ASPECTS OF GREEN MANURING WITH SPECIAL REFERENCE TO SOIL CARBON DIOXIDE EVOLUTION

by

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Declaration

I hereby declare that this Thesis has been composed by myself, that it has not been accepted in any previous application for a degree, that the work of which it is a record has, unless acknowledged otherwise, been done by myself and that all quotations have been distinguished by quotation marks.

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SUMMARY

Early investigations into the effects of the incorporation of a green crop into the soil in tropical areas produced conflicting results. There was evidence in Nigeria particularly to show that green manures benefited the succeeding crops. In Uganda, however, no lasting effects were found and the practice was abandoned as a means of maintaining soil fertility.

The objective of the experiments to be described was to re-examine the practice of incorporating green manure in terms of yield from a succeeding crop and effects on the soil. The work was carried out at Makerere University College Farm, ten miles from Kampala, Uganda.

In Part I the green manuring experiment, chemical analysis of the soil and test cropping results are described.

The crops grown as green manures were sunn hemp (*Crotalaria juncea*) and maize and they were compared to weed fallow. The crops were incorporated by rotary cultivation and four crops were grown in one year. Supplementary water was applied to two of the treatments to determine whether water was a factor limiting growth, and nitrogen fertilizer was applied to two of the maize green manure treatments.

The total dry matter incorporated in the year from the weed fallow was 3,400 lbs/acre (3,800 kg/ha) and from the sunn hemp 11,000 lbs/acre (12,400 kg/ha). The maize green manure without nitrogen produced 20,800 lbs/acre (23,300 kg/ha) and with nitrogen 29,000 lbs/acre (32,550 kg/ha).

A test crop of maize was then planted to determine if in fact there was any effect on soil fertility as measured by yield. The original green manure plots were split for fertilizer treatments into two, one half receiving inorganic fertilizer in the ratio of 3:2:1 of Nitrogen, Phosphate and Potash respectively, the other none. The growth of the test crop was followed by height measurements. The analysis of the data obtained showed that there was a significant interaction between the fertilizer applied and the green manure treatments.

When the test crop was harvested, the only significant response was to the application of the fertilizers, for the test crop did not respond to the intensive green manuring.

Soil chemical analysis showed that the incorporation of green manures significantly increased soil carbon, potassium and calcium plus magnesium. Foliar analysis of the test crop showed that nitrogen, phosphorus and potassium levels were all above the accepted critical levels. Also the analysis showed that greatest response of the leaves was to nitrogen in the fertilizers applied to the test crop.

In Part II some aspects of soil carbon dioxide evolution are discussed.

The objectives of this series of experiments were to measure the soil carbon dioxide flux, to relate the loss of carbon dioxide to the breakdown of organic matter, to examine the effects of temperature and moisture and to compare an accepted laboratory method with results obtained in the field.

In Chapter 3 the field experiments are described where a method using soda lime as a carbon dioxide absorbent was employed. Measurements of carbon dioxide flux were made on the green manuring experiment, where it was found that the soil in the maize green manure treatments produced significantly larger quantities of carbon dioxide than either the sunn hemp or weed fallow treatments. An equation of the type $\delta x/\delta t = A - yx$, where A = kg carbon returned per year, x = total carbon in the active soil layer and y = fraction of total carbon lost annually by decomposition, was used to relate the carbon loss with time. On the weed fallow treatment the half-life of organic matter was found to be 6.4 years.

The moisture content of the soil was found to be the most important factor governing the production of soil carbon dioxide. When the soil was dry and saturated with water the carbon dioxide flux was severely reduced. Soil temperatures at 5 cm depth did not have any effect on carbon dioxide flux.

An experiment was carried out to determine the effect of cultivation on carbon dioxide flux and also whether maize decomposed more quickly than sunn hemp. After rotary cultivation of both maize and sunn hemp, carbon dioxide flux rose significantly but after two weeks fell back to its original level. Where similar quantities of maize and sunn hemp were incorporated it was found that firstly there was a linear relationship between carbon dioxide flux and quantity of material incorporated and secondly sunn hemp decomposed more quickly than maize.

Maize and sunn hemp were grown in hydroponic beds to determine the influence of root respiration on total carbon dioxide flux. The roots of the maize and sunn hemp were found to produce about 3.3 gm carbon dioxide/m^2/day; as the root weights were found to be higher than in the field the figure was probably rather lower under field conditions.

When laboratory methods were being examined the use of the macro-respirometer was found to be unsatisfactory. A barium peroxide method was used, which shewed that sunn hemp decomposed more quickly than maize and that when the quantity of material was increased, so the carbon recovered rose. A comparison was made between the laboratory and field methods, and it was found that where similar quantities of dry matter were incorporated the laboratory method over-estimated the rate of decomposition by about 400%.

Measurements of the heats of combustion and carbon content of the green manures were made, so that an estimate of the accuracy of the field method of measuring carbon dioxide flux could be obtained. When equations relating energy content of the organic matter with energy liberated in the evolution of carbon dioxide were used, the calculated and measured carbon dioxide fluxes compared very favourably, indicating that the field method was reasonably accurate.

Part III is a discussion of some aspects of the experiments.

Soil moisture and temperature records from the green manuring experiment are described in the Appendix, together with methods of soil and foliar analysis, and rainfall confidence limits at the experimental area.

REVIEW OF LITERATURE

Introduction

Much attention has been given to the subject of soil fertility since the development of agriculture. The Greeks and Romans knew of methods of maintaining soil fertility such as application of lime, animal dung, the growing of legumes and the fallow period.

One of these practices was that of green manuring, which is the growing of a crop for subsequent incorporation into the soil whilst still immature. Most crops used as green manures are legumes; lupins and vetches have been used for more than two thousand years for this purpose (Pieters, 1929).

Developed in the temperate areas, green manuring is a means of maintaining soil fertility. It is used in Europe, Russia and the United States (Martin and Leonard, 1949), where the green manure crop, having been grown over winter, is ploughed under prior to sowing the main crop. Experimental results in the temperate areas have shown that green manures improved the soil structure, the nutrient status of the soil and disease resistance of the main crop. Cooke (1967), however, reviewing recent work in the United Kingdom has pointed out that there is evidence to show that the increased yields of crops grown after the incorporation of a leguminous green manure are largely due to increased supplies of nitrogen. Some experiments (Dyke, 1963) have found that green manures can increase yields to a level greater than can be obtained with inorganic nitrogen fertilizers; how this was achieved is not clear. Now the green manure will also affect the phosphate, calcium, magnesium and sulphur status of the soil as well as nitrogen, but Dyke made no allowances for these effects.

In tropical and equatorial areas during the 1920's and 1930's, in Nigeria and Uganda particularly, many experiments were carried out with green manures. These were done because at that time it was thought that imported fertilizers would be uneconomic and that the African cultivator was too conservative to use them. The most detailed experiments were carried out at Ibadan, Nigeria, and have been reported by Webster (1938) and Vine (1953). The results showed that the yields of maize improved considerably after a leguminous green manure of velvet bean (Mucuna utilis Wort.) had been dug into the ground. The green manure also maintained maize yields over a period of twelve years. The digging in of the green manure crop by hand proved a physical problem, but, when the green manure crop was burnt in situ, the maize still gave the same yield. The main effect of the green manure on the soil was then thought to be the increased availability of phosphate and nitrate.

In Uganda green manures were tested in arable rotations but without success (Martin and Biggs, 1937; Martin, 1944). These results led the Department of Agriculture to abandon the use of green manures and to introduce a modified form of shifting agriculture of three years' cropping followed by three years of rest. The experiments, however, involved the use of a green manure once or twice in a four year rotation and the levels of yield of the successive crop by present day standards was very low. These workers, working with low yielding crops as well as partially failed green manure crops, failed to show any significant responses to green manures.

Green Manures and Soil Organic Matter

One of the stated objectives of green manuring has always been to increase the organic matter content of the soil. Organic matter in soil consists of two fractions: a) undecomposed plant remains and b) humus (Russell, 1961). By incorporating the green crop, part of the plant material is converted to humus by the action of soil micro organisms. The contributions that organic matter make to the soil have been reviewed by Russell (1961; 1963) and by Whitehead (1963).

The rate of breakdown of the green manure crop is dependent on adequate moisture, temperature and aeration, and the constituents of the green manure itself. The final contribution by the green manure to the total quantity of soil organic matter appears to be dependent on the 'initial' organic matter content. Nye and Greenland (1960) working in West Africa have stressed the importance of the 'equilibrium-level' concept where, under steady state conditions, the soil has an equilibrium level of organic matter. The degree of increase of humus carbon from added organic matter will depend on how far removed the soil is from its equilibrium level. Thus, with initial low levels of organic matter, additions by green manuring may considerably improve the humus content but, with initial high levels, no increase can be expected.

Laboratory and field studies of organic matter incorporation into the soil in temperate and tropical/equatorial areas have often produced conflicting results. At Woburn in England, Crowther and Mann (1933) compared rotational systems and found that there was a greater loss of total organic matter from a green manuring/wheat rotation than from a continuous wheat one. Later, Mann (1959), working on the same farm, found that plots receiving green manures did not lose so much organic matter as those not receiving them. Cooke (1967) reported that the ploughing under of green manures for seven years, again at Woburn, increased the soil organic matter by one tenth. Visselink (1961), however, working in Holland, found no changes after the incorporation of green manures.

Joffe (1955), reviewing the subject, stated that it was futile to try to build up organic matter in the 'zone of laterization' or tropical areas. He quoted Bonnet and Lugo-Lopez (1953), working in Puerto Rico, who found no increase in the organic matter content of soils except where 25 tons per acre of velvet beans were incorporated. Haylett (1960), working in South Africa, reported results of experiments carried out over twenty-five years and, although green manures benefited the succeeding crop, no increase of organic matter was found.

In India, Singh (1963) found that sugar cane benefited from the incorporation of sunn hemp (<u>Crotalaria juncea</u>) but found no increases of organic carbon. Yadav and Agarwal (1961) and Sen (1964) have reported increases of both organic carbon and nitrogen after green manures.

One of the reasons that Russell (1961) gives for the ineffectiveness of green manures in building up organic matter, is that soil microbial activity is so stimulated with the addition of fresh material, that the 'native' resistant humus is attacked and the total level reduced. This action was demonstrated by Broadbent (1946) and Broadbent and Norman (1947) using isotopes of carbon and nitrogen. Later work by Hallam and Bartholemew (1953) confirmed this.

More recently, however, Stotzky and Mortensen (1958) and Mortensen (1963) have found no evidence of the breakdown of soil humus after addition of decomposable plant material or 'priming action' as it is called. They compared the loss of carbon from soil alone and soil with additions of plant material. They found that there were no significant differences of carbon loss from the soil _per se_, whereas Broadbent had found a greater loss of carbon from the soil with the plant additions.

Jenkinson (1963 b), reviewing the subject, has described mechanisms which could explain how results from isotopically labelled plant material could be misinterpreted and that it would be unwise to extend laboratory evidence to the field.

Also in Clark's (1967) opinion, the 'priming' effect as such was largely illusory and he doubted whether claims that the incorporation of fresh organic matter into the soil depleted the humus reserves should be taken at face value.

