



ORIGINAL ARTICLE

Decomposition and Nutrient Release from Wheat and Guar Residues Using the Litterbag Method

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Abstract

Recycling of crop residues is essential to maintain integrated and sustainable agricultural management system. Thus, it is of crucial importance to study the decomposition of crop residues particularly in arid tropics. A litterbag experiment was carried out during June - August 2010 on a sandy soil at the experimental farm of Omdurman Islamic University, Omdurman, Sudan. Such an area (15°19.9 N, 32°39'E, and with an elevation of 381 m above the sea level) lies within the arid zone of the country. Straw from wheat (*Triticum aestivum*) and residue from guar (*Cyamopsis tetragonoloba*) were placed inside nylon 2 mm mesh bags (20 cm X 10 cm) and buried in the soil (5 cm below surface) in the field with a wheat-guar rotation system. A total of 24 bags for wheat and equal number for guar residues were placed in a field plot. Four bags of each residue type were retrieved at 2, 4, 6, 8, 10 and 12 weeks of decomposition. The decomposed tissues were analyzed for remaining dry matter weight (DMW), nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) contents. According to results, dry matter disappearance rate constant (0.0388% week⁻¹) from guar was significantly $P \leq 0.0001$ faster than that from wheat residue (0.0285% week⁻¹). A 50% loss of N content was attained after 14.44 days and 8.43 days, for wheat and guar residues, respectively. Generally, nutrients released from both residues was in the order of Mg > K = N > P > Ca. It is concluded that sowing time of subsequent crop after residue application is crucial to synchronize nutrient release with plant uptake.

Keywords: Cropping systems, residues management, poor sandy soil, nutrient cycling and arid-tropics.

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Introduction

Increasing the knowledge of crop residue decomposition and nutrient release is important for nutrient recycling and soil organic matter formation. Incorporation of crop residues with high C/N ratio,

immobilize N during decomposition in soil, thus reducing N losses through leaching (Muhammad *et al.*, 2011). Recycling of crop residues is important since crop residues in developing countries contain nutrients that are seven to eight times higher than

quantities of these nutrients applied as fertilizers (Poulain, 1980). For such studies, the litterbag method which was earlier developed by Bock and Gilbert (1957) is still considered to be a useful approach under field conditions (Knacker *et al.*, 2003 and Joergensen *et al.*, 2009). The important advantage of this method is the relatively simple recovery of litter transferred to the field and the possibility of excluding specific groups from the decomposition process (Joergensen *et al.*, 2009). Synchronizing soil N availability with plant requirements improves the soil-plant system N use efficiency and reduces N losses through leaching below the crop rooting depth and/or from gaseous emissions (Vanlauwe *et al.*, 2001). Kaewpradit *et al.* (2009) reported that mixing groundnut (*Arachis hypogaea* L.) residues and rice (*Oryza sativa* L.) straw could delay N release during the pre-rice lag phase, leading to an improved synchrony in N demand/ supply, increased growth and yield of the succeeding rice crop and reduced N losses from the soil-plant system. The high cost of mineral fertilizers, their limited availability and possible leaching loss, especially nitrates, in the arid-tropics has generated an interest in cropping system that rely more on crop residue recycling.

Substrate quality predictors of decomposition have been reported by several researchers to be governed by many factors, of which C to N ratio (Trinsoutrot *et al.*, 2000), lignin content (Hofmann *et al.*, 2009) and polyphenol (Chaves *et al.*, 2005), are important.

Most studies on decomposition had concentrated on plant litters in the temperate region; those from field crop residues are rare (Kaboneka and Wayne, 1995). Under the arid-tropics of Sudan, most results are from studies on decomposition and nutrients

release concentrated on either tree litter (Mubarak *et al.*, 2008a, and Mubarak and Badr Eldin 2009) or other residues like water hyacinth (Mubarak *et al.*, 2008b), but those from crop residues are greatly lacking. A long-term experiment has been conducted to study the role of crop residue recycling in sustaining yields of wheat and guar in a rotation system. Such a study involved incorporation of guar and wheat residues after harvest (Rezig *et al.*, 2012; Rezig *et al.*, 2013a; Rezig *et al.*, 2013b, and Rezig *et al.*, 2014). Therefore, the objectives of this work were to monitor the decomposition of wheat and guar residues remained from the previous work, and to determine nutrients (N, P, K, Ca, and Mg) release pattern.

