Investigations on decomposition of foliage of woody species using a perfusion method
Author(s): DANIEL O. NYAMAI
Source: *Plant and Soil*, Vol. 139, No. 2 (January (II), 1992), pp. 239-245
Published by: Springer
Stable URL: https://www.jstor.org/stable/42937939

Plant and Soil **139**: 239–245, 1992

PLSO 8816

Investigations on decomposition of foliage of woody species using a perfusion method

DANIEL O. NYAMAI
Kenya Forestry Research Institute, P.O. Box 20412, Nairobi, Kenya

Received 20 July 1990. Revised August 1991

Key words: C:N ratio, foliage decomposition, release of nitrogen, woody legumes

Abstract

The time for half of the total oxidizable carbon to be converted into CO_2 and other gaseous products ($t_{1/2}$) was studied for five tree species used in agroforestry. The study was conducted in a perfusion system with continuous aeration, and moisture content maintained at field capacity. This method was found to be suitable for studies of the initial stages of tree foliage decomposition. The overall rate was in the decreasing order: Leucaena > Calliandra > Gliricidia > Prosopis > Cassia. Decomposition started rapidly and then decreased rapidly for 2 to 3 weeks followed by a gradual decrease which continued for the remainder of the time.

The time for 50 per cent of total oxidizable carbon to decompose was about 19 days for Leucaena, 30 days for Calliandra and Gliricidia, while Prosopis and Cassia took more than 30 days. Leucaena released the largest quantity of total N into the perfusing solution while Cassia gave the lowest amount.

Introduction

Knowledge of decomposition rates and patterns of release of nitrogen in mixed agroecosystems is important for management purposes, particularly for woody species, if best use is to be made of them as sources of N in alley cropping. The rate of decomposition of plant material depends to a large extent on the chemical composition of the tissues. In this regard, the ratio of C:N has been noted to be of critical importance in determining the rate of mineralization. The low C:N ratio of most woody legumes enables them to decompose rapidly, thereby serving as efficient sources of nitrogen when used as green manures. By contrast, a high C:N ratio is associated with slow decay. Therefore, the relationship between decomposition and C:N ratio has been used frequently as a convenient means of predicting the rate of decomposition.

Most tropical soils are deficient in N. Use of nitrogen fertilizer in the tropics is limited because it is scarce and expensive. To solve the problem of declining food production per unit area, closer integration of trees into tropical crop production systems, particularly woody legumes with high capacity for N_2 fixation, is necessary. In this regard, alley cropping (hedgerow intercropping) has been found to be technically feasible and viable as an alternative N source for resource-poor farmers.

Few studies have been carried out to critically examine the rate of decomposition of woody species currently used in alley-cropping systems, thus justifying an evaluation of a wide range of potential trees and shrubs for alley cropping on the basis of their rate of decomposition and N release.

Materials and methods

The experiment was set up to investigate the rates of decomposition of *Leucaena leuco-*

cephala, *Calliandra calothyrsus*, *Gliricidia sepium*, *Cassia siamea* and *Prosopis juliflora* foliage when used as sources of green manure, and also to determine the potential rate of release of nitrogen from decomposing foliage. The perfusion apparatus used in this experiment is illustrated in Figure 1. A perfusion method was chosen for this study after taking into consideration the extent to which it fulfills the requirements for a decomposition study. Some of the principal advantages are: Solution content is constant and homogeneously distributed; drainage and aeration are maximized and waterlogging minimized; ionic equilibrium between the substrate and perfusion solution is rapidly established and is thereafter undisturbed by factors other than metabolic changes; the substrate is isolated from atmospheric contamination; gas inflow and outflow as well as gaseous products can be measured; and finally, external temperature variations found under field conditions can be minimized. As a result of these factors, the perfusion method was found to be suitable for maximizing the efficiency required in decomposition investigations. It works on the principles of simulating optimum field conditions required for the decomposition of organic matter. This is achieved by maintaining a continuous aeration with CO_2 produced by microbial respiration.

