05

Table 3. Magnesium content (m.e/100 g) of grass pea, butter bean, common bean and chickpea residues at various incubation periods in 2007 short rains and 2008 long rains season.

	Sampling period (weeks after residue incubation)							
Crop residue	0	2	4	6	8	10	12	14
2007 short rains season								
Grass pea	45.73b	45.58b	45.23b	44.99b	44.85b	44.77b	44.71b	44.67b
Butter bean	65.07a	64.86a	64.43a	64.15a	63.96a	63.86a	63.79a	63.74a
Common bean	39.57b	39.48b	39.30b	39.16b	39.08b	39.02b	39.00b	38.98b
Chickpea	35.20b	35.13b	35.06b	34.97b	34.92b	34.88b	34.86b	34.85b
Mean	46.39	46.26	46.00	45.82	45.70	45.63	45.59	45.56
LSD(p=0.05)	18.99	17.21	17.64	15.85	16.74	18.48	17.31	15.33
2008 long rains season								
Grass pea	43.92b	43.82b	43.65b	43.37b	43.26b	43.20ab	43.16b	43.13b
Butter bean	62.44a	62.30a	62.09a	61.76a	61.62a	61.54a	61.49a	61.45a
Common bean	36.91b	36.85b	37.41b	36.62b	37.89b	36.51b	36.49b	36.48b
Chickpea	29.59b	29.54b	29.48b	29.44b	28.08b	29.39b	29.38b	29.37b
Mean	43.21	43.13	43.16	42.80	42.71	42.66	42.63	42.61
LSD (p=0.05)	15.01	17.17	15.99	16.90	16.28	18.39	15.38	14.48

For each column, figures followed by the same letters are not significantly different using LSD p=0.05

Mean dry matter disappearance rate of grass pea residue was significantly higher than for all the other legumes while dry matter disappearance rate of butter bean residue was comparable to that of common bean residue and significantly higher than that of chickpea residue. Overall dry matter disappearance rate was in the order grass pea>butter bean>common bean>chickpea. Generally, nutrients disappearance rate constants were in the order K>P>N>Mg>Ca (Table 5 and 6).

Residue types significantly differed in nutrients disappearance rate constants at most incubation periods in both seasons. Averaged across the incubation periods, mean N and K release rates from grass pea residue were significantly faster than from other residue types while release rate from chickpea residue was significantly lower than from butter bean and common bean residues. Grass pea and butter bean residues were comparable in mean P, Mg and Ca release rates and had significantly higher values than common bean and chickpea residues. Mean P, Mg and Ca release rates from chickpea residue were significantly lower than from other residues.

Table 4. Dry matter disappearance rate constants (% week-1) of butter bean, grass pea, common bean and chickpea residues at various incubation periods in 2007 short rains and 2008 long rains seasons.

	Sampling period (weeks after residue incubation)							
Crop residue	0-2	2-4	4-6	6-8	8-10	10-12	12-14	Mean
				2007 short rains season				
Grass pea	0.64a	1.57a	0.92	1.23	0.72	0.33a	0.17a	0.80a
Butter bean	0.37b	1.25ab	0.75	0.95	0.68	0.28a	0.15ab	0.63b
Common bean	0.18bc	1.08bc	0.63	0.83	0.68	0.13b	0.09bc	0.52bc
Chickpea	0.11c	0.90c	0.52	0.83	0.54	0.13b	0.06c	0.44c
Mean	0.33	1.20	0.71	0.96	0.66	0.22	0.12	0.60
LSD (p=0.05)	0.19	0.35	Ns	Ns	Ns	0.13	0.06	0.12
				2008 long rains season				
Grass pea	0.41a	0.58	1.00a	0.80	0.47	0.21a	0.11a	0.51a
Butter bean	0.22b	0.47	0.79ab	0.61	0.44	0.18a	0.09ab	0.40b
Common bean	0.11bc	0.39	0.69b	0.54	0.44	0.08b	0.06bc	0.33bc
Chickpea	0.06c	0.33	0.58b	0.54	0.36	0.08b	0.04c	0.28c
Mean	0.20	0.44	0.76	0.62	0.43	0.14	0.07	0.38
LSD(p=0.05)	0.12	Ns	0.24	Ns	Ns	0.09	0.04	0.08

