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ORIGINAL RESEARCH

Decomposition and nutrient release pattern of wheat (*Triticum aestivum*) residues under different treatments in desert field conditions of Sudan

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Abstract
Background Recycling of crop residues is essential to sustain soil fertility and crop production. Therefore, it is of crucial importance to study the decomposition of crop residues particularly in the arid tropics. The decomposition and nutrient release pattern from crop residues incorporated in the soil have rarely been investigated under semi-arid climatic conditions in Sudan. Decomposition and nutrient release pattern from wheat residue were investigated in a 12 week litter bag experiment under field condition. Litter bags contain 50 g wheat residue were buried in plots cultivated with guar and treated with following treatments: crop residue (CR), recommended fertilizer + crop residue (RF + CR), sewage sludge (SS) and non treated control (C). In each plot of each block, 12 litter bags were buried. Four bags from each treatment were retrieved at 2, 4, 6, 8, 10 and 12 weeks of decomposition. The decomposed residue was analysed for remaining dry matter (DM), nitrogen (N), phosphorus (P), potassium (K) calcium (Ca), and magnesium (Mg) contents. Mass loss and nutrients released from wheat residue followed the exponential model, $W_t = W_0 \times e^{-kt}$ from which the specific decay rate constants (k) and $t_{0.5}$ and $t_{0.95}$ were calculated.
Results The result show that the mineral fertilization combined with crop residues (RF + CR) resulted in the maximum decomposition and nutrient release compared to the other treatments. The half-life ($t_{0.5}$) values of the treatments were in the following order: RF + CR (6.70 weeks) < SS (8.0 weeks) < CR (9.60 weeks) < C (11.91 weeks). The percentage remaining DM in the litter bags followed the order C (73.25 %) > CR (66.45 %) > SS (59.85 %) > RF + CR (53.85 %). A 50 % loss of residue N was found after 8.88 weeks in the C treatment and 5.04 weeks in RF + CR treatment. Generally, nutrient loss from all treatments in the order of Mg > K = N > Ca > P.
Conclusions Application of mineral fertilizer or sewage sludge enhances the decomposition of low-quality residue (wheat). Therefore, it is essential to apply fertilizer in degraded soil before incorporation of crop residue with high carbon to nitrogen ratio.

Keywords Inorganic fertilizers · Mass loss · Crop residues · Sewage sludge

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Background

Crop residues are an important source of organic nutrients, are available in large quantities, and are not being fully utilized. The economic value of crop residues mainly focuses on the equivalent fertilizer cost of the nutrients that they contain. Crop residue decomposition is affected by the physical and chemical characteristic of both crop residue and the soil where the crop residue is incorporated. Kriaučiūnienė et al. (2012) reported that C:N ratio and lignin concentration are most important factors affecting the decomposition of incorporated crop residue. Swift et al. (1979) suggest that availability of soil nutrients is one of the factors affecting the rate of litter decomposition. However, reported results from the effects of increased soil N and P on the rate of litter decomposition and nutrient dynamics are inconsistent. The effect of increased soil N and P on the rate of litter decomposition varied from no effect (Hobbie and Vitousek 2000) positive effects on decomposition (Vestgarden 2001) and negative effects (Magill and Aber 1998)

Several studies have addressed litter decomposition under field conditions of humid temperate climate (Joergensen et al. 2009; Robinson et al. 1994), boreal, and wet tropical conditions (Tam et al. 1990; Saini 1989). Plurality of these studies have been carried out in forest soils under semi natural conditions (Xianiu and Hirata 2005; Alhamed et al. 2004). Fertilizer management and cultivation of different crops may have strong effects on the decomposition of plant residues, due to the difference in nutrient inputs by the fertilizers and the difference in nutrient demand by the crops.

Wheat residue used in this experiment had a low N content, and thus, the activity and the growth of microorganism were limited by the availability of N. An increase in the size of the soil microbial biomass is considered essential for soil fertility improvement (Singh et al. 2006).

Kwabiah et al. (1999) found that application of fertilizer urea or triple super phosphate enhanced the decomposition of litter from *Croton megalocarpus* and *Sesbania sesban* in the early stages of decomposition compared to control. Liu et al. (2006) noted that adding N alone or in combination with P stimulated the decomposition rate of *Allium bidentatum* and *Stipa krylovii*, which can be explained by the consequent increases in the availability of N and P, which are considered the main determinants of mass and nutrient loss during decomposition (Alexander 1977). As inputs of inorganic N or P increased soil N and P contents, microorganism activities may become limited more by carbon availability than by the available N and P. Under such conditions, C may be released from the decomposing litter and used as an energy source for catabolic and anabolic activities, resulting in further increases in rates of litter breakdown (Muhammad et al. 2011).

