

DECOMPOSITION OF CROTALARIA AND LEUCAENA GREEN
MANURES AND THEIR NUTRIENT RELEASE PATTERNS



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ABSTRACT

The decomposition of Crotalaria ochroleuca and Leucaena leucocephala green manures, contained in litter bags and placed on the surface or buried into the soil (8- 10 cm), was studied during 12 weeks of incubation. The study was conducted under laboratory conditions to determine and compare decomposition and nutrient release patterns of the two green manures. The effect of method of green manure application on decomposition and subsequent nutrient release was investigated. Changes in soil microbial numbers with incubation time were determined and related to decomposition. Analyses of the manure residual materials, and microbial counting were done at three week intervals.

The rate of decomposition was expressed in terms of dry matter, organic carbon, total nitrogen and organic phosphorus in the residual material. All these parameters were expressed as percentages of the original quantities added through the manure.

Generally decomposition was fast during the first six weeks of incubation and slowed down thereafter. The rate of decomposition was similar in both green manures, and decomposed by almost 50 and 70% after six and 12 weeks of incubation, respectively. In addition they had


similar nutrient releasing capacities. However, soil-incorporated manure decomposed faster and released more nutrients than surface-applied.

In treated soil there were rapid increases in microbial numbers during the first six weeks of incubation after which populations almost levelled off. The soil-incorporated green manure resulted in larger microbial numbers than the surface-applied one. In the control soil such changes were small.

From the results of this study it was speculated that when used the two green manures, should be incorporated into the soil at least six weeks before the period when the intended crop has its maximum need for nutrients. This will allow synchronization of maximum nutrient release with high nutrient demand by the crop.

DECLARATION .

I, CHAIS ADAM NIKOKWE, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is the result of my own original work. I further declare that it has neither been submitted nor being concurrently submitted for a similar degree in any other institution.

Signature:.....

Chais A. Nikokwe

Date:.....th 27 April 1992

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1.0 INTRODUCTION

1.1 General

Applications of organic materials to land/soil have traditionally been used as methods of maintaining or improving soil fertility. This has been practiced in most countries of the world. Land fallowing has also been used extensively in the past. The fallowing system has usually involved using land for several (e.g. three to five) and then leaving it for at least ten years for vegetation regeneration and, hence, soil fertility restoration.

Application of organic material for soil fertility management is the addition, to the soil, of different types of litter including crop residues, animal excreta and, nowadays, some industrial wastes. These are intended to decompose and add to the soil organic matter together with plant nutrients.

During the last few decades there has been rapid population increases, with a consequent need for more food production. In developed countries traditional methods of increasing food production have been replaced by the use of inorganic fertilizers and effective soil conservation practices. In the third world countries, on the other hand, the fallow system has either been abandoned or shortened because of pressure on land and

permanent settlements. However, soil conservation practices are less effectively carried out. As a result, agricultural soils in many tropical countries have undergone serious degradation such as surface runoff followed by excessive soil erosion, resulting in decreased organic matter levels and depletion of plant nutrients. This has led to a decline in soil productivity, calling for increased efforts to arrest and reverse the situation in order to increase food production.

The fallow system is becoming increasingly impracticable because the land area under forests has dwindled and population densities are now high. The use of inorganic fertilizers is still at an overall low level because peasant farmers cannot afford the high prices and have no experience in their use. Moreover, awareness of possible pollutive effects of agricultural chemicals, including fertilizers may, in future, call for a reduction in their use. With these counter forces, therefore, the use of organic materials seems to be a practical option. Through proper management and utilization of agricultural residues and other types of organic litter, the degraded soils may be reclaimed.

Green manuring, as one method of soil amendment, is the use of green plants to supply organic matter and

plant nutrients to agricultural soils. The plants may be established and allowed to grow for several weeks and then be incorporated into the soil to benefit the following crop. Alternatively, the green manure may be obtained from prunings of interrow cropped shrubs (such as in alley cropping systems) or they may be collected from elsewhere and applied to the field. In each case the plant nutrients and organic matter are added to the soil after decomposition of the added material.

Leguminous crops are largely used for green manuring because they add substantial amounts of nitrogen which is very important for the crop plants. Such high nitrogen additions are due to the legumes' inherent ability to fix nitrogen in association with nitrogen fixing bacteria of the genus Rhizobium. The amount of nitrogen fixed by tree, forage or grain legumes varies between 40 and 500 kg/ha depending on plant species and environmental factors. Thus, substantial amounts of nitrogen can be added to the soil through green manuring.

1.2 Problem analysis

The effective nutrient contribution by any green manure, particularly for annual crops, depends on the decomposition and nutrient release pattern of the incorporated plant litter. Effective green manuring

requires that the period of high nutrient demand by the crop coincide with the period of highest nutrient release by the manure. This synchrony is a very crucial factor for annual crops because, for practical reasons, the green manure may only be applied only once during the cropping season. Thus in the absence of synchrony, the crop will not make use of the released nutrients. This implies that information pertaining to the rate of decomposition of the manure is as important as its nutrient content in order to make effective use of green manures for annual cropping systems.

In Tanzania, information on nutrient release patterns by different green manure legumes is non-existent and, consequently, the choice of leguminous green manures and time of application is done quite arbitrarily. This consideration is, therefore, a practical problem warranting investigation.

1.3 Objectives

In the light of the foregoing analysis, research was undertaken to determine the decomposition and nutrient release patterns of Leucaena leucocephala and Crotalaria ochroleuca and the implication of such phenomena on the nutrient needs of annual crops and other soil management considerations. The specific objectives of this research were:

- a. To investigate the rate of decomposition and nutrient (N & P) release patterns from the two legumes.
- b. To compare the two legumes on the basis of nutrient (N & P) releasing capacity.
- c. To determine the effect of method of placement (surface-application or soil-incorporation) of the manures on their decomposition, an important consideration particularly for alley cropping systems where prunings are initially surface-applied.
- d. On the basis of information obtained from the above objectives, to speculate on appropriate timing of application of these materials, for their effective utilization as fertilizers particularly for annual crops.

2.0 LITERATURE REVIEW

2.1 The nitrogen potential of green manure and hence its fertilizer value

In the practice of green manuring the material is either surface applied or incorporated into the soil. It involves first the growing of the manure 'crop' for several weeks, thereafter applying it to the soil before growing the next food crop. It is also possible to collect plant material from elsewhere or to apply prunings of alley shrubs within the field. The incorporated material will decompose and release nutrients. For example Leucaena leucocephala forage can supply 500, 44 and 187 kg of nitrogen, phosphorus and potassium (Guevara 1976, cited by Brom and Van der Wal 1988), per hectare per year.

Prunings of Gliricidia sepium and Leucaena leucocephala in alley cropping with food crops was reported to have added to soil more than 100 and 200 kgN/ha/yr, respectively (Kang and Duguma 1985). Yamoah et al. (1985) reported that prunings of Gliricidia sepium, Flemingia congesta and Cassia siamea released 252, 70 and 120 kgN/ha/yr, respectively. Under Tanzania's southern highlands conditions, Crotalaria zanzibarica supplied to soil upto 120kgN/ha/yr (Temu 1986).

The fertilizer value of a green manure crop depends

The fertilizer value of a green manure crop depends on the amount of nutrients it can supply, especially nitrogen. It therefore follows that the ability of certain plants, especially the legumes, to fix nitrogen has an important role in their choice as sources of green manure.

2.2 Use of legumes for green manuring

Different legumes are used for green manuring depending on soil conditions, climatic conditions, pressure on land and farmers' food habits. In Indonesia, the legumes commonly used include sunnhemp and Phaseolus lunatus (Hodiono and Hartono 1978). In Burma, green manuring is commonly done with sunnhemp, Sesbania aculeata, cowpea, black gram and green gram (Thant 1978). Green gram, peas, cowpea, mung bean (Vigna radiata), lentil and sunnhemp are commonly used in India (Vidyarthi and Misra 1978). A decided advantage of legumes is their ability to fix nitrogen.

In Tanzania, green manuring is still not very common with many farmers. However, church missionaries in Ruvuma region in southern Tanzania introduced the use of Crotalaria ochroleuca as early as 1939 (Ruper 1986). Some farmers have now adopted the use of C. ochroleuca for green manuring in order to improve soil fertility and other soil conditions. Likewise the use of Leucaena

leucocephala, in alley cropping for soil conservation, is being advocated. A good example of this practice can be seen in the Usambara mountain areas, where a project on soil conservation is underway. However, the potential of these green manure species (C. ochroleuca and L. leucocephala), when used as sole sources of N in annual crop production, has not been fully evaluated in Tanzania.

Apart from legumes, several other plants have been used as green manures. Among them are blue-green algae in association with Azolla, the water hyacinth, and a number of other aquatic weeds which may have 1 - 2% N. In some cases, these aquatic green manures may be as nutrient-rich as, or richer than, many terrestrial green manures. A major deterrent to their use is bulk needed, due to their high water content, up to about 92% (Roger and Watanabe 1984); which will require a high labour input.

There are certain desirable characteristics which plants must have in order for them to be effective as green manure. Such characteristics include:

- a. Ability to add substantial amounts of nitrogen to the soil.

- b. Ease of establishment and fast growth that produces large amount of succulent tops and roots in a short time.
- c. Ability to grow on poor soils where the benefit of green manuring is most needed.

By a large measure, legumes generally excel in the above characteristics, and have, thus, been the popular choice for green manuring.

2.3 Factors affecting nitrogen fixation in legumes

The efficiency of symbiotic nitrogen fixation depends on plant species, stage of growth of the plant, soil and climatic conditions (Heichel and Barnes 1984). These factors, though important, will be reviewed only briefly since they are somewhat outside the scope of the present study.

2.3.1 Legume and rhizobia species

For any legume species to fix nitrogen it must be in association with a specific compatible rhizobial species in its roots (Brady 1984). Due to such specificity, legumes have in the past been classified into several classical "cross inoculation groups" each of which was thought to be compatible with specific species of nitrogen fixing bacteria of the genus Rhizobium. The classical specific rhizobial species

were R. trifolii; R. japonicum; R. lupini; R. phaseoli; R. leguminosarum and R. meliloti. The corresponding plant groups are clover, soybean, lupin, bean, pea/vetch and alfalfa, respectively (Brady 1984). However, it is now recognized that the bacteria which nodulate legumes and which were considered to be under the general name "rhizobia" belong to more than one genera: Rhizobium, Bradyrhizobium (Jordan 1982, 1984) and Azorhizobium (Semu, E. Personal communication 1991). All the strains of the Rhizobium genus are fast growing and include R. leguminosarum, R. meliloti, R. loti and R. fredii. Rhizobium leguminosarum results from the fusion of three classical species namely, R. phaseoli, R. trifolii and R. leguminosarum. The genus Bradyrhizobium comprises all slow-growing strains of the former Rhizobium spp. (the cowpea miscellany) and R. japonicum. Current advances of rhizobial taxonomy are likely to resolve new species or subspecies.

Generally, the amount of nitrogen fixed by pulse legumes is in the order of 40 to 200 kg/ha/yr depending on species (Date 1972). In a study done in Tanzania, Hogberg and Kvarnstrom (1982) reported that a four year old crop of Leucaena leucocephala could fix 80 - 140 kg N/ha/yr.

2.3.2 Stage of growth

It has been shown that nitrogen fixation changes with stage of growth of the legume plant. In perennials, symbiotic activity peaks during mid season. But in annual legumes it is maximum at the onset of flowering (Heichel and Barnes 1984). Because of the tendency of nitrogen fixation to peak in the early period of maximum flowering, this period was considered optimum for harvesting Crotalaria zanzibarica as a source of green manure (Temu 1986).

2.3.3 Soil and climatic conditions

Soil and climatic conditions affect nitrogen fixation through the effects of soil moisture, texture, compaction, nutrient content and temperature, all of which influence plant growth. Studies conducted in Minnesota, revealed that soybeans at different locations could fix nitrogen at levels ranging from 90 to 140 kg/ha/yr as a result of varying soil and climatic conditions (Heichel and Barnes 1984). In experiments conducted to compare the efficiency of sunnhemp, Sesbania and Vigna spp. Panse et al. (1965) found that sunnhemp performed better than the other legumes in low rainfall areas. Uppal (1955) found Sesbania to perform better than sunnhemp and cluster bean in alkali soils.

2.4 Decomposition of green manure and its significance to soil fertility

2.4.1 The decomposition process

The release of nutrients from green manure occurs during the process of decomposition. This is the process by which the organic material is degraded into simple forms which can be taken up by higher plants or microorganisms. It is a series of enzymatic oxidative steps performed by soil organisms, which obtain energy from the sugars and amino acids in the organic material. The simple substances/products are used for microbial protoplasmic synthesis.

The decomposition process occurs in three stages. In the first instance the bulk material is oxidized to produce O_2 , H_2O and energy. Concomitantly, essential elements, notably N, P and S are released or immobilized in ways/rates quite unique to each of the elements. Lastly, compounds which are resistant to microbial action are left as undecomposed constituents or as resistant products of microbial synthesis.

2.4.2 Factors affecting decomposition

Decomposition of organic materials, including green manure, is largely influenced by soil and substrate

factors (Parr and Papendick 1978). These are reviewed as follows:

a. Soil factors

Soil factors which have an influence on decomposition of green manure include moisture, temperature, oxygen supply and pH.

Unfavourable soil moisture conditions such as water saturation or inadequate moisture to levels of desiccation can be harmful to some microorganisms, leading to retarded decomposition. Increasing temperature from 20 to 60°C will accelerate decomposition because microorganisms are activated. At higher temperatures actinomycetes outnumber bacteria and fungi (Biederbeck and Campbell 1971). At temperatures below 20°C decomposition is slowed (Stefaniak 1968). Aerobic conditions favour fast decomposition rate and a pH range of 5.5 to 7.5 seems to be quite favourable for optimum decomposition rate.

b. Substrate factors

Substrate factors which can influence decomposition include chemical composition, specifically C/N ratio, lignin or tannin content and method of application (placement). However, the last is more of a management aspect than substrate factor.