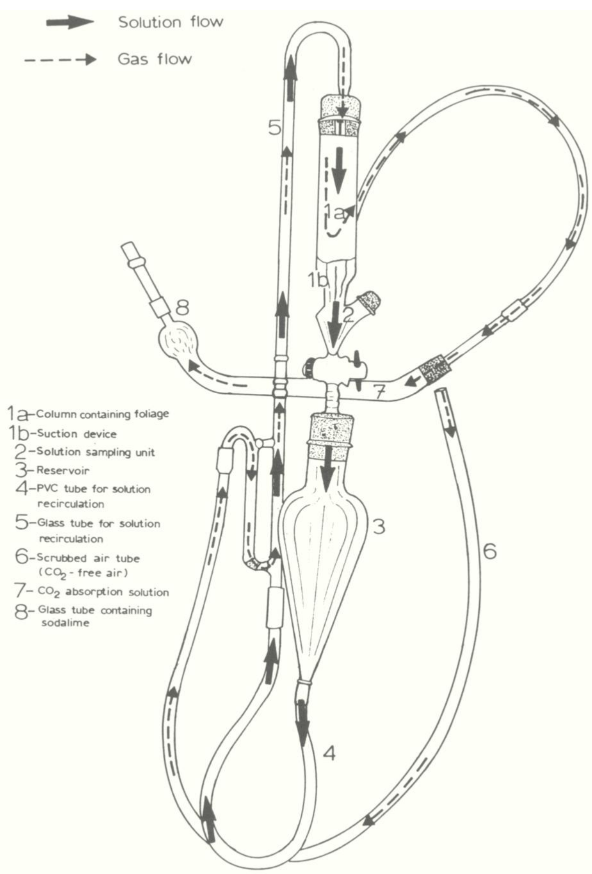

Fig. 1. Perfusion apparatus.

The perfusion method comprises the following main components: sample column, solution sampling device, reservoir for collecting and mixing perfusate before recirculation, and an adequate air flow rate to provide enough suction pressure for recirculating the solution. The details concerning each component and the general principles are discussed by Tester et al. (1977), Nyamai (1987) and Watt-Symrk (1981).

The experiment was run for 45 days including the preliminary operational checks. The rates of decomposition of the different green manures were determined by comparing the rates at which they released CO_2. The concentration of total $N(NH_4^+$ and $NO_3^-)$ in the circulating solution was monitored regularly using the Micro-Kjeldahl method modified to include nitrate followed by analysis with an Auto-analyser so that the rates of release of N from the decomposing foliage of the different species could be determined and compared. The pH of the perfusion solution was measured using a combined electrode method. The techniques, including the routine procedure used to run the experiment, are briefly described below.

About 30 g fresh material (approximately 10 g dry material) of each type of foliage and twigs was weighed. The samples were put in the column of the perfusion apparatus and retained in the sleeve by nylon mesh secured with rubber adhesive. The reservoir was then filled with 250 mL of 0.005 *M* calcium chloride solution, a concentration aimed at simulating a soil solution. Carbon dioxide produced by microbial respiration was estimated daily by titrating the barium hydroxide solution (0.05 *M*) in the absorption bottles against HCl (0.10 *M*). The rate of CO_2 production was used to describe the rate of foliage decomposition. CO_2-free air was provided to enable measurement of the amounts of CO_2 produced by microbial respiration from the decomposing foliage of the different species. The rate of flow of the incoming CO_2-free air was standardized in each treatment in this experiment by counting the air bubbles. The air flow rate was measured daily in order to check for leaks, reduction in CO_2-free air pressure, or blockage of capillary columns. If blockage occurred (as happened in the Cassia treatment), porosity was increased with glass beads to facilitate drainage.

The perfusion solution flow rate was approximately 5 mL h^{-1}, which is equivalent to about 12 cm of rainfall per day. Although this rate was extremely high compared with the actual rainfall in the field, it was applied in order to guarantee the minimum air pressure required for continuous circulation of the solution.

A thermostatically controlled heater was installed to maintain the ambient temperature of the chamber at 25°C. Insulation and provision for heating were necessary, as a controlled temperature room was not available.

Results of the preliminary trials confirmed that the perfusion apparatus for investigating foliage decomposition was suitable and indicated the levels of soluble N compounds and CO_2 production to be expected in subsequent work. One perfusion experiment was run for a period of up to 30 days, using the foliage and twigs of different tree species, as already mentioned.

Experimental treatments

The experiment was carried out during June and July, 1986. The trees used in the experiment were raised in a greenhouse of the University of Oxford (UK) Field Station. The N- and CO_2 productions were monitored, and the perfused foliage analysed for total N and organic C at the beginning and end of the experiment. CO_2 released during degradation of foliage in the continuously recirculated system was measured daily. The amount of N released and pH were measured at five-day intervals.

During the initial stages of the experiment, CO_2 measurement was carried out three times a day for most tree species, as initial decomposition rates were very high. This continued for at least one week. The frequency of CO_2 measurement was then reduced to twice a day for six days, and to once a day for the remainder of the experiment.