As for biological effects on soil, application of sewage sludge increased soil microbial biomass C and soil respiration (an index of general metabolic activity of soil microorganisms) when compared to a control (Bhattacharyya et al. 2003). Soil enzymes are extensively used as biological assay in soil. Perucci (1990) found that after application of 75 Mg ha^{-1} of municipal sludge compost increased the enzyme activities of phosphodiesterase, alkaline phosphomonoesterase, arylsulphatase, deaminase, urease and protease.

Synchronizing soil nutrients availability with plant requirements can improve the soil–plant system, N use efficiency and reduce nutrients losses through leaching below the crop rooting depth and/or from gaseous emissions (Vanlauwe et al. 2001).

Litter bag method developed by Bocock and Gilbert (1957) is used to study decomposition processes of plant residues under field conditions. Although this method creates a microenvironment, it is still considered to be a useful approach, due to the relatively simple recovery of litter transferred to the field and the possibility of excluding specific fauna groups from the decomposition process (Joergensen et al. 2009; Knacker et al. 2003). Litter bags have been less intensively used in studying the decomposition of green manure and harvest residues in arable areas (Knacker et al. 2003; Berg 2000; Christensen 1985).

Decomposition and nutrient release from the crop residues with organic and inorganic fertilizers have rarely been studied in Sudan. Therefore, the objective of this research was to determine rate of decomposition and nutrient (N, P, K, Ca, Mg) release patterns resulting from decomposition of wheat residues in a field cultivated with guar *Cyamopsis tetragonoloba* and treated with organic and inorganic fertilizers.

Methods

Site, soil, and climate

Field experiment to determine the decomposition of wheat residues with litter bags was carried out from June to August 2010 in the main field experiment of Omdurman Islamic University, Sudan (15°19.9N, 32°39′E, and with an elevation of 381 m above the sea level). The study was conducted for five seasons (wheat- guar- wheat -gaur- wheat) to study the contribution of organic residues in sustaining yields of wheat (*Triticum aestivum* var. Imam.) and guar (*Cyamopsis tetragonoloba* local var.) in a crop rotation system (Rezig et al. 2013). Treatments included recommended inorganic fertilizer 92 kg P_2O_5 ha^{-1} (204.4 kg triple super phosphate ha^{-1}) and 125 kg N ha^{-1} (271.7 kg urea ha^{-1}) with crop residues (RF + CR), crop residues (CR), 10 t ha^{-1} sewage sludge (SS) and control (C). The whole plant residue was used in this study after removing the roots. The soil properties and chemical composition of wheat residue were given in Tables 1 and 2.

Table 1 Some chemical properties of the experimental site

Treatments	pH ± SD	TN g kg^{-1} ± SD	TMN mg kg^{-1} ± SD	O.C % ± SD	CEC $cmol_c$ kg^{-1} ± SD	Ca Meq L^{-1} ± SD	Mg	K	P mg kg^{-1} ± SD
C	8.38 ± 0.05	0.20 ± 0.06	64.60 ± 0.1	0.23 ± 0.01	19.15 ± 0.06	4.20 ± 0.08	2.88 ± 0.1	2.60 ± 0.08	7.46 ± 0.11
CR	7.80 ± 0.08	0.34 ± 0.08	106.20 ± 0.08	1.25 ± 0.06	20.95 ± 0.06	4.55 ± 0.06	3.20 ± 0.08	3.00 ± 0.08	8.87 ± 0.07
SS	7.40 ± 0.08	0.36 ± 0.08	107.38 ± 0.08	1.85 ± 0.06	30.45 ± 0.06	5.13 ± 0.1	3.88 ± 0.1	3.90 ± 0.08	9.69 ± 0.11
RF + CR	7.60 ± 0.08	0.39 ± 0.06	149.53 ± 0.09	1.73 ± 0.1	31.50 ± 0.08	4.93 ± 0.1	3.78 ± 0.1	3.65 ± 0.06	12.93 ± 0.07

Table 2 Chemical composition of wheat residue

N g kg^{-1}	P	K	Ca	Mg	C/N	C %	Li	Ce	He	PP	Ash alkalinity
7.0 ± 0.17	11.0 ± 0.35	9.8 ± 0.06	3.4 ± 0.10	1.0 ± 0.15	41.3	59.0 ± 0.06	22.3 ± 0.16	34.4 ± 0.13	15.7 ± 0.15	0.12 ± 0.04	3.24 ± 0.05