The whole question of the build-up of soil organic matter after incorporation of organic matter, green manures, plant stover, farm yard manure, etc., is very complex. Conflicting evidence can be found from different areas of the world, and it would seem that much of it stems from the fact that the environmental factors of rainfall, soil reaction, temperature, aeration, etc., are very different. The concept of the equilibrium level may be more important than generally realized. Furthermore, as far as the hotter areas are concerned, Nye and Greenland (1960) have shown that, not only does organic matter returned to the soil make a small contribution in relation to the total present, but that the amount of plant material which is converted into humus may only be between 1/10 and 1/5 of the total incorporated.

Green Manuring and Plant Nutrient Supply

When green manures are ploughed into the soil there is a flush of decomposition brought about by the activity of the soil micro-organisms, so long as the soil is moist, warm and adequately aerated (Russell, 1963). This activity will in turn bring about the release of plant nutrients.

Nitrogen

Where legumes are grown for green manures then the nitrogen fixed by the nodule bacteria will be available for the succeeding crops. The provision of nitrogen has been widely reported on many soils (Martin and Leonard, 1949;

Yardav and Agarwal, 1961; Shevchuk, 1962; Gol'fand, 1963; Sen, 1963; Tsai, 1963). Cooke (1967) has stated that, in recent American work, the nitrogen supply has been responsible for nearly all the increased yields of crops following green manures; legumes, therefore, have been more effective than non-legumes.

At Salisbury, Rhodesia, the use of legumes (sunn hemp or velvet bean) as a green manure, alternating with maize, maintained yields for many years (Rattray and Ellis, 1953) and nitrogen was the most important contribution of the green manure.

The stage of maturity of the green manure crop at incorporation is important, because the carbon:nitrogen ratio of the plant material widens with age. If a green manure crop is allowed to ripen and set seed then there is a consequent reduction in available nitrogen of the soil (Rattray, 1956). This is due to there being a fairly constant carbon:nitrogen ratio in the soil. If plant material is added with a high ratio, the soil micro-organisms will remove all the available ammonium and nitrates to lower the ratio.

There must be adequate moisture to allow decomposition of the green manure to take place before the next crop is planted but, if there is too long a wet period, then much of the nitrate-nitrogen may be leached before the next crop can make use of it.

Phosphate and Potash

On some soils the mobilization of phosphate and potash may be more important than that of nitrogen (Vine, 1953). Maylett (1943) and Orchard and Greenstein (1949) attributed increases in maize yield after a green manure to the phosphate content of the legume. Later, Maylett (1959; 1961), reporting the work of the Agricultural Research Institute at Pretoria, South Africa, suggested that the primary benefit of green manures was due to a mobilization of plant nutrients; this occurred with non-legumes as well, therefore, nutrients other than nitrogen were involved.

Some legumes are able to extract more phosphate and potash from the soil than other crops (Sherbatoff, 1949), which may, therefore, make these two nutrients more available than in the control plots.

Although evidence has shown on some soils that the response to green manures has been mainly due to phosphate, no critical work has been done in East Africa.

Other Nutrients

Reviews by Joffe (1955) and Negash (1966) have suggested that green manures return to the soil and subsequent decomposition releases many known and unknown substances. These may include minor elements, plant vitamins, hormones and fungistatic components. Whitehead (1963) and Baker and Snyder (1965) have reviewed the role of some of these substances in the soil. Little is known and critical work needs to be done for there have been isolated cases, for example, in Rhodesia, where Shepherd (1952) attributed the benefits of green manures after decomposition to the release of antibiotics.

As the respiration processes of the soil micro-organisms increase after incorporation of a green manure, so there is a rise in the evolution of carbon dioxide from the soil. It has been suggested by Joffe (1955), Russell (1963) and Negash (1966) that the carbon dioxide so evolved may be available for the photosynthesis of the succeeding crop. Investigations, however, by Monteith, Sceiss and Yabuki (1964) have found that both the quantities of carbon dioxide are too small and that atmospheric turbulence maintained the concentration almost constant under field conditions. These results were obtained in temperate areas, however, and the subject requires further study in tropical and equatorial areas where rates of decomposition are higher.

Conclusions

In the past many workers have tried to ascribe either the beneficial or detrimental results of green manuring to a single effect. The soil, however, is a dynamic system involving many organisms in a continuous process of production, transformation and decomposition. Many inter-related factors of the soil environment such as moisture, aeration, reaction and temperature play a most important part in the growth of the succeeding crop.

In many instances the experiments in the tropical and equatorial areas were performed with partially failed green manure crops. On many of the early experiments, inorganic fertilizers were applied in rather a haphazard way by present-day practices. Some of the 'beneficial' effects of green manuring may have been no more than the application of 'balanced' plant nutrients. Now that more aspects of agronomy such as time of planting, clean weeding, good cultivations and plant nutrients are understood, then, in tropical areas where new systems of farming are being developed, consideration must be given to all farming practices. Many of them may have to be adapted to the environment. Green manuring may provide means of improving soil fertility on some soils and not others. It is necessary to experiment with different crops, timing and

PART I

THE SYSTEM AND RESULTS OF GREEN MANURING

CHAPTER 1

THE GROWTH OF THE GREEN MANURES AND SUBSEQUENT INFLUENCE ON TEST CROP

1.1 DESCRIPTION OF GREEN MANURE GROWTH

1.1.1 The Locality of the Trial

The experiments were carried out at Makerere University College Farm, Kabanyolo (0° 28'N, 32° 37'E, altitude 1,204 metres), which is situated about ten miles north of Kampala, Uganda. The University Farm is in the lake-shore region of southern Uganda and, as an uplifted peneplain, the topography is highly dissected and characterized by small, flat-topped hills averaging between 30-100 metres above the valley swamps. The vegetation is typically long grass (*Pennisetum purpureum*) on the hills with papyrus (*Cyperus papyrus*) dominant in the swamps (Rattray's (1960) classification P.3) and forest remnants.

The area lies in the Inter-tropical Convergence Zone and the most variable seasonal factor is rainfall. The rainfall, which is localized in the form of convection storms, is bimodally distributed with the peaks occurring in April/May and October/November (see Appendix). A detailed account of the climatic factors have been given by Huxley (1961, 1962, 1963) and Huxley and Beadle (1964).

The soils on the farm belong to the Buganda catena of red-clay loams and have been fully described by Radwanski (1960).

1.1.2 Introduction and Background to Trial

During the 1930's, in Uganda and Nigeria particularly, there were a number of experiments designed to determine the effect of green manuring on soil fertility and the succeeding crops (Martin and Biggs, 1937; Webster, 1938). These experiments showed no conclusive benefits and in Uganda the official practice of green manuring was abandoned; since then there have been no further serious investigations.

In recent years, however, there have been two particular cases in southern Uganda where green manures have been used on the supposition that they maintain and increase soil fertility. The first is an estate growing tomatoes and green peppers where, after harvest, the crop residues and grass mulch are incorporated into the soil and weeds allowed to grow. Two or three months later the weeds are incorporated into the soil by rotary cultivation and, after a short period to allow the weeds to decompose, the young crop plants are transplanted into the field (Streeter, 1968).

The second case is where a sugar estate grows sunn hemp (Crotalaria juncea) for about ten to twelve weeks, after which it is ploughed into the ground prior to planting cane cuttings (Patel, 1967). As the cane cycle on the estate is about six years, then the time occupied by green manure is relatively very small.

There is, however, no experimental justification of these practices.

Recent work in India on green manures has produced conflicting results both on the effect on succeeding crops and various aspects of soil fertility (Singh, 1963; Sen, 1963), particularly the effect on organic matter, soil phosphate and soil structure.

In the work quoted above, green manures were sometimes incorporated once a year but, more often, once every three or four years. In the tropics where the environment is more conducive to rapid growth and subsequent decomposition of crops, a great deal, in the past, was expected from a single green manure crop in a rotation. The amounts of dry matter incorporated from a single crop probably never exceeded 4,000 or 5,000 kg per hectare - a small proportion of the total organic matter present in the soil.

In the past green manures have been incorporated once or perhaps twice in a four or six year rotation with limited success. There is no evidence of any work having been done on the application of more than one green manure crop a year.

If there had been little success with low levels of organic matter incorporated then possibly repeated incorporation of several crops could help. An attempt was made, therefore, to grow and incorporate four green manures in one year, and to investigate some of the effects on the soil and succeeding crop, the green manures, a legume and a non-legume, would be compared to a weed fallow.

1.1.3 Treatments and Design of Trial

Treatments: The decision to grow four crops in one year necessitated that the green manure should have the following qualities:-

a) Seed should be available in reasonable quantity;

b) It should be capable of producing large amounts of dry matter in a short growth period;

c) It should not be susceptible to any serious pest or disease;

d) It should be reasonably drought resistant.

Leguminous crops are most often used as a green manure and obviously complicate the results by adding considerable quantities of nitrogen; it was decided, therefore, to compare the non-legume maize with a legume sunn hemp.

Maize treatments

As the largest amount of plant material possible was needed, the maize was planted in 2-foot (61 cm) rows, 6 inches (15 cm) apart, to achieve a plant population of about 43,000 plants/acre (107,000 per ha).

It is known that, when a massive amount of organic material is incorporated into the soil, a temporary nitrogen deficiency may occur in the succeeding crop; on one of the treatments, therefore, nitrogen, as ammonium sulphate nitrate, was applied at the 4th to 5th leaf stage at 30 lbs/acre (33.6 kg/ha). An irrigated treatment was included to determine whether there would be an additive effect of water on the dry matter yields.

Sunn hemp treatments

As with the maize, sunn hemp was planted in rows 2 feet apart at a rate of 40 lbs/acre (44.8 kg/ha). No additional fertilizer was applied as it was hoped the crop would nodulate and fix atmospheric nitrogen. As with the maize an irrigation treatment was included.

Weed fallow treatment

A 'control' treatment not involving green manures was required and it was decided that weeds should be allowed to grow for the same period, to be incorporated at the same time as the green manure treatments. This weed fallow would enable a comparison to be made between large amounts of organic matter and the natural production of the soil.

The six treatments were:-

1. Sunn hemp planted at 40 lbs/acre
2. Sunn hemp as above plus irrigation
3. Maize at 43,000 plants/acre with neither fertilizer nor irrigation
4. Maize as above with 30 lbs nitrogen/acre applied to each crop
5. Maize as (4) plus irrigation
6. Weed fallow

Prior to planting, single super phosphate was applied to the whole trial at 100 lbs/acre (112 kg/ha) of P_2O_5 and muriate of potash at 50 lbs/acre (56 kg/ha) of K_2O. This was done to raise the 'base-level' of these two nutrients so that they would not limit the production of dry matter (see Chapter 3).

The maize was planted by making holes 6 inches (15 cm) apart and 2½ inches (6 cm) deep and placing in each hole two seeds. The seeds were covered with soil and compressed. At the 4th leaf stage the plants were thinned to one plant per hole and, shortly after, nitrogen was applied to the maize-plus-nitrogen treatments.

The sunn hemp was sown continuously in a furrow 2 - 3 inches deep which was then covered with soil and compressed.

Each of the four green manure crops was allowed to grow for about ten weeks in order to fit the four crops into one year. All the green manure crops were cut by hand, weighed, distributed evenly over the plot and incorporated into the soil with a rotavator.

