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INVESTIGATIONS ON DECOMPOSITION OF FOLIAGE OF WOODY SPECIES USING PERFUSION METHOD

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Abstract

The overall rate of decomposition can be described by the time taken for half of the total oxidizable carbon to be converted into CO_2 and other gaseous products. The rate of decomposition depended on the species. The overall rate was in decreasing order:-

Leucaena > Calliandra > Gliricidia > Prosopis > Cassia
Figure 2 shows that 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 the 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 (Figure 3). Leucaena released the greatest quantity of total N into solution while Cassia gave the lowest amount. The remaining species gave significantly higher amounts than Cassia.

1. Introduction

Knowledge of decomposition rates and the patterns of release of nitrogen is important for management purposes, particularly for woody species if best use is to be made of them as sources of N. One of the objectives of alley cropping (a system of crop production in which hedgerows of trees and shrubs is intercropped with agricultural crops and pasture grasses) studies is to investigate the effects of growing woody species with crops on crop performance and soil fertility status.

It is noted that N is a very important element for crop production and yet most tropical soils are deficient in N. Use of fertilizer N is limited in so many areas of the tropics due to high cost and lack of availability.

Attempts to solve declining food production per unit area in the tropical countries calls for closer integration of trees in crop production systems, particularly woody legumes with high capacity for N-fixation for N provision from green manure production. In this regard, alley cropping (hedgerow intercropping) system has been found to be technically feasible and viable alternative N source for the resource poor farmers in order to reduce dependency on commercial fertilizer nitrogen sources.

However, few studies have been carried out to critically examine the rate of decomposition of woody species currently recruited in alley cropping system of crop production. This, therefore, necessitates an evaluation of a wide range of potential trees and shrubs for alley cropping system on the basis of rate of decomposition and N release.

1.1 Materials and Methods

The experiment was set up to investigate the rates of decomposition of Leucaena leucocephala, Calliandra calothyrusus, Gliricidia sepium, Cassia siamea and Prosopis juliflora foliage when used as sources of green manure; and also to determine the rate of release of nitrogen from decomposing foliage. The perfusion apparatus used in this experiment is illustrated in Fig. 1. It works on the principles of simulating optimum field conditions required for the decomposition of organic matter. This is acheived by maintaining a continuous aeration with CO_2-free air and field capacity moisture content while at the same time providing the facility for the measurement of the CO_2 produced from microbial respiration.

It comprises the following main components: sample column, solution sampling device, reservoir for collection and mixing perfusate before recirculation, and an adequate air flow rate to provide enough suction pressure for solution recirculation. 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 of release of CO_2 from them. 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 nitrates followed by analysis by 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 general principles and operational techniques including the routine procedures used to run the experiment are briefly described below.

1.1.1 General Operation of the Experiment

About 30g wet weight (approximately 10g dry weight) of each type of foliage and twigs was weighed. The samples were then put in the column of the perfusion apparatus and retained in sleeve by nylon mesh secured with rubber adhesive. Ruservoirs were then filled with 250 ml of 0.005M calcium chloride solution, this concentration was aimed at simulating soil solution. CO_2 produced by microbial respiration was