Li Lignin, *Ce* Cellulose, *He* Hemicellulose, *PP* Polyphenol

Litter bag experiment

Decomposition (mass loss) of the wheat, residues and nutrient release were monitored in the field using the litter bags method (Anderson and Ingram 1989). Nylon bags of 20 × 10 cm dimensions with a mesh size of 2 mm were used for this study. The straw of the wheat was cut into length of about 20 cm and 50 g of oven-dried crop residues were placed into each litter bag. One side of the bag was left open for faunal activity. Ninety-six litter bags were used for this study. The litter bags from wheat residue were distributed in the control (C), crop residue at the rate of 2.5 t ha^{-1} (CR), recommended fertilizer + crop residue at the rate of 6.63 t ha^{-1} (RF + CR) and sewage sludge (SS) treatment. In each plot of each block, 6 l bags were buried. The litter bags were numbered and buried 5 cm below the ridge top to simulate residue incorporation into the plough layer. The growing guar plants were left standing for the duration of the experiment for 3 months and harvested manually in September 2010. The experiment was terminated 7 days after crop harvest. At each sampling 2, 4, 6, 8, 10 and 12 weeks after application of the residues 4 l bags from each of the four treatments (16 l bags per sampling) were retrieved and soil attached to the plant part was carefully removed. Each bag was placed inside a paper envelope and transferred to the laboratory for analysis. The content was emptied and extraneous materials, such as soil, visible animals and fine roots were removed. The decomposing crop residues were oven-dried at 65–70 °C for 48 h or constant weight and weighed to determine litter mass loss rates (Anderson and Ingram 1989). The remaining non-decomposed 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 mass remaining (DM) in each bag was calculated using the following equation:

$$\mathrm{MR} = (\mathrm{W}_t/\mathrm{W}_0)\times 100,$$

where W_t = Weight remained after each sampling week (g) and, W_0 = Initial weight (g) which is potentially decomposable

The data for dry mass remaining from each treatment were fitted to a negative exponential model (Olson 1963): Exponential decomposition models have been extensively used to describe the decomposition of litter in litter bags (Patricio et al. 2012):

$$\mathrm{W}_t = \mathrm{W}_0\mathrm{eo}^{-\mathrm{kt}},$$

where W_0 = initial residue weight at time zero, W_t = litter remaining after a given time (t), t = time interval of sampling expressed in weeksm, k = rate constant (decomposition rate constant per week) and, e = base of natural logarithms

Nutrients content (N, C, P, K, Ca^{2+} and Mg^{2+}) of decomposing crop residue was determined by the following equation:

$$\%\ \text{remaining element} \ (= (\mathrm{W}_t/\mathrm{W}_0)\times(\mathrm{C}_t/\mathrm{C}_0)\times 100,$$

where W_t is the remaining mass at time t (in weeks), W_0 is the initial weight of the litter, C_t is the concentration of element in decomposing litter at the time of sampling and C_0 the initial concentration of element. The regressions of ln (W_t/W_0) over time were performed separately for each set of litter bags in each plot to provide independent estimates of k and R^2 for each treatment. Further, the time required for 50 % ($t_{0.5}$) and 95 % ($t_{0.95}$) decay was calculated as $t_{0.5} = 0.693/k$ and $t_{0.95} = 3/k$, respectively. Statistical analysis software (SAS 1985) was used to test variations between treatments and least significant difference (LSD) was used to determine differences between treatment means.

Results

Mass loss

Prior treatment of the field plots with organic and inorganic fertilizers significantly affected the amount of wheat residue lost during incorporation (Fig. 1). After 12 weeks of incorporation, wheat residue had lost 26.8, 33.6, 40.2 and 46.2 % of its initial mass in the C, CR, SS and RFCR plot, respectively. The data on decomposition rate constants (k) values, R^2 and the days taken for 50 and 95 % of residues to decompose ($t_{0.5}$ and $t_{0.95}$) were presented in Table 3. The half-life ($t_{0.5}$) values (i.e. the time for the wheat residue to lose half their initial mass) of the treatments were in the following order: RF + CR (6.70 weeks) < SS (8.0 weeks) < CR (9.60 weeks) < C (11.91 weeks). Generally, carbon decomposition followed the same trend as dry matter disappearance. The per cent DM remaining at the end of the study period was of the order: C (73.25 %) > CR (66.45 %) > SS (59.85 %) > RF + CR (53.85 %). The decomposition rate constant (k $week^{-1}$) of the treatments also showed statistical difference ($P < 0.0001$). RF + CR had the highest k value (0.104 $week^{-1}$) and C the lowest (0.057 $week^{-1}$). Intermediate values were recorded by SS (0.087 $week^{-1}$) and CR (0.072 $week^{-1}$). This means decomposition was