Design of the Trial

A randomised block design was used with six treatments and five replications (see Figure 1). The land was slightly sloping and therefore the treatments were placed across the slope (North-South) and the replications down the slope (East-West).

Each plot was 33 feet (10.06 cm) long and 18 feet (5.49 cm) wide with 3 feet (0.91 cm) paths between replications.

FIGURE 1   Layout of green manuring trial

LAYOUT OF GREEN MANURING TRIAL

4	3	2	1	6	5
2	6	3	4	5	1
2	1	6	4	3	5
6	4	5	1	3	2
5	3	1	4	2	6

TREATMENTS

1. Sunn hemp
2. Sunn hemp + Irrigation
3. Maize
4. Maize + Nitrogen
5. Maize + Nitrogen + Irrigation
6. Weed fallow

1.1.4 Green manure crop growth pattern

First crop cycle

The rainfall during February 1967 gave only 38 mm in scattered light showers and not until March was the experiment planted (see Appendix). There was an even germination and all the crops grew well. Measurements of the height of the maize green manures were made after 3, 5, 7 and 9 weeks after planting. The mean height of the uppermost reflexed leaf was taken, for which 10 plants in each plot were measured. Figure 2 shows the height of the first maize green manure at the various stages.

Nodules appeared on the young sunn hemp 10 days after planting but were whitish at the centre; after 20 days they became a pinkish colour and were assumed to be active.

The weeds on the fallow plots established quickly and by the fourth week there was 80% ground cover. The species found were:-

Digitaria scalarum	Galinsoga parviflora
Cynodon dactylon	Senecio discifolius
Oxalis latifolia	Oxygonum sinnuatum
Bidens pilosa	Brassica schimperi
Commelina benghalensis	

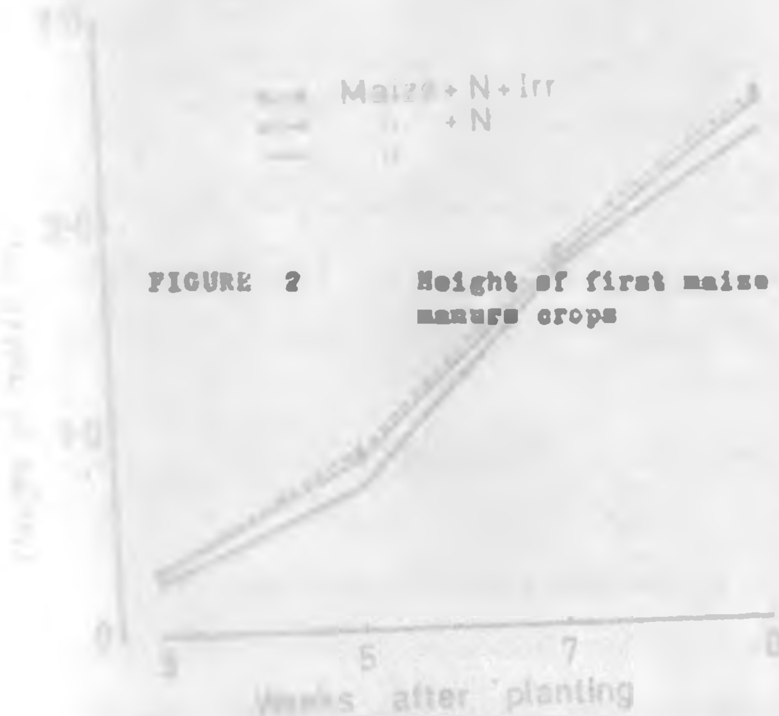
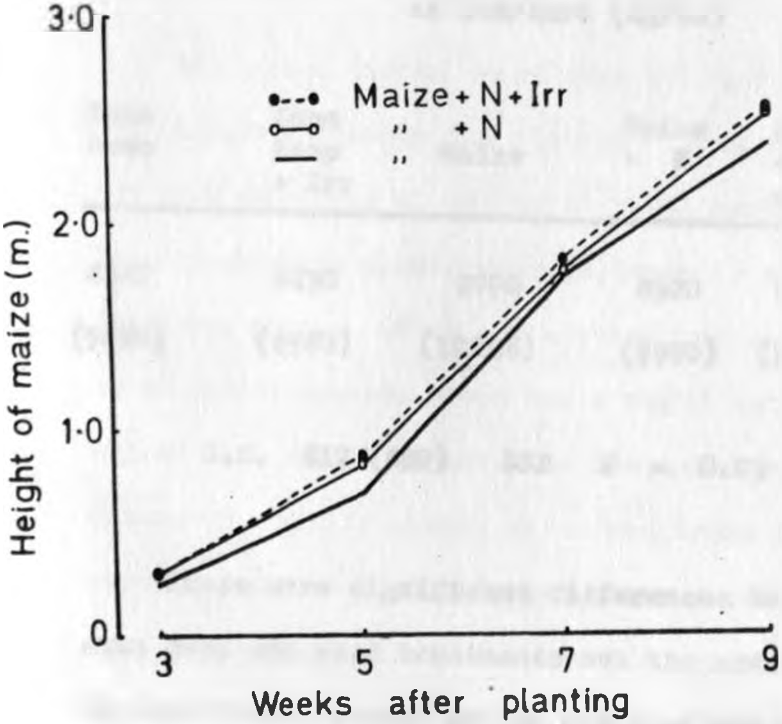


FIGURE 2 Height of first maize green manure crops


Maize + N + Irr
" + N
"
Height of maize (m.)
3·0
2·0
1·0
0
3
5
7
9
Weeks after planting

The green manures were cut and weighed on 30th and 31st May, 1967.

TABLE 1

Mean yield of dry matter of top growth
of first green manure crop
as lbs/acre (kg/ha)

Sunn hemp	Sunn hemp + Irr	Maize	Maize + N	Maize + N + Irr	Weed fallow
4840	4430	9000	8920	10300	1370
(5420)	(4960)	(10086)	(9990)	(11540)	(1530)

S.E. 617 (690) LSD P = 0.05 = 1800 (2016)

There were significant differences between the maize, sunn hemp and weed treatments but the additional nitrogen had no significant effect on the yield of dry matter.

Therefore, there was enough nitrogen available in the soil at the beginning of the experiment for the growth of the maize.

Throughout the growing period rainfall was adequate and no irrigation was applied.

Considerable difficulty was experienced with the incorporation of the large amounts of maize material which had to be rotovated twice in order to achieve reasonable mixing with soil; the sunn hemp and weeds were incorporated without difficulty.

Second crop cycle

The green manure crops were planted on 12th June, 1967, and within two weeks the nitrogen 'lock-up' effect following the incorporation of the maize green manure became apparent. The young maize plants were yellower in colour than the previous crop. After the application of nitrogen to the maize green manures there was a rapid improvement in both colour and growth compared to the maize green manure without nitrogen. Maize streak virus was found after four weeks of growth, but D.D.T. 25% spray failed to control the vectors (*Cicadulina mbila*) and the disease spread rapidly causing 95% infection of the crop. The plants which were attacked became chlorotic and stunted.

The germination of the sunn hemp was very patchy as it was difficult to compress the soil over the seed after planting for the top soil contained much organic matter. After three weeks the sunn hemp was attacked by a leaf miner and an unidentified disease, which resulted in poor growth and much reduced yield of dry matter.

Figure 3 shows the height of the second maize green manure crop at various stages.

As soil moisture was low, one inch of water was applied to the maize plus irrigation green manure on July 20th.

The weed fallow plots took much longer to establish than the previous crop. After seven weeks only one replicate had 90% ground cover, the others varied between 20% and 50%.

TABLE 2

Mean yield of dry matter top growth of second green manure crop in lbs/acre (kg/ha)

Sunn hemp	Sunn hemp + Irr	Maize	Maize + N	Maize + N + Irr	Weed fallow
1190	1230	2590	4080	4480	460
(1330)	(1380)	(2900)	(4570)	(5620)	(515)

S.E. 195 (220) LSD P = 0.05 = 570 (638)

The additional nitrogen on the maize green manure crops showed a significant effect on both height of the plants and dry matter production. Although the maize growth was poor,

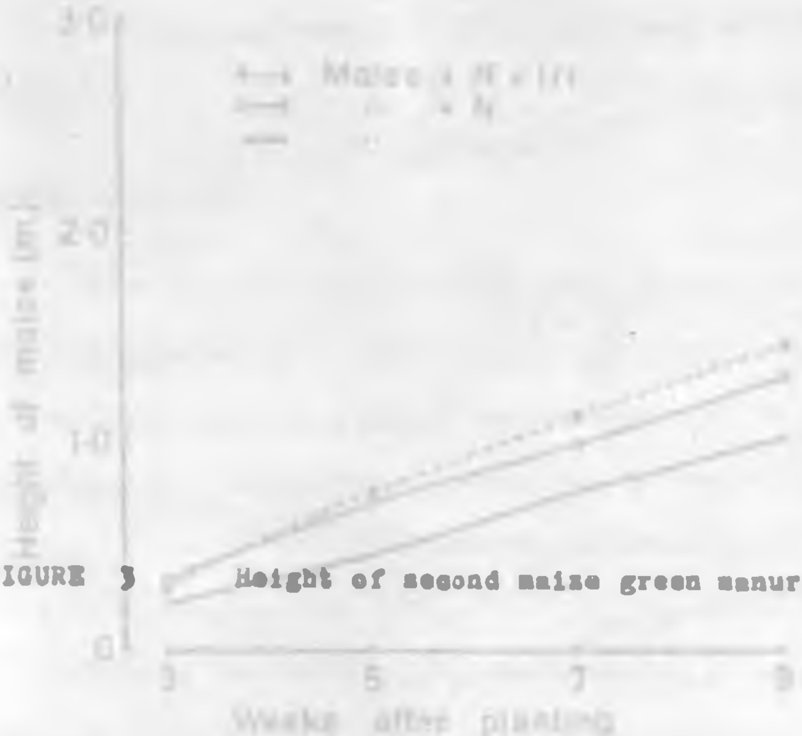
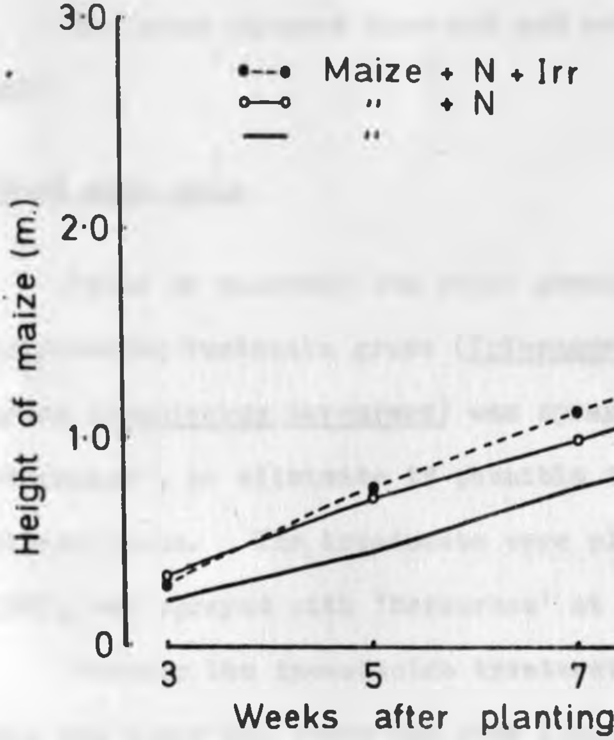


FIGURE 3 Height of second maize green manure crops



Maize + N + Irr
" + N
"
Height of maize (m.)
3·0
2·0
1·0
0
3
5
7
9
Weeks after planting

30 lbs/acre of nitrogen was probably enough to counteract the nitrogen 'lock-up' effect with the three rates of incorporated dry matter.