The major organic constituents of plant material are divided into six broad categories that is : Cellulose, Hemicellulose, Water solubles, Ether and alcohol solubles, Proteins and Lignins (Alexander 1961). Of the six constituents, celluloses and hemicelluloses are 30 - 65%, lignin 8 - 25% while protein and amino acids are 1 - 5% of the biomass (Flaig 1984). As the green manure crop grows its biomass, fibre and lignin contents, which greatly affect its decomposition, increase. At the same time, its C/N ratio increases with age. All these trends make the material less decomposable. Normally, decomposition of plant material of C/N ratio wider than 30:1 is slow owing to the low content of nitrogen. For such materials mineral nitrogen has to be added to meet the demands of microorganisms in decomposition (Parr and Papendick 1978). On the other hand decomposition of succulent materials which are rich in protein, hence have a narrow C/N ratio, is very fast. Leucaena leucocephala, with a C/N ratio of 10:1, could decompose by as much as 50% in six weeks (Msumali, G.P. Personal communication 1989).

However, the C/N ratio concept itself is not enough to adequately describe the pattern of decomposition if the plants' lignin or tannin contents are also considered. Thus, substrates with similar C/N ratios may differ in lignin or tannin contents. This fact has,

therefore, an important bearing on the choice of plant species for green manuring.

The method of application can affect the speed of green manure decomposition. Parker (1962) reported 65% and 50% decomposition in 140 days for buried and surface applied material, respectively. Brown and Dickey (1970) found weight losses of 93%, 31% and 22% for plant residue which was placed 12 cm in the soil, on the soil surface, and 2.5 cm above the soil, respectively, for 18 months. However, contrary to the above findings, Goodding and McCalla (1945) found no differential effect of substrate position on decomposition rate.

2.5 Effect of green manuring on soil properties

Green manure has several effects on soils' physical, chemical and biological properties (Ayanaba and Okigbo 1974; Sanchez 1976 and Soffes et al. 1980) in the following ways:

2.5.1 Effect on physical properties

The organic matter added to soil after decomposition of green manure aids in the formation of larger and more stable aggregates (William and Joseph 1970). The aggregate size characterises soil structure and pore size distribution, both of which influence

aeration, temperature and water holding capacity of the soil. It has been found that at any level of soil moisture, soils with high organic matter content have more available water than those with low organic matter content (Lal and Kang 1985). Consequently soil crusting, bulk density, runoff and erosion are reduced.

The improvement of soil structure by organic matter is due to humus (Brady 1984) which is the final material in the course of decomposition of all organic substances. Humus has low plasticity and cohesion, hence it has favourable effects on aggregate formation and stability.

2.5.2 Effect on chemical properties

Green manure, like all other manures, can influence soil chemical properties (Sanchez 1976). Beneficial effects of green manure on soil chemical properties are as follows:

- a. It can supply most of the nitrogen, sulphur and small amounts of phosphorus taken up by crops. About 20 - 80% of soil nitrogen is contained in organic matter (Stevenson 1982 cited by Flaig 1984). Nitrogen and sulphur are released slowly from organic materials during mineralization, thus

reducing their loss by leaching (Evans and Bolle-Jones 1978).

- b. It can supply most of the cation exchange capacity especially in acid, highly weathered soils. This is due to the high density of pH-dependent negative charges on the humus. The CEC of humus is about 350 me/100 g, which is nearly 30 times that of kaolinitic clays.

- c. Organic matter from such manures can form complexes with amorphous oxides of iron and aluminium, thus preventing them from crystallizing. In this way availability of phosphorus can then be improved because those complexes block the P-fixation sites. Singh and Srivastava (1971) reported an increase in the availability of native soil phosphorus as a result of organic manuring. Through chelation, organic matter is also known to facilitate availability of micronutrients such as iron, manganese, copper, zinc and cobalt (Brady 1984). This is important particularly in calcareous soils. However, excessive quantities of organic matter may decrease zinc or copper availability by forming metal-organic complexes which are sometimes immobilized (William and Joseph 1970).

2.5.3 Effect on biological properties

Green manure influences the biological properties of the soil since it provides energy and carbon for synthesis of new microbial tissue. Any addition of organic material to the soil will stimulate growth of the soil organisms, whose population will change as a response to addition of readily decomposable material.

It has been reported that green manure can reduce or increase crop infestation by pests. Soffes et al. (1980) investigated the effect of several legumes used for green manuring on nematode populations. They found that hairy indigo (Indigofera hirsuta), pigeon pea and Crotalaria generally controlled nematodes, but that lablab, mung bean and Sesbania increased root-knot, ring and stubby root nematodes. Linderman (1970) reported that root rot in tobacco was increased by application of organic manure.

2.6 Interaction between green manure and inorganic fertilizers

Farmers can minimise fertilizer costs by using green manure. There is enough data to show that low fertilizer levels when combined with leguminous green manures can result in yield increases equivalent to those attained by high levels of chemical fertilizer

applications. Kang (1982) cited by Brom and Van der Wal (1988) obtained comparable yields of maize from a field treated with 120 kg N/ha and another with 80 kg N/ha combined with Gliricidia sepium green manure. The yields were 2,735 and 2,611 kg of maize grain per hectare, respectively. Ogbonna and Mabbayard (1983) reported high maize yields from a combination of Stylosanthes and low nitrogen fertilizer. Maize grown with 90 day Stylosanthes green manure with addition of 30 kg N, 30 kg P₂O₅ and 30 kg K₂O/ha gave grain yields comparable to that given 90 kg N with comparable levels of P and K (4.38 and 4.74 t/ha, respectively). Tiwari et al. (1980) cited by Singh (1984) reported that 40 kg N/ha along with green manuring compared well with application of 120 kg N/ha without green manuring in terms of availability of nutrients in the soil, their uptake and subsequent rice yield.

2.7 Effect of green manure on crop yields

Many reports are available on the response of crops to green manuring. Overall yield increases by as much as 20% have been reported in Indonesia (Hodiono and Hartono 1978). Kolar and Grewal (1981) found that Sesbania esculentus, Vigna sinensis, and Crotalaria juncea when incorporated into the field after 40, 50 or 60 days of growth with or without 60, 90 or 120 kg N/ha

resulted in yield increases of 18 to 20% as compared with yields from plots where green manure was not applied. Bhardwaj, Prasad and Singh (1981) cited by Brom and Van der Wal (1988) reported a 22% yield increase for rice as a result of green manuring with Sesbania cannabina. Yield from green manured field was 3930 kg/ha while 3224 kg of grain/ha was obtained from untreated field (control).

2.8 Timing of green manure application

Effective green manuring requires that the time of maximum nutrient release from green manure coincide with the time when the crop exerts a peak demand for the nutrients. Panse et al. (1965) observed that when using eight week old Sesbania, rice yields decreased as the interval between plowing-under of the manure and planting of the rice increased from zero to eight weeks. For a 12 week old green manure, it took almost eight weeks to decompose (Vachhani and Murty 1964 cited by Singh 1984). The effect of plant age at time of incorporation on release of organic P by Sesbania and Melilotus alba (Indian clover) showed that maximum increase in organic P in the soil occurred after 30 days of decomposition of a 60 day old manure crop. But it took 60 days for a 75 to 90 day old manure to attain the maximum increase in organic P in the soil.

2.9 Problems of green manure use and management

There is no dispute about the role of green manures as sources of organic matter and nitrogen. The capacity of green manure to mobilise soil-P and other nutrients is also recognised. However, besides their beneficial effects to agricultural soils, a few limitations do exist with regard to their use and management.

The materials are bulky, requiring time consuming and labour intensive work of establishing, collecting, transporting and application. It takes considerable time from the time of application until the nutrients are released. For example in an experiment to compare the effect of anhydrous ammonia and legumes as green manures on cotton production, Curtis *et al.* (1984) found that during the first few years ammonia produced higher cotton yields than the green manures. However, after several years, yields from cotton following green manuring began to equal those where the cotton received ammonia. During the following twelve years, seed cotton yield from soils amended with hairy vetch (*Vicia vilosa*) was about 360 kg/ha higher than plots fertilized with 62 kg of nitrogen as ammonia. Similarly, in a three to four year experiment on alluvial soil in India, green manures of *Sesbania aculeata*, *Crotalaria juncea*, *Penisetum americanum* and *Vigna radiata* did not affect potato tuber yield in the first two to three years

(Sharma et al. 1985). These sources of literature indicate the need for continuous use of green manure, rather than sporadic use, for its effectiveness as fertilizer to be realised.

The other constraint is the fact that green manure cannot be the complete solution to soil fertility problems. Leguminous green manures are good at supplying nitrogen because of the nitrogen fixing property of such plants. But the other nutrients may have to be added to the soil, as chemical fertilizers, when they are deficient.

3.0 MATERIALS AND METHODS

The intention of this study was to investigate the decomposition rate and nutrient (N & P) release patterns of Leucaena leucocephala and Crotalaria ochroleuca under laboratory conditions. A laboratory study was preferred to a field one for better control of environmental conditions.

3.1 Soil sampling and analysis

3.1.1 Sampling

Surface (0 - 15 cm) soil was taken from a site in the University Campus, namely one-quarter kilometre uphill (south) of the Miembeni staff housing flats, known to be very low in total and available N and P. Routine soil analyses were first carried out to determine the soil physico-chemical and biological properties. The soil samples were first ground and passed through a 2 mm sieve, except for determination of biological properties and available nitrogen.

3.1.2 Physical properties

Soil texture was determined using the Bouyoucos hydrometer method as described by Day (1965). The textural triangle was used to arrive at the soil's

textural class. The moisture content at field capacity was determined as approximately 50% of the maximum water holding capacity. The latter was found by the capillary method as described by Childs (1979).

3.1.3 Chemical properties

Soil pH was measured electrometrically in a (1:1 W/W) soil-water suspension according to the procedure described by Juo (1978). Total and available nitrogen were determined by the Macro-Kjeldahl digestion-distillation, and steam distillation methods, respectively, according to procedures described by Bremner (1965a, 1965b). Extractable phosphorus was obtained by the Bray and Kurtz (1945) method as described by Juo (1978). Organic carbon was determined by the wet-oxidation method of Walkley and Black (1945) as described by Juo (1978).

Cation exchange capacity was determined by summation. The basic ions (Na^+ , K^+ , Mg^{++} and Ca^{++}) were replaced from the soil's exchange sites by NH_4^+ which was added to the soil as 1N NH_4OAC (Chapman 1965). The concentrations of those ions were found by atomic absorption spectrometry (Dale and Norman 1982) and expressed as me/100 g oven dry soil.

Exchangeable aluminium and hydrogen were determined according to Mclean (1965), as follows: The exchangeable acidity was first extracted with 1N KCl and determined by titrating the extract with 0.1N NaOH. Thereafter 4% NaF was added to the titrated solution to change $\text{Al}(\text{OH})_3$ to NaAlF_6 . The amount of Al^{+++} was obtained by titrating the NaOH so formed, using 0.1N HCl. The amount of H^+ was given by the difference between exchangeable acidity and exchangeable aluminium. The CEC was given as the sum of the individual ionic concentrations determined above.

3.1.4 Viable microbial count

Microbial activities have a profound influence on soil fertility. Such activities are, in turn, governed by the size of the microbial populations. The addition of fresh plant material or organic residues often results in an upsurge of microbial population and activities. It was therefore desired, in this study, to observe and try to relate changes in microbial populations to the decomposition of the added green manure. Hence viable counts were determined at the start of the experiment and at the four intervals of sampling, namely three, six, nine and 12 weeks thereafter.

Determination of the microbial count was done by the pour plate technique as described by Wollum (1982).

The growth medium in this determination was the soil extract agar, prepared according to Parkinson et al. (1971), as described by Wollum (1982).

All the above soil characteristics are shown in Table 3.1. From the table, it is seen that the relatively low contents of organic carbon, total and available nitrogen, extractable phosphorus and cation exchange capacity underscore the low fertility status of the soil. The viable microbial count in this soil is lower than that expected in soils of average fertility, which may be expected to have as high as 10^7 CFU (Alexander, 1977). This is another indication of the low fertility status of this soil.

3.2 Green manure plant materials

A Crotalaria crop was established and allowed to grow for eight weeks before it was harvested for use in the experiment. At the stage of harvesting the plants had just started to flower and were still succulent. Leucaena material was obtained from existing stands around the University campus. Eight weeks before the material was to be collected for the experiment, the Leucaena plants were pruned so that the experimental material would involve an eight week succulent regrowth

Table 3.1: Some physico-chemical characteristics of the soil used

| Characteristic | Value |
|---|-------------------------------|
| Clay | 45% |
| Silt | 6% |
| Sand | 49% |
| Textural class | Sandy loam |
| Moisture content at field capacity | 24.4% |
| pH (soil:water, 1:1 W/W) | 5.00 |
| Organic carbon | 0.83% |
| Total nitrogen | 0.07% |
| Available nitrogen | 14.0 ppm |
| Extractable P (Bray-Kurtz No. 1) | 1.2 ppm |
| Ca ⁺⁺ | 0.38 me/100g [*] |
| Mg ⁺⁺ | 0.75 me/100g |
| Na ⁺ | 0.60 me/100g |
| K ⁺ | 0.58 me/100g |
| H ⁺ | 2.27 me/100g |
| Al ⁺⁺⁺ | 0.26 me/100g |
| Cation exchange capacity (by summation) | 4.84 me/g |
| Total microbial count | 1 172 210 CFU [*] /g |

* Oven dry basis

* CFU = Colony Forming Units.

just as would be for the Crotalaria. In both cases only stems and leaves were used, but not roots.

Each of the plant materials used in this study was analysed to determine the moisture content, the organic carbon, nitrogen and phosphorus contents (hence C/N and C/P ratios) prior to incubation with the soil. Plant samples were first oven dried (60° C) and ground into fine material (1.0 mm mesh) before analysing for the above chemical properties.