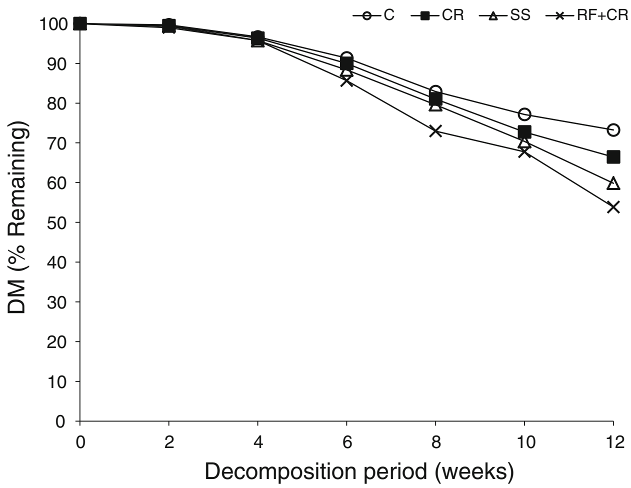

Fig. 1 Dry matter weight (DM) (% of original content) remaining during decomposition of wheat residues

fastest in plot treated with inorganic fertilizer + crop residue (RF + CR) and slowest in untreated plots (C).

Nutrient release pattern

Nutrient release patterns are shown in Figs. 2, 3, 4, 5 and 6. After 2 weeks of decomposition, 92.64, 94.43, 95.95 and 97.56 % of the initial N contents remained in the RF + CR, SS, CR and C treatments, respectively (Fig. 2). Fifty percentage N loss was attained after 5.04, 6.47, 7.53 and 8.88 weeks for RF + CR, SS, CR and C treatment, respectively, while at the end of the period, 29.81, 35.70, 46.28 and 55.98 % of the initial N contents remained in RF + CR, SS, CR and C treatment, respectively. The RF + CR treatment had the highest decomposition rate constant value (0.098 $week^{-1}$) indicating fast decomposition over all treatments.

Phosphorus release during study was shown in Fig. 3. Generally, release of P during the study period was slow compared to nitrogen in all treatments (Table 3). After 2 weeks, 84.94, 86.85, 95.88 and 96.75 % of the initial P remained in the SS, RF + CR, CR and C treatments, respectively. Fifty per cent of P remained of the treatments were in the following order: RF + CR (8.41 weeks) < SS (9.75 weeks) < CR (10.91 weeks) < C (16.83 weeks). At the end of the study period, 37.45, 41.62, 48.32 and 62.1 % of the initial P contents were remaining for RF + CR, SS, CR and C treatments, respectively. The highest decomposition rate constant (0.083 $week^{-1}$) in RF + CR treatment indicates of fast decomposition relative to other treatments. Generally, the release of K in all treatments was higher than that of N and P (Table 3). The per cent of K that remained after 2 weeks was in the order: C

Table 3 Decomposition constant (K), R^2, half-life ($t_{0.50}$) and $t_{0.95}$ for nutrient loss from wheat residues

Treatments	Nutrient	K	R^2	$t_{0.50}$	$t_{0.95}$
C	DM	0.057	0.94	11.91	52.41
	K	0.053	0.84	13.28	57.45
	N	0.048	0.92	8.88	38.46
	P	0.042	0.98	16.83	36.14
	Ca	0.044	0.99	15.93	72.85
	Mg	0.075	0.97	9.28	40.18
CR	DM	0.072	0.93	9.60	41.52
	K	0.077	0.78	9.00	38.98
	N	0.062	0.90	7.53	32.61
	P	0.064	0.98	10.91	47.22
	Ca	0.064	0.98	10.96	47.43
	Mg	0.086	0.98	8.12	35.18
SS	DM	0.087	0.92	8.00	34.58
	K	0.110	0.85	6.30	27.25
	N	0.083	0.89	6.47	27.96
	P	0.073	0.99	9.75	41.34
	Ca	0.081	0.99	8.60	37.25
	Mg	0.142	0.99	4.90	21.20
RF + CR	DM	0.104	0.92	6.70	28.99
	K	0.126	0.88	5.51	23.84
	N	0.098	0.91	5.04	21.82
	P	0.083	0.99	8.41	36.38
	Ca	0.094	0.98	7.37	31.92
	Mg	0.170	0.98	4.14	17.91
Probability	DM	0.0001	–	0.0001	0.0001
	K	0.0001	–	0.0001	0.0001
	N	0.0001	–	0.0001	0.0001
	P	0.0001	–	0.0001	0.0001
	Ca	0.0001	–	0.0001	0.0001
	Mg	0.0001	–	0.0001	0.0001

(97.66 %) > CR (96.45 %) > SS (93.28 %) > RF + CR (92.18 %) (Fig. 4). Fifty per cent of K remained from wheat residue were in the following order: RF + CR (5.51 weeks) < SS (6.30 weeks) < CR (9.00 weeks) < C (13.28 weeks). At the end of the study period, 21.02, 23.97, 34.75 and 50.08 % of the initial K content were remaining in RF + CR, SS, CR and C treatment, respectively.