Preparation of green manures for the perfusion column

Foliage consisting of young twigs of all species (with the exception of Cassia, in which the foliage was first dried and then ground into powder) were chopped into small pieces and put in plastic pots in the open air at about 20°C. Five-mL volumes of soil solution containing inoculum were added to the partially wet leaves in an attempt to ensure sufficient soil microbial activity without adding the soil itself.

The experiment was not replicated due to a shortage of apparatus and space. Figure 1 illustrates the positioning of the samples in the perfusion column (position 1a).

Calculations

Because the $CaCl_2$ solution used in this experiment was continuously recirculated, the concentrations (C) of soluble nitrogen compounds (NH_4^+ and NO_3^-) in a solution volume (V) were assumed to have remained constant, assuming the balance between loss and uptake by microorganisms to be negligible. If decomposition did take place and N compounds were released from the decomposing foliage, then the rate of release (r) was assumed to be:

$$r = V(dc/dt)$$

One basic assumption with this equation is that solution volume and concentration remained constant, although regular sampling reduced the original volume and N compounds concentrations very slightly. It is also assumed that there was no denitrification within the 5-day sampling intervals. This implies, therefore, that cautious interpretation of the results is necessary.

The rate of decomposition can be expressed as the percentage of carbon (C) in the original material which decomposed to CO_2 during a stated period of time (t days), and can be calculated as follows:

$$\%\ \text{decomposition} = \%\text{C converted to } CO_2 = 100(C_t/C)$$

in which

Ct = the quantity of carbon in the original mixtures which was converted to CO_2 after time t, and
C = initial quantity of carbon in the foliage as determined with the Walkey-Black method (Black, 1965).

Results

Decomposition of the different materials

Figure 2 indicates that the initial decomposition rates were generally high and increased to a maximum over a period varying from 5 to 9 days before decreasing rapidly. The pattern of decomposition depended on the tree species. Leucaena had the highest initial rate and most rapid decrease. Cassia decomposed most slowly and there was little difference between Gliricidia and Calliandra. Prosopis had a slower rate of decomposition than Calliandra and Gliricidia.

Table 1 shows the estimated quantities of organic C in the foliage at the beginning and end of the experiment as well as the percentages of oxidizable material originally present that were converted to CO_2. Calculations based on the time course of decomposition indicate $t_{1/2}$ as follows: Leucaena: 19; Calliandra and Gliricidia: 30; Prosopis: 40; and Cassia: 50. The results (Fig. 2) indicate that among the trees tested, Leucaena manure contained the largest quantity of readily degradable organic matter in the experimental conditions (low C:N which is about 4:1) as shown in Table 3.