For organic carbon, the same procedure as that used for the determination of soil organic carbon was followed (see section 3.1.3). Total nitrogen was determined using the procedure followed for the determination of total nitrogen in the soil (see section 3.1.3). For the determination of organic phosphorus, plant samples were dry ashed (450 - 500° C) for at least five hours, and the P (now in ash) was dissolved in 1N HNO₃. The solution was evaporated and reignited at 400° C for 10 - 15 minutes after which it was dissolved in 1N HCl and filtered, followed by addition of several washings using 0.1NHCl to obtain the required volume of the filtrate. Phosphorus content was then determined calorimetrically by the method of the Association of Official Agricultural Chemists (AOAC) as described by Juo (1978).

Table 3.2 shows the values of the different parameters determined as described above. From the table it can be seen that except for organic phosphorus and C/P ratios, the two green manure plants did not differ very much in their characteristics, namely moisture content, total nitrogen, organic carbon and C/N ratio.

3.3 Plastic litter bags

Standard litter bags (30 x 30 cm with 7 mm mesh) (Anderson and Ingram 1989), were used to contain the green manure material the decomposition of which was being investigated. By using such bags it was possible to retrieve undecomposed litter after prescribed periods of incubation (section 3.5) so as not to overestimate the decomposition rates due to unretrieved plant material. The lower, inside surfaces, of the bags were lined with fine mesh material (mosquito plastic net) to lessen losses to soil of undecomposed leaflets which could pass through the large (7 mm mesh) openings of the litter bags.

3.4 Incubation vessels

A rectangular wooden trough of 1190 x 45 x 20 cm dimensions was constructed. The inside of the trough was lined with plastic material to make it leakproof. It was partitioned into 34 compartments (as plots) of

Table 3.2 : Some properties of the green manures used, at the time immediately prior to incubation with soil

| Characteristic | Green manure | |
|-----------------------------------|----------------------|------------------------|
| | <u>C. ochroleuca</u> | <u>L. leucocephala</u> |
| Moisture content (oven dry basis) | 86.7% | 78% |
| Total nitrogen | 5.2% | 4.2% |
| Organic carbon | 41.5% | 40.1% |
| Organic phosphorus | 2600 ppm | 3470 ppm |
| Carbon/nitrogen ratio | 8:1 | 9.8:1 |
| Carbon/phosphorus ratio | 160:1 | 117:1 |

equal size (35 x 45 x 20 cm), each enough to accommodate one litter bag. Partitioning was done by using hard board which was itself lined with impervious plastic material to prevent cross contamination between the plots. The plots were each loosely filled with 30 kg of the air dry soil (described in section 3.1).

3.5 Green manure treatments, incubation, and subsequent monitoring of changes in soil properties following green manuring

3.5.1 Treatment allocation and experimental set-up

Plant material of the two leguminous species was loosely packed in the litter bags which were then either buried in the soil (8 - 10 cm) or placed on the soil surface, and left to incubate at room temperature for three, six, nine or 12 weeks. The rate of green manure application was that which could provide 60 kgN/ha (assuming complete decomposition). This was arrived at as follows: Based on the moisture and nitrogen contents of the plant materials (Table 3.2) and the amount of soil per plot (30 kg), 130.345 g of fresh Crotalaria (8.7 ton/ha) and 98.465 g of fresh Leucaena (6.7 ton/ha) were weighed to provide the desired level of 60 kg N/ha. The 60 kg N/ha was regarded as the rate of nitrogen

input at which plants were expected to perform fairly well when the nitrogen was added to an infertile soil (such as that used in the present study).

Thirty two litter bags were filled with the manures (16 with Crotalaria and 16 with Leucaena) so as to suffice sampling at four intervals, namely three, six, nine and 12 weeks after the start of the experiment. The zero time of sampling/incubation refers to the initial characterizations of the soil and green manure material as reported in Tables 3.1 and 3.2, respectively. Of the 16 litter bags with Crotalaria eight were incorporated (8-10 cm) into the soil while the other eight were placed on the soil surface. Heavier objects were placed on top of the surface-applied bags to ensure good contact with the soil. A similar arrangement was followed for the bags containing Leucaena. There were two control plots in which green manure was not included. The experimental design was a completely randomized design in a 2 x 2 x 5 factorial arrangement, that is two sources of green manure, two placement methods, and five sampling times/incubation periods.

Throughout the period of incubation, except 3 - 4 days prior to sampling, the soil moisture in the plots was maintained at around field capacity. This was done

as follows: Having determined the soil moisture retention at field capacity which was 24.4% (Table 3.1), a small experiment was conducted to determine the rate of water loss by evaporation at the room temperature conditions in which the experiment was to be conducted. This was achieved by determining moisture content changes for five consecutive days, as shown in Table 3.3. From these data it was determined that it was necessary to add 300 ml of water to every plot on every fourth day so as to approximately maintain the field capacity condition.

3.5.2 Sampling and monitoring of chemical properties

At three weeks after incubating the green manures, two samples were taken from two replicates of the same treatment. The litter bags were first removed, and soil mixed thoroughly to a depth of 10 cm before sampling. The same was done at each of the other sampling times using fresh plots, so that overall each plot was sampled only once. Determination of microbial count in the soil was done in fresh soil without drying or grinding it. When time did not allow for immediate determination the soil was stored at 4° C but for less than 48 hours. The determination was done using the procedure described in section 3.1.4.

Table 3.3: Rate of moisture loss from the experimental soil, leading to determination of amount and frequency of water replenishment

| Time of incubation (days) | Soil moisture content on oven dry basis (%) | Weight of water per plot (g) | Weight of water lost per plot (g) |
|---------------------------|---|------------------------------|-----------------------------------|
| 1 | 24.4 | 6 770.00 | - |
| 2 | 23.91 | 6 626.40 | 144.10 |
| 3 | 23.36 | 6 473.80 | 296.70* |
| 4 | 22.67 | 6 282.80 | 487.70 |
| 5 | 21.03 | 5 828.30 | 942.20 |

* To approximately maintain the field capacity condition, 300 ml of water was added to each plot every fourth day.

During sampling, the plant material that was placed on the soil surface was easily retrieved just by lifting the litter bags and carefully removing out the material. Any material that had fallen onto the soil was picked by using pair of forceps. For the soil - incorporated green manure, the litter bags were unearthed and brushed lightly to remove soil that had adhered onto the outside. This was done while holding tightly the open ends of the bags to prevent loss of material from inside. The plant material was then removed, followed by separating of particles from the litter material by successive sieving using 2, 1 and 0.8 mm sieves. For the 0.8 mm sieve, water was simultaneously splashed on the soil-litter admixture to break adhering soil aggregates and to get rid of them through the sieve openings. All litter material which had fallen to the soil in the plots was collected by using forceps and, where necessary, successive sieving was applied as described above.

The plant residue samples were oven dried (60° C) and ground to pass through a 1.0 mm mesh sieve using the LABO laboratory mill. The following parameters were determined as in sections 3.1.3 -4 and 3.2.

1. Residual dry matter (gravimetrically), organic carbon, total nitrogen and organic phosphorus in litter material.
2. Total microbial count in the soil.

The data were analysed statistically using the factorial arrangement as described by Little and Hills (1978).

For the residual green manure material the parameters determined above were presented as percentage of the original quantities applied. This presentation was preferred to that of using the absolute quantities so as to be able to compare the decomposition trend against a common reference, that is 100%, representing the quantities originally applied. Microbial count was converted and presented as \log_{10} for easy handling of the data in the statistical analysis.

4.0 RESULTS AND DISCUSSION

4.1 Decomposition of green manure and its nutrient release

The decomposition of the green manures was rated using four parameters, namely changes/decreases in dry matter, organic carbon, total nitrogen and organic phosphorus. To be able to compare the changes in these various parameters, they were expressed as percent residual values relative to 100% as the reference starting point. Using the absolute (determined) values would render such comparison impossible. It was deemed reasonable that such a multivariate comparison would best characterize the pattern of decomposition of the green manures, more than only one parameter would.

4.1.1 Residual dry matter

Overall, incubation time influenced the decomposition, resulting in lower residual dry matter with longer incubation periods (Fig. 4.1). It was fast during the initial period up to the sixth week of incubation, by which time nearly 50% of the material had already decomposed. Decomposition was much slower thereafter.

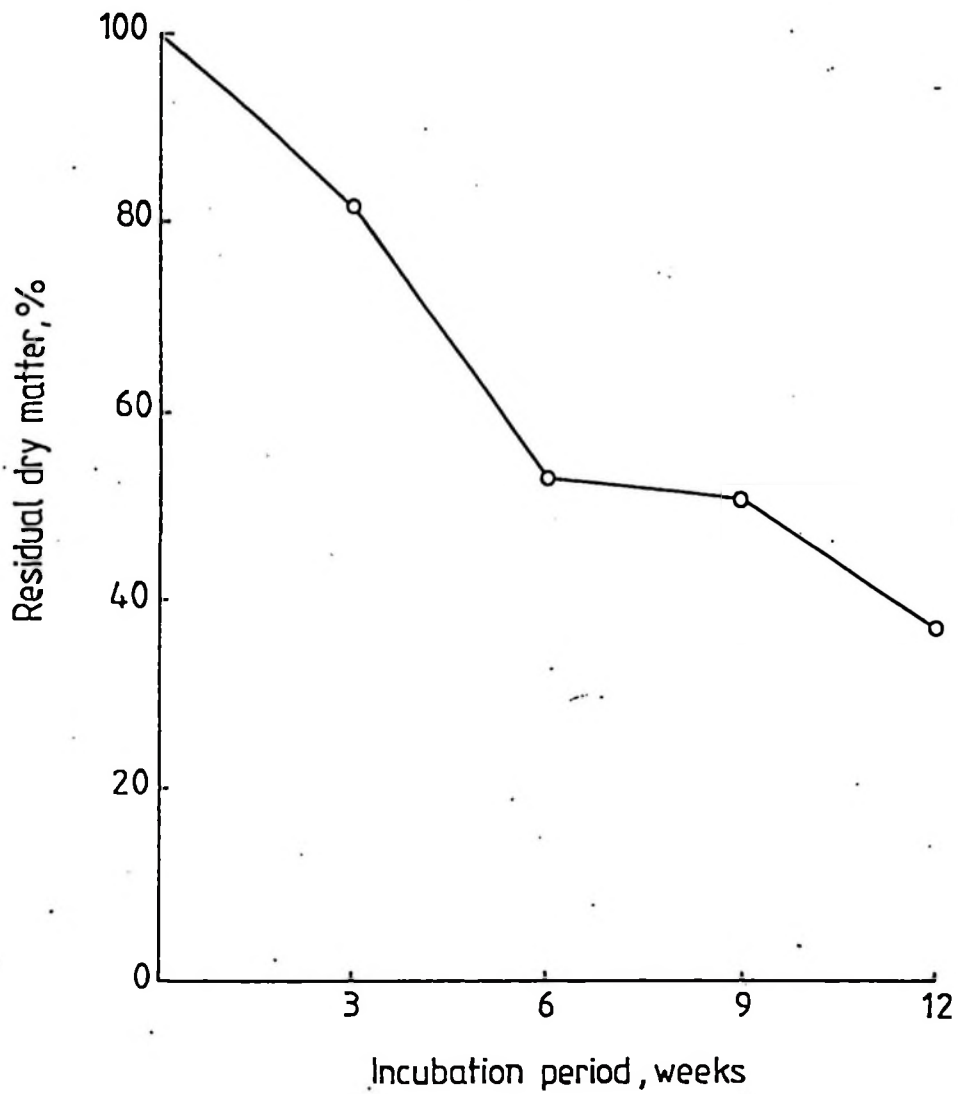


Fig. 4.1. Overall* changes in dry matter of Crotalaria and Leucaena green manures with time of incubation
(*Averaged over sources of green manure and methods of placement)

The results of this study further revealed that there was no significant difference ($P = 0.05$) between the rates at which the two green manures, namely Crotalaria and Leucaena, decomposed (Table 4.1). Thus, those rates were averaged as shown in Fig. 4.1.

Placement method influenced the rate at which the two green manures decomposed. Incorporated manure decomposed significantly ($P = 0.05$) faster than that which was surface applied (Table 4.1, Fig. 4.2).

Decomposition is a biological process which occurs when microorganisms utilize the carbon of the substrate as a source of energy and carbon for protoplasm synthesis. When organic material is introduced to soil, microorganisms start to scavenge on it. To begin with the microorganism population increases very rapidly and the decomposing material disappears very fast. According to the results of the present study, the period of fast disappearance of the decomposing material was the first six weeks after the onset of incubation of the green manures.