Treatments significantly increased the decomposition rate of both Ca and Mg from wheat residue. The release of Ca was slow in all the treatments compared to other nutrients (Table 3). RF + CR treatment decomposed 50 % of its initial Ca and Mg content at the 7.37, and 4.41 weeks, respectively. At week 12, 60.86, 48.86, 38.73 and 33.26 % of the initial Ca contents were remaining in C, CR, SS and RF + CR treatments, respectively (Fig. 5). After 2 weeks, the Mg remaining in RF + CR treatment (89.11 %) was

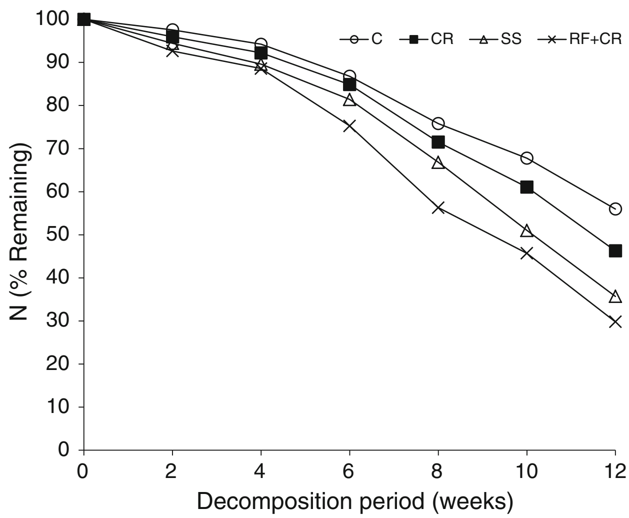

Fig. 2 Nitrogen remaining (% of original contents) during decomposition of wheat residues

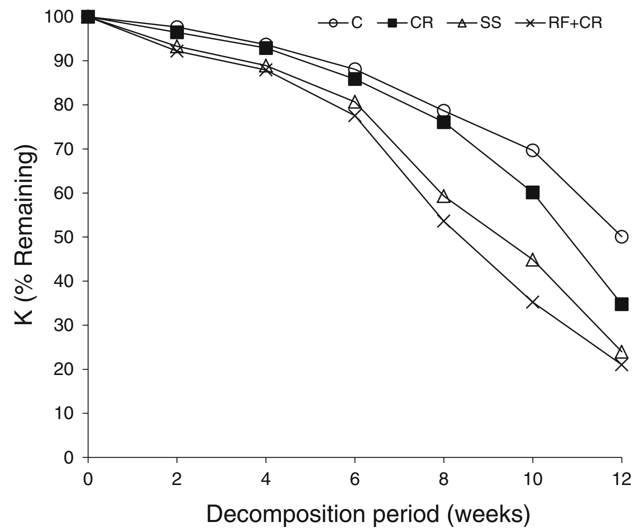

Fig. 4 Potassium remaining (% of original content) during decomposition of wheat residues

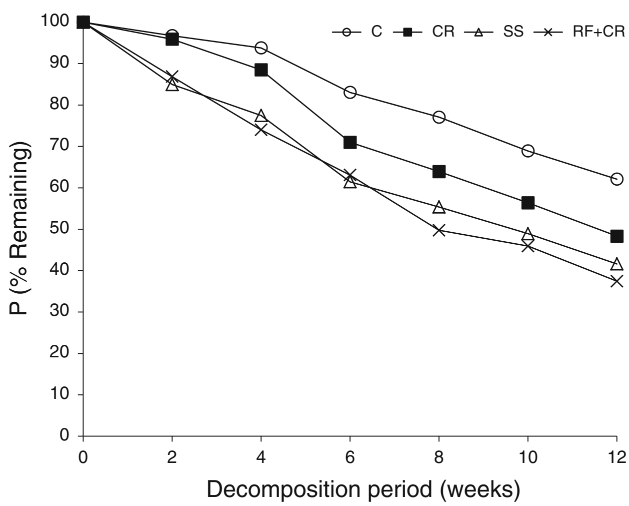

Fig. 3 Phosphorous remaining (% of original contents) during decomposition of wheat residues

