Effects of Nitrogen and Phosphorus Fertilizer Addition on Wheat Straw Carbon Decomposition in a Burundi Acidic Soil

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Abstract

Two laboratory incubation studies were conducted for 56 days in an acidic high altitude Burundi soil, to evaluate the effect of increasing application rates of N and P fertilizers on carbon (C) decomposition from wheat straw (*Triticum aestivum* L.). Nitrogen was applied as NH_4NO_3 at 0, 40, 80 and 120 kg N ha^{-1}, while P was applied at 0, 17.6, 35.2 and 52.8 kg P ha^{-1} as K_2HPO_4. Carbon dioxide (CO_2) evolution was regularly monitored using the alkali absorption method. At the completion of the studies, % C decomposition from wheat straw was equal to 18.8, 34.1, 45.4 and 48.1 % for straw + 0, straw + 40, straw + 80 and straw + 120 kg N ha^{-1}, respectively. Comparatively, similar values were 21.4, 40.4, 51 and 58.6 % for straw + 0, straw + 17.6, straw + 35.2 and straw + 52.8 kg P ha^{-1}, respectively. Straw C decomposition kinetics was described by a simple exponential model and decomposition rate constants (k), half-lives ($t_{1/2}$), together with the time periods required for 90 and 99 % straw C mineralization were evaluated. The data indicated that % straw C mineralization increased with increasing application rates of N and P fertilizers. The highest decomposition rates were obtained with P fertilizers. The investigations illustrated the benefit of the combined use of low-quality organic materials and inorganic nutrient sources in enhancing decomposition and implicitly increasing total available nutrients for plant uptake.

Introduction

Carbon (C) decomposition from organic residues is controlled by as many factors as soil environmental conditions (temperature, moisture, aeration, soil pH, nutrient availability, etc), substrate quality (chemical composition) and quantity, soil residue pre-treatment, application methods and their potential interactions (Marion and Black, 1987).

Organic materials are used in many conflicting ways in developing countries in general and in Burundi in particular. They can serve as cooking fuel, livestock feed, building materials, animal litter, substrate for edible mushroom production or mulch, when they are not used in soil fertility replenishment either by direct application or through composting. Subsistence agriculture in Burundi is very much dependent on organic materials (which include crop residues, animal manure and agroforestry species biomass) to replenish soil organic matter and supply nutrients.

Fertilization could offset the negative effects of low-quality organic materials (Palm *et al.*, 1997) and accelerate their decomposition, thereby releasing over a relatively short time nutrients, which normally would be cycled over a more extended period (Kelly and Henderson, 1978). These released nutrients added to those contributed by fertilizer applications, would increase total available nutrients for plant uptake (Palm *et al.*, 1997).

The objective of the present laboratory studies was to evaluate the short-term effects of N and P mineral fertilizer addition on the decomposition of wheat straw incorporated in a Burundi acidic soil.

Materials and Methods

Soil

The soil used in the studies was collected in April 1999 from the Ruzibazi Seed Center in Mukike District, Rural Bujumbura Province. Selected physical and chemical properties of the soil are given in Table 10.1. Niyongabo (1986) described a similar soil.

Table 10.1: Physical and chemical properties of the soil used in the study

Parameter	Value
% clay	64.9
% sand	24.5
pH_{water}	4.7
pH_{KCl}	4.0
Electrical conductivity (dS/m)	0.0845
% C	5.65
% N	0.61
C/N	9.18
CEC ($cmol_c$ kg^{-1} soil)	33.38
Al^{3+} ($cmol_c$ kg^{-1} soil)	4.91
Exchangeable acidity ($cmol_c$ kg^{-1} soil)	5.50
% Al saturation	4.71
P-Olsen (mg kg^{-1} soil)	

Wheat straw

Wheat straw was collected after crop harvest. The material was dried at 70° C to a constant weight and subsamples were ground in a Wiley mill before chemical analyses were performed. Total N was determined by a Leco N analyser model FP 428 (Leco Corporation, St Joseph, MI). Total C was determined by dry combustion (Nelson and Sommers, 1982). Total P, S, K, Ca and Mg were analyzed by ICP spectrometry after digestion of a 0.2-g sample with HNO_3 and H_2O_2 at 120° C for 3 hours (Zarcinas *et al.*, 1987). Selected properties of the wheat straw used in the study are shown in Table 10.2.

Incubation Procedure

Each incubation vessel (250-mL) was fitted with 2 test tubes each containing 5 mL of 2 N NaOH to capture evolved CO_2.