Materials and Methods

A study site

An experiment to determine the decomposition of wheat and guar residues with litterbags was carried out from June to August 2010 at the experimental farm (15°19.9 N, 32°39'E, and with an elevation of 381 m above the sea level) of Omdurman Islamic University, Omdurman, Sudan. The data of rainfalls regarding this area was taken from Khartoum Metrological Station.

The experiment

This experiment was conducted to study the role of crop residue recycling of wheat and guar in a crop rotation system. A litterbag experiment was carried out from June to August (2010) to compare the decomposition of wheat (*Triticum aestivum*) and guar (*Cyamopsis tetragonoloba*) residues in irrigated field during the guar crop period. The wheat plants were cut 2 to 5 cm above the ground and only stems and leaves (straw) were retained for the study, while for guar the whole plant was used in the study after removal of roots. The chemical composition of the residues is given in table 1.

Table 1. Chemical composition of wheat and guar residues remained at the experimental farm of the Omdurman Islamic University, during June 2010.

Residue type	P	N	K	Ca	Mg	C	C/N	Lignin	Cellulose	Hemicelluloses	Polyphenol
	mg kg ⁻¹	g kg ⁻¹						%	%		
Wheat	11.0	7	9.8	3.4	1	41.3	59	22.3	34.4	15.7	0.121
Guar	72.0	19	25.5	14.2	11.1	29.7	15.6	10.9	19.6	15.6	0.151

Decomposition (mass loss) of the wheat and guar residues and nutrients release was monitored in the field using the litterbags method (Anderson and Ingram, 1998). Leaves and stems of gaur or wheat straw were cut into small pieces of about 5 cm length, sun dried to a constant weight, after which samples of 50 g each were transferred into litterbags of 2 mm nylon mesh with size of 20 cm X 10 cm. The bags were sewn with nylon thread with one sided left unsealed to ease accessibility by fauna. The litterbags were distributed randomly in the field, but at equidistant between ridges in the first week of June 2010. Some chemical properties of the soil were shown in table 2. The litterbags were numbered and buried 5 cm below the ridge top in direct contact with the soil, so that the experiment was arranged in a Randomized Complete Block design with four replications. In each plot, 12 litterbags were buried, the total number of litterbags used were 48 (2 crop residues X 4 replicates X 6 periods of residue retrieval).

The growing guar plants were left standing for the duration of the experiment for three months and harvested manually in September 2010. The experiment was terminated 7 days after crop harvest. Four litterbags from each residue type were retrieved at 2, 4, 6, 8, 10, and 12 weeks intervals after burying of the residues. The bags were carefully removed and put into paper envelopes and taken to the laboratory for analysis. The content of the retrieved litterbag was quantitatively emptied in a sieve and the extraneous materials, such as soil, visible animals and fine roots were removed. The remaining materials were oven-dried at 65-70 °C for 48 h for constant weight. The dry weight was taken and used

to determine the weight loss due to decomposition. The remaining materials were ground to pass 1 mm sieve for chemical analysis. The ground samples were analysed for Nitrogen (Bremner and Mulvaney, 1982), P, K, Ca and Mg (Chapman and Pratt, 1961).

Statistical analysis

The percentage of Dry Matter Remaining (DMR) in each bag was calculated using the following equation:

$$DMR = (W_t/W_o)*100$$

W_t = Weight (g) remained after each sampling week.

W_o = Initial weight (g) which is potentially decomposable.