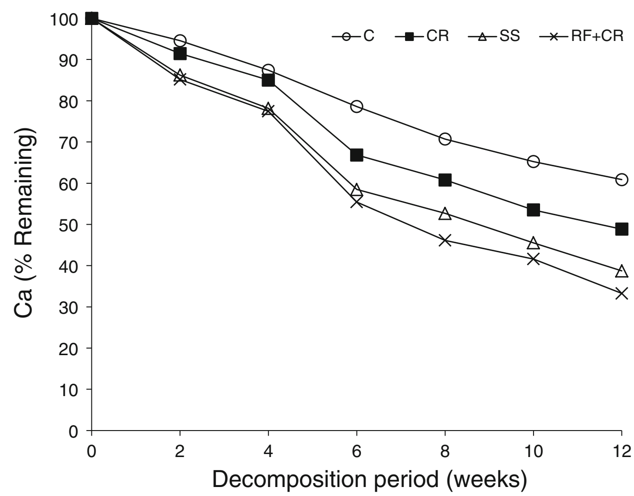

Fig. 5 Calcium remaining (% of original contents) during decomposition of wheat residues

significantly ($P \leq 0.0002$) lower than that in all treatments. The half-life ($t_{0.5}$) values of the treatments were in the following order: RF + CR (4.14 weeks) < SS (4.9 weeks) < CR (8.12 weeks) < C (9.28 weeks). The per cent Mg remaining (Fig. 6) at the end of the study period was at the order of C (43.95 %) > CR (38.22 %) > SS (19.90 %) > RF + CR (14.81 %); the decomposition rate constant (k week^{-1}) of the treatments also showed statistical difference ($P < 0.0001$). RF + CR treatment had the highest k value (0.170 week^{-1}) and C had the lowest (0.075 week^{-1}). SS (0.142 week^{-1}) and CR recorded intermediate values (0.086 week^{-1}). This means decomposition was fastest for RF + CR and slowest for C treatments.

Discussion

Incorporation of crop residue with or without fertilizer and sewage sludge significantly changed soil physicochemical properties (Rezig et al. 2013). The decomposition rate of wheat residue increased with the increase in N and P content in the soil. The initial N and P concentration in the plots was in the following order: RFCR > SS > CR < C

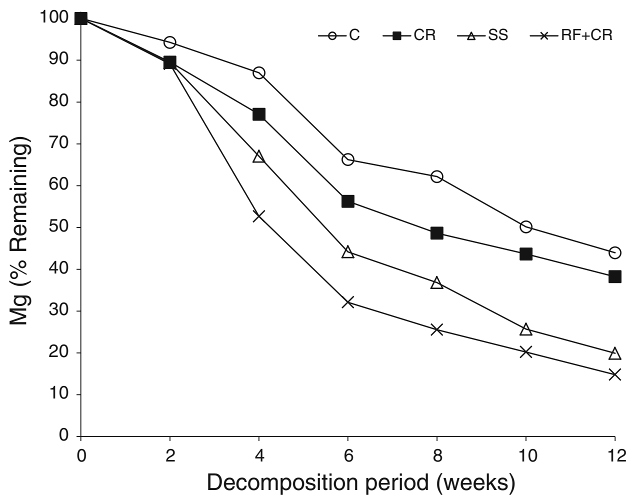

Fig. 6 Magnesium remaining (% of original contents) during decomposition of wheat residues

(Table 1). The increase in the decomposition of wheat residue with the increase in soil nutrients is consistent with previous study report that increase in nutrient supply (N and P) increased litter decomposition (Thirukkumaran and Paskinson 2002). The decomposition of plant litter is limited by the concentration of inorganic N and P (Alexander 1977). The increase in decomposition of wheat residue may be attributed to the increase in microbial biomass and efficiency (Thirukkumaran and Paskinson 2002; Qualls and Richardson 2000); increase in degradation of cellulose (Sinsabaugh et al. 2002); change in soil microorganisms community; increase in microbial activity (Gulis and Suberkropp 2003) and increase in extracellular enzymes such as Urease, acid phosphatase and glycosidase in the soil and in the litter (Saiya-Cork et al. 2002). However, the finding of the current study is in contrast with result reported by Chen et al. (2013). They reported that addition N and P decreased litter decomposition. They attributed the negative effect of N addition on litter decomposition to related high N-saturation in the soil and the negative effect of P addition to the suppression of microbial P mining. Knorr et al. (2005) concluded that N addition may stimulate litter decomposition in N-limited forest, but inhibit litter decomposition in N-rich forest.

Pernin et al. (2006) reported that application of sewage sludge increased mesofauna population in treated plots. Similarly, Bhattacharyya et al. (2003) found that application of sewage sludge increased soil microbial biomass C and soil respiration when compared to a control. Application of 75 Mg ha^{-1} of municipal sludge compost increased the activity of enzyme such as phosphodiesterase, alkaline phosphomonoesterase, arylsulphatase, deaminase, urease and protease (Perucci 1990).

The lower nitrogen remaining from incorporated wheat residue in RF + CR and SS treatment compared to Cr and C treatment might be attributed to their higher N content (Table 1). Increase in soil N improved the activities of microorganisms, which enhanced the transformation process in soil including the decomposition of plant residues and accumulation of N in the soil (Bhattacharyya et al. 2008; Anwar et al. 2005). Addition of N to the soil accelerates the decomposition and release of nutrients from material with high C:N ratio (Sinsabaugh et al. 2002). The release of P from wheat residue increased with the increase in the soil P in the soil. This result was similar to the pattern of N released.