The laboratory incubations were conducted at room temperature (25 ± 1° C) in the soil laboratory facilities of the Faculty of Agricultural

Sciences, University of Burundi. Soil samples (50 g d.w. basis) were mixed with wheat straw to approximate a field application of 3000 kg ha^{-1}, corresponding to wheat straw production in the wheat producing region of Mugamba, where wheat straw is used as animal litter or composting materials (Niyongabo, 1986). Plant materials were cut into approximately 0.5 cm-long sections and were incorporated in soil in combination with N and P fertilizers. In the first study, N was applied as NH_4NO_3 at 0, 40, 80 and 120 kg N ha^{-1}. In the second study, P was applied at 0, 17.6, 35.2 and 52.8 kg P ha^{-1} as K_2HPO_4, which simultaneously brought 0, 44.3, 88.6 and 132.9 kg K ha^{-1}, respectively. In the latter investigation, fertilizer K was adjusted in all treatments using KCl in order to nullify the effect of K on straw decomposition.

Table 10.2: Chemical Composition of the wheat straw used in the study

Parameter	g kg^{-1}
C	420
N	5.5
P	0.4
S	0.9
K	10.4
Ca	2.9
Mg	0.6
C/N	76.4
C/P	1050
C/S	466.7
N/P	13.8
N/S	6.1

CO_2 sampling was performed at 3, 7, 14, 21, 28, 42 and 56 days of incubation. All incubation vessels were opened and aerated for about 5 minutes at each sampling period to maintain aerobic conditions, while test tubes containing the alkali solution were simultaneously changed and titrated (Stotzky, 1965; Zibilske, 1994).

Control soils without straw and fertilizer were run, and empty incubation vessels were used as controls for CO_2 absorbed from the atmosphere during the incubation procedure. Soil moisture was adjusted to 60 % water holding capacity (WHC). The total quantity of CO_2 collected in the dilute NaOH solution was determined by titration to a phenolphthalein indicator endpoint with standardized HCl following addition of $BaCl_2$, according to the following reactions (Stevenson, 1986):

$$2NaOH + CO_2 \quad - \quad Na_2CO_3 + H_2O \qquad (1)$$
$$Na_2CO_3 + BaCl_2 \quad - \quad BaCO_3\,(\_) + 2\,NaCl \qquad (2)$$
$$NaOH\,(exc.) + HCl \quad - \quad NaCl + H_2O \qquad (3)$$

Calculations

Carbon evolved as CO_2 was estimated by the following formula (Stotzky, 1965):

$$(\text{mg C as } CO_2 = (B - V) \times N \times E \quad (4)$$

where;
B = mL of standard acid for the blank;
V = mL of standard acid for amended treatments;
N = normality of standard acid;
E = equivalent weight of C (= 6).

The evolution of wheat organic C evolved as CO_2 from soils amended with straw was determined by subtracting the quantity of CO_2–C evolved from control samples from the quantity of CO_2–C evolved, from wheat-amended soils. This is the usual method of determining decomposition of unlabelled substrate in soils. As in many other studies of this nature, the decomposition rate of native soil organic matter C in the presence of wheat straw was assumed to be the same for each treatment, meaning that there was no priming effect (Ajwa and Tabatabai, 1994).

Percentage decomposition was estimated by calculating the percentage of C added evolved as CO_2 after correction for the CO_2 evolved from unamended soils according to the following equation:

$$(\% \text{ C decomposition} = [(X - Y) / Z)] \times 100 \quad (5)$$

where
X = mg of C evolved as CO_2 from wheat-fertilizer treatments;
Y = mg of C evolved as CO_2 from unamended soil (control);
Z = mg of C added in the wheat straw.

Decomposition model

Numerous mathematical models have been tested to describe C mineralization from soil organic matter or plant materials. Most models follow the first-order kinetics, for which the magnitude of decomposition is assumed proportional to the quantity of mineralizable C. The simple or one-component exponential model is the oldest (Stanford and Smith, 1972). The model assumes that only one form of potentially mineralizable C exists and mineralizes at a rate proportional to its concentration.

Statistical analyses

The incubation studies were conducted in a completely randomized design (CRD). Experimental treatments consisted of a blank, a control (soil only) and wheat-amended treatments. In each one of the two studies, each treatment was replicated three times to make a total of 18 experimental units. Straw C decomposition can be described by the following equation:

$$dt = -k\ C \quad (6)$$

$$C_t = C_o \exp(-kt) \quad (7)$$

where
C_t = carbon content at time t (day),
C_o = initial C content,
k = first-order rate constant,
t = time, days.

Decomposition rate constants (k) were estimated by using the Linear Least Squares (LLS) procedure by plotting the natural logarithm of % C remaining versus time of incubation in days. The software used to evaluate the fitness of different models of C decomposition kinetics from wheat straw was version 3.2 of SAS JMP IN (SAS, 1996). Mean separation of % C decomposition was performed with the Newman and Keuls test. The 0.05 level of probability was used as the criterion for accepting or rejecting null hypotheses in all statistical analyses.