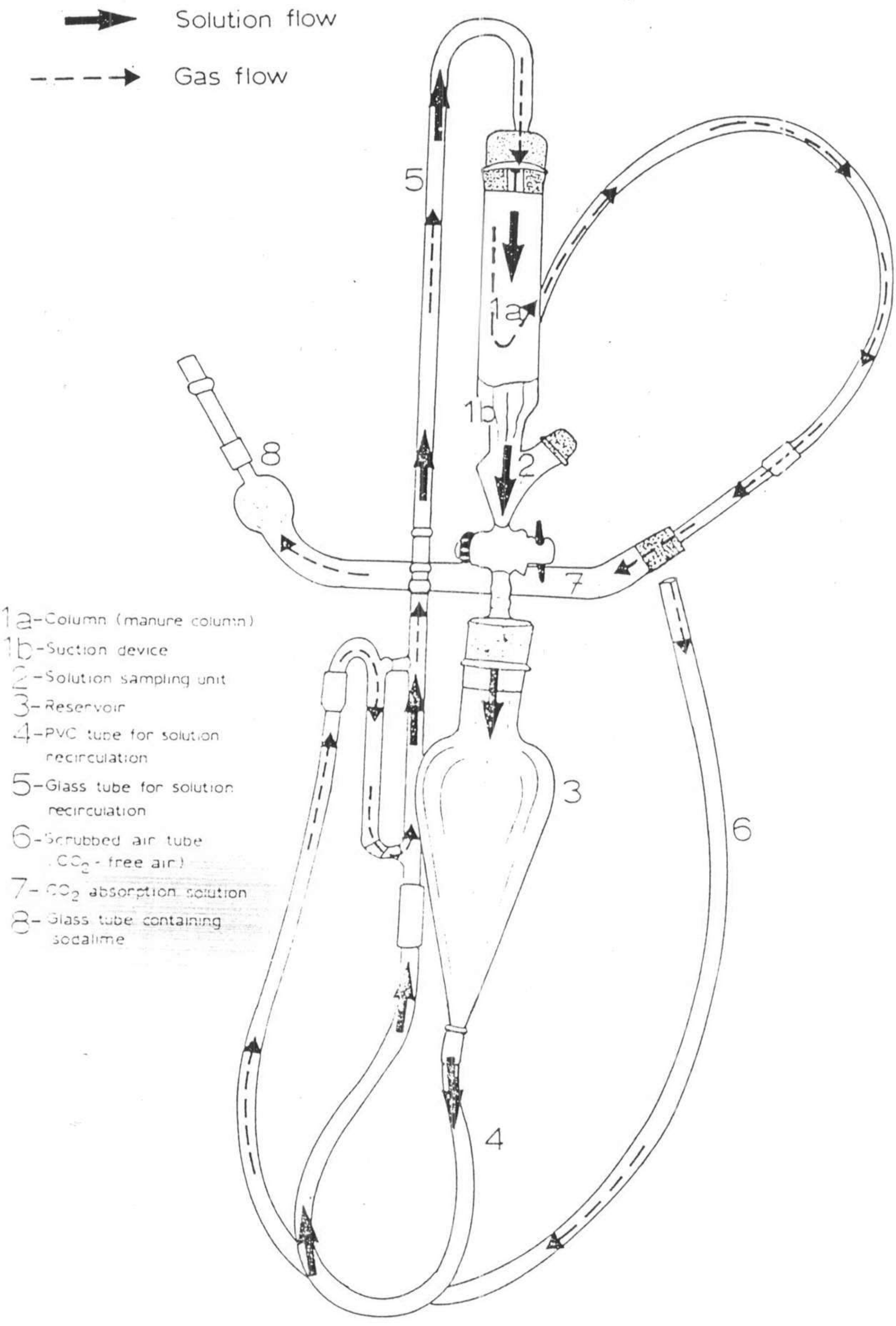

FIG. 1. PERFUSION APPARATUS

estimated daily by titrating the barium hydroxide solution (0.05M) in the absorption bottles against HCl (0.10M). 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 blocks occurred (as happened in the Cassia treatment), porosity was increased by glass bead to facilitate drainage.

The perfusion solution flow rate was approximately 5 ml hr^{-1} which is equivalent to about 12 cm^3 of rainfall per day. Although this rate was extremely high compared with the actual amount of rainfall in the field, this rate was given at the minimum air pressure required for continuous circulation of solution.

A thermostatically controlled heater was installed to control the ambient temperature of the chamber. Insulation and provision for heating were necessary as a temperature controlled room was not available.

1.1.2 Experimental Treatments

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.

The experiment was carried out during June and July, 1986. The trees used in the experiment were raised in the greenhouse at the University of Oxford Field Station. The concentration of N and CO_2 production was monitored, and the perfused foliage was analysed for total N and organic C contents at the beginning and end of the experiment. The production of CO_2 and total N released during the degradation of foliage in the continuously recirculated system was measured daily for CO_2 and five day intervals for N and PH.

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

1.1.3 Preparation of Green Manures for Perfusion Column

Foliage consisting of young twigs of all species with the exception of Cassia, (in which the foliage was first dried then ground into powder) were chopped into small pieces and put in plastic pots in the open air at about 20°C. A 5 ml solution containing soil inoculum was added to the partially wet leaves per treatment in an attempt to ensure sufficient soil microbial activity without adding the soil itself.