The decreased rate of green manure decomposition after the sixth week may be explained as follows:

Table 4.1 : Effect of source of green manure and method of its placement in soil on residual dry matter, averaged over all sampling times

| Source of green manure | Method of placement | | Source of green manure means | LSD for source of green manure means (P=0.05) |
|--|---------------------|-------------------|------------------------------|---|
| | Surface-applied | Soil-incorporated | | |
| --- % residual dry matter --- | | | | |
| <u>Crotalaria ochroleuca</u> | 72.61 | 51.70 | 62.15 | |
| | | | | ± 5.02 |
| <u>Leucaena leucocephala</u> | 79.53 | 53.62 | 66.58 | |
| Method of placement means | 76.07 | 52.66 | | |
| LSD for method of placement means (P=0.05) | | | | ± 5.02 |
| LSD for Table body values (P = 0.05) | | | | ± 15.9 |

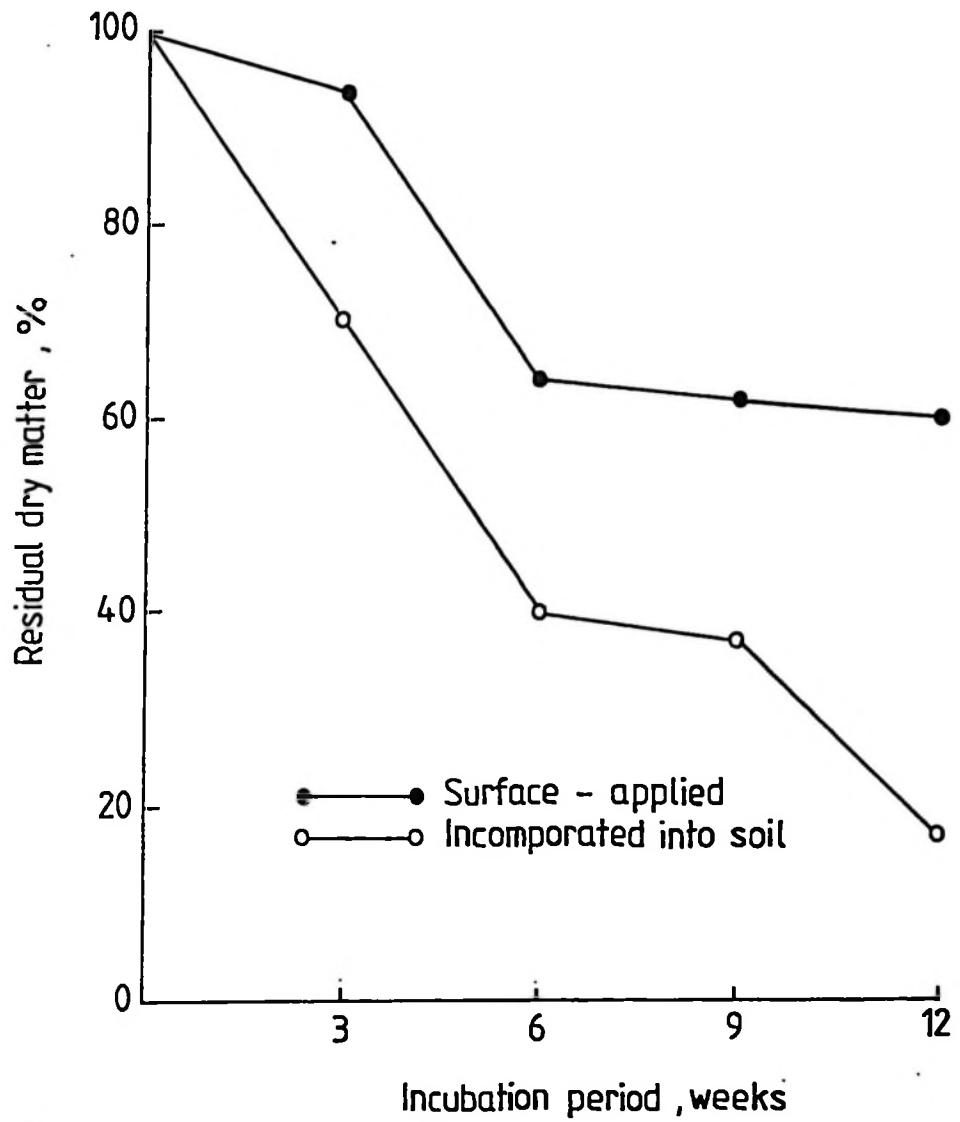


Figure 4.2. Effect of method of green manure placement on residual dry matter over the entire incubation period.

With time (i.e. after six weeks incubation) the substrate may have become depleted of easily decomposable components, leaving behind material which was relatively more resistant to microbial degradation. Therefore the rate of decomposition (i.e. disappearance of organic material) decreased. In the present study, this situation was reached six weeks after incubation was started (Fig. 4.1). This agrees well with the results of Reinertsen et al. (1984) who found that a water soluble component of crop residues was readily decomposable. Similarly Smith and Peckenpaugh (1986) found that the water soluble and other easily decomposable fractions of several cereal-grain straws were decomposed considerably faster during the first 67 days of incubation in the field, resulting in substantial decreases in the residual weight of the materials.

The observed difference in the rate of decomposition of surface-applied and soil-incorporated materials may have been due to more contact between the green manure and the soil in the case of the incorporated material, thereby enabling greater contact with soil microorganisms. This may be the case because incorporated manure stimulated microbial growth to a greater extent than did the surface-applied manure (Section 4.1.5).

Similarly it may also be considered that the intermittently lower moisture status of the surface soil, as a result of the surface losing moisture faster than the substrate, could be additional explanation for the reduced rate of decomposition of the surface-applied compared to the soil-incorporated manures. It may be mentioned here that although 300 ml of water were replenished in the soil after every four days so as to maintain moisture conditions at around field capacity, it was visually observed that at the time of such replenishments the surface was less moist than the subsurface. Bent (1986) reported that surface-applied barley straw was dry on several sampling dates as compared with incorporated straw; Bartholomew and Norman (1946) observed slowed decomposition of oat straw at moisture content levels below 60% in the substrate and it ceased completely at 16%.

Differences in the rate of decomposition of surface-applied and soil-incorporated manure have also been reported by Parker (1962), Brown and Dickey (1970), Bent (1986) and Msumali, G.P. (Personal communication, 1989). Parker (1962) reported 65 and 50% decomposition after 20 weeks of incubating buried and surface-applied materials, respectively. Brown and Dickey (1970) reported weight losses of 93 and 31% for plant residues which were placed 12 cm deep in the soil and on the soil

surface, respectively, for 18 months. Bent (1986) observed weight losses amounting to 80 - 90 and 36% after 12 months of incubating soil-incorporated and surface-applied barley straw, respectively. Msumali found buried Leucaena to have decomposed to a greater extent (50%) in six weeks compared to that which was surface-applied (33%). But the effects of mulching, those of conserving moisture and regulating soil temperature, should also be considered as added advantages of surface application of green manure in addition to nutrient release considerations per se.

4.1.2 Residual organic carbon

The residual organic carbon followed a trend similar to that of residual dry matter (section 4.1.1) in that it decreased as incubation period increased (Fig. 4.3). The rate of decrease was faster in the first six weeks of incubation, whereby 50% of the carbon was lost. The rate of loss was much slower subsequently. By the twelveth week the material had lost 69% of its organic carbon. There was no significant difference ($P = 0.05$) between the trends of carbon loss from Crotalaria and Leucaena manure (Table 4.2, Fig. 4.3). Incorporated green manure lost organic carbon faster than the surface-applied one (Fig. 4.4).

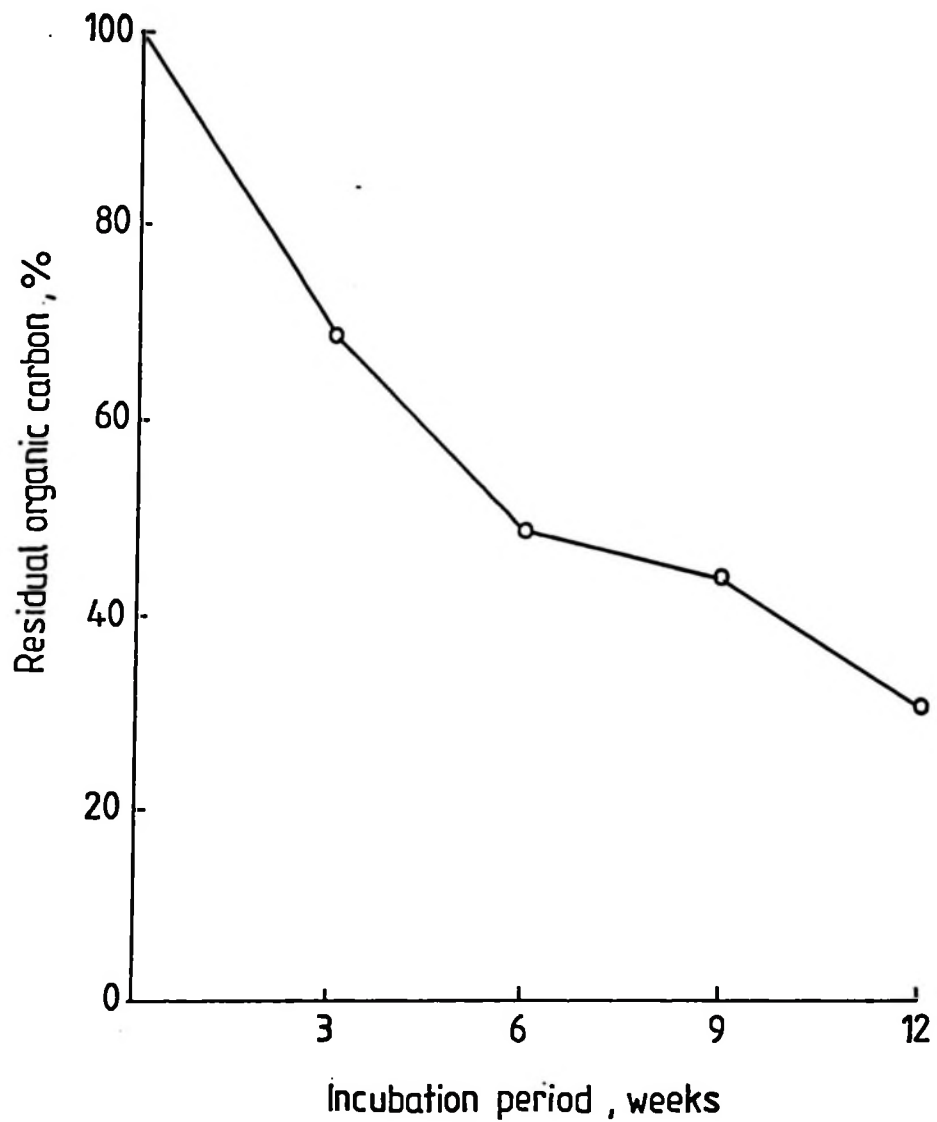


Figure 4.3 . Overall changes of organic carbon of Crotalaria and Leucaena green manures with time of incubation .

Table 4.2 : Effect of source of green manure and method of its placement in soil on residual organic carbon averaged over all sampling times

| Source of green manure | Method of placement | | Source of green manure means | LSD for source of green manure means |
|--|----------------------------------|-------------------|------------------------------|--------------------------------------|
| | Surface-applied | Soil-incorporated | | |
| (P=0.05) | | | | |
| | ---% residual organic carbon --- | | | |
| <u>Crotalaria ochroleuca</u> | 66.69 | 49.15 | 57.92 | + 0.57 |
| <u>Leucaena leucocephala</u> | 70.15 | 45.86 | 58.01 | |
| Method of placement means | 68.42 | 47.51 | | |
| LSD for method of placement means (P = 0.05) | | | | + 0.57 |
| LSD for Table body values (P = 0.05) | | | | ± 1.8 |

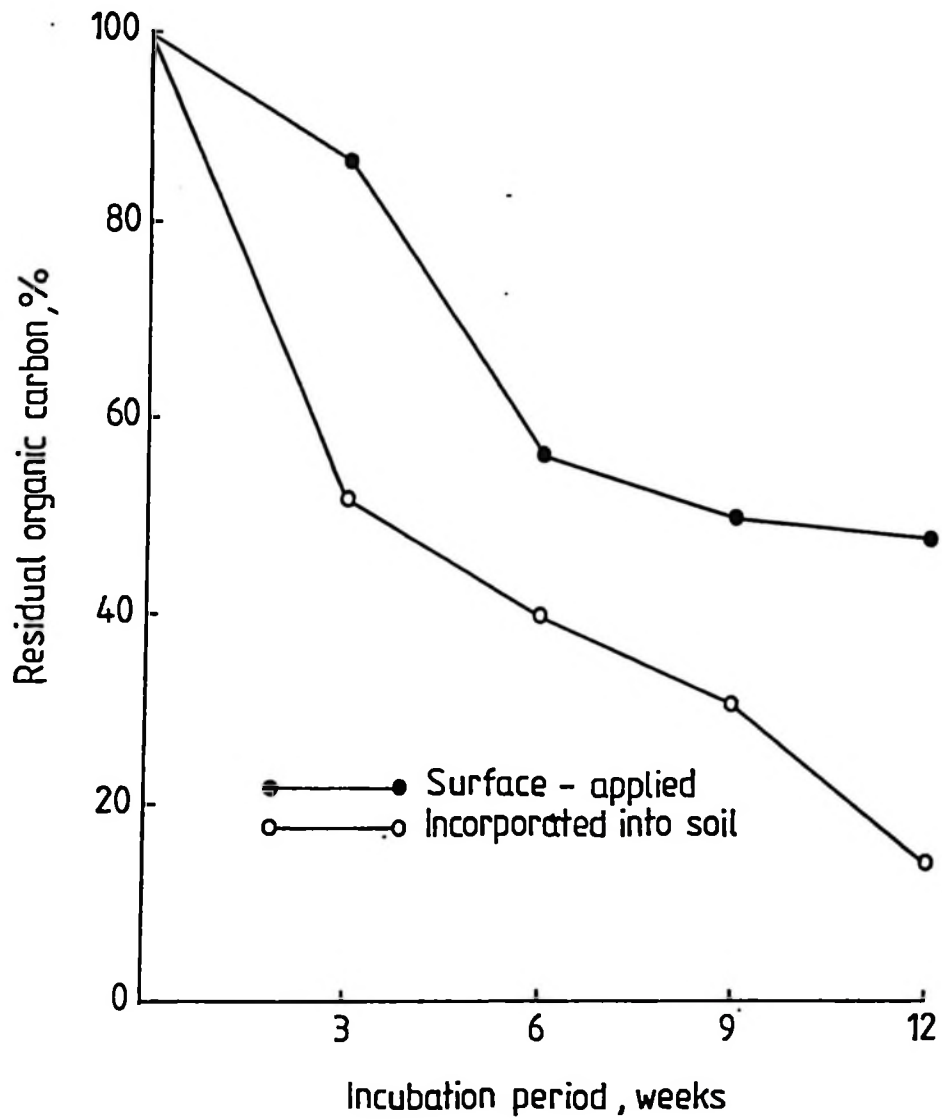


Figure 4.4 . Effect of method of green manure placement on residual organic carbon over the entire incubation period .