For each column, figures followed by the same letters are not significantly different using LSD p=0.05

Linear regression relationship between mean dry matter and nutrient disappearance rates and both C/N and lignin/nitrogen ratios were negative (Figure 1a, 1b, 2a and 2b). The R^2 values for the relationship between decomposition rates and lignin/nitrogen ratio were in most cases more than double of those between decomposition rate and C/N ratio.

Discussion

Nitrogen concentrations in all residue types were above the critical values (18-22 g/kg) required for the transition between net N immobilization and net mineralization (Palm *et al.,* 1997). Differences in decomposition and nutrient release rates among the residues could be attributed to differences in susceptibility to microbial degradation. The low P concentrations observed in chickpea and common bean residues may have affected decomposition of these residues as they were below the value of 2.5 g/kg required for net P mineralization in plant residues (Palm *et al.,* 1997).

Butter bean and grass pea residues experienced the most rapid decomposition partly because of their relatively lower lignin and lignin/nitrogen ratio. The slower decomposition and nutrient release from chickpea residue on the other hand may have been due to the higher lignin content and wider lignin/nitrogen ratio observed in the residue. Plant residues with high lignin/nitrogen ratios are reported to have lower decomposition rates (Morreto *et al.,* 2001; Smestad *et al.,* 2002). Lignins are relatively resistant fibres to decomposition (Heal *et al.,* 1997); therefore, high lignin content is reported to retard decomposition (Fosu, 2003).

The correlation coefficients (R^2 values) between C/N ratio and decomposition rates were lower than those between lignin/nitrogen ratio and decomposition rate suggesting that lignin/nitrogen ratio of the residues may have more impact on decomposition than C/N ratio. Frank *et al.* (2004) and Gorrisen and Cotrufo (2000) also indicate that residue C/N ratio is not a major determinant of decomposition rate but rather an indicator of residue quality.

Table 5. Nutrient disappearance rate constants (% week^{-1}) of grass pea, butter bean, common bean and chickpea residues in 2007 short rains season.