Using decay coefficient (k) values and assuming constant decay rates for specific treatments, half-lives ($t_{1/2}$) together with the time periods required for 90 and 99 % straw C mineralization were estimated according to equations 8, 9 and 10, respectively.

$$t_{0.5} = \ln 2 / k = 0.693 / k \quad (8)$$

$$t_{0.9} = \ln 10 / k = 2.303 / k \quad (9)$$

$$t_{0.99} = \ln 100 / k = 4.605 / k \quad (10)$$

Results and Discussion

Data were fitted to the simple (one-component) exponential model and decomposition rate constants, $t_{0.5}$, $t_{0.9}$ and $t_{0.99}$ were estimated. For convenience, the results obtained from the two laboratory studies are discussed separately.

Effect of N fertilizer on straw C Mineralization

The addition of N fertilizer significantly increased wheat straw C decomposition. At the completion of the study, % straw C decomposition as affected by N fertilizer ranged from 18.8 with no N addition to 48.1 % with 120 kg N ha^{-1} as shown in Table 10.3. No significant differences were observed between treatments fertilized with 80 and 120 kg N ha^{-1}. Overall, % straw C decomposition followed the order: Straw + 120 kg N ha^{-1} = Straw + 80 kg N ha^{-1} > Straw + 40 kg N ha^{-1} > Straw alone.

Table 10.3: Percent wheat straw decomposition as affected by N fertilizer rates

Treatment	% Decomposition	% Increase
Straw + 120 kg N ha^{-1}	48.10 ± 1.53[a*]	+ 155.9
Straw + 80 kg N ha^{-1}	45.40 ± 2.28[a]	+ 141.5
Straw + 40 kg N ha^{-1}	34.11 ± 1.47[b]	+ 81.4
Straw + 0 kg N ha^{-1}	18.80 ± 2.41[c]	–

*Values followed by the same letter are not significantly different at 5 % probability level.

Table 10.4: Decomposition model and rate constants of wheat straw fertilized with N

Treatment	Decomposition Model	Prob.	R^2	Decomposition Time (days) $t_{0.5}$	$t_{0.9}$	$t_{0.99}$
Straw + 0 kg N ha^{-1}	Y = 4.576626 (± 0.009675) – 0.003497 (± 0.000320)	< 0.0001	0.86	198	658	1317
Straw + 40 kg N ha^{-1}	Y = 4.536913 (± 0.001655) – 0.006944 (± 0.005480)	< 0.0001	0.89	100	332	663
Straw + 80 kg N ha^{-1}	Y = 4.492028 (± 0.002539) – 0.009955 (± 0.008410)	< 0.0001	0.88	70	231	463
Straw + 120 kg N ha^{-1}	Y = 4.474588 (± 0.002411) – 0.010637 (± 0.007990)	< 0.0001	0.90	65	216	433

Table 10.4 shows that N application hastened straw decomposition. When compared to straw alone, addition of 40 kg N ha^{-1} doubled the decomposition rate, while application of higher N rates (80 and 120 kg N ha^{-1}) tripled it (Table 10.4).

Effect of P fertilizer on straw C Mineralization

At the completion of the study, % wheat straw C decomposition as affected by P fertilizer ranged from 21.4 with no P addition to 58.6 % with 52.8 kg P ha^{-1}) as shown in Table 10.5. Overall, percent straw C decomposition followed the order: Straw + 52.8 kg P ha^{-1} > Straw + 35.2 kg P ha^{-1} > Straw + 17.6 kg P ha^{-1} > Straw alone.

It can be observed that P addition brought about higher percent straw C decomposition when compared to N fertilizer addition. When compared to straw alone, addition of 17.6 kg P ha^{-1} doubled the decomposition rate, while application of 35.2 and 52.8 kg P ha^{-1} tripled and quadrupled it, respectively (Table 10.6).