The green manures were cut and weighed on 25th August, 1967.

Third crop cycle

Prior to planting the third green manure crop the surrounding Guatamala grass (*Tripsacum laxum*) and Elephant grass (*Pennisetum purpureum*) was sprayed with an insecticide 'Mercabam', to eliminate if possible the vectors of maize streak virus. The treatments were planted on 9th September, 1967, and sprayed with 'Mercarbam' at the fourth leaf stage.

Whether the insecticide treatment *per se* was effective was not clear but there was very little incidence of the virus. From all the maize treatments only twenty-five plants were found with the disease and removed.

Figure 4 shows the height of the second green manure crop at various stages.

Weeds growing in fallow plots established 80% ground cover by the fifth week.

It was noticed that the weed, *Oxalis latifolia*, was more widespread than at the start of the experiment and it was concluded that rotary cultivation dispersed the *Oxalis* bulbs.

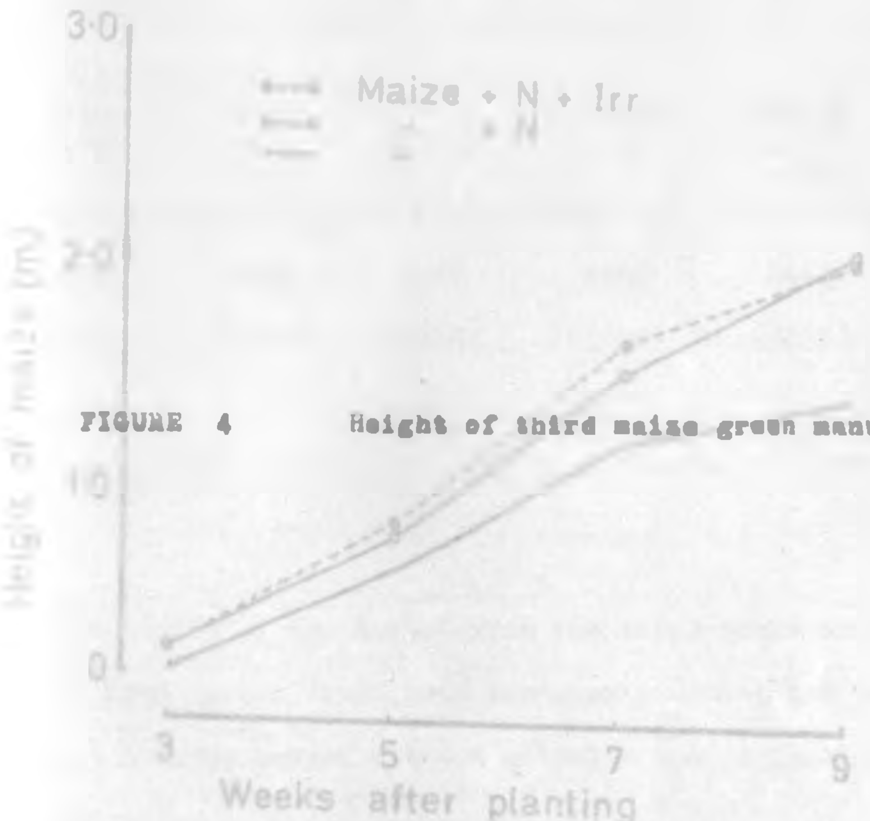
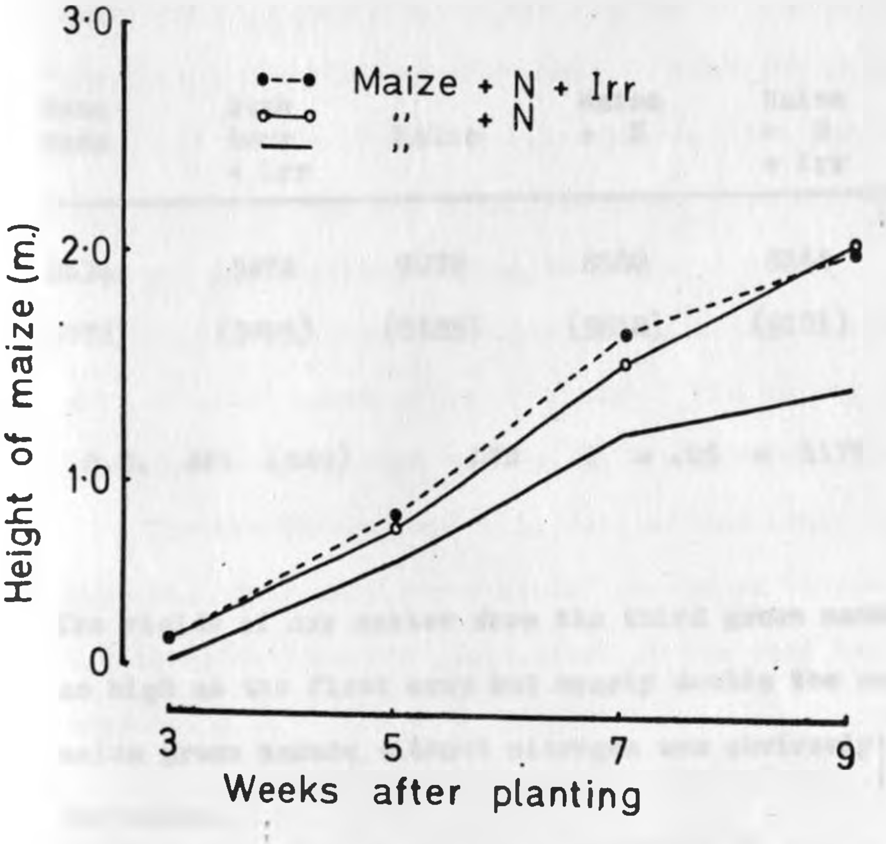


FIGURE 4 Height of third maize green manure crops



3·0
2·0
1·0
0
Maize + N + Irr
" + N
"
Height of maize (m.)
3
5
7
9
Weeks after planting

TABLE 3

Mean yields of dry matter of top growth

of third green manure crop

lbs/acre (kg/ha)

Sunn hemp	Sunn hemp + Irr	Maize	Maize + N	Maize + N + Irr	Weed fallow
3636	3478	5076	8588	8144	1324
(4072)	(3895)	(5685)	(9618)	(9121)	(1482)

S.E. 401 (449) LSD P = .05 = 1175 (1316)

The yields of dry matter from the third green manure were not as high as the first crop but nearly double the second. The maize green manure without nitrogen was obviously nitrogen deficient.

The treatments were cut and weighed eleven weeks after planting on 25th November, 1967, as the soil was very wet.

Fourth crop cycle

Planting of the fourth crop was delayed as there was very heavy rainfall at the end of November and, as there was no growing crop, the soil remained saturated for about three weeks. The treatments were planted on 19th December, 1967.

The germination of maize and sunn hemp was even and there was no difference between green manure crop. Three weeks after planting water was applied to the irrigated treatments of maize and sunn hemp. From 3rd to 28th January, 1968, two inches (5 cm) of water was applied per treatment plot but water was not available after this and both the sunn hemp and maize wilted during the day.

Figure 5 shows the height of the fourth green manure crop at 3, 5 and 7 weeks after planting. The poor growth at the fifth and seventh week was due to the lack of water.

The fourth crop was cut, weighed and incorporated into the soil after only seven weeks' growth on February 7th. This was to allow time for preparation of the seed bed for the test crop.

Table 4 shows the dry matter yield of the green manure which was very low. It is of interest to note that the yield of maize-without-nitrogen was similar to the yield of maize-with-nitrogen where water was limited, and that supplementary water made no difference to dry matter yield of the sunn hemp.

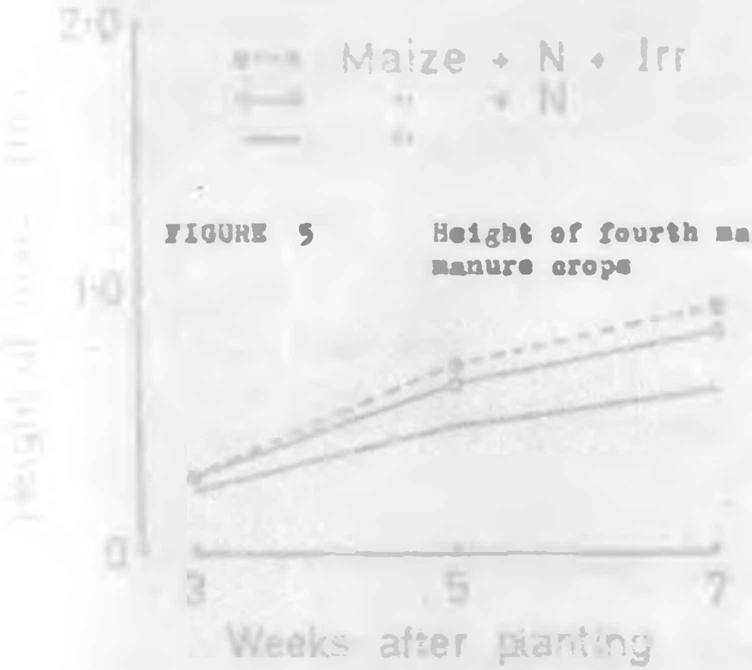


FIGURE 5 Height of fourth maize green manure crops

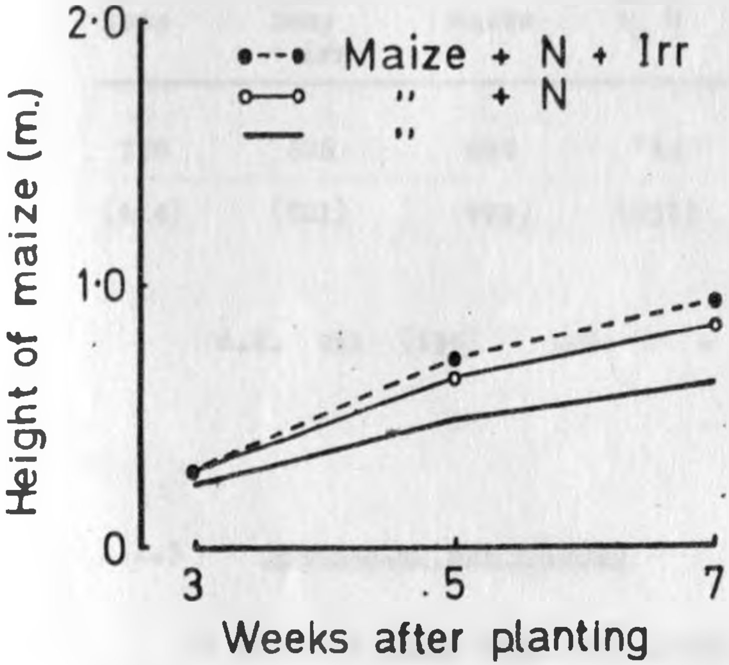

Maize + N + Irr
" + N
"
Height of maize (m.)
2·0
1·0
0
3
5
7
Weeks after planting

TABLE 4

Mean yield of dry matter of top growth

of fourth green manure crop

in lbs/acre (kg/ha)

Sunn hemp	Sunn hemp + Irr	Maize	Maize + N	Maize + N + Irr	Weed fallow
538	626	696	744	1454	140
(614)	(701)	(779)	(833)	(1628)	(157)

S.E. 211 (136) LSD P = .05 = 438 (490)

1.1.5 Discussion and summary

It has been shown that four crops of green manures can be grown and incorporated in one year in southern Uganda. The actual length of the individual growth periods depend largely on the climate, especially when mechanical cultivations are used.