The experiment was not replicated as there was a shortage of apparatus and space. Figure 1 illustrates the arrangement of the samples in the persusion column.

1.2 Results

Because the solution ($CaCl_2$) used in this experiment was continuously recirculated, the concentrations (C) of soluble nitrogen compounds (NH_4+ and NO_3-) in a solution volume (V) was assumed to have remained constant unless there was net release into solution or uptake by micro-organisms. 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 the solution volume and concentration remained constant, but regular sampling reduced the original volume very slightly as well as N compounds concentrations. It is also assumed that there was no denitrification within 5 days sampling intervals. This therefore implies that cautious interpretation of the results is necessary.

1.2.1 Decomposition of the different manures

The rate of decomposition can therefore 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:-

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

Where:

Ct = The quantity of carbon in the original mixtures which was converted to CO_2.

C = Initial concentration of carbon in foliage which was determined using the method of Walkley-Black (Black, 1965).

Results Fig. 2 indicated that initial decomposition rates were generally high and increased to maximum over a period of no more than 15 days before decreasing rapidly. This was followed by a slow steady decrease which continued for the remainder of the experiment. 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 quantity of organic C in the manures at the beginning and end of the experiment as well as the percentage of oxidizable material originally present in the manures that was converted to CO_2.

Figure 3 further shows the time taken for the oxidisable carbon in the

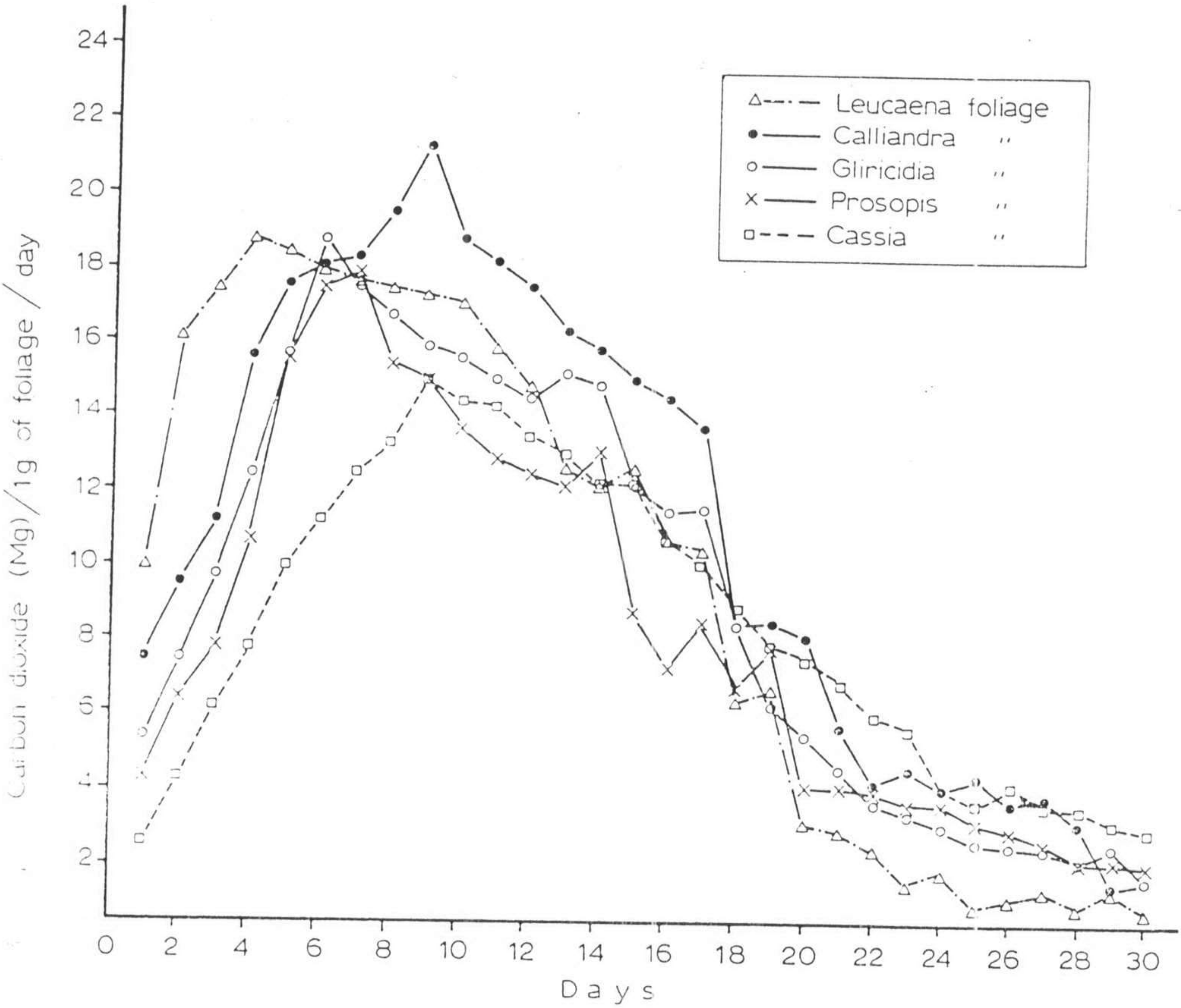

FIG. 2. TOTAL CARBON DIOXIDE PRODUCED DURING DECOMPOSITION OF FOLIAGE

various manure to be converted to CO_2 (i.e. half lives of the manures).

The results (Figs. 2 and 3) indicate that among the trees tested, Leucaena manure contained the greatest quantity of readily degradable organic matter in the experimental conditions (low C:N which is about 4:1 as shown in Table 3.

Table 1: Estimated total amount of organic carbon (%) in the manures at the beginning and end of the experiment, and the percentage converted into CO_2 at day 30

Type of manure (Tree species)	Amount at (Day 0) (%)	Amount left at (day 30) (%)	Percentage converted into CO_2 (%)
Leucaena	20.1	9.0	55
Calliandra	23.1	11.8	49
Gliricidia	21.3	11.0	48.5
Prosopis	22.6	13.5	40
Cassia	24.9	16.4	34

1.2.2 Soluble N Compounds

The concentrations of N compounds released from the decomposing manures into solution significantly increased with time depending on the type of manure (Table 2). As in decomposition rate, Leucaena released N-compounds most quickly while Cassia was the slowest. Analyses for N 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 the 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 cen total N.