Table 10.5: Percent wheat straw decomposition as affected by P fertilizer rates

Treatment	% Decomposition	% Increase
Straw + 52.8 kg P ha^{-1}	58.6 ± 0.2^{a*}	+ 173.8
Straw + 35.2 kg P ha^{-1}	51.0 ± 3.3^{b}	+ 138.3
Straw + 17.6 kg P ha^{-1}	40.4 ± 0.6^{c}	+ 88.8
Straw + 0 kg P ha^{-1}	21.4 ± 3.4^{d}	–

Table 10.6: Decomposition model and rate constants of wheat straw fertilized with P

Treatment	Decomposition Model	Prob.	R^2	Decomposition Time (days)		
				$t_{0.5}$	$t_{0.9}$	$t_{0.99}$
Straw + 0 kg P	Y = 4.567626 (± 0.151300) – 0.004290 (± 0.000500)	< 0.0001	0.78	162	537	1073
Straw + 17.6 kg P	Y = 4.546650 (± 0.016548) – 0.009040 (± 0.005480)	< 0.0001	0.91	77	255	509
Straw + 35.2 kg P	Y = 4.531140 (± 0.030420) – 0.012942 (± 0.001008)	< 0.0001	0.89	54	178	356
Straw + 52.8 kg P	Y = 4.522903 (± 0.037912) – 0.016430 (± 0.001260)	< 0.0001	0.89	42	140	280

Results obtained in this study were in agreement with those found by Smith and Douglas (1971), who reported greater decomposition of wheat straw with N than without it. Also, in a study conducted in a Kenyan ferralsol, Munyampundu *et al*. (1997) reported that the combination of wheat straw and increasing rates of inorganic N and P enhanced growth and yields of *Leucaena leucocephala*, *Sesbania sesban*, maize grain and stover.

However, conflicting results have also been reported elsewhere. For example, Kelly and Henderson (1978) found that urea application had little effect and superphosphate addition depressed the decomposition of white oak leaves (*Quercus alba* L.) in litter bags. Also, recent field experiments conducted in India (Goyal *et al*., 1992) and in Malawi (Jones *et al.*, 1997), have shown mixed results with regard to the effect of combining organic and inorganic inputs on yield and nutrient uptake (Palm *et al.*, 1997). In a 4-year experiment using pearl millet [*Pennisetum glaucum* (L.) R. Br.], Goyal *et al.* (1992), indicated that inorganic N addition to wheat straw did not improve yields, N uptake and N recovery by the test plant. On the contrary, Jones *et al.* (1997) reported a significant increase in yields and N-use efficiency when Leucaena [*Leucaena leucocephala* (Lam.) de Wit.] leaf residues were combined with urea in the 1: 3 ratio (Palm *et al.*, 1997).

The study reported in this paper concerned CO_2 evolution. One can argue that this parameter does not have a practical agronomic meaning. However, it has been proved that C decomposition controls nutrient release from organic materials. In particular, Clark and Gilmour (1983) and Castellanos and Pratt (1981) proposed CO_2 evolution as a means of providing a general estimate of net N mineralization. In fact, Gilmour *et al.* (1985) and Moorhead *et al.* (1987) showed significant linear relationships between N mineralization (g kg^{-1} N) and carbon dioxide evolution (g kg^{-1} C) for a number of organic substrates (Table 10.7).

Table 10.7: Selected linear relationships between carbon evolution as carbon dioxide (C) and N mineralization (N) for some organic substrates.

Substrate	Equation	Correlation coefficient
Sewage sludge	N = 1.01 C + 48	r = 0.90
Alfalfa	N = 0.98 C + 79	r = 0.96
Clover	N = 0.97 C + 84	r = 0.995
Bermudagrass	N = 0.43 C + 396	r = 0.94
Ryegrass	N = 0.53 C + 291	r = 0.97
Low-N plant biomass		
Fresh	N = 0.15 C - 36	r = 0.73
Digested	N = 0.32 C + 15	r = 0.94
High-N plant biomass		
Fresh	N = 0.52 C + 89	r = 0.77
Digested	N = 0.30 C + 9	r = 0.95

Source: Gilmour *et al*., 1985 Moorhead *et al*., 1987

Conclusion

The two laboratory studies have indicated that N and P fertilizers significantly increase percent straw C decomposition and decomposition rate. The response of straw C decomposition to N fertilizer addition followed the order: Straw + 120 kg N ha^{-1} = Straw + 80 kg N ha^{-1} > Straw + 40 kg N ha^{-1} > Straw alone. On the other hand, straw C decomposition as affected by P fertilizer rates followed the order: Straw + 52.8 kg P ha^{-1} > Straw + 35.2 kg P ha^{-1} > Straw + 17.6 kg P ha^{-1} > Straw alone. Straw C decomposition was higher in P- than N-fertilized treatments, presumably because P is generally the most limiting nutrient in acid, weathered soils of the subhumid and humid tropics in general (Buresh *et al.*, 1997) and in Burundi high altitude soils in particular (Ntiburumusi *et al.*, 1998).

Although our results could not simultaneously be validated under field conditions, they are in agreement with field experiments conducted with similar organic materials and soils in Kenya (Munyampundu *et al.*, 1997). Both studies illustrate the benefit of the combined use of low-quality organic materials and inorganic nutrient sources in enhancing organic material decomposition and increasing total available nutrients for plant uptake.

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