Plot yields declined with time; however, the total amounts of dry matter produced, by the maize especially, were considerable and equal to an Elephant grass (*Pennisetum purpureum*) ley (Tiley, 1965; Vincente-Chandler, 1965).

TABLE 5

Mean total weight of dry matter of top growth from the four green manure crops in lbs/acre (kg/ha)

Sunn hemp	Sunn hemp + Irr	Maize	Maize + N	Maize + N + Irr	Weed fallow
10,194	9764	17352	22332	24378	3294
(11,417)	(10935)	(19434)	(25011)	(27303)	(3689)

S.E. 1277 (2430) LSD P = .05 2660 (2979)

P = .01 3630 (4066)

There was no significant difference between the dry matter yields of the two sunn hemp treatments nor between the irrigated and non-irrigated maize treatments despite supplementary water. The most significant effect was that of nitrogen on the maize treatments. The large amounts of dry matter incorporated caused the available nitrogen to be 'locked-up' by the soil micro-organisms resulting in a decrease in dry matter yield. It appears, therefore, as though, in the locality of the experiment, no additional increase in dry weight can be achieved with supplementary irrigation on maize with a ten-week growth period, as the maximum water requirement does not occur until the 12th or 13th week (Hearn, 1968).

The previous table shows the dry matter obtained from the top growth only. An attempt was made to estimate the contribution of roots to the total amount of dry matter. At the end of each growth cycle ten average-sized plants were taken from each treatment. The plant roots were carefully withdrawn from the soil, washed, dried and weighed together with the tops. The dry weight of the roots were then expressed as a percentage of the dry weight of tops shown in the following table.

TABLE 6

Dry weight of roots expressed as a percentage of dry weight of top growth from the green manure crops

	Crop Cycle			
Treatments	1st	2nd	3rd	4th
Sunn hemp	10	9	11	9
Sunn hemp + Irr	12	9	13	9
Maize	20	22	20	20
Maize + N	22	24	25	24
Maize + N + Irr	22	23	27	25
Weed fallow	5	5	5	5

To the dry weights of the tops from the green manure was then added the weight of roots to give an estimation of the total dry matter produced.

TABLE 7

Estimated mean total weights of dry matter incorporated from roots and tops from the four green manure crops in lbs/acre (kg/ha)

Sunn hemp	Sunn hemp + Irr	Maize	Maize + N	Maize + N + Irr	Weed fallow
11234 (12582)	10914 (12224)	20876 (23381)	29070 (32558)	30202 (33826)	3456 (3870)

S.E. 1058 (1185) LSD P = .05 = 3112 (3485)

P = .01 = 4245 (4754)

The table shows that the effect of nitrogen was the most significant effect between the treatments and was more marked when the root weights were included.

In conclusion, therefore, the four green manure crops yielded large amounts of dry material, particularly as the plants were immature, despite difficulties with the second and third crops. Nitrogen fertilizers applied to non-leguminous green manures can increase yields by nearly 50% and are essential if large quantities of plant material are required.

PLATE 1 View from the South of the third green manure crop. The plots from left to right are weed fallow, sunn hemp, maize, sunn hemp and maize.

1.2 DESCRIPTION OF TEST CROP

1.2.1 Introduction

A maize hybrid was chosen for the test crop which was planted on all the green manure treatments and the weed fallow. It was hoped by using a hybrid maize that any change in soil fertility status would be shown. In addition, it was thought that a useful comparison could be made between the green manure treatments if inorganic fertilizers were added to a half of the original plots because:-

a) There would be a nitrogen deficiency in the test crop grown on the maize plots due to the 'lock-up' effect which had already been shown.

b) It would be of great interest to compare the weed fallow plots plus fertilizer with the green manure treatments.

c) There could be an interaction between fertilizers and the green manure treatments.

A fertilizer mixture of nitrogen, P_2O_5 and K_2O was therefore applied in the ratio 3:2:1 respectively, with the nitrogen split so that one half of the quantity was mixed into the seedbed, and the other applied when the maize was 18 inches (46 cm) high.

1.2.2 Layout and treatment of test crop

All the green manure plots were split into two, one half receiving fertilizers, the other not, giving a split-plot randomized block design (see Figure 6). Each sub-plot was 1/140 acre.

Treatments

The Kitale maize hybrid 622 was used, planted at 24 inches (61 cm) by 18 inches (46 cm) to give a plant population of 14,520 per acre (35,864 per ha). The fertilizer treatments, Nitrogen, P_2O_5 and K_2O, were applied at the rate of 60 lbs, 40 lbs and 20 lbs/acre respectively (68.2, 44.8 and 22.4 kg/ha).

1.2.3 Test crop growth pattern

The seed was sorted by hand and the largest, most even seed was selected. The test crop was planted on 20th and 21st February, 1968. Two seeds were placed in each hole and then a furrow was made about 3 inches deep and 2 inches to the side of the line. The fertilizer was placed in the furrow and covered with soil.

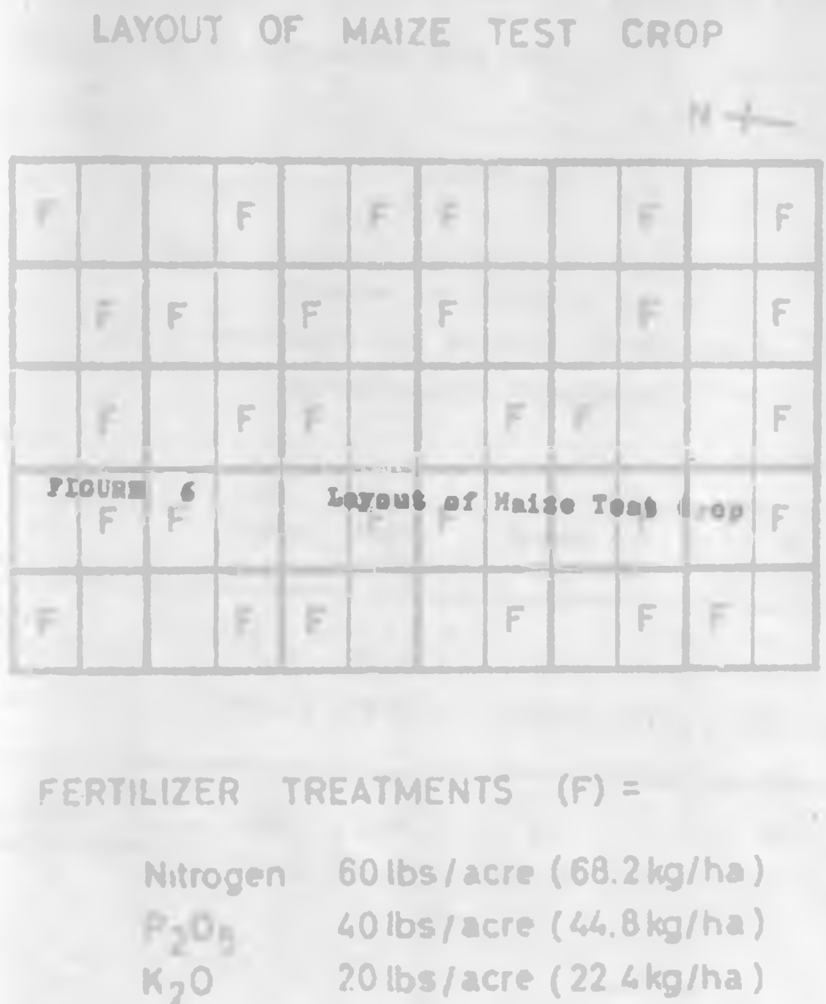


FIGURE 6 Layout of Maize Test Crop

LAYOUT OF MAIZE TEST CROP

N →

F			F		F	F			F		F
	F	F		F		F			F		F
	F		F	F			F	F			F
	F	F			F	F			F		F
F			F	F			F		F	F	

FERTILIZER TREATMENTS (F) =

Nitrogen 60 lbs/acre (68.2 kg/ha)
P_2O_5 40 lbs/acre (44.8 kg/ha)
K_2O 20 lbs/acre (22.4 kg/ha)

One week after planting the germination of the test crop was 93% and there were no differences between fertilizer or green manure treatments. At three weeks the effects of the fertilizers became apparent and the following table shows the mean height of the maize test crop.

TABLE 8

Mean height of maize test crop in inches
(figures in brackets in cm)
at 3 weeks with and without fertilizer on the
green manure treatments

	Sunn hemp	Sunn hemp + Irr	Maize	Maize + N	Maize + N + Irr	Weed fallow	Mean
With fertilizer	9.8	10.2	11.6	11.3	11.6	9.5	10.7
	(24.9)	(25.9)	(29.5)	(28.7)	(29.5)	(29.5)	(24.2)
Without fertilizer	8.9	9.4	8.1	8.6	8.7	8.4	8.7
	(22.6)	(23.9)	(20.6)	(21.8)	(22.1)	(21.3)	(22.1)

		S.E.	LSD P = 0.05	LSD P = 0.01
Comparison	1) With and without fertilizer on same green manure treatment	.41 (1.1)	1.8 (4.5)	2.4 (6.1)
	2) With and without fertilizer with different green manures	.39 (1.0)	1.6 (4.1)	n.s
	3) Interaction	.43 (1.1)	3.5 (8.9)	n.s

Examination of Table 8 shows the significant response of the test crop to the fertilizers and that the sunn hemp green manures without fertilizer gave a higher response than the maize green manures, though not significantly so. The response was probably due to increased availability of nitrogen provided by the legume. The interaction between fertilizers and the green manure treatments was significant at the 5% level and the table shows that, at this early stage, the response of the test crop was greater in the presence of the fertilizers on a maize green manure treatment than sunn hemp or weed fallow. This may have been due to the fact that after planting there was a storm with 75 mm rainfall, which appeared to 'cap' the soil in the sunn hemp and weed fallow plots and not in the maize green manure plots. Therefore, the roots of seedlings in the maize green manure plots may have had better aeration.

The following table shows the height of the test crop 5 weeks after planting.