The data for dry mass remaining from each residue was fitted to a negative exponential model (Olson, 1963): Exponential decomposition models have been extensively used to describe the decomposition of litter in litterbags:

$$W_t = W_o e^{-kt}$$

Where W_o = initial residue weight at time zero.

W_t = litter remaining after a given time(t).

t = time interval of sampling expressed in weeks.

k = rate constant (decomposition rate constant per week).

e = base of natural logarithmic.

Nutrients contents (N, P, K, Ca and Mg) of decomposing crop residue were determined by the following equation:

% remaining element =

$$(W_t/W_o)*(C_t/C_o)*100$$

Table 2. Some chemical properties of the soil of the experimental site, Omdurman Islamic University farm (June-August 2010).

pH	TN	TMN	O.C	CEC	Ca	Mg	K	P
	%			cmol _c kg ⁻¹	Meq L ⁻¹			mg kg ⁻¹
8.38	0.20	0.065	0.23	19.15	4.20	2.88	2.60	7.46

Note, TMN: total mineral nitrogen.

Where W_t was the remaining mass at time t (in weeks), W_0 was the initial weight of the litter, C_t was the concentration of element in decomposing litter at the time of sampling, C_0 was the initial concentration of element. The regressions of $\ln(W_t/W_0)$ over time were performed separately for each set of litterbags in each plot to provide independent estimates of k and R^2 for each crop residue. Further, the time required for 50% (t_{50}) and 95% (t_{95}) decay were calculated as $t_{50} = 0.693/k$ and $t_{95} = 3/k$, respectively. Statistical difference between the two-residue types was determined by subjecting the data to t-test analysis using the SAS program.

Results and Discussion

1. Mass loss

Figure 1 shows percents of initial dry matter remained from the residue of wheat and guar during the decomposition period. After two weeks, the dry matter weight remained in guar residues (96.7%) was significantly ($P \leq 0.0002$) lower than that of wheat (99.7%). After the end of the incubation period (90 days), 38.7% of guar residues and 26.7% of wheat residues had decomposed. The single exponential model was found the best among other models to describe decomposition of crop residues (Table 3). Accordingly, fifty

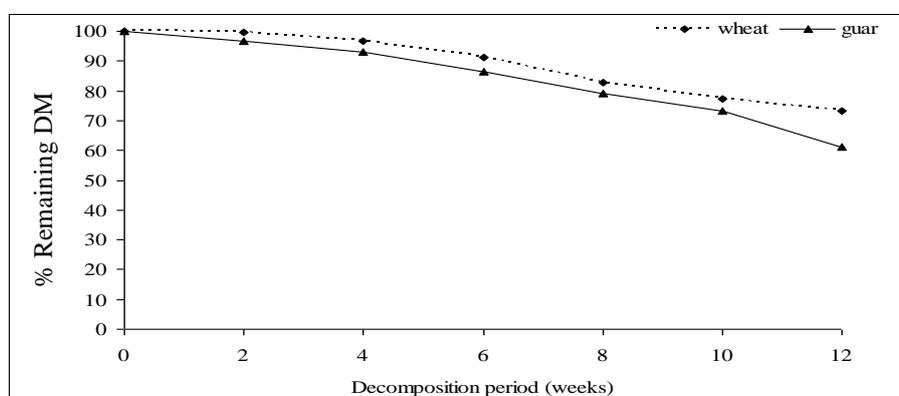


Figure 1. Dry matter (DM) weight (% of original content) remaining during decomposition of guar and wheat residues, Omdurman Islamic University farm (June-August 2010).

Table 3. Decomposition rate constant (k), R^2 , half-life ($T_{0.50}$), $T_{0.95}$ and nutrient pool (W_0) for nutrient released from wheat and guar residues, June-August 2010, Omdurman Islamic University Farm.