Nutrient /Residue	Sampling period (weeks after residue incubation)							Mean
	0-2	2-4	4-6	6-8	8-10	10-12	12-14	
				Potassium				
Grass Pea	0.46a	0.87a	0.62a	0.30a	0.21a	0.16a	0.15a	0.39a
Butter bean	0.29b	0.70a	0.45b	0.21ab	0.18ab	0.20ab	0.15a	0.31b
Common bean	0.22c	0.46b	0.28c	0.14b	0.13b	0.11b	0.09b	0.21c
Chickpea	0.12d	0.16c	0.22c	0.14b	0.12b	0.12b	0.09b	0.14d
Mean	0.27	0.55	0.39	0.20	0.16	0.15	0.12	0.26
LSD(p=0.05)	0.05	0.18	0.12	0.09	0.06	0.06	0.03	0.05
				Phosphorus				
Grass Pea	0.33a	0.66a	0.44a	0.27a	0.19	0.15a	0.13	0.31
Butter bean	0.29ab	0.57ab	0.40ab	0.27a	0.17	0.14a	0.13	0.28
Common bean	0.21bc	0.41b	0.32bc	0.22ab	0.16	0.10b	0.08	0.21
Chickpea	0.16c	0.21c	0.24c	0.17b	0.14	0.09b	0.08	0.16
Mean	0.25	0.46	0.35	0.23	0.17	0.12	0.10	0.24
LSD(p=0.05)	0.10	0.19	0.10	0.06	NS	0.02	0.02	0.04
				Nitrogen				
Grass Pea	0.21a	0.43a	0.30a	0.15a	0.09a	0.07ab	0.06a	0.19a
Butter bean	0.15b	0.35b	0.23b	0.12a	0.08ab	0.08a	0.06a	0.15b
Common bean	0.11c	0.23c	0.16c	0.07b	0.06bc	0.04bc	0.03b	0.10c
Chickpea	0.07d	0.10d	0.11c	0.07b	0.05c	0.05c	0.03b	0.07d
Mean	0.14	0.28	0.20	0.10	0.07	0.06	0.05	0.13
LSD(p=0.05)	0.02	0.06	0.06	0.04	0.03	0.02	0.02	0.02
				Magnesium				
Grass Pea	0.17	0.40a	0.25	0.15a	0.09	0.07a	0.05a	0.17a
Butter bean	0.15	0.34ab	0.22	0.15a	0.08	0.05ab	0.04a	0.15a
Common bean	0.11	0.24bc	0.19	0.10b	0.07	0.03bc	0.02b	0.11b
Chickpea	0.10	0.10c	0.14	0.08b	0.05	0.03c	0.02b	0.07c
Mean	0.13	0.27	0.20	0.12	0.07	0.05	0.03	0.12
LSD(p=0.05)	NS	0.15	NS	0.05	NS	0.02	0.02	0.02
				Calcium				
Grass Pea	0.14a	0.19a	0.14a	0.09	0.09	0.07	0.07a	0.11a
Butter bean	0.12ab	0.16ab	0.14a	0.09	0.08	0.07	0.07a	0.10a
Common bean	0.08bc	0.13b	0.10b	0.10	0.07	0.06	0.05b	0.08b
Chickpea	0.06c	0.09c	0.09b	0.07	0.08	0.06	0.05b	0.07c
Mean	0.10	0.14	0.12	0.09	0.08	0.06	0.06	0.09
LSD(p=0.05)	0.06	0.04	0.04	NS	NS	NS	0.01	0.01

Figures in the same column followed by the same letters are not significantly different using LSD p=0.05. Ns= not significant.

The observed order of nutrient release rates (K > P > N > Mg > Ca) indicates that planting time is crucial to synchronize nutrient release with plant nutrient uptake.