The faster rate of organic carbon decrease in the first six weeks may be due to fast rate of decomposition of readily decomposable compounds. Alexander (1977) has categorised simple sugars, amino acids and aliphatic acids as water soluble which, he considered, would be the first to be decomposed followed by cellulose and hemicelluloses. After the six weeks, presumably more resistant compounds remained, thus reducing decomposition rate in the present study. This may be true of both manure materials since they exhibited a similar trend of decomposition.

Debnath and Hajra (1972) studied the transformation of organic matter in soil in relation to mineralization of carbon and to nutrient availability. Their study utilized farm-yard manure, Sesbania and rice straw. They found that within 48 hours after the onset of incubation microbial activity shot up, with subsequent decreases in residual carbon. After nine weeks, changes in residual carbon were minimal. In another study, Amato et al. (1984) reported rapid decreases in residual ^{14}C of Medicago spp. during the initial four weeks, after which changes were small. The findings just cited were obtained using green manure materials which were different from the ones used in the present study. Yet the results had shown a trend similar to those of the present study.

The observed similarity in decomposition of organic carbon compounds of the two green manures in the present study may be an indication that those plant materials contained similar amounts of easily decomposable carbon compounds. If the two plants had differed substantially in their contents of such readily decomposable compounds, it may be conceivable that some differences would also have been observed in their decomposition patterns. This view is consistent with the conclusion made by Amato et al. (1984) that the different patterns of ^{14}C decomposition in different parts of Medicago spp. suggested that those parts differed mainly in their contents of readily decomposable substances. These workers had observed that after 4 weeks of incubation, percent residual ^{14}C in the leaf, stem and root material declined to 62, 70 and 80% indicating that the contents of easily decomposable substance decreased from leaves to roots.

The faster loss of carbon in the incorporated manure (see also section 4.1.1) may be due to improved contact between the manure and a greater population of soil microorganisms. These considerations, involving the role of microorganisms, are discussed further in section 4.1.5.

4.1.3 Residual total nitrogen

The percentage of total nitrogen in the residual green manure materials followed a trend similar to that of dry matter and organic carbon. It decreased sharply during the first weeks (Fig. 4.5), losing 50% of the total nitrogen after six weeks of incubation. From the sixth week to the ninth, residual total nitrogen decreased at a relatively slower rate, but the decline almost levelled off during the last three weeks of incubation. About 70% of total nitrogen was lost during the whole incubation period (12 weeks), but 90% of this loss occurred during the period up to week nine.

Both of the green manures lost nitrogen at almost the same rate (Table 4.3). Figure 4.6 and Table 4.3 show that incorporated manure lost total nitrogen faster than that which was surface-applied, as depicted by lower residual N values in the incorporated green manure relative to the surface-applied one. These trends are similar to those described in sections 4.1.1 and 4.1.2 for dry matter and organic carbon, respectively.

The amounts of nitrogen (kg/ha) released from the green manures after six and 12 weeks of incubation are shown in Table 4.4. The two green manures did not

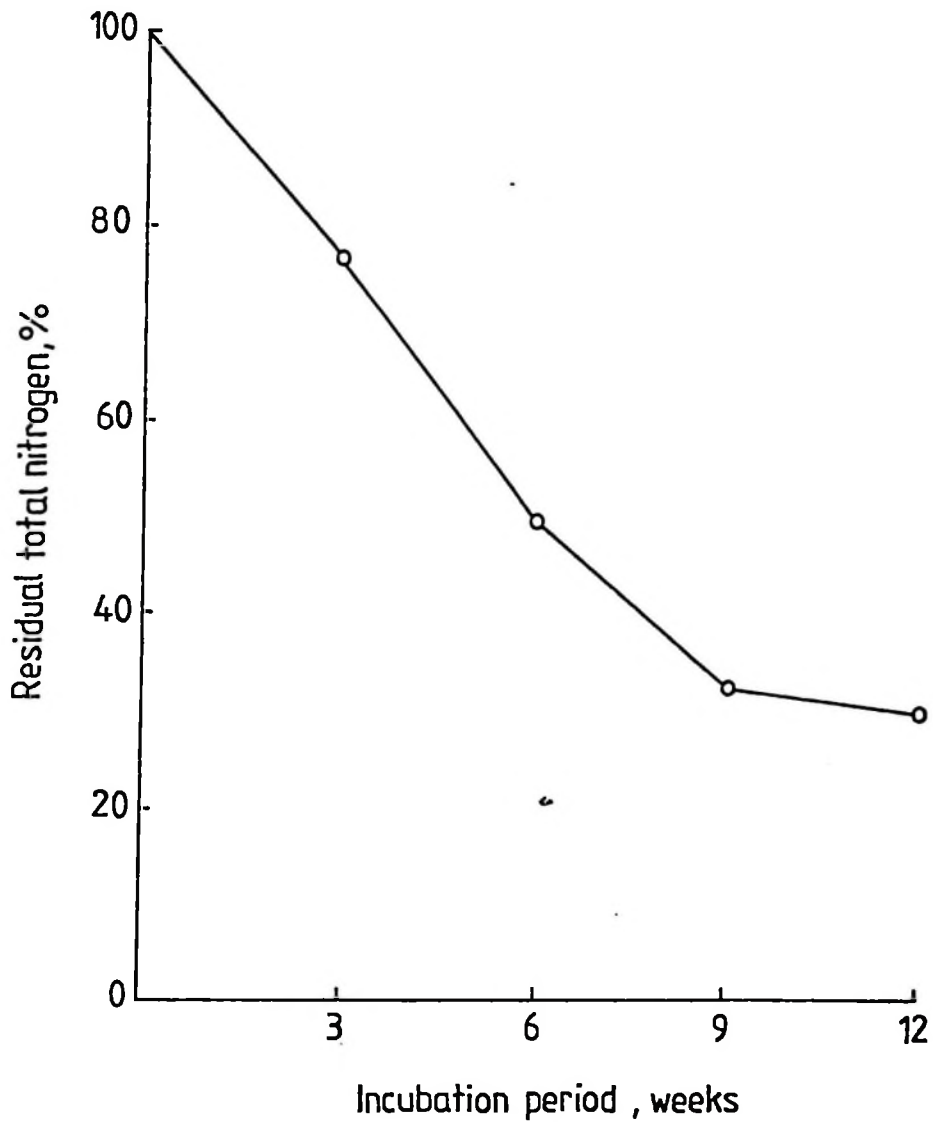


Figure 4.5 . Overall changes in total nitrogen of Crotalaria and Leucaena green manures with time of incubation .

Table 4.3 : Effect of source of green manure and method of its placement in soil on residual total nitrogen, averaged over all sampling times

| Source of green manure | Method of placement | | Source of green manure means | LSD for source of green manure means (P=0.05) |
|--|---------------------|-------------------|------------------------------|---|
| | Surface-applied | Soil-incorporated | | |
| ---% residual total nitrogen--- | | | | |
| <u>Crotalaria ochroleuca</u> | 66.0 | 48.7 | 57.3 | |
| | | | | ± 1.3 |
| <u>Leucaena leucocephala</u> | 66.6 | 49.5 | 58.1 | |
| Method of placement means | 66.3 | 49.1 | | |
| LSD for method of placement means (P = 0.05) | | | | ± 1.3 |
| LSD for Table body values (P = 0.05) | | | | ± 4.0 |

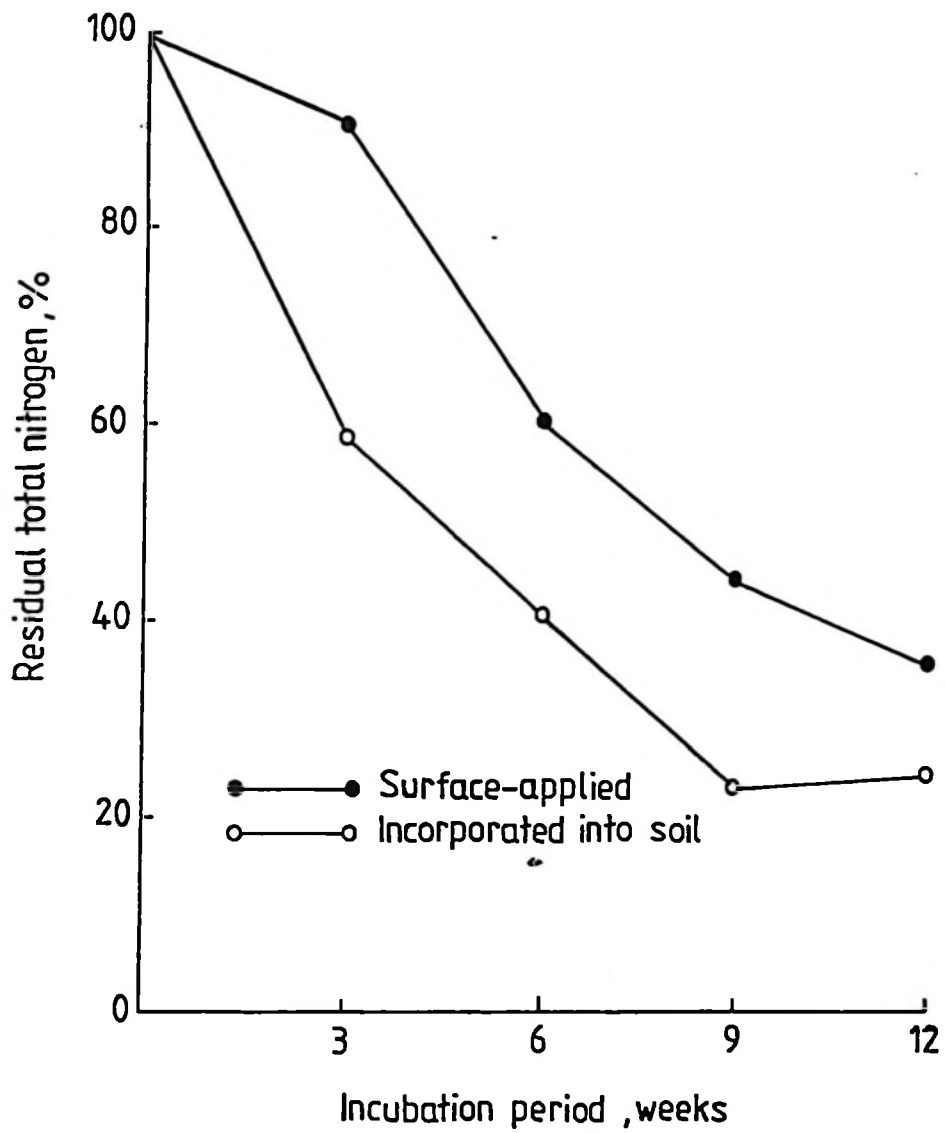


Figure 4.6 . Effect of method of green manure placement on residual total nitrogen over the entire incubation period.

Table 4.4 : Effect of method of green manure incorporation into soil on nitrogen release upon manure decomposition

| Method of green manure placement | Nitrogen released after : | |
|----------------------------------|---------------------------|----------|
| | 6 weeks | 12 weeks |
| | ----- kg N/ha ----- | |
| Surface-application | 25 (42)* | 38 (63) |
| Soil-incorporation | 36 (60) | 46 (77) |

* Numbers in parentheses are percentages of the original total N (60 kg/ha) added as green manure.

differ significantly ($P = 0.05$) in the amounts of nitrogen they released.

On average, nitrogen released from surface-applied green manure (average for both types of green manure) was 25 and 38 kg/ha (corresponding to 42 and 63% of initial input) after six and 12 weeks of incubation, respectively (Table 4.4). During the same times, nitrogen released from soil-incorporated manures was 36 and 46 kg/ha (corresponding to 60 and 77% of N input), respectively. When averaged over all treatments, the green manure released 51% and 70% of the N input after six and 12 weeks of incubation.

For the first three weeks C/N ratio of the residual material changed little. Thereafter the ratios increased both in surface and incorporated manure (Fig. 4.7).

The initial fast rate of manure decomposition has been explained in terms of availability of easily degradable compounds (section 4.1.1). As decomposition proceeded, a stage was reached when easily decomposable nitrogen compounds became depleted, thereby slowing down the rate of disappearance of nitrogen after nine weeks (Fig. 4.5). From the literature it is known that amino acid nitrogen decomposes faster, followed by amino sugar

(Paul and Clark 1989). Therefore depletion of the former, and accumulation of the latter, may have accounted for the slower rate of the disappearance of total nitrogen between the sixth and the ninth weeks of incubation. Decomposition was slowest after nine weeks when, presumably, all the easily degradable components were completely depleted.

Changes in total nitrogen with incubation time have been reported also by Amato et al. (1984). These workers found rapid disappearance of residual ^{15}N in Medicago spp. during the first four weeks of incubation. At the end of the four weeks period 64% of leaf ^{15}N had decomposed, but decomposition was retarded thereafter. Weeraratna (1980) observed a rapid release of nitrogen from Crotalaria, Gliricidia, sunflower, Centrosema and Calopogonium during the first two weeks of incubation. Thereafter the rate of release was slower. Smith and Peckenpaugh (1986) observed rapid losses of nitrogen during the early days of incubation of organic materials only to be followed by small disappearances of N after 67 days of decomposition. From this they concluded that where large losses of nitrogen occur in the early stages of incubation the residual materials become depleted of nitrogen, water-soluble, and readily decomposable components.