Crop residue type	Nutrient	k (wk^{-1})	R^2	$T_{0.50}$ (days^{-1})	$T_{0.95}$ (days^{-1})	W_0
Wheat	DM	0.0285	0.95	24.32	105.29	104.58
	N	0.048	0.93	14.44	62.54	108.13
	P	0.041	0.94	16.97	73.46	104.58
	K	0.0523	0.84	13.27	57.44	110.25
	Ca	0.044	0.98	15.80	68.41	101.88
	Mg	0.073	0.93	9.53	41.25	106.68
Guar	DM	0.0388	0.94	17.89	77.43	105.13
	N	0.082	0.94	8.43	36.48	112.55
	P	0.060	0.94	11.56	50.02	108.03
	K	0.081	0.92	8.56	37.06	112.45
	Ca	0.059	0.94	11.70	50.64	108.75
	Mg	0.092	0.92	7.54	32.62	115.4
Probability	DM	0.0001	0.0498	0.0001	0.0001	0.0075
	N	0.0001	0.0138	0.0001	0.0001	0.0001
	P	0.004	0.541	0.0027	0.0027	0.0190
	K	0.0001	0.0001	0.0001	0.0001	0.0012
	Ca	0.0017	0.0096	0.004	0.0040	0.009
	Mg	0.0041	0.0422	0.0091	0.0091	0.014

percent mass losses were attained after 17.76 and 24.24 weeks of decomposition for guar and wheat residues, respectively (Table 3). Generally, carbon decomposition followed the same trend as dry matter disappearance. The total annual rainfall in the study area was 250.00 mm. Therefore, possibly it may result in heavy losses of the soluble components from the substrates during the decomposition period.

The results of this study support the findings of Parson *et al.* (1990) who attributed the initial rapid mass loss to the removal of the water-soluble compounds like reduced sugars, phenols and amino acids. Dry matter disappearance rate from guar (C/N = 15.6) was 0.0388% week⁻¹ faster than that from wheat residues 0.0285% week⁻¹ (C/N = 59).

Generally, organic materials with low C/N ratios decomposed faster compared to high C/N ratio residue (Somda and Powell, 1998; Mubarak *et al.*, 2002; Muhammad *et al.*, 2011, and Rottmann *et al.*, 2011). Faster rate of decomposition could be attributed to higher amounts of soluble C and N in residue with low C/N ratio (Reinertsen *et al.*, 1984). Under similar environmental conditions, Mubarak *et al.* (2008a) reported dry-matter weight loss from guava, mango, *Leuceana leucocephala*, *Eucalyptus microtheca* and *Ficus* spp. of 0.098, 0.04, 0.053, 0.0522 and 0.044 week⁻¹, respectively. However, lately Mubarak and Badr Eldin (2009) reported a decomposition

(16 weeks) rate from *Prosopis* spp., and *Azadirachta indica* of 0.25 and 0.12 week⁻¹, respectively. Differences in decay rate are controlled by many factors including residue quality (Zhang *et al.*, 2008), particle size (Cabiles *et al.*, 2008) and environmental conditions (Cornejo *et al.*, 1994).

2. Nutrient release pattern

Nitrogen: The pattern of nitrogen (N) release was illustrated in Fig. 2. After two weeks of decomposition, 94.29 and 97.66% of the initial N contents remained in the guar and wheat residues, respectively. An amount of 50% N loss from guar and wheat residues was attained after 8.43 and 14.44 days while at the end of the period, 38.07 and 55.98% of initial N contents of guar and wheat residues were remained, respectively. Statistically, N release rate from guar residues during the 12 weeks of decomposition (0.082% week⁻¹) was significantly ($P \leq 0.0001$) higher than, and almost close to doubling of, the N release rate from wheat residues (0.048% week⁻¹). The faster released rate of N from guar residues as compared with wheat residues could be attributed to the higher initial N content and lower C/N ratio of the guar residues (Frankenberger and Abdelmagid, 1985). A decomposition study carried out by Pare and Gregorich (1999) showed N mineralization from alfalfa residues (C/N = 13), N was faster compared to maize (C/N = 81) and soybean (C/N = 26) residues. The N release rates in this study are