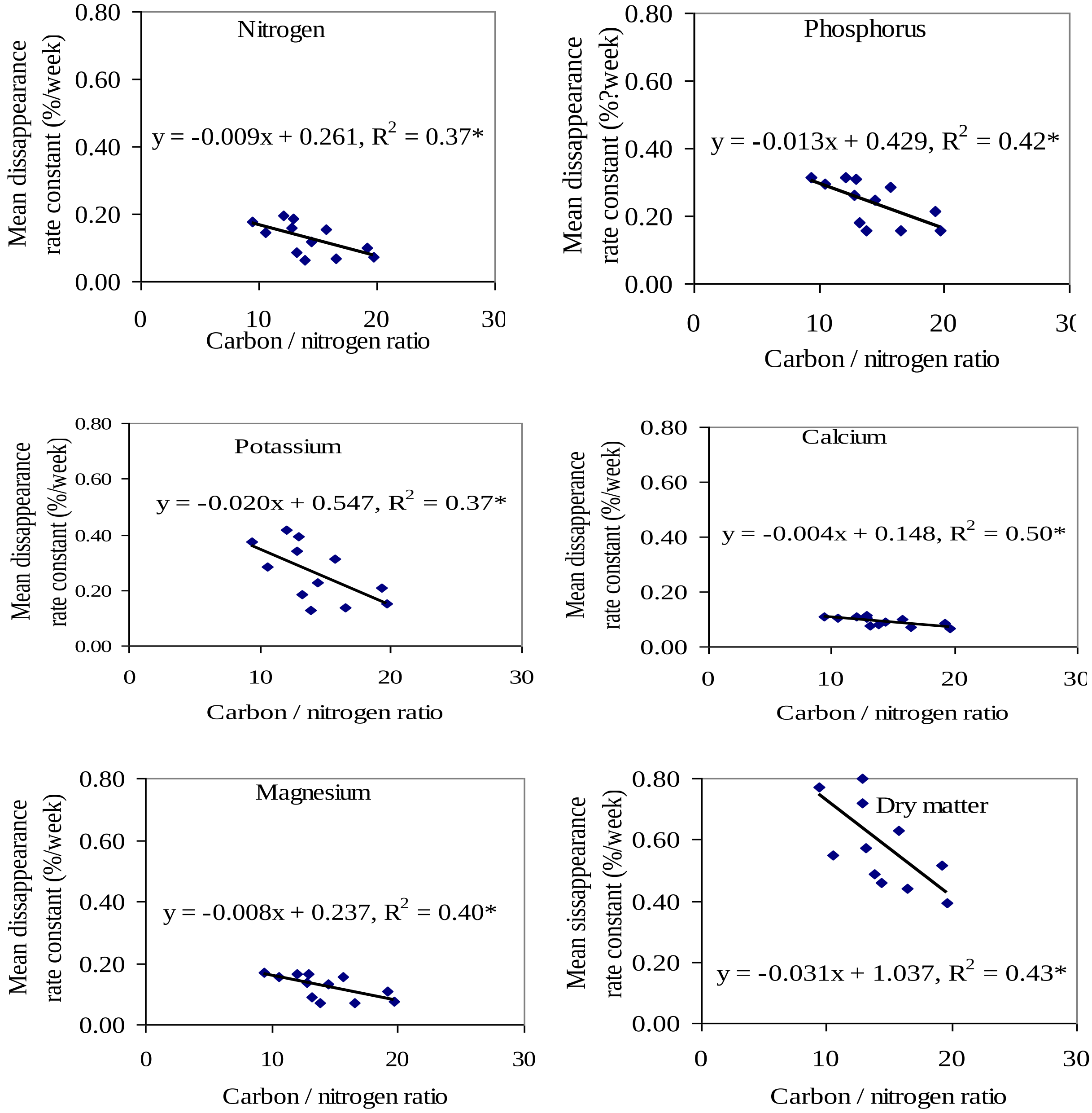
Table 6. Nutrient disappearance rate constants (% week-1) of grass pea, butter bean, common bean and chickpea residues in 2008 long rains season.