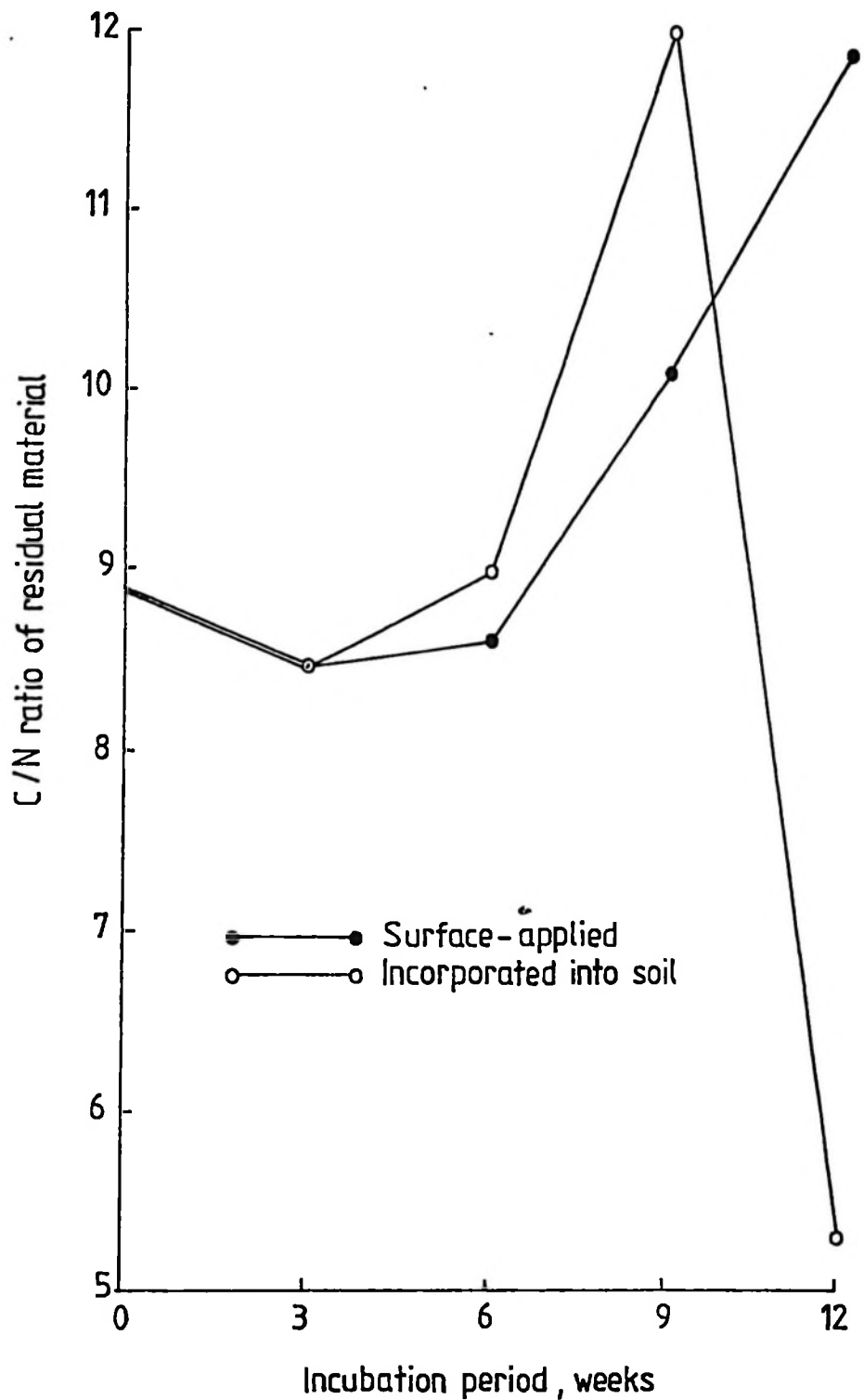


Figure 4.7. Changes in the C/N ratio of Crotalaria and Leucaena green manures with time of incubation.

The greater loss of nitrogen from the soil-incorporated manure, relative to that which was surface-applied, may be due to enhanced contact between the manure and the correspondingly bigger microbial population (section 4.1.5) responsible for the decomposition (section 4.1.1). That greater contact may have enhanced the availability of the nitrogen to the microorganisms, making them able to decompose the manure at a faster rate in the case of the incorporated manure. Similar results were reported by Bent (1986). In his study he found that buried barley straw lost 47 - 60% of nitrogen in 14 months of incubation while surface-applied straw lost 37% of its nitrogen.

The amounts of nitrogen released after 12 weeks of decomposition in the present study were substantial. Still, there were considerable amounts of nitrogen remaining in the residual materials. The residual manure would continue to supply the nutrient to the soil/plants beyond the 12 weeks. This explains why green manures are regarded as slow-release nutrient sources and are highly placed for their residual effects (Sharma and Mitra 1988). The slow-release pattern is unlike in inorganic nitrogen fertilizers which, although easily available to the plant, can easily be lost through leaching and volatilization (Sanchez 1976).

The increase in C/N ratio especially after three weeks of incubation implied that nitrogen was utilized by the microbes during decomposition of the manures. However, incorporated material had higher ratio than surface-applied up to week nine. This means more nitrogen was used from incorporated manure, a reflection of greater decomposition in the incorporated manure. This may be attributed to better contact between the incorporated manure and the microbes in the soil (Pritam and Broadbent 1977). The drop of C/N ratio of incorporated manure after nine weeks is difficult to explain at present.

Having seen the pattern of nitrogen release by the two green manures it is the author's suggestion that further research in Tanzania should be directed at determining the available nitrogen gains in the soil. It should then be possible to find out how much of the nitrogen that is released from the green manure is immediately available to plants. This can possibly be done by tracer techniques by which it will be possible to differentiate the soil available N that has been mineralised from soil organic matter and that which has been released from the manure.

4.1.4 Residual organic phosphorus

Generally as in the case of dry matter, organic carbon and total nitrogen there was a decrease in organic phosphorus in the residual material as incubation period increased (Fig. 4.8). It may be noted (Fig. 4.8) that 40% of organic phosphorus was lost by the sixth week of incubation, and by the twelfth week about 73% had been lost.

Overall there was no significant difference ($P=0.05$) in the percent residual organic phosphorus between the two green manure materials (Table 4.5, Fig. 4.8). Surface-applied green manure retained significantly ($P = 0.05$) higher levels of residual organic phosphorus compared to that which was incorporated into the soil (Table 4.5, Fig. 4.9).

The amount of phosphorus released from the green manure after six and 12 weeks of decomposition are shown in Table 4.6. These have been worked out as differences between input P in the two manures (3 kg/ha for Crotalaria and 5 kg/ha for Leucaena) and residual P. Average input of phosphorus was therefore 4 kg/ha. The average phosphorus release from surface-applied manure after six and 12 weeks of decomposition was 0.8 and 2.2 kg/ha (corresponding to 20 and 55% of P input),

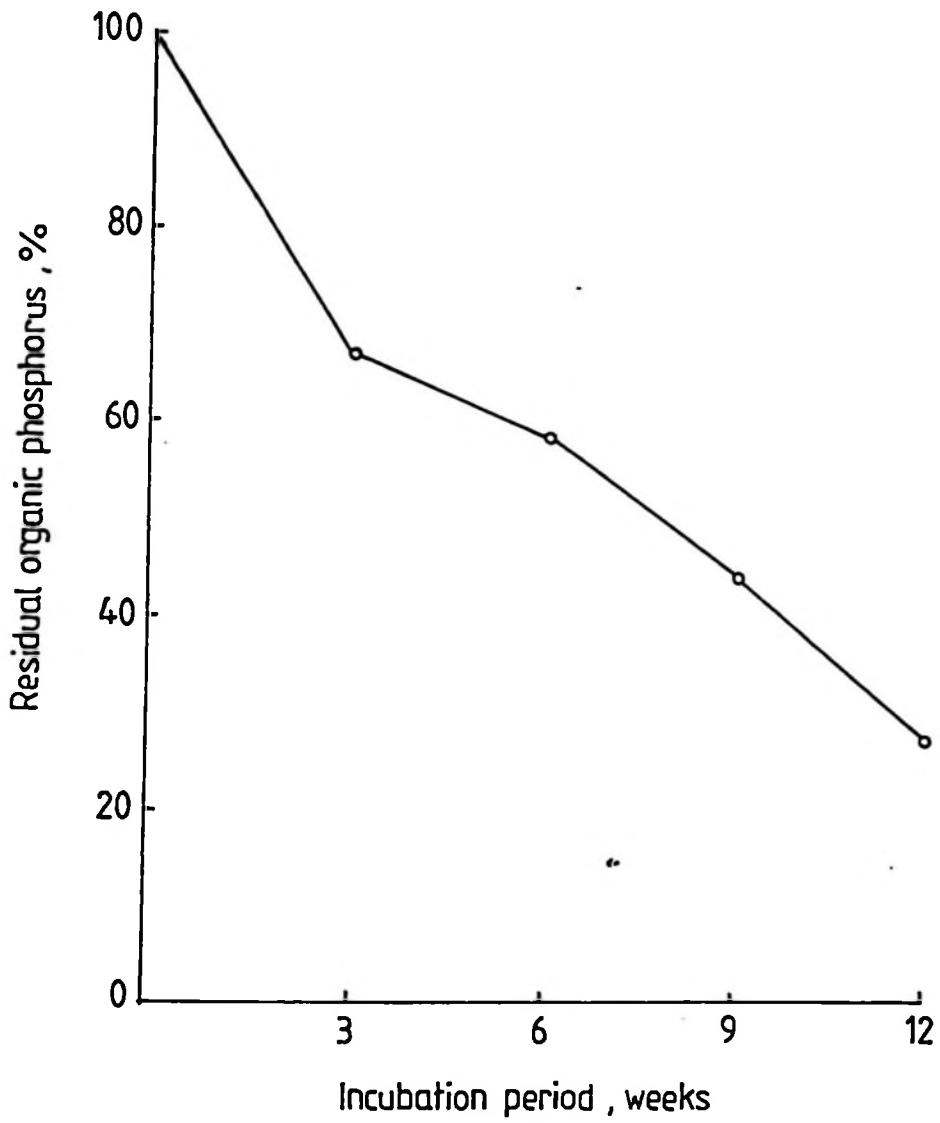


Figure 4-8. Overall changes in organic phosphorus of Crotalaria and Leucaena green manures with time of incubation.

Table 4.5 : Effect of source of green manure and method of its placement in soil on residual organic phosphorus, averaged over all sampling times.

| Source of green manure | Method of placement | | Source of green manure means | LSD for source of green manure means (P = 0.05) |
|--|---------------------|-------------------|------------------------------|--|
| | Surface-applied | Soil-incorporated | | |
| <u>Crotalaria ochroleuca</u> | 78.46 | 40 | 59.23 | ± 2.68 |
| <u>Leucaena leucocephala</u> | 72.56 | 47.18 | 59.87 | |
| Method of placement means | 75.51 | 43.59 | | |
| LSD for method of placement means (P = 0.05) | | | | ± 2.68 |
| LSD for Table body values (P = 0.05) | | | | ± 8.46 |

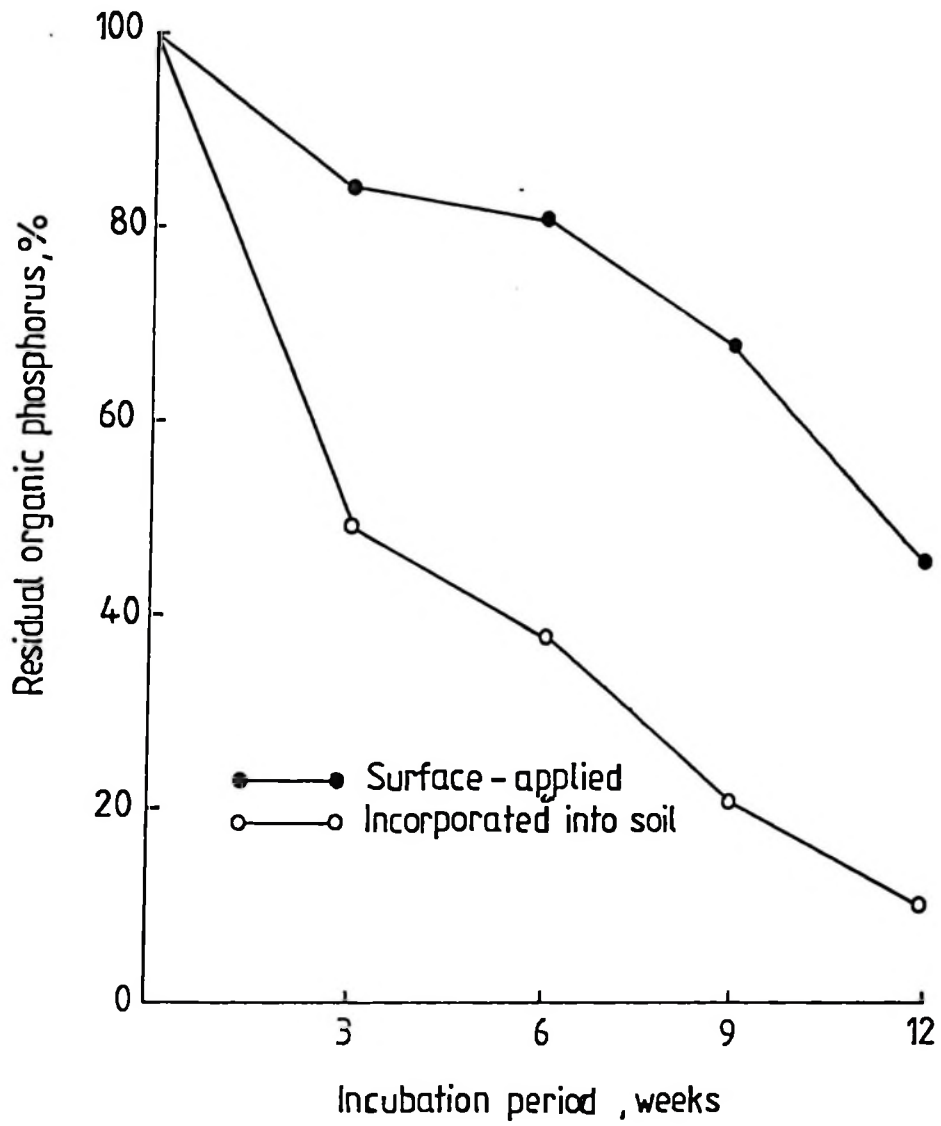


Figure 4.9 . Effect of method of green manure placement on residual organic phosphorus over the entire incubation period .

respectively (Table 4.6). During the same times, incorporated manure lost 2.4 and 3.6 kg/ha (corresponding to 60 and 90% of P input), respectively. On the average, green manure released 40% of input P after six weeks of decomposition and about 73% after 12 weeks.