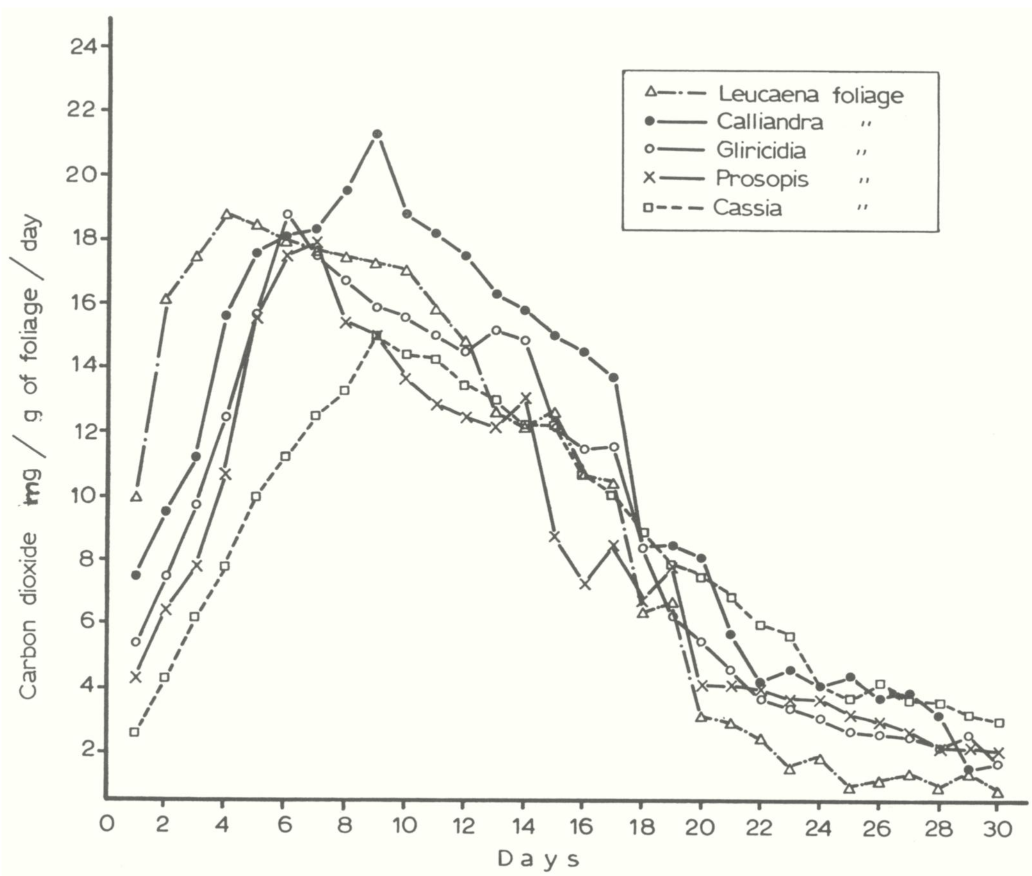

Fig. 2. Carbon dioxide produced during decomposition of foliage.

Table 1. Estimated organic carbon percentages in the foliage at the beginning and end of the experiment, and the percentages C converted into CO_2 after 30 days

Type of foliage (tree species)	% C at day 0	% C left at day 30	% C converted into CO_2
Leucaena	20.1	9.0	55.0
Calliandra	23.1	11.8	49.0
Gliricadia	21.3	11.0	48.5
Prosopis	22.6	13.5	40.0
Cassia	24.9	16.4	34.0

Soluble N compounds

The concentration of N compounds released from the decomposing manures into solution significantly increased with time depending on the type of manure (Table 2).As in CO_2 release, Leucaena released its N compounds most quickly, while Cassia was the slowest. N percentages in the different foliage at the beginning and end of the experiment are shown in Table 3. The results show that approximately 70 per cent of total N was released into solution from Leucaena foliage, compared with 35 per cent of Cassia which released the lowest amount of N. Gliricidia, Calliandra and Prosopis each released 60 per cent of total N.

Discussion

It is evident that Leucaena manure had the highest overall decomposition rate. In this study, the half-life of Leucaena manure as extrapolated from Figure 2, is 19 days. The half-life obtained in the field in a similar study conducted by the author in 1987 was about 25 days. The differences in the results are of course due to the fact that the experimental conditions were different. The other species, with the exception of *Cassia siamea*, were not tested in the field and are therefore not compared. The results obtained in the perfusion experiment for Cassia decomposition show no difference with those obtained in the field. However, under the present ex-

Table 2. Nitrogen concentration (mg L^{-1}) in the perfusion solution over time

Day	Leucaena	Calliandra	Gliricidia	Prosopis	Cassia
1	230	215	238	225	176
5	375	340	365	320	265
10	445	400	400	370	285
15	445	405	435	400	285
20	490	425	455	405	295
25	520	435	428	405	315
30	550	475	485	425	320

Table 3. Percent total N in foliage at the beginning and end of the perfusion period, and the C:N ratio in each foliage at day 0

Type of manure (tree species)	C:N Ratio %	N at day 0 %	N at day 30 %	N released into solution %
Leucaena	4:1	5.3	1.6	70
Calliandra	4:1	4.7	1.9	60
Gliricidia	5:1	4.5	1.8	60
Prosopis	5:1	4.3	1.7	60
Cassia	8:1	3.1	2.0	36

perimental conditions (leaves ground into powder), it is highly possible that the physical state of Cassia material could have caused compaction, with possible waterlogging resulting in reduced aeration and drainage. The rapid rate of Leucaena foliage decomposition was also observed by other workers (Kang and Duguma, 1984; Weeraratna, 1979). Kang and Duguma indicated that under field conditions in Ibadan, Nigeria, fresh and dried Leucaena foliage buried in the soil have half-lives of about 10 and 15 days, respectively. Weeraratna (1979), in his incubation studies under aerobic conditions with ground (2 mm) Leucaena, observed that decomposition in the soil started within the first week, which agrees with the present results.

Decomposition of Cassia manure was slowest, as by day 30 only 35 per cent of total carbon had been converted to CO_2. The differences in foliage decomposition rates are probably the result of variation in organic compounds present in the manures. Of significance in this regard is the high C:N ratio, viz 8:1, compared with 4:1 to 5:1 for the other species. Amounts of CO_2 released indicate that there is a close relationship between this ratio and the rate of decomposition. Similar observations have also been made by Keya (1975) and Alexander (1977).