Nutrient /Residue	Sampling period (weeks after residue incubation)							Mean
	0-2	2-4	4-6	6-8	8-10	10-12	12-14	
				Potassium				
Grass Pea	0.29a	0.39a	0.54a	0.19a	0.14a	0.11ab	0.10a	0.25a
Butter bean	0.19b	0.28b	0.44a	0.14ab	0.12ab	0.14a	0.10a	0.20b
Common bean	0.14c	0.18c	0.29b	0.09b	0.09b	0.08b	0.07b	0.14c
Chickpea	0.09d	0.15c	0.10c	0.09b	0.09b	0.09b	0.07b	0.10d
Mean	0.18	0.25	0.34	0.13	0.11	0.11	0.09	0.17
LSD (p=0.05)	0.04	0.07	0.13	0.06	0.04	0.04	0.02	0.03
				Phosphorus				
Grass Pea	0.23a	0.29a	0.43a	0.18	0.14	0.11a	0.10a	0.21a
Butter bean	0.20ab	0.27ab	0.36ab	0.18	0.12	0.11a	0.10a	0.19a
Common bean	0.14bc	0.21bc	0.27b	0.16	0.12	0.08b	0.07b	0.15b
Chickpea	0.11c	0.17c	0.15c	0.12	0.11	0.08b	0.07b	0.11c
Mean	0.17	0.23	0.30	0.16	0.12	0.09	0.08	0.17
LSD (p=0.05)	0.06	0.07	0.10	Ns	Ns	0.02	0.01	0.02
				Nitrogen				
Grass Pea	0.17a	0.23a	0.34a	0.11a	0.07a	0.05ab	0.05a	0.15a
Butter bean	0.11b	0.18b	0.27b	0.08ab	0.06ab	0.07a	0.05a	0.12b
Common bean	0.08b	0.11c	0.18c	0.05b	0.04b	0.03c	0.03b	0.08c
Chickpea	0.04c	0.08c	0.07d	0.05b	0.04b	0.04bc	0.03b	0.05d
Mean	0.10	0.15	0.21	0.07	0.06	0.05	0.04	0.10
LSD(p=0.05)	0.03	0.05	0.06	0.04	0.02	0.02	0.01	0.02
				Magnesium				
Grass Pea	0.12	0.19	0.31a	0.12a	0.07a	0.05a	0.03a	0.13a
Butter bean	0.10	0.14	0.20ab	0.12ab	0.06a	0.04ab	0.03a	0.10a
Common bean	0.08	0.14	0.18bc	0.08bc	0.06ab	0.03bc	0.02b	0.08b
Chickpea	0.08	0.11	0.06c	0.06c	0.04b	0.02c	0.02b	0.05c
Mean	0.09	0.14	0.19	0.10	0.06	0.03	0.02	0.09
LSD(p=0.05)	Ns	Ns	0.12	0.04	0.02	0.02	0.01	0.02
				Calcium				
Grass Pea	0.07	0.11a	0.16a	0.06	0.04	0.03	0.02a	0.07a
Butter bean	0.06	0.10a	0.14ab	0.06	0.03	0.02	0.02a	0.06a
Common bean	0.05	0.08a	0.09bc	0.04	0.03	0.01	0.01b	0.04b
Chickpea	0.03	0.04b	0.06c	0.04	0.02	0.02	0.01b	0.03c
Mean	0.05	0.08	0.11	0.05	0.03	0.02	0.02	0.05
LSD(p=0.05)	Ns	0.03	0.06	Ns	Ns	24.03	0.01	0.01

Figures in the same column followed by the same letters are not significantly different using LSD p=0.05. Ns= not significant