TABLE 9

Mean height of the maize test crop in inches
(figures in brackets in cm)
at 5 weeks with and without fertilizer on the
green manure treatments

	Sunn hemp	Sunn hemp + Irr	Maize	Maize + N	Maize + N + Irr	Weed fallow	Mean
With fertilizer	26.6 (67.6)	27.6 (70.1)	28.7 (72.9)	28.7 (72.9)	29.1 (73.9)	25.4 (64.5)	27.7 (70.3)
Without fertilizer	24.2 (61.5)	23.1 (58.7)	20.6 (52.3)	22.0 (55.9)	23.7 (60.2)	20.9 (53.1)	22.4 (56.9)

		S.E.	LSD P = 0.05	LSD P = 0.01
Comparison	1) With and without fertilizer on same green manure treatment	.79 (2.0)	3.3 (8.4)	7.8 (19.9)
	2) With and without fertilizer with different green manures	.79 (2.0)	3.3 (8.4)	n.s
	3) Interaction	.79 (2.0)	6.6 (16.8)	n.s

TABLE 10

Mean height of maize test crop in inches
(figures in brackets in m)
at 7 weeks with and without fertilizer on the
green manure treatments

	Sunn hemp	Sunn hemp + Irr	Maize	Maize + N	Maize + N + Irr	Weed fallow	Mean
With fertilizer	55.2 (1.40)	55.8 (1.42)	58.2 (1.48)	58.8 (1.49)	60.0 (1.52)	52.2 (1.32)	56.7 (1.44)
Without fertilizer	49.8 (1.26)	42.0 (1.07)	37.8 (0.96)	45.0 (1.14)	42.6 (1.08)	39.0 (1.00)	42.7 (1.08)

		S.E.	LSD P = 0.05	LSD P = 0.01
Comparison	1) With and without fertilizer on same green manure treatment	1.7 (0.04)	7.02 (0.18)	9.5 (0.24)
	2) With and without fertilizer with different green manures	2.1 (0.05)	n.s	n.s
	3) Interaction	1.7 (0.04)	14.0 (0.36)	19.0 (0.48)

Table 10 shows that the interaction is significant at the 1% level indicating the increased response of the test crop to fertilizers in the presence of the green manures. It was thought that at about two months after the last incorporation of the green manure there would be a release of nutrients into the soil. However, this did not appear to happen because the weed fallow without fertilizers showed a slightly higher response than maize green manure without fertilizer.

At the ninth week after planting the test crop showed signs, on the lower leaves, of a lack of nitrogen and potassium. The symptoms were less obvious on the plots which had had fertilizer applied but, as they occurred in many cases on the same leaf, no attempt was made to score the experiment on this basis. It was observed that the symptoms were less marked in the plots which had received the largest amounts of green manure incorporated.

In the ninth week tassels of the test crop began to emerge on the green manure treatments with fertilizers and by the eleventh week the whole test crop had tasselled.

The following table (Table 11) shows the height of the test crop at nine weeks.

It will be seen from the table that there was no significant difference between the green manures and weed fallow treatment with fertilizer as shown by the growth of the test crop. Also because the plots on which the maize and maize-plus-nitrogen without fertilizers were grown appear to depress the response of the test crop, the interaction is significant at the 5% level.

TABLE 11

Mean height of maize test crop in inches (figures in brackets in m) at 9 weeks with and without fertilizers on the green manure treatments

	Sunn hemp	Sunn hemp + Irr	Maize	Maize + N	Maize + N + Irr	Weed fallow	Mean
With fertilizer	95.4 (2.42)	95.4 (2.42)	96.6 (2.45)	99.6 (2.53)	102.6 (2.61)	92.4 (2.33)	97.0 (2.46)
Without fertilizer	87.0 (2.21)	76.2 (1.93)	68.4 (1.74)	75.6 (1.92)	77.4 (1.96)	72.0 (1.83)	76.1 (1.93)

		S.E.	LSD P = 0.05	LSD P = 0.
Comparison	1) With and without fertilizer on same green manure treatment	2.7 (.07)	11.2 (.28)	15.2 (38.0
	2) With and without fertilizer with different green manures	3.2 (.08)	n.s	n.s
	3) Interaction	2.7 (.07)	2.4 (.06)	n.s

Therefore, the main factors of the experiment are becoming clear. Namely, that the response to inorganic fertilizer is greater than one to green manuring and that there is a very little response to green manuring on the soils at Kabanyolo.

Examination of the Tables 8, 9, 10 and 11 shows that in every case the response of the test crop to the sunn hemp green manure without fertilizer was greater, though not always significantly so, than the maize green manure without fertilizer. Therefore, it appears that, although the response to nitrogen from the legume outweighs any benefit that the incorporation of large amounts of organic matter into the soil may have had, the maize green manure plus nitrogen plus irrigation gave the most significant response.

No further measurements of the responses of the test crop in terms of height were made.

1.2.4 Yield of test crop and discussion

When the cobs of the test crop had just passed the milky stage on June 5th, 1968, there was a storm with intense rainfall and high wind. As a result two replicates lodged, but it was interesting to note that only the plots without the added fertilizer lodged.

On July 12th, 143 days after planting, the maize test crop was harvested and the moisture content of the grain was 22%. The cobs were placed in sacks, dried artificially and mechanically shelled.

The following table shows the yields obtained from the test crop.

TABLE 12

Mean yield of shelled grain of test crop at 15% moisture from the green manure treatments in lbs/acre (kg/ha)

	Sunn hemp	Sunn hemp + Irr	Maize	Maize + N	Maize + N + Irr	Weed fallow	Mean
With fertilizers	5744 (6433)	5744 (6433)	5951 (6665)	6491 (7270)	5765 (6457)	5910 (6619)	5934 (6651
Without fertilizers	4521 (5063)	3297 (3693)	2488 (2787)	4127 (4622)	3525 (3948)	3235 (3623)	3532 (3959

		S.E.	LSD P = 0.05	P = 0.0
Comparison	1) With and without fertilizer on same green manure treatment	344 (385)	999 (1120)	1356 (1520)
	2) With and without fertilizer with different green manures	398 (446)	1642 (1840)	n.s
	3) Interaction	344 (385)	n.s	n.s

Examination of the above table shows that the greatest significant response of the test crop was to the fertilizer applied to the green manure treatment, and that there was no difference in yield between the green manure treatments when fertilizer was applied. Also there was a significant depression of yield by the maize alone green manure without fertilizer, which must have been due to the lack of nitrogen. Another rather surprising result was that the green manure treatments with irrigation depressed the yield of the test crop. How this came about is not clear.

Although the green manures alone did not have any influence on the yield of the test crop, a most important point has been made - that under good husbandry and all other factors being equal, the highest yields can only be obtained with the use of fertilizers. At low levels of husbandry and with soil in low fertility, no doubt yields can be raised with green manuring, as was shown in Nigeria (Vine, 1953). It is worthy of note that the yield of the maize test crop from the weed fallow treatment without fertilizer was over four times the national average yields of Uganda.

In summary, there was no apparent increase in soil fertility where intensive green manuring was employed as measured by one test crop. Perhaps the physical condition and nutrient status of the soil was at a relatively high enough level initially to show little response in the short term.

CHAPTER 2

PLANT AND SOIL ANALYSIS

2.1 ANALYSIS OF PLANT LEAVES AND SOIL PRIOR TO THE GREEN MANURING EXPERIMENT

2.1.1 Foliar Analysis

Sweet potatoes were growing on the experimental area for three months before the green manuring experiment was carried out. The objectives of foliar analysis of the sweet potato leaves were:

a) to determine whether the leaves were deficient in a major nutrient;

b) to determine whether there were any significant differences in nutrient availability between the proposed plots of green manuring trial.

2.1.2 Methods of Sampling

The first fully developed leaf (lamina and petiole) from the apex was removed from 20 random sweet potato plants in each plot. All the samples were taken between 0730 hrs. and 0830 hrs., placed in polythene bags and weighed. They were dried for 24 hours at 80°C and reweighed.

The dried samples were ground to a powder and analysed for nitrogen, phosphorus, calcium, magnesium and potassium.

For methods of analysis used, see Appendix 3.

2.1.3 Results and Discussion

Analysis of the dry weight of the leaf samples showed that there was a significant decline of leaf weight down the slope of the experimental area. Also, it was found that there was a tendency for the percentages of nitrogen, phosphorus and potassium to decline similarly. The potassium probably dominated the base up-take; since the potassium decreased down the slope, so calcium and magnesium increased.

All of the % nutrient levels were above the established critical levels and there was, therefore, no apparent nutrient deficiency for the crop.

TABLE 13

Mean dry matter and % nutrients of total dry weight of sweet potato leaves in replicate blocks of green manuring trial area

	Dry matter	N	P	K	Ca	Mg	Slope
A	4.7	4.07	.34	5.35	.79	.48	↓
B	5.2	3.73	.31	5.17	.75	.50	
C	4.9	3.88	.30	5.34	.80	.50	
D	4.5	3.63	.29	4.80	.82	.57	
E	3.9	3.68	.28	4.72	.99	.54	
S.E. of mean	.17	.24	.025	.16	.045	.037	
LSD P=0.05	.50	.70	.07	.47	.13	n.s	
LSD P=0.01	.68	.96	n.s	n.s	n.s	n.s	

2.1.4 Soil Analysis

The objectives of soil analysis were the same as the foliar analysis but, in addition, knowledge was required of:

a) the pH of the soil;

b) the texture of the soil;

c) the carbon and nitrogen content of the soil.

One of the objectives of the green manuring trial was to determine whether the incorporated plant material had had any effect on the carbon content of the soil. In addition it was not known what effects the green manures would have on the available phosphorus, bases and pH of the soil.

2.1.5 Methods of Sampling

In each of the proposed plots three random soil samples were taken to 23 cm depth. These were then bulked and after thorough mixing a 1 kg working sample obtained. In three of the plots a further three samples were taken and analysed separately as a check on the composite sample.

For the methods used, see Appendix 3.

2.1.6 Results and discussion

As with the foliar analysis a general decline of plant nutrients was found down the slope. The carbon content and pH, however, remained fairly constant over the trial area. In general, the nitrogen and potassium levels were reasonably high. There was a large difference in P_2O_5 down the slope and it was unlikely that blocks A, B and C would give a phosphate fertilizer response, whereas D and E blocks probably would.

The following table shows the means for the replicates where A is at the top and E at the bottom of the slope.

TABLE 14

Soil chemical and mechanical analysis shown as mean values for replicate blocks before incorporation of the green manures

BLOCKS	C %	N %	P_2O_5 ppm	K me%	Ca me%	Mg me%	pH	Clay mean %	Silt mean %
A	2.09	.159	136	1.41	6.87	2.45	5.6	32.1	10.2
B	2.27	.153	63	1.30	6.33	1.33	5.6		
C	2.09	.151	95	1.17	6.01	1.71	5.6		
D	1.97	.129	21	1.01	6.05	1.88	5.5		
E	1.98	.130	28	1.03	6.44	1.81	5.5		
S.E. of mean	.09	.005	12	.081	.32	.21	.05		
LSD P=0.05	n.s	.015	35	.24	n.s	.44	n.s		
LSD P=0.01	n.s	.020	48	.32	n.s	.60	n.s		

As the phosphate showed such a wide range of values and that the quantities of dry matter produced were probably going to be high, 100 lbs/acre (112 kg/ha) of P_2O_5 and 50 lbs/acre (56 kg/ha) of K_2O were applied to the whole trial area. Thus it was hoped that the variation between treatment replications would be reduced.

The mechanical analysis showed that the soil was a sandy clay loam by the United States Department of Agricultural classification.

There appears to be no reason why the nutrient status was higher at the top of the slope, for no fertilizers were applied within three years of the beginning of the experiment, but it may have been due to settlement and refuse disposal in the past.