The low C:N ratio of most of the foliages reduced competition by micro-organisms for available N during decomposition. This consequently enhanced the rates of decomposition by maintaining a high microbial activity at the beginning. Buckman and Brady (1971) and Alexander (1977) reported that the rate of decomposition of plant material depends on the nitrogen content of the tissue and that nitrogen-rich substrates are metabolized most rapidly.

The C:N ratios (Table 3) for the leguminous tree species used in this study agree with the findings of Alexander (1977), but differ greatly from the figures for legumes mentioned by Buckman and Brady (1971). The differences could be explained by the variability in this ratio existing among different plant families and even within families. For instance, Cassia and other members of the Leguminosae family used in this experiment show large variations in this ratio. The variability would have been even greater if comparisons would have been made between nodulated and non-nodulated legumes (e.g. Cassia is non-nodulated), different plant parts and different ages.

All leguminous manures used in this study were found to have C:N ratios similar to those of microbes, based on the data quoted by Buckman and Brady (1971) and Alexander (1977), with Leucaena and Cassia being the extremes. The differences in C:N ratios among species are reflected in the rates of decomposition. Sprent (1983) stated that for rapid mineralization, plant foliage should have N contents higher than 2 per cent . She observed that C:N ratios in excess of 15:1 result in virtually no mineralization, because all N is utilized by micro-organisms. The fast rate of foliage decomposition, particularly that of Leucaena, resulted in a rapid initial release of nitrogen as indicated by the high N concentration in solution over time. With Leucaena foliage, Weeraratna (1979) observed a similarly rapid increase (within the first three weeks) in total available N under laboratory incubation conditions.

The fast decomposition rates and quick release of N from all species, except Cassia, suggest that the foliage can be applied in the middle of the cropping season as an alternative to the traditional practice of topdressing with N fertilizers in cereals just before flowering.

However, in contrast to inorganic N fertilizers which release nitrogen (NH_4^+ and NO_3^-) into the soil shortly after application, the rapid initial release of N into the soil followed by a gradual one may result in the more efficient use of the nitrogen. Leaching is a particularly serious problem in the tropics where rainfall reaches very high intensities and is often unevenly distributed.

Because of their ability to decompose fast, coupled with the evidence of high N contents, leguminous tree as sources of green manure in an intercropping system with arable crops, are becoming popular with farmers in tropical countries.

The results of this study have demonstrated the significance of determining the rate of decomposition and patterns of N release as being of crucial importance in management decision-making. Leucaena with a rapid rate of foliage decomposition can be applied at seeding time and even at the vegetative stage of crop growth.

For a timely N release with a slow rate of decomposition, it should be applied at least two weeks prior to seeding.

Future management decisions in alley-cropping systems, concerning quantity of manure to be applied, method and time of application, species and site to be used, should be based on such information.

References

Alexander M 1977 Organic matter decomposition. *In* Introduction to Soil Microbiology, 2nd ed. pp 128–146 Wiley, New York.

Bremner J M 1965 MacroKjeldahl methods to include nitrate. *In* Methods of Soil Analysis, Part 2, Chemical and Microbiological Properties, Ed. C A Black. Agron. No. 9, Madison, WI.

Buckman H O and Brady N C 1971 The Organic Matter of Mineral Soils: The Land Properties of Soils, 7th ed. pp 132–160. Macmillan, London.

Kang B T and Duguma B 1984 Nitrogen management in alley cropping systems. Paper presented at the International Symposium on Nitrogen Management in Farming Systems in the Tropics. IITA. Ibadan, Nigeria, 1984, 17 p.

Keya S O 1975 Microbiology Practicals. Technical Comm. No. 6. Dept of Soil Sci., Univ. of Nairobi 22 p.

Nyamai D O 1987 Crop Production in an Intercropping System with Tropical Leguminous Trees. Thesis (D. Phil.), University of Oxford.

Sprent J I 1983 Agricultural and horticultural systems: Implications forestry. *In* Biological Nitrogen Fixation in Forest Ecosystems: Foundations and Applications. Eds. J C Gordon and C T Wheeler, pp 213–232. Nijhoff/Junk, The Hague, The Netherlands.

Tester C F, Sikora L J, Taylor J M and Parr J F 1977 Decomposition of sewage sludge compost in soil. 1. Carbon and nitrogen transformations. J. Environ. Quality 6, 459–463.

Watt-Smyrk J S 1981 Studies on the Initial Degradation of Sludge in Soil. Thesis (D. Phil.), University of Oxford.

Weeraratna C S 1979 Patterns of nitrogen release during decomposition of some green manures in a tropical alluvial soils. Plant and Soil 53, 287–294.