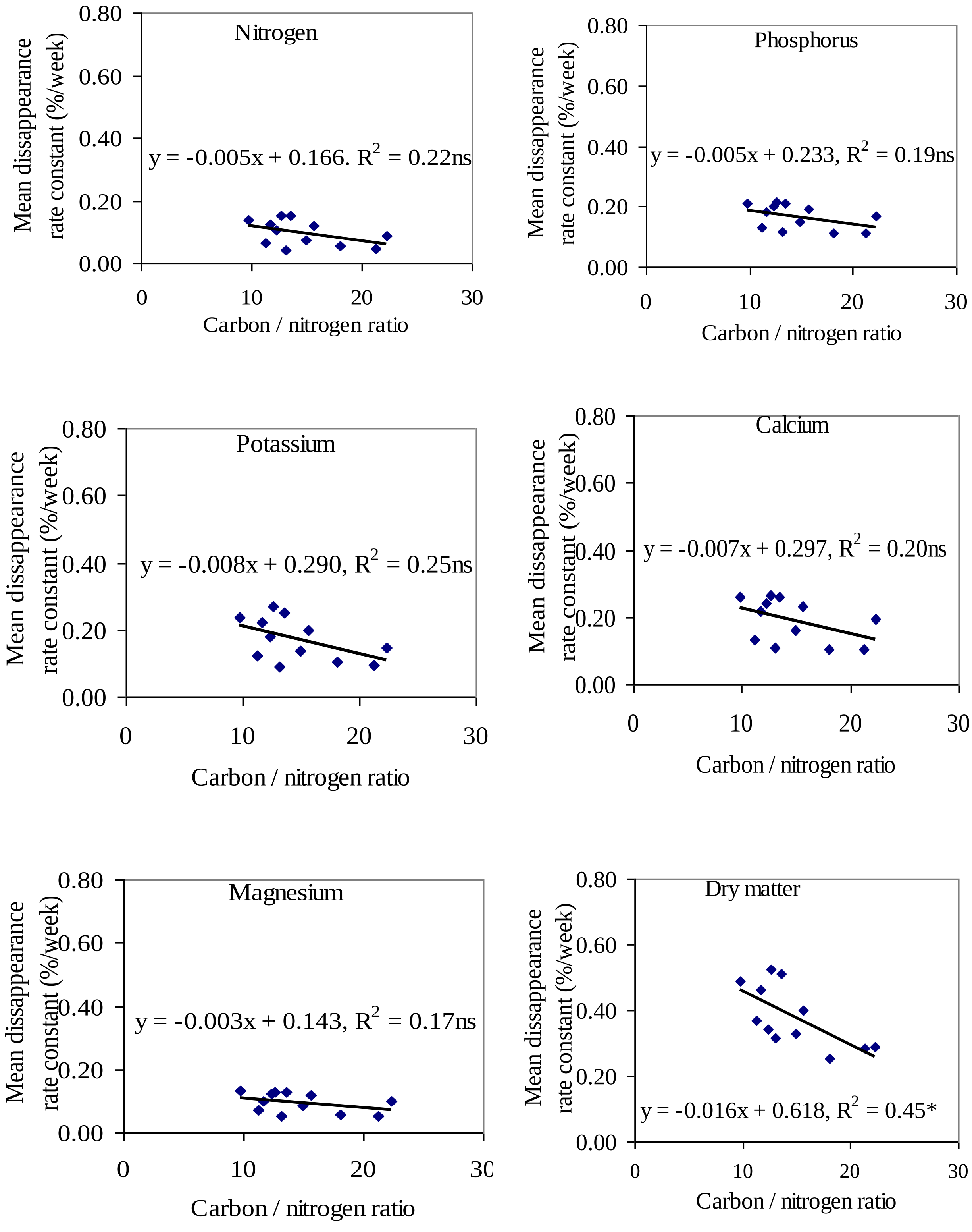
The order is similar to that reported for maize stover and groundnut haulm in Malaysia of K ≥ P = N = Mg ≥ Ca (Mubarak *et al.,* 2002), but differs from those reported for crotalaria and dolichos residues in Kenya of K > P > Mg > N and K > Mg > P > N, respectively (Njunie *et al.,* 2004).

The higher rate of residue decomposition observed in the 2007 short rains season trial could most likely have been due to higher rainfall (548 mm) received during this season than during the 2008 long rains trial (209.8 mm). Increased residue decomposition rates due to improved soil moisture have been reported by several researchers (Insam, 1990; Stot *et al.,* 1986; Wagger, 1989).