There was only little change in C/P ratio for surface-applied manure. Increasing C/P ratios were observed in the case of incorporated manure (Fig. 4.10).

The effects of incubation period, source of green manure and placement method on residual dry matter, residual organic carbon and residual total nitrogen have been discussed in sections 4.1.1, 4.1.2 and 4.1.3, respectively. The reasons given to account for the observations made in the above three sections, that is faster disappearance of easily decomposable components, and greater contact with microorganisms, may also hold true for the case of residual organic phosphorus.

The small amounts of phosphorus released by the green manures is a reflection of the low phosphorus content of the two manures (Brom and Van der Wal 1988). This means that in soils which are deficient in phosphorus, green manuring should be supplemented with phosphatic fertilizers.

Table 4.6 : Effect of method of green manure incorporation into soil on phosphorus release upon manure decomposition

| Method of green manure placement | <u>Phosphorus released after:</u> | |
|-------------------------------------|-----------------------------------|----------|
| | 6 weeks | 12 weeks |
| | ----- kg P/ha ----- | |
| Surface-application | 0.8 | 2.2 |
| Soil-incorporation | 2.4 | 3.6 |

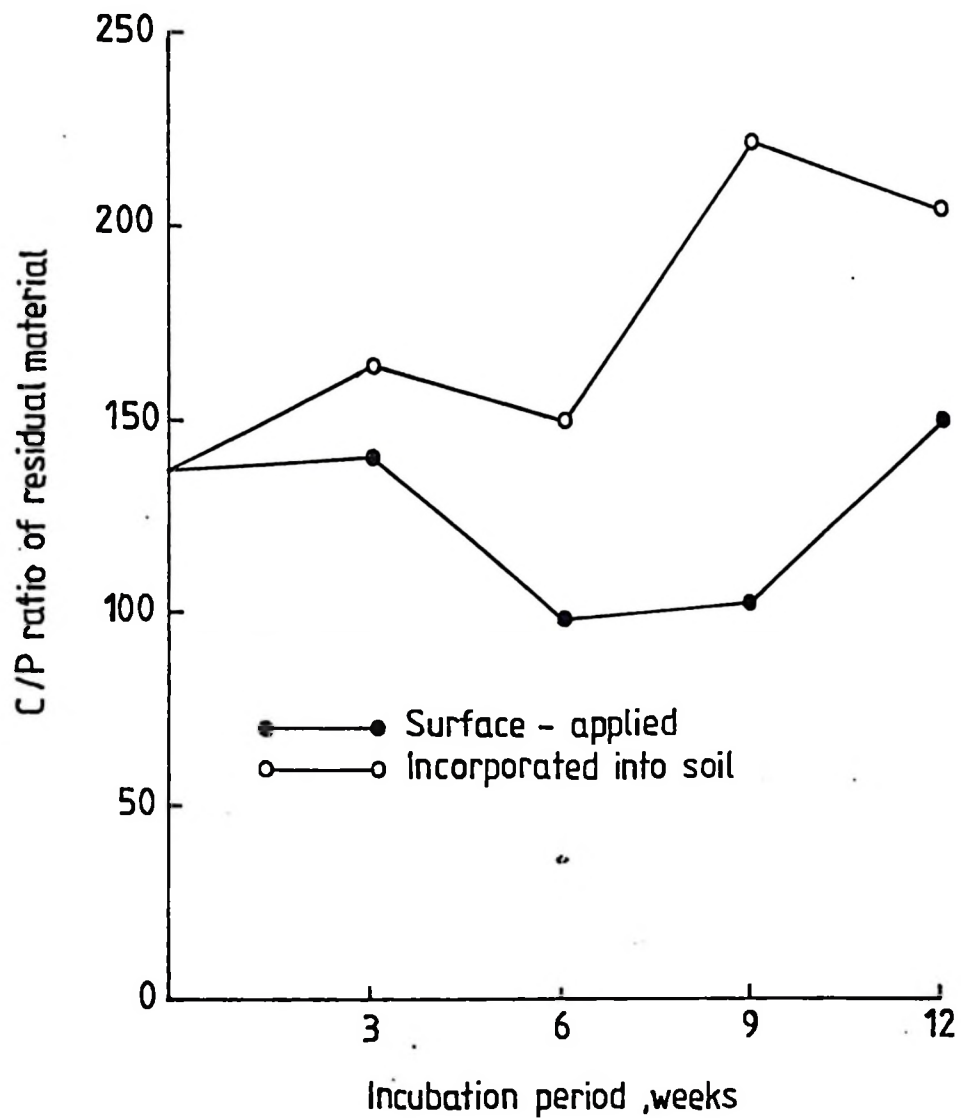


Figure 4.10. Changes in the C/P ratio of Crotalaria and Leucaena green manures with time of incubation.

The observed higher levels of C/P ratios in incorporated manure was an indication of the fact that more P was utilized by microorganisms in the incorporated manures, than in surface-applied ones. This was due to higher rate of decomposition which was enhanced by greater contact between soil-incorporated material and soil microorganisms.

4.1.5 Changes in microbial numbers in relation to manure decomposition

The overall trend of changes in microbial numbers during the decomposition of Crotalaria and Leucaena green manures is shown in Fig. 4.11. The numbers increased rapidly with length of incubation time reaching, in the sixth week, a level which was almost sixfold that observed before incubation was started. Thereafter, up to the twelveth week, the rate of increase was slower.

There was no significant difference in the microbial numbers between soils which were treated with Crotalaria and those treated with Leucaena materials. The soils which were treated with green manure had significantly ($P = 0.01$) higher microbial numbers than the controls (Fig. 4.11). The incorporation of green

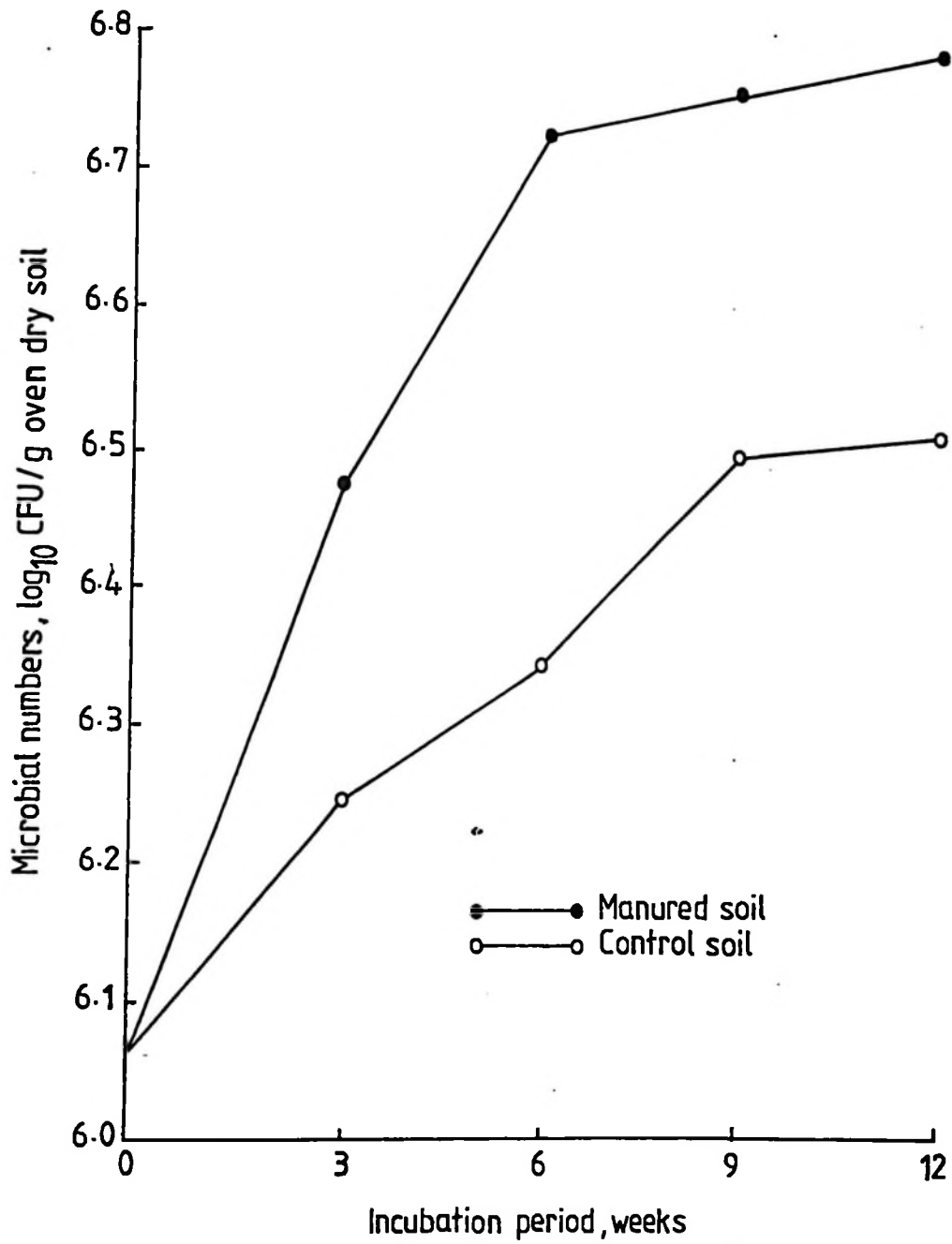


Figure 4.11. Overall changes in soil microbial numbers under Crotalaria and Leucaena green manures and in control soil with time of incubation.

manure into the soil resulted in significantly ($P = 0.01$) larger microbial populations than where the manure was surface-applied (Fig. 4.12).

The rapid increases in microbial population during the first six weeks of incubation of the green manures corresponds well with the rapid disappearance (degradation) of the green manure during the same period, as depicted by the various indexes, that is, residual dry matter, residual organic carbon, residual total nitrogen, and residual organic phosphorus (sections 4.1.1 to 4.1.4). The slower increases after the sixth week also relate well with the observed decline in the rate of degradation of the organic materials beyond the sixth week. This trend implies that it is the increased microbial populations which resulted in the rapid increase in manure decomposition rates during the first six weeks of incubation. This relationship is depicted in Fig. 4.13, which shows that rapid increases in microbial populations were associated with rapid declines in the percentages of residual manure materials. This gives an indication that as the decomposers' numbers increased the decomposition rate increased. It may be assumed that when the green manure was introduced into the soil, the microorganisms degraded it to obtain simpler compounds for their

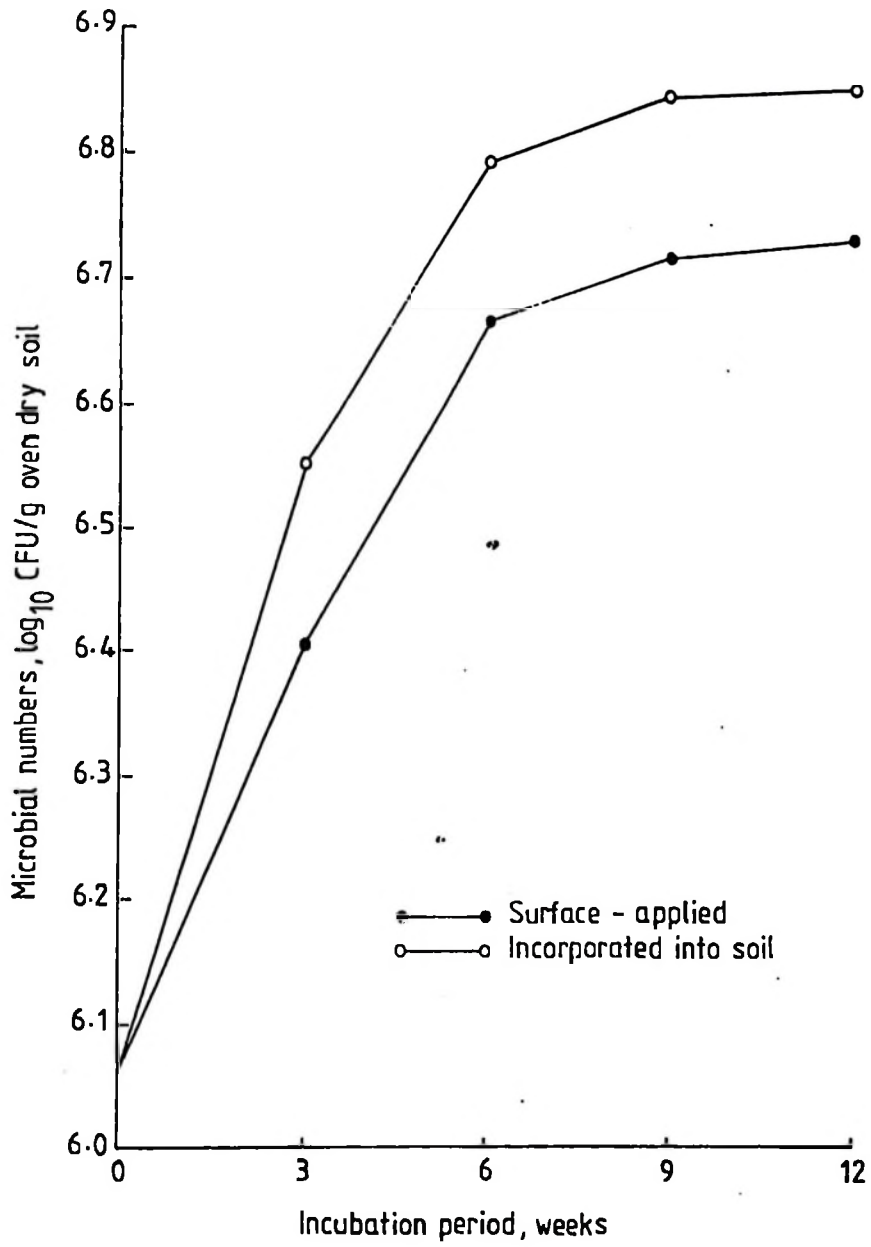


Figure 4.12 . Effect of green manure placement on soil microbial numbers over the entire incubation period.