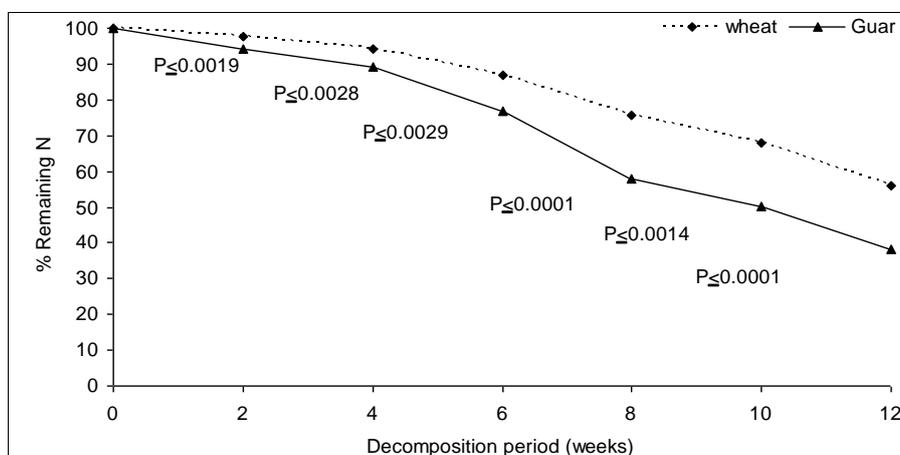


Figure 2. Nitrogen remaining (% of original contents) during decomposition of guar and wheat residues, Omdurman Islamic University farm (June-August 2010).

within the range recorded in other studies (0.098 to 0.035% Week⁻¹) from guava and mango trees (Mubarak *et al.*, 2008a). However, high N release rates constants (0.201 to 0.120% Week⁻¹) were reported for groundnut and maize, respectively (Mubarak *et al.*, 2002). This discrepancy might be due to the variations in chemical composition of the residues or climatic conditions. The absence of significant net N immobilization and the continuous decrease in N content along with decomposition is consistent with the studies conducted elsewhere (Swift *et al.*, 1981; Upadhy and Singh, 1985, and Palm and Sanhchez, 1990).

Phosphorous: Phosphorous release pattern is shown in Fig. 3. After two weeks, 95.85 and 96.75% of the initial P remained in the guar and wheat residues, respectively. At the end of the period, 48.39% and 62.1% of initial P remained in guar and wheat residues, respectively. Fifty percent of P release from guar and wheat was attained after 11.50 and 16.68 days (Table 3). After week four through the end of the study period, the release of phosphorous from guar was significantly ($P \leq 0.003$) higher than from wheat residues. The exponential model (Table 3) showed that P release rate constant from guar residues (0.06 wk⁻¹) was significantly ($P \leq 0.004$) higher than that of wheat residue (0.041 wk⁻¹). Both residues showed no period of P immobilization during decomposition. Tian *et al.* (1992) reported that residues high in P decompose faster and release more P within a shorter period. Lupwayi *et al.* (2003) in a litter bag experiment found that green manure field pea released significantly higher P than wheat. The authors attributed the higher release of P from field pea to its P content and the ease of decomposition. Unlike C: N ratio the critical C: P ratio reported in the literature vary widely, ranging from as low as 55 to as high as 1000 (Chelsie and Chapman, 1996, and Saggar *et al.*, 1998). Therefore, it is difficult to interpret the specific role of C: P ratio in relation to P decomposition. The organic P fraction might be more in the fresh guar than in the wheat

residues. Organic P was found to constitute 40 to 60% of the total P in selected grass and legumes (Jones and Bromfield, 1969).