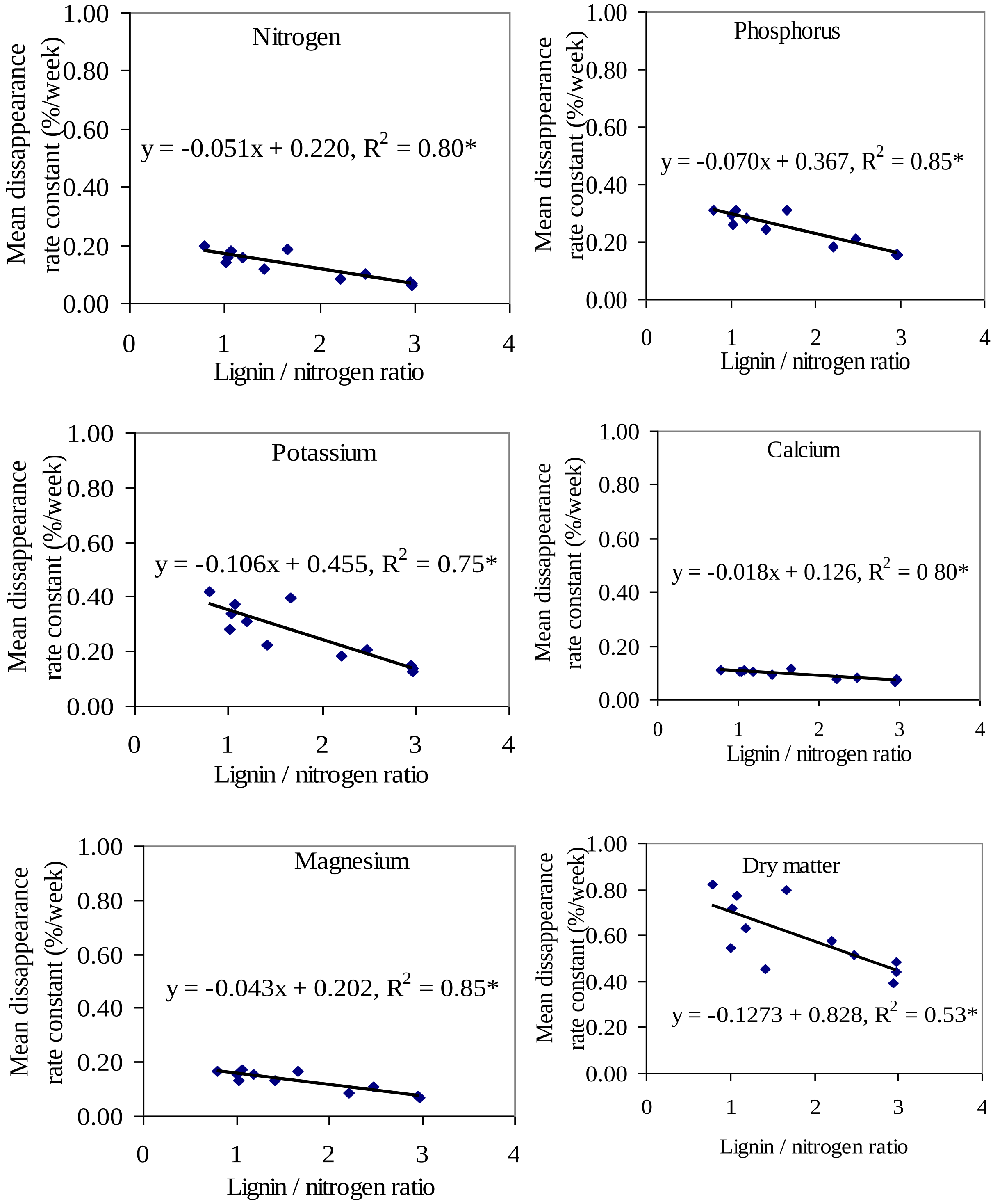
*significant at *p*=0.05

Fig. 1a Linear regression curves describing the relationship between decomposition rates and carbon/nitrogen ratio of grass pea, butter bean, chickpea and common bean residues in 2007 SR season.