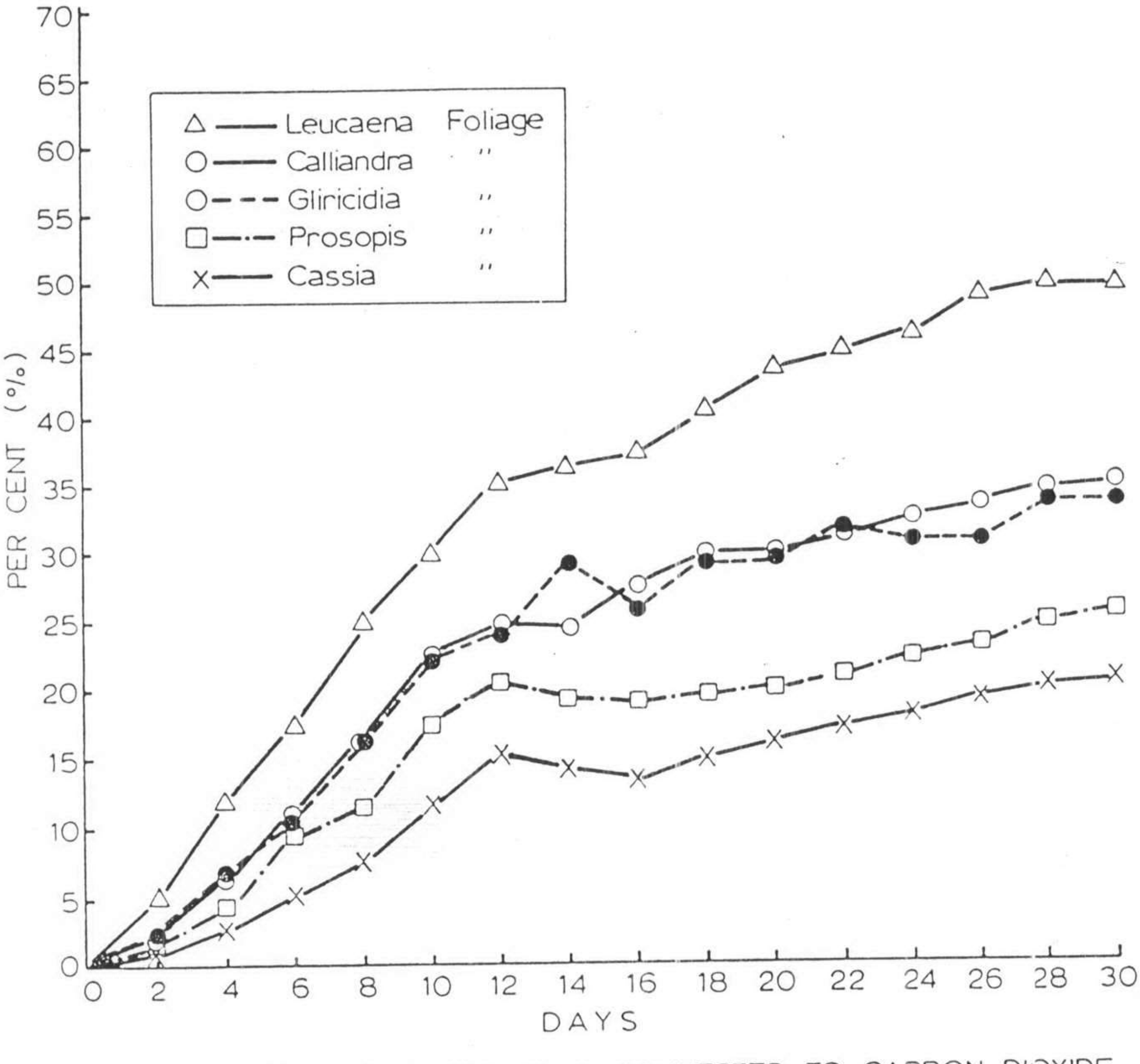

FIG. 3. PERCENTAGE OF ORIGINAL C CONVERTED TO CARBON DIOXIDE OVER TIME.

Table 2: Nitrogen concentration (mg/l) in 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: Per cent total N in foliage at the beginning and end of perfusion, carbon to nitrogen ratio (C:N) 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

1.3 Discussion

The patterns of release of CO_2 and N have been described in this paper. Minor fluctuations occurred (Figure 2) caused mainly by changes in the air pressure from the pump. They are ignored as regards the treatment effects.

It is evident from the results that Leucaena manure had the greatest overall decomposition rate compared with any other species. In this study, the half life for Leucaena manure decomposition, as extrapolated from Figure 3 is 19 days; while that obtained in the field in Kenya 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; however, 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 shows no difference with that of the field. The rapid rate of Leucaena foliage decomposition has also been 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 (2mm) Leucaena, observed that they started to decompose in soil within the first week, which agrees with the results obtained here.

Cassia manure decomposition was the slowest since by day 30 only 35 per cent of the total carbon had been converted to CO_2.
The differences in the decomposition rates of foliage are probably the result of the various organic compounds present in the manures. Of significance in this regard is the ratio of carbon to nitrogen. Amounts of CO_2 released indicate that there is close relationship between the ratio and the rate of decomposition. Similar observations have also been made by Keya (1975) and Alexander (1977).

The low C:N ration of most of the tree foliage reduced competition by the micro-organisms for available N during decomposition. This consequently enhanced the rates of decomposition by maintaining a high microbial activity especially at the beginning. Alexander (1977) reported the work of a number of investigators into the decomposition of organic matter and stated that the rate of decomposition of plant material depends on the nitrogen content of the tissues and that nitrogen-rich substrates are metabolized most rapidly. He demonstrated this by arranging plant residues in order of their N content and decreasing rates of mineralization as follows: sweet clover (3.14 per cent N); alfalfa (3.07 per cent); a group of red clovers (2.20 per cent); soybean (1.85 per cent); millet (1.17 per cent); flax (1.73 per cent); corn (1.20 per cent); Sudan grass (1.06 per cent) and lastly wheat and oat straw with 0.50 and 0.61 per cent N respectively.