Fertilization with sewage sludge or crop residue with fertilizer significantly ($P < 0.0001$) enhances K decomposition. The fast release of K in all treatment relative to other nutrient may be attributed to its existence in the cell fluid as non structural components (Christensen 1985). Similar results were reported by Mubarak et al. (2002); Attiwell (1968); Christensen (1985).

Similar trend was observed for the release of Ca and Mg. The release of Ca and Mg is related to mass loss trend. Therefore, increase in mass loss with the increase in nutrient content in the soil resulted in increase in Ca and Mg decomposition rate from wheat residue. Hodges (2010), Demarty et al. (1984) suggest that Ca is structural component of plant cell.

Conclusions

Soil nutrient contents have strong effects on the decomposition of low-quality residue (wheat residue). Mineral fertilization combined with crop residues significantly enhanced decomposition and nutrient release. Application of N and P is important management practice to enhance the decomposition of high C:N ratio crop residue in the field.

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Author contributions Rezig F.A.M she is the main author and did the field and laboratory work and drafted the manuscript. Elhadi, E.A participates in several field works, statistical analysis and participates in correction of the manuscript. Mubarak, A. R He is the main supervisor and drafts the proposal and participates in the correction of the manuscript. All authors read and confirmed the final manuscript.

References

Alexander ML (1977) Introduction to soil microbiology. Wiley, New York

Alhamed L, Arakaki S, Hagihara A (2004) Decomposition of leaf litter of four tree species in a subtropical evergreen broad-leaved forest Okinawa Island. Japan. For Ecol Manag 202:1–11

Anderson JM, Ingram JSI (1989) Tropical soil biology and fertility. A handbook of methods. CAB International, Aberystwyth

Anwar M, Patra DD, Chand S, Alpesh K, Naqvi AA, Khanuja PS (2005) Effect of organic manures on growth, herb and oil yield, nutrient accumulation, and oil quality of French basil. Commun Soil Sci Plant Anal 36:1737–1746

Attiwell PM (1968) The loss of elements from decomposing litter. Ecology 49:142–145

Berg B (2000) Litter decomposition and organic matter turnover in northern forest soils. Ecol Manag 133:13–22

Bhattacharyya P, Chakrabarti K, Chakraborty A (2003) Effect of MSW compost on microbiological and biochemical soil quality indicators. Compost Sci Util 11(3):220–227

Bhattacharyya R, Kundu S, Prakash V, Gupta HS (2008) Sustainability under combined application of mineral and organic fertilizers in a rain fed soybean–wheat system of the Indian Himalayas. Eur J Agron 28:33–46

Bocock KL, Gilbert O (1957) The disappearance of leaf litter under different woodland conditions. Plant Soil 9:179–185

Bremner JM, Mulvaney CS (1982) Nitrogen total. In: Page AL (ed) Methods of soil analysis. Agron. No. 9. Part 2: chemical and microbiological properties, 2nd edn edn. Am Soc Agron, Madison, pp 595–624

Chapman HD, Pratt PF (1961) Methods of analysis for soil, plant and water. University of California Riverside

Christensen BT (1985) Wheat and barley straw decomposition under field conditions: effect of soil type and plant cover on weight loss, nitrogen and potassium content. Soil Biol Biochem 17:691–697

Demarty M, Morvan C, Thellier M (1984) Calcium and the cell wall. Plant Cell Environ 7:441–448

Gulis V, Suberkropp K (2003) Leaf litter decomposition and microbial activity in nutrient-enriched and unaltered reaches of a headwater stream. Freshw Biol 48:123–134

Hobbie SE, Vitousek PM (2000) Nutrient regulation of decomposition in Hawaiian montane forests: do the same nutrients limit production and decomposition? Ecology 81:1867–1877

Hodges SC (2010) Soil fertility basics, soil science extension. North Carolina State University, Raleigh

Joergensen RG, Scholle GA, Wolters V (2009) Dynamics of mineral components in the forest floor of an acidic beech (*Fagus sylvatica* L.) forest. Eur J Soil Biol 45:285–289

Knacker T, Förster B, Römke J, Framptom G (2003) Assessing the effects of plant protection on organic matter breakdown in arable fields—litter decomposition test systems. Soil Biol Biochem 35:1269–1287

Kriaučiūnienė Z, Velička R, Raudonius S (2012) The influence of crop residues type on their decomposition rate in the soil: a litter bag study. Žemdirbystė Agriculture 99(3):227–236

Kushwaha CP, Tripathi SK, Singh KP (2000) Variations in soil microbial biomass and N availability due to residue and tillage management in a dry land rice agroecosystem. Soil Tillage Res 56:153–166