Potassium: Potassium release patterns were significantly different between the two residues (Fig. 4). During the entire decomposition period, potassium release was very rapid. After 6 weeks, 74.9 and 88.1% of the initial contents of guar and wheat residues remained in the litterbags. Fifty-percent loss was reached after 8.56 and 13.27 days for guar and wheat, respectively. At the end of the study period, only 36.24 and 50.08% of the initial K contents were left from guar and wheat residues, respectively. The K release rate constant from guar residues (0.081 wk⁻¹) was significantly ($P \leq 0.0001$) faster than that of wheat residue (0.0523 wk⁻¹). These release patterns indicate high solubility of K. Potassium is not a structural component of the cell and exists mainly in solution in plant cells (Christensen, 1985). Similar results were reported elsewhere (Attiwell, 1968; Christensen, 1985; Mubarak *et al.*, 2000, and Mubarak *et al.*, 2002).

Calcium and magnesium: Calcium and Magnesium release patterns are shown in Fig. 5 and 6, respectively. The release of Ca from both residue types was slow compared to N, K, and P. After 8 weeks, the percent of Ca remained (68.92%) in the guar residues was significantly ($P \leq 0.02$) lower than that remained (70.71%) in wheat residues. Fifty-percent release of Ca was attended after 11.7 and 15.80 days for guar and wheat residues, respectively, whereas, 50% of Mg release was attained after 7.54 and 9.53 days for guar and wheat residues, respectively. At the end of the study period, Ca remained in guar and wheat was 49.21 and 60.86% while remaining Mg was 34.79 and 43.95%, respectively. Both residues showed higher release rates of Mg than Ca. Calcium was the slowest nutrient in terms of mobility that could be attributed to its linkage with the cell wall constituents (Attiwell, 1968). The general order of nutrient release from guar residues was Mg > K=N > P > Ca while that from wheat residues was Mg > K=N > Ca > P.

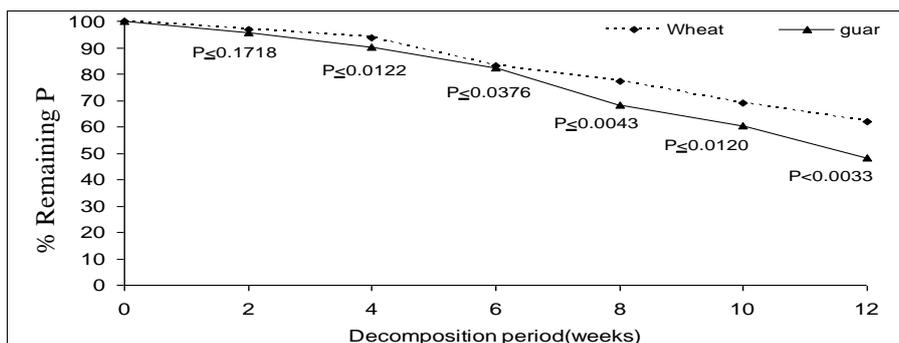


Figure 3. Phosphorous remaining (% of original contents) during decomposition of guar and wheat residues, Omdurman Islamic University farm (June-August 2010).

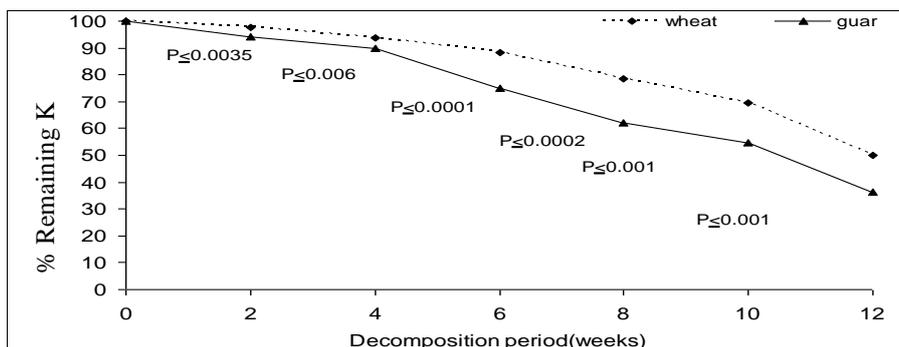


Figure 4. Potassium remaining (% of original contents) during decomposition of guar and wheat residues, Omdurman Islamic University farm (June-August 2010).