He noted that crop plants generally contain about the same amount of carbon, usually 40 per cent of dry weight hence it is possible to compare N content by use of the C:N ratio. Thus a low N content, or a high C:N ratio, is associated with slow decay. He pointed out that it is not easy to determine precisely the causal relationship of decomposition since other factors operate in addition to the C:N ratio, although the C:N ratio is frequently a convenient means of predicting the rate of decomposition.

Alexander (1977) also noted that the average C:N ratio of the soil organic matter is 10:1 but values from 15:1 are not uncommon, and that the C:N ratio of humus is similar to that of microbial cells. He added that the C:N ratio of the decomposing material is critical since the magnitude of immobilization of N in the soil by micro-organisms is proportional to the net microbial cell carbon assimilation which is governed by the C:N ratio.

Buckman and Brady (1971) have also examined this ratio in soil, plants and in the tissues of micro-organisms and linked it with the decomposition of various substrates. They observed that the C:N ratio of micro-organisms tissue is much narrower, falling within the range of 4:1 and 9:1, while that of higher plants vary from 20 or 30 to 1 for legumes and farm manure. They stated that the values for the soils fall between that of the higher plants and that of the microbes. The C:N ratio (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 above by Buckman and Brady (1971). The differences could be explained by the variability in this ratio that exists among the different plant families and even within the families. For instance, Cassia and other members of the Leguminosae family used in this experiment show a great difference in this ratio. The differences would be even greater when comparison is made between nodulated and non-nodulated legumes (e.g. Cassia is non-dodulated), different parts of the plant and age.

These figures show that all the leguminous manures used in this study have carbon-nitrogen ratios similar to those of microbes based on the figures quoted by Buckman and Brady (1971) and Alexander (1977) with Leucaena and Cassia being at the extremes. The differences in the C:N ratios of these species are reflected in the rates of decomposition. Sprent (1983) stated that plant foliage should have N content greater than 2 per cent for rapid mimeralization. She observed that C:N ratio of foliage in excess of 15:1 results in virtually no mimeralization because all the N is transferred to the 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. Weeraratna (1979) observed a similarly rapid increase (within the first three weeks) in total available N of Leucaena foliage under laboratory incubation conditions.

Knowledge of decomposition rates and the patterns of release of nitrogen is important for management purposes. One of the objectives of alley cropping (a system of crop production in which hedgerows of trees and shrubs is intercropped with agricultural crops) studies is to investigate the effects of growing leguminous trees with crops on N-fixation and green manure production so that the farmers may avoid overdependence on costly N fertilizers. Unless such information is available the use of green manures for this purpose could be inefficient with regard to the time and possibly method of application.

Few studies supported with adequate methodology exist which address the subject of leguminous tree foliage decomposition and the patterns of nitrogen release. However, there seems to be a general agreement on the pattern of N release irrespective of the substrate or method of investigation. A few examples from laboratory perfusion experiments dealing with different substrates from the ones under investigation can be drawn from the work of Tester et al. (1977) and Watt-Smyrk (1981). The former stated that the rate of release of nitrate from sludge compost mixed with soil and incubated was generally rapid during the first 14 days, followed by a slower release. The latter also made similar observations. She indicated that activated sludge/soil mixtures in continuously circulating perfusion systems showed a rapid release of N. The fast decomposition rates and quick release of N of all the species except Cassia suggest that they can be applied in the middle of the cropping season as an alternative to the traditional practice of top dressing with N fertilizers in cereals just before flowering.

However, in contrast to inorganic N fertilizers which release nitrogen (NH_4^+ and NO_3^-) quickly into the soil once it is applied, 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 particular problem in the tropics where rainfall intensity is very high and haphazardly distributed.

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

1.4 Conclusions

The results from 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. Leucaena with a rapid rate of foliage decomposition can be applied at seeding time and even at the vegetative stage of crop growth, while Cassia with slow rate of decomposition would be better applied at least two weeks prior to seeding to maximize N released.

Thus, future management decisions, (such as the quantity of manure method of application, time, species and site) concerning the use of these species in alley cropping systems should normally be based on such informations.

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