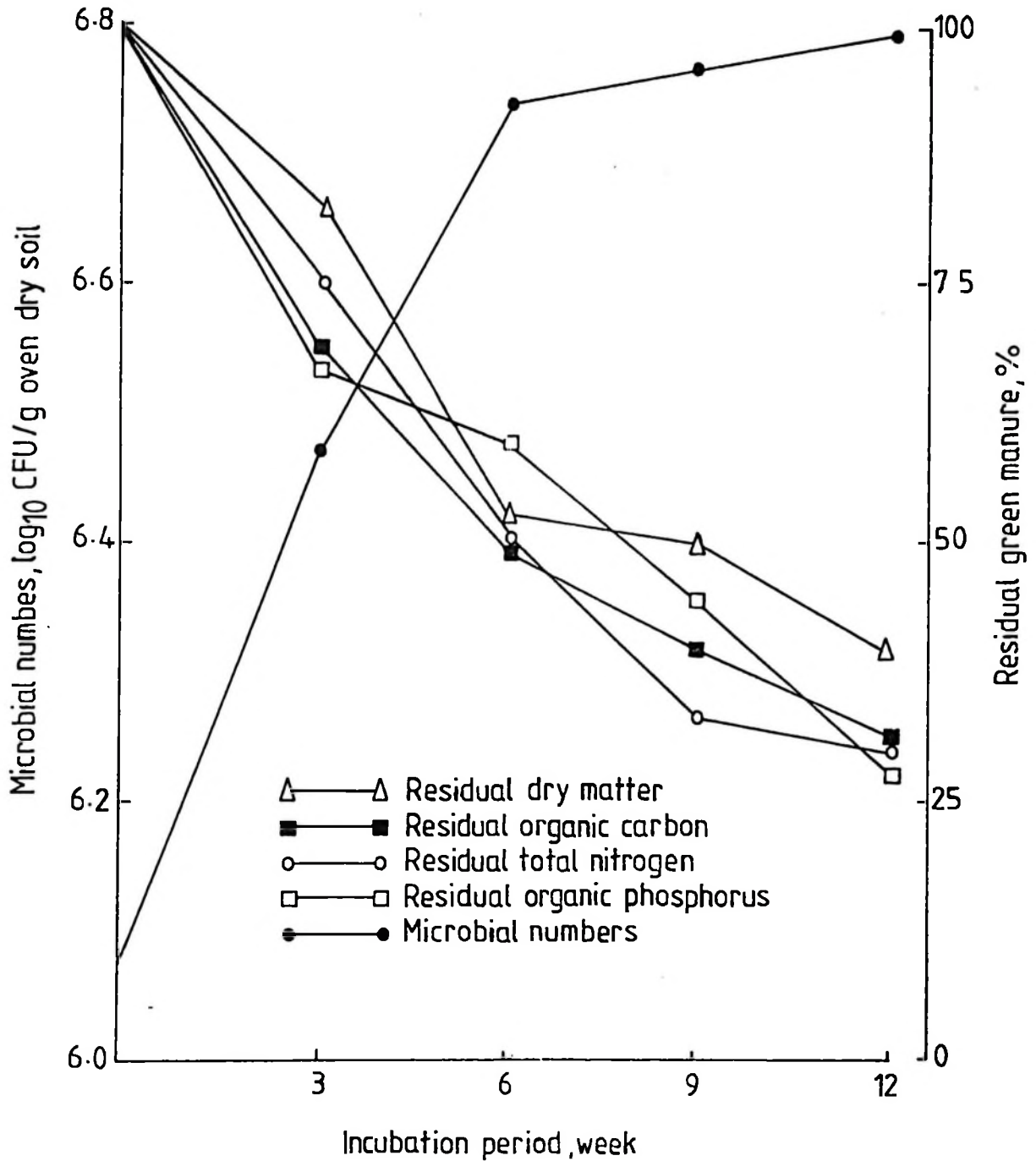


Figure 4.13 . Relationship of increase in soil microbial population and overall pattern of decomposition of Crotalaria and Leucaena green manures .

metabolic processes. The rapid increase in microbial populations may have been due to presence of readily decomposable components in the organic manures. This may be in contrast with the control soil whose organic matter had decomposed over a long time, thus reaching the stage at which the remaining material was relatively more resistant, thereby unable to stimulate microbial growth to the same extent as did the fresh manures (Fig. 4.11). As the decomposition of the manure proceeded it is probable that there was a concomitant depletion of the readily degradable components, leaving behind materials which were more resistant to decomposition. This may explain why microorganism numbers increased at a slower rate after the sixth week and, consequently, why decomposition proceeded at a slower rate during that period.

Results similar to those of the present study have been reported by Campbell and Biederbeck (1982) and Jawson and Elliott (1986). Campbell and Biederbeck (1982) observed that the highest bacteria: actinomycete ratio occurred immediately after cropping but as the quantity of the plant residues diminished the ratio narrowed. They therefore held the view that organic substrates were involved in the microbial growth. Jawson and Elliott (1986) observed increased soil microbial numbers 12 days and 24 days after adding roots and

straw, respectively. After those times microbial growth rate declined with time. They explained the decline as being a reflection, of among other things, changes in substrate composition with time. Thus, in the present study the slower rate of microbial population increase after six weeks may be due to a depletion of easily metabolizable components (see section 4.1.1 to 4.1.4).

The lack of a significant difference in the microbial population under Crotalaria and under Leucaena may imply that, at the stage of growth in which the materials were used as manure, the two materials furnished similar levels, and possibly types, of the readily decomposable components. This inference is supported by Jawson and Elliott (1986) who observed a larger microbial biomass associated with wheat straw rather than roots because the straw had more readily decomposable components than the roots. Based on this observation, it is conceivable that if one of the green manures used here had more readily decomposable material then it would have been associated with significantly larger population of microorganisms than the other manure.

The higher microbial populations in the soils where the manure was incorporated relative to those in which it was surface-applied may be due to enhanced contact

between the soil and most of the incorporated manure. Thus, the more accessible manure stimulated a greater population. This increased population may then explain the increased rate of decomposition of the incorporated vis-a-vis the surface-applied manure.

4.1.6 General discussion

4.1.6.1 Consistency of the four indexes used to assess decomposition of the green manures

In the present study, the four parameters/indexes used to monitor and determine decomposition rate were reasonably consistent. It was observed that the rates of decomposition as depicted by the different parameters, were generally very similar.

It was observed that after six weeks of decomposition, 48, 51, 50 and 41% of dry matter, organic carbon, total nitrogen and organic phosphorus, respectively, had been lost. Similarly after 12 weeks 62, 69, 70 and 73% of the dry matter, organic carbon, total nitrogen and organic phosphorus, respectively, had been lost. These trends were thus similar, giving an indication that all the indexes were suitable means of assessing decomposition of those green manures.

4.1.6.2 Some practical problems in the timing of green manuring operations

Much work has been done and results reported on green manuring (Brom and Van der Wal 1988). The results of the present study generally agree with previous reports in that green manures can release substantial amounts of nutrients to the soil. Based on the conclusions drawn in the previous studies, as well as those of the present study, the potential and benefits of green manuring are not doubted.

However, some questions need to be raised which are relevant from the operational view point, especially when dealing with peasant farmers and rainfed crops. These questions relate to the timing of green manuring. Timing, in this context, may involve all the considerations from planting of the green manure to its application.

The results of the present study indicated that it took six weeks (section 4.1.1 to 4.1.5) for the manures to release 50% of their nitrogen. More nitrogen was also released subsequently. The implication here is that the manures should be applied at least six weeks before the time of maximum nutrient requirements of the crop in the field, for it to satisfy those requirements. This means, in turn, that the manure (especially if it

is of the annual type) should be grown (raised) much earlier. This raises some practical/operational problems when we consider rainfed agriculture, with no possibilities for initial and/or supplemental irrigation.

In rainfed agriculture, seeds are sown at the beginning of the rainy season, before which conditions of drought, very extreme on many occasions, exist. This means that the manure cannot be raised during the dry season. An alternative would be to sow it (the manure) immediately following the onset of rains, so as to use it later in the season. This may have practical problems in that the rainy season is usually short, coupled with unreliability of the rains. So to delay sowing of the crop in order to raise the green manure may be disastrous, the end result being no harvest due to curtailing of the growth season. One way around this would be to sow the green manure at the same time as the crop and to harvest the manure and apply it at a time that it may still allow enough time of decomposition to satisfy nutrient requirements of the crop at the maximum need. One disadvantage here is that part of the space which would otherwise be taken up by the crop will now be used for raising the green manure. Thus crop yields per unit of land will decrease (due to reduced plant population). These ideas may, however, merit further

research into. The research may focus on patterns of intercropping of crop and green manure, methods of incorporation when the crop is still in the field, etc.

Another approach would be to subdivide the farm so that that piece used for raising of the green manure would be the one manured and then cropped in the subsequent season. This, too needs further research, especially on the nutrient retention characteristics of the soil between one growing season and the next. This option may be thwarted also by the fact that many farmers may have only one piece of land, insufficient for subdivision.

The labour requirement in green manuring is another area which needs to be addressed. The materials are bulky, sometimes requiring time-consuming and labour-intensive work of establishing, collecting, transporting and application. Application rates of as much as 6.7 or 8.7 ton/ha as in the present study, or higher at times, are considerably tedious to the farmer who has no machinery but depends on his own labour. The labour needed to be invested in the green manure (ploughing of field, sowing of manure seeds, ploughing under of the manure etc.) may be the equivalent of that needed to raise a crop. To the poor farmers, this may be looked upon simply as a waste of labour. Research needs to be

directed to this area to find ways of stream-lining the labour involvement.

These are just a few, by no means all, of the concerns which need to be addressed in the concept and practice of green manuring, beyond the findings that the practice is beneficial. It is the considered view of this author that these are formidable problems. Solution to these would, therefore, be a pre-requisite before one can hope that this practice of green manuring will be widely adopted by, especially, the peasant farmers.

5.0 SUMMARY AND CONCLUSIONS

Generally, the results obtained in the present study have shown that with time residual dry matter, organic carbon, total nitrogen and organic phosphorus decreased with comparable patterns in both green manures. All the indexes decreased faster during the first six weeks of incubation and at slower rates thereafter. It was concluded that the observed trend reflected changes in substrate composition as incubation time increased: The period of faster disappearance of dry matter, organic carbon, total nitrogen and organic phosphorus was due to degradation of readily decomposable components of the green manures. Resistant compounds were left behind as the readily decomposable materials were depleted, thus contributing to the subsequent slower rate of decomposition.

The two manures decomposed at similar rates. Possibly this was due to the two materials having almost similar amounts of total nitrogen, organic carbon and presumably readily decomposable components at the stage of growth when they were used.

More specifically, the soil-incorporated manures decomposed significantly ($P = 0.05$) faster than those which were surface-applied. This can be due to enhanced

contact between the incorporated material and soil microorganisms. It is also assumed that moisture condition differences between the surface and subsurface, with the latter being favourably more moist for microbial growth, could also explain the observed differences in decomposition. It is also concluded that incorporating of green manure is better than surface-applying it.

There was consistency in the four decomposition indexes, which suggests that those indexes attempted almost equally to characterize decomposition patterns of the two green manures. It was found, for example, that the green manure had lost 48,51,50 and 41% of dry matter, organic carbon, total nitrogen and organic phosphorus, respectively, after decomposing for six weeks. It was further observed that 62,69, 70 and 73% of dry matter, organic carbon, total nitrogen and organic phosphorus, respectively, had been lost after 12 weeks of incubation. With such observations it was concluded that the four indexes were suitable means of assessing decomposition of those manures.

A substantial amount of nitrogen was released from the green manures. There was no significant ($P = 0.05$) difference between the capacities at which the two manures released nitrogen. After six weeks of

incubation, the surface-applied manure had released the equivalent of 25 kgN/ha while incorporated manure was found to have released 36 kgN/ha. Similarly, after 12 weeks of incubation the surface-applied manure released the equivalent of 38 kgN/ha while incorporated manure released 46 kgN/ha. It was therefore evident that incorporated manure released more nutrients at any one time than the surface-applied. This could be accounted for by the fact that decomposition of incorporated manure was significantly ($P = 0.05$) faster than that of surface-applied manure as discussed above.

Microbial numbers increased rapidly during the first six weeks from the onset of incubation. The increase declined and then almost levelled off thereafter. The rapid multiplication of microorganisms was due to availability of easily decomposable compounds, depletion of which resulted in the subsequent slow multiplication rate. Soil microbial populations were significantly larger in the case of soil-incorporated manure than surface-applied because incorporated manure was more accessible to microorganisms than the surface-applied manure. It is also considered that moisture condition in the subsurface may have been more favourable to the microorganisms than on the surface. Generally, increases in microbial numbers were highly associated

with increasing decomposition rates of the green manure, thus supporting the fact that the decomposition was carried out by the microorganisms.

From the observed decomposition and nutrient (N & P) release patterns of the two green manures it is speculated that these green manures should be applied at least six weeks before the period of maximum nutrient requirements of the crop. When this is done it is hoped that the period of maximum rate of nutrient release from the green manure will be synchronised with peak nutrient demand by the intended crop. The findings of this study are basically under conditions which were maintained at near optimum. Under natural field conditions, however, the rate of nutrient release would be different. More research is needed to establish it under field conditions.

The potential of green manures in improving the productivity of our soils is well understood. However, before the practice of green manuring is widely adopted, there are pertinent issues which have to be addressed. These include extra farm labour requirements, climatic constraints, and land pressure relative to farmers' own cropping systems. This calls for concerted efforts to strengthen research in these aspects so as to come up

with appropriate recommendations which address these issues.

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