2.2 SOIL ANALYSIS DURING AND AFTER INCORPORATION OF GREEN MANURES

2.2.1 Introduction

Soil samples were taken, as previously described, after incorporation of two and four green manure crops. The analysis was carried out to determine what influence the green manures had had on the nutrient status of the soil. Determinations were made for carbon, nitrogen, phosphate and potassium.

The methods of analysis used are described in Appendix 4.

2.2.2 Results and Discussion

The results were analysed using the figures before the incorporation of the green manures for comparison, and both time and the interactions between treatments and time were tested for significance. The following tables give the results for carbon, phosphorus, nitrogen, calcium plus magnesium, potassium and pH.

TABLE 15(a)

Mean organic carbon content % of soil under the green manure treatments

	Sunn hemp	Sunn hemp + Irr	Maize	Maize + N	Maize + N + Irr	Weed fallow	Mean
Before incorp.	2.14	2.17	2.16	2.11	2.17	2.17	2.15
After 2 incorps.	2.04	2.06	2.22	2.23	2.28	2.09	2.15
After 4 incorps.	2.20	2.02	2.24	2.40	2.32	2.13	2.21

S.E. for table means = .069

LSD for table between times of incorporation P = 0.05 = .14

P = 0.01 = n.s

Although there was a rise of organic carbon content with time in the maize treatment, it was not significant. However, it does represent an increase of about 4.000 kg/ha of humus carbon for the extraction method does not include undecomposed plant material. This figure appears to agree with Nye and Greenland's (1960) estimate for the retention of organic carbon in tropical areas. The only significant increases were in the sunn hemp and maize plus nitrogen green manures between the second and fourth incorporation. The replicate variation was high with the three samples per plot so that an increase of 3130 kg/ha of carbon was needed to attain significance.

The variation between the replicate treatments was so large even with the application of phosphate fertilizers that there were no significant differences between treatments, time nor the interactions. Therefore, although no estimation can be made as to whether there was any mobilisation of phosphate by the green manures, the figures do show that in these soils there was no phosphate 'fixation'.

TABLE 15(b)

Mean Truog phosphate ppm from soil under the green manure treatments

	Sunn hemp	Sunn hemp + Irr	Maize	Maize + N	Maize + N + Irr	Weed fallow
Before incorp.	68	50	67	57	64	65
After 2 incorps.	56	48	63	62	71	48
After 4 incorps.	42	49	71	92	81	56

S.E. for table means = 13

LSD for table between times of incorporation P = 0.05 = n.s
P = 0.01 = n.s

TABLE 15(c)

Mean total nitrogen % of soil before
and after incorporation of four green manure crops

	Sunn hemp	Sunn hemp + Irr	Maize	Maize + N	Maize + N + Irr	Weed fallow
Before incorp.	.136	.130	.145	.144	.142	.133
After 4 incorps.	.141	.136	.138	.140	.138	.139

S.E. for table means = .0043 LSD for table differences

P = 0.05 = n.s

P = 0.01 = n.s

The analysis of variance showed that there were no significant differences with time, between treatments, nor their interaction. This result was surprising, considering the quantities of organic matter which were incorporated. Nitrogen at 120 lbs/acre had been applied to two of the maize green manures and the sunn hemp appeared to be fixing nitrogen; the lack of significance, however, was probably due to inadequate sampling.

TABLE 15(d)

Mean soil carbon:nitrogen ratios
before and after incorporation of green manures

	Sunn hemp	Sunn hemp + Irr	Maize	Maize + N	Maize + N + Irr	Weed fallow
Before incorp.	15.4	15.5	15.7	15.6	15.8	15.4
After 4 incorps.	15.9	15.5	15.6	16.7	16.5	16.1

S.E. for table means = 0.4 LSD for table differences
P = 0.05 = n.s
P = 0.01 = n.s

Although no significant differences of carbon:nitrogen ratio between treatments were found, there was a significant overall increase at the 5% level. This was anticipated because of the quantities of organic matter added. It was also thought that there would be large differences between the maize and sunn hemp treatments because of the plant carbon: nitrogen ratios, but these were not found. Sampling errors as well as time of sampling probably accounted for this, but there is a clear indication that, under the conditions imposed on the soil, there were very efficient decomposition processes taking place.

TABLE 15(e)

Mean potassium % m.e. of soil
under the green manure treatments

	Sunn hemp	Sunn hemp + Irr	Maize	Maize + N	Maize + N + Irr	Weed fallow
Before incorp.	.77	.84	.87	.79	.96	.81
After 2 incorps.	.77	.76	.69	.69	.87	.84
After 4 incorps.	.93	.87	1.14	1.13	1.07	.88

S.E. for table = .11

LSD for table between times of incorporation P = 0.05 = .22
P = 0.01 = .54

There was no significant difference between treatments but differences between incorporations and the interaction between treatments and time were significant at the 1% and 5% levels respectively. The significant increase of soil potassium under the maize and maize plus nitrogen green manure indicated that there was a build-up. The sunn hemp did not make any appreciable contribution and was probably unable to extract much potassium from the soil.

TABLE 15(f)

Mean calcium plus magnesium m.e. % of soil under the green manure treatments

	Sunn hemp	Sunn hemp + Irr	Maize	Maize + N	Maize + N + Irr	Weed fallow
Before incorp.	8.53	8.68	8.89	8.73	8.76	8.30
After 2 incorps.	8.35	8.25	8.80	8.68	8.85	7.68
After 4 incorps.	8.71	8.06	9.46	8.51	8.84	8.28

S.E. for table means = .37 LSD for table differences

P = 0.05 = .74

P = 0.01 = n.s

There was a significant difference between treatments at the 5% level, also the interaction between treatments and time was significant. It is of interest to note that, although the calcium plus magnesium levels remained fairly constant in the maize green manure treatments, the available soil potassium levels rose.

TABLE 15(g)

Mean soil pH from soil under the green manure treatments

	Sunn hemp	Sunn hemp + Irr	Maize	Maize + N	Maize + N + Irr	Weed fallow
Before incorp.	5.6	5.7	5.6	5.5	5.7	5.5
After 2 incorps.	5.6	5.7	5.8	5.7	5.7	5.7
After 4 incorps.	5.3	5.3	5.5	5.3	5.6	5.4

S.E. for table means = .1   LSD for table differences
P = 0.05 = n.s
P = 0.01 = n.s

The analysis of variance showed no significant differences. Therefore the incorporation of the green manures had no significant effect on soil reaction.

In general the effect of incorporation of four green manure crops on the soil was not as large as anticipated. Although there were slight increases of carbon, potassium and carbon:nitrogen ratio, they were not really different from the weed fallow treatments.

The analysis of variance showed that the between replication error accounted for a large proportion of the variation, hence no small changes of the nutrients could reach significance. The soil analysis was carried out only a short time after incorporation and, because the soil had been rotary cultivated six times since the beginning of the experiment, the sampling errors were large.

2.3 TEST CROP FOLIAR ANALYSIS

2.3.1 Introduction

Although the yields of the test crop were to be the main indication of any effects the green manures may have had, foliar analysis was carried out on the test crop. The analysis figures would provide an indication as to whether a particular plant nutrient was having a dominant effect on yield. Furthermore, if there was severe damage to the test crop and the yields showed no significant effects, they could be revised by covariance analysis with the foliar analysis.

2.3.2 Method of Sampling

Leaf samples were taken just after 'silking', twelve weeks after planting. The leaf selected for analysis was opposite and below the lowermost ear. From each plot, ten leaves were taken between 0730 and 0830 hours and weighed. The centre 20 cm on either side of the mid-rib was cut out for analysis and the leaves and sections were dried for two days at 60°C and reweighed. The leaf sections were analysed for total nitrogen, phosphorus and potassium by the methods described in Appendix 4.

2.3.3 Results and Discussion

The following table shows the mean values of total leaf phosphorus as % of dry weight.

TABLE 16(a)

Mean leaf phosphorus (% of dry weight) from the test crop on the green manure treatments

	Sunn hemp	Sunn hemp + Irr	Maize	Maize + N	Maize + N + Irr	Weed fallow	Mean
With fertilizer	.33	.33	.32	.33	.33	.31	.325
Without fertilizer	.30	.27	.30	.30	.27	.27	.285

		S.E.	LSD P = 0.05	P = 0.0
Comparison	1) With and without fertilizers on same green manure treatment	0.05	n.s	n.s
	2) With and without fertilizers under different green manure treatments	0.036	n.s	n.s
	3) Interaction	0.05	n.s	n.s

No significant differences were found with any variance ratio of the analysis. The other soil and foliar analysis had shown the inter-block and effect of fertilizers to be significant. A level of 0.15% phosphorus of dry weight is considered to be low and 0.30% is considered intermediate. Therefore the phosphorus was at a high enough level to prevent differences between treatments from being significant. The 100 lbs/acre of P_2O_5 applied at the beginning of the green manure sequence must have carried over to the test crop.

TABLE 16(b)

Mean leaf potassium (% of dry weight) from the test crop on the green manure treatments

	Sunn hemp	Sunn hemp + Irr	Maize	Maize + N	Maize + N + Irr	Weed fallow	Mean
With fertilizer	2.17	2.29	2.10	2.20	2.14	2.32	2.20
Without fertilizer	2.12	1.98	2.14	2.20	2.05	2.16	2.11

		S.E.	LSD P = 0.05	LSD P = 0.01
Comparison	1) With and without fertilizer on same green manure treatment	.06	.25	.34
	2) With and without fertilizer on different green manure treatment	.07	n.s	n.s
	3) Interaction	.06	n.s	n.s

Table 16(b) shows that the effect of potassium fertilizer was significant only on the plots which had received the sunn hemp-plus-irrigation treatments. The 50 lbs/acre of K_2O applied at the beginning of the green manuring sequence was carried over to the test crop.

TABLE 16(c)

Mean leaf total nitrogen (% of dry weight) from the maize crop on the green manure treatments

	Sunn hemp	Sunn hemp + Irr	Maize	Maize + N	Maize + N + Irr	Weed fallow	Mean
With fertilizer	2.86	2.74	2.39	2.55	2.52	2.78	2.64
Without fertilizer	2.10	1.70	1.86	1.89	1.92	1.75	1.86

		S.E.	LSD P = 0.05	LSD P = 0.01
Comparison	1) With and without fertilizer on same green manure treatment	0.13	0.39	0.53
	2) With and without fertilizer on different green manure treatment	0.12	n.s	n.s
	3) Interaction	0.39	n.s	n.s

The analysis of variance showed that, although the main treatments and the interaction between fertilizer and treatments were not significant, the effect of the nitrogen fertilizers were. A low level of leaf nitrogen is considered to be 1.10% and the economic optimum 2.4%. It will be seen that the without fertilizer levels are fairly high and that the 60 lb of nitrogen/acre in the fertilizer showed a highly significant response raising all levels to optimum.

Further asymetrical comparison analysis showed no significant difference between the green manure treatments nor the interaction between the green manure and the weed fallow. However, the leaf nitrogen proved to be the most sensitive nutrient to the applied fertilizers; therefore, assuming all the other factors to be equal, nitrogen was the most important determining factor of yield under the conditions at Kabanyolo.