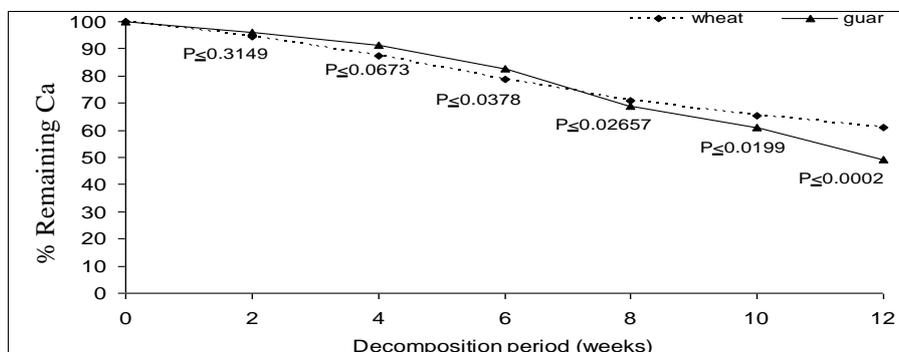


Figure 5. Calcium remaining (% of original contents) during decomposition of guar and wheat residues, Omdurman Islamic University farm (June-August 2010).

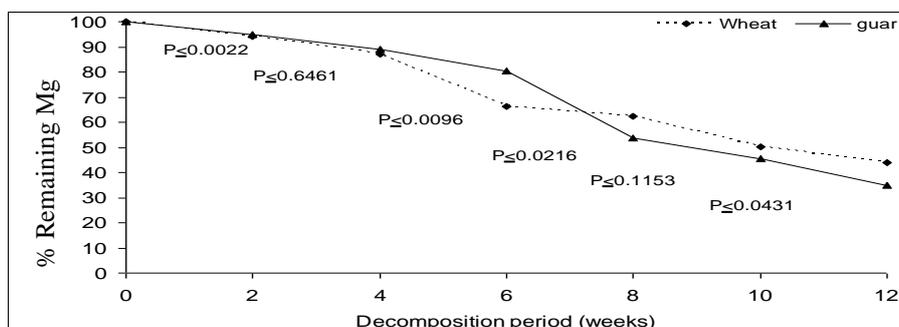


Figure 6. Magnesium remaining (% of original contents) during decomposition of guar and wheat residues, Omdurman Islamic University farm (June-August 2010).

3. Implications on residue management

The results of this study showed differences in the nutrient release rates of the two plants residues. Therefore, it seems important, particularly in cropping systems, where crop residues are returned, to estimate the nutrient pools of the residues in the same manner as that explained in table 1. These are quite useful in synchronizing nutrient release with uptake by subsequent crops. Nitrogen being the most important element, its maximum pool released from both crop residues was approximated after 8 weeks from residue application. Generally, the highest proportions of nitrogen released after residue application were between 2 to 6 weeks for guar and 2 to 8 weeks for wheat residues. These results indicate that a shorter fallow period after guar residue application is necessary to optimize N uptake by subsequent crop, compared to wheat residue.

Conclusion

Shortly (two weeks) after incorporating guar residues, an equivalent of 18.65 g N kg⁻¹ guar residue was readily available. This constituted about 45% of the recommended N applied as inorganic fertilizer at sowing for the subsequent crop of wheat. Similarly, 6.85 g N kg⁻¹ wheat residue was readily available after wheat residue application; this constituted about 23% of the recommended inorganic N fertilizer applied at sowing for the subsequent crop of guar. In the arid tropic of Sudan, decomposition of crop residues was relatively fast, the fallow period may be long (4 months) as observed in this experiment which renders considerable amounts of nutrients to be lost before the peak demand of the subsequent crop. Therefore, this fallow period theoretically should be customized to three month after guar and five month after wheat residue application for maximum utilization of nutrient released. Further research is needed to study the effect of residue management on nutrient availability and efficient utilization by proceeding crops.

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