Kwabiah AB, Voroney RP, Palm CA, Stoskpf NC (1999) Inorganic fertilizer enrichment of soil: effect on decomposition of plant litter under sub-humid tropical conditions. Biol Fertil Soils 30:224–231

Liu P, Huang JH, Han XG, Sun OJ, Zhou Z (2006) Differential responses of litter decomposition to increased soil nutrients and water between two contrasting grassland plant species of Inner Mongolia, China. Appl Soil Ecol 34:266–275

Magill AH, Aber JD (1998) Long-term effects of experimental nitrogen additions on foliar litter decay and humus formation in forest ecosystems. Plant Soil 203:301–311

Mubarak AR, Rosenani AB, Zauyah SD, Anuar AR (2000) Decomposition and nutrient release from Maize (*Zea mays* L.) residues and N uptake by groundnut (*Arachis hypogea*). J Soil Sci 3:93–107

Mubarak AR, Rosenani AB, Anuar AR, Zauyah S (2002) Decomposition and nutrient release of maize stover and groundnut haulm under tropical field conditions of Malaysia. Commun Soil Sci Plant Anal 33(3):609–622

Muhammad W, Sarah M, Vaughan SM, Dalal RC, Menzies NW (2011) Crop residues and fertilizer nitrogen influence residue decomposition and nitrous oxide emission from a Vertisol. Biol Fertil Soils 47:15–23

Olson JS (1963) Energy storage and the balance of producers and decomposers in ecological systems. Ecology 44:322–331

Patricio MS, Nunes LF, Pereira EL (2012) Litterfall and litter decomposition in chestnut high forest stands in northern Portugal. For Syst 21(2):259–271

Pernin C, Cortet J, Joffre R, Le Petit J, Torre F (2006) Sewage sludge effects on mesofauna and cork oak (*Quercus suber* L.) leaves decomposition in a Mediterranean forest firebreak. J Environ Qual 35:2283–2292

Perucci P (1990) Effect of the addition of municipal soild-waste compost on microbial biomass and enzyme activities in soil. Biol Fertil Soils 10:221–226

Qualls RG, Richardson CJ (2000) Phosphorus enrichment affects litter decomposition, immobilization, and soil microbial phosphorus in wetland mesocosms. Soil Sci Soc Am J 64:799–808

Rezig FAM, Elhadi EA, Mubarak AR (2013) Impact of organic residues and mineral fertilizer application on soil-crop systems I: yield and nutrients content. Arch Agron Soil Sci 59(9): 1229–1243

Robinson CH, Dighton J, Frankland JC, Roberts JD (1994) Fungal communities on decaying wheat straw of different resource qualities. Soil Biol Biochem 26:1053–1058

Saini RC (1989) Mass loss and nitrogen concentration changes during the decomposition of rice residues under field conditions. Pedobiologia 33:229–235

Saiya-Cork KR, Sinsabaugh RL, Zak DR (2002) The effects of long term nitrogen deposition on extracellular enzyme activity in an Acer saccharum forest soil. Soil Biol Biochem 34:1309–1315

SAS (1985) SAS user's guide: statistics, 5th edn. SAS Institute, Cary

Singh S, Ghoshal N, Singh KP (2006) Variations in soil microbial biomass and crop roots due to differing resource quality inputs in a tropical dry land agroecosystem. Soil Biol Biochem 17:547–551

Sinsabaugh RL, Carreiro MM, Repert DA (2002) Allocation of extracellular enzymatic activity in relation to litter composition, N deposition, and mass loss. Biogeochemistry 60:1–24

Swift MJ, Heal OW, Anderson JM (1979) Decomposition in terrestrial ecosystems. University of California press, Berkley

Tam NFY, Vrijmoed LLP, Wonf YS (1990) Nutrient dynamics associated with leaf decomposition in a small subtropical mangrove community in Hong Kong. Bull Mar Sci 47:68–78

Thirukkumaran CM, Parkinson D (2002) Microbial activity, nutrient dynamics and litter decomposition in a Canadian Rocky Mountain pine forest as affected by N and P fertilizers. For Ecol Manage 159:187–201

Vanlauwe B, Wendt J, Diels J (2001) Combined application of organic matter and fertilizer. In: Tian G, Ishida F, Keatinge JDH (eds) Sustaining soil fertility in West Africa. Soil Science Society of America and American Society of Agronomy, Madison, pp 247–279

Vestgarden LS (2001) Carbon and nitrogen turnover in the early stage of Scots pine (*Pinus sylvestris* L.) needle litter decomposition: effects of internal and external nitrogen. Soil Biol Biochem 33:465–474

Xianiu X, Hirata E (2005) Decomposition patterns of leaf litter of seven common canopy species in a subtropical forest: N and P dynamics. Plant Soil 273:279–289