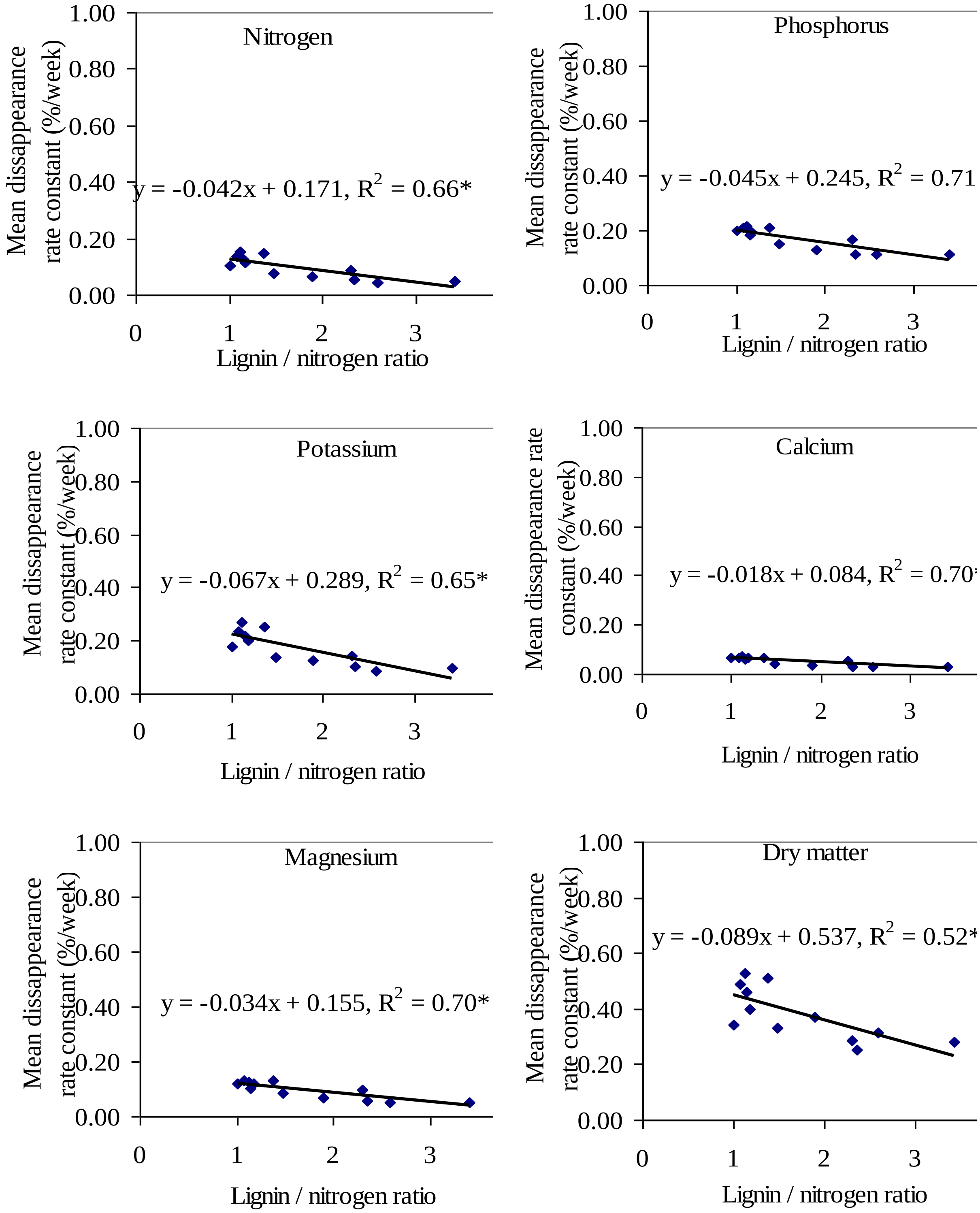
*significant at *p*=0.05, ns=not significant

Fig.1b. Linear regression curves describing the relationship between decomposition rates and carbon/nitrogen ratio of grass pea, butter bean, chickpea and common bean residues in 2008 LR season.



*significant at p=0.05

Fig. 2a. Linear regression analyses curves describing the relationship between decomposition rates and lignin/nitrogen ratio of grass pea, butter bean, chickpea and common bean residues in 2007 SR season.



*significant at p=0.05

Fig. 2b. Linear regression analyses curves describing the relationship between decomposition rates and lignin/nitrogen ratio of grass pea, butter bean, chickpea and common bean residues in 2008 LR season.

Conclusion

Potentially butter bean and grass pea residues through their decomposition can provide N, P, K and Mg to cropping systems in the cold semi-arid region. Chickpea residue has slower nutrient release rates compared to other residues which may also be desirable as there may be fewer opportunities for nutrient loss during the non-growing periods.

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