In general, the phosphorus and potassium levels were well above the critical levels in all the treatments, and the fertilizer showed little response. This may have been due to the 100 lb/acre of P_2O_5 and 50 lb/acre of K_2O which were supplied at the start of the green manuring trial. The foliar analysis has shown that the most significant response of the test crop was to nitrogen applied in the fertilizers. It has also indicated the efficiency of the soil decomposition processes, for where the maize green manure-without-nitrogen or irrigation was incorporated, the level of leaf nitrogen in the test crop was much higher than the critical level. The sunn hemp and maize-plus-nitrogen green manure without fertilizers showed little response in the test crop, in terms of nitrogen, over the weed fallow. This was most probably due to the heavy rainfall at the beginning of the first rains in 1968 which could have leached a large proportion of the available nitrogen out of the soil.

PART II

THE DYNAMICS OF CARBON DIOXIDE EVOLUTION FROM THE SOIL

CHAPTER 3

FIELD MEASUREMENTS OF SOIL CARBON DIOXIDE FLUX

3.1 THE DETERMINATION OF CARBON DIOXIDE FLUX FROM THE SOIL AND RELATIONSHIP TO THE BREAKDOWN OF ORGANIC MATTER

3.1.1 Review of Literature

When organic matter is incorporated into the soil, it serves two primary purposes for the microflora:

a) supplying energy for growth;

b) providing carbon and nitrogen for the formation of new cell material.

Under aerobic conditions these two functions involve the uptake of oxygen and release of carbon dioxide. The more efficient the organism is in converting subtrate-carbon to cell-carbon, the smaller the quantity of carbon dioxide and organic waste products released.

All heterotrophic organisms can degrade organic carbon and the rate is used as a measure of microbial activity. The methods developed have been both the measurement of carbon dioxide evolution and oxygen uptake. These are measures of respiratory activity which basically follow the equation:

$$(1) \quad C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + 686 \text{ kcals}$$

Therefore, carbon dioxide release and oxygen uptake take place in equal proportions and, as an enzymic reaction, the rate is dependant on temperature, moisture and substrate concentration.

Both laboratory and field methods have been employed and these have been described by Domsch (1962), Mina (1962), Novak (1963), Monteith, Szeicz and Yabuki (1964) and Drobníková and Drobník (1965).

In recent years most experiments on soil respiration have been carried out by Russian, German and Czechoslovakian workers in temperate areas. The most important factors affecting soil respiration have been found to be temperature (Kogotkov, 1960; Drobník, 1962; Krzysch, 1965; Tamm and Krzysch, 1966) and moisture (Gaader, 1957; Novak and Novakova, 1962; Freytag, 1967). Other workers have reported that when organic manures are incorporated into the soil there was an increase of carbon dioxide evolution (Apfethaler and Novak, 1966; Zameck, 1966). There have been reports of other factors influencing soil respiration; sub-tilling and ploughing (Olson and McCalla, 1960), trace elements (Bershova, 1960), salt concentration (Johnson and Guenzi, 1963), fungicides (Domsch, 1964) and herbicides (Kulínska, 1967). In the tropical and equatorial areas, however, very little work has been done (Hilger, 1963; Schulze, 1967). The rates of carbon dioxide evolution given by Hilger, working in the Congo, were from 500 - 1400 mg carbon dioxide/m^2/hour and by Schulze in Costa Rica 300 - 2550 mg carbon dioxide/m^2/hour. Both these sets of figures were considerably higher than in temperate areas of 26 - 146 mg carbon dioxide/m^2/hour (Krzysch, 1965) evolved during the summer months.

Most workers have carried out their experiments by measuring either carbon dioxide release or oxygen uptake. Where field methods have been employed only carbon dioxide release has been measured (Monteith, Szeicz and Yabuki, 1964; Krzysch, 1965; Witkamp, 1966; Schulze, 1967) as measurement of oxygen uptake is difficult. The estimation of carbon dioxide release has been criticized by Hofmann and Hoffman (1962) who found that, in the temperate areas, most of the carbon dioxide produced by the soil micro-organisms did not escape to the soil surface but moved further down the profile with leaching. Therefore, they reasoned, as carbon dioxide moves down the profile, oxidation processes take place without carbon dioxide evolution and carbon dioxide may originate from processes other than soil respiration; oxygen consumption then was the only valid measure of soil respiration. These aspects have not been followed up by any other workers but there have been reports by Monteith <u>et al</u> (1964), Wiant (1967) and Macfadyan (1968) on the effects of root respiration on total soil carbon dioxide flux.

In general, the temperate zones have received far more attention than tropical and equatorial areas. Therefore, some attempts were made to measure total soil respiration in the experimental area and elucidate some of the contributory factors, both by laboratory and field methods.

3.1.2 Introduction

The role of organic matter in soil productivity has received much attention particularly in the temperate areas of the world. In the equatorial and tropical areas, however, workers have in the past referred to the rapid disappearance of soil organic matter due to the high temperatures (Keen, 1939; Martin, 1944; Joffe, 1955). However, Birch and Friend (1956a) and Nye and Greenland (1960) have shown that the organic matter content of humic tropical soils in these areas in general compare very favourably with temperate areas.

Actual measurement of soil organic matter presents innumerable problems particularly with sampling errors. If measurements of increase or decline are required, then many samples have to be taken at exactly the same place for a number of years. However, an indirect method can be employed by measurement of soil respiration, where the sampling errors are not so great.

Both laboratory and field methods can be employed but, in the past, most investigations have employed laboratory techniques. It was, therefore, decided to adopt a field method to determine soil respiration and compare results with a laboratory technique.

The objectives of the experiments to be described were:-

1) to determine the flux of carbon dioxide from the soil under the green manure treatments;
2) to relate the loss of carbon dioxide with the rate of breakdown of organic matter;
3) to examine the effects of temperature and moisture on soil respiration;
4) to relate the quantity of fresh organic material incorporated and the rate at which it decomposed;
5) to determine the influence of cultivation on respiratory activity of the soil.

3.1.3 Description of Field Method and Design of Experiment

The method used has been described by Monteith *et al* (1964) with slight modification and has been used for all the field experiments.

A quantity of soda lime (5 - 10 mesh) is dried for about two hours in a force air-draught oven at 100°C. Then 30 gm measured to 0.05 gm are weighed out into a glass petri dish of 14 cm diameter which is placed in a dessicator. In the field the dish is mounted two to three cm above the ground on pegs within an inverted white painted metal tank of 0.057 sq metre area. The metal tank is pushed down about four cm into the ground. The soda lime does not absorb carbon dioxide then but, when exposed in the field, it is quickly reactivated by the absorption of moisture diffusing from the soil. After several days the soda lime is removed, oven-dried and reweighed. The flux of carbon dioxide is determined by dividing the weight increase per day by the area of the tank.

The site of the tank was moved every few days when the soda lime was changed.

Preliminary Tests

Measurements of carbon dioxide flux were made with varying numbers of samples. This was done to determine the minimum number required to give a standard deviation of one tank ± 20% of the mean. These preliminary tests showed that:-

1) five replicates of any treatment were the minimum number required;
2) there were significant differences between the maize and the sunn hemp green manure treatments and also between them and the weed fallow;
3) the moisture status of the soil influenced the carbon dioxide flux;
4) when the soil was dry there was difficulty in pressing the tanks into the ground. This was overcome by digging the soil away from the outside of the tank and covering the sides with soil to about 8 cm.

As five replicate samples were found to be necessary, one tank with soda lime was placed in each of the plots of the green manure treatments. The experiment was then analysed similarly to the green manure experiment as a randomized block design.

Plate 2 shows the tanks in position on the green manure treatment plots.

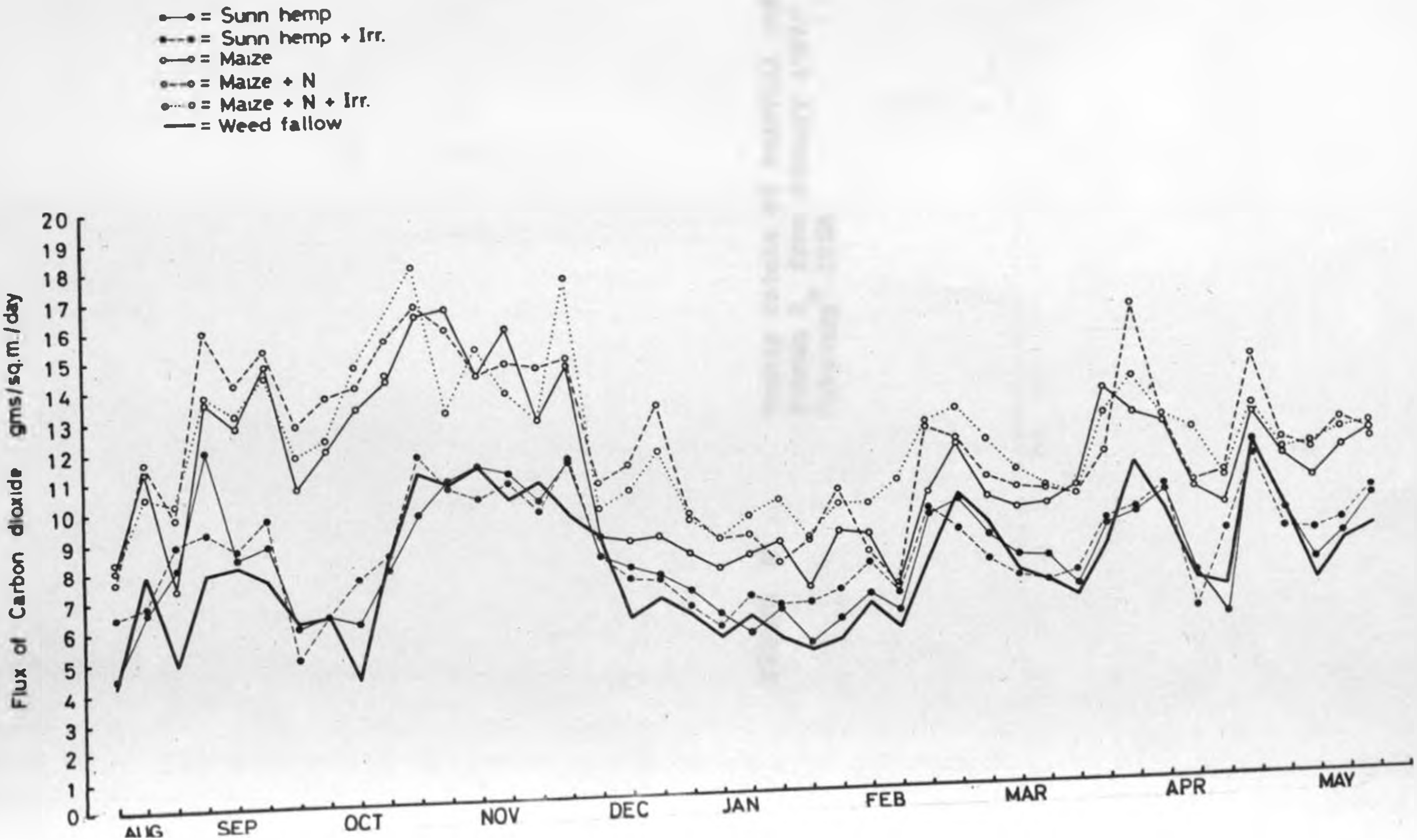
PLATE 2 Preliminary tests with the soda lime method of measuring soil carbon dioxide flux in the green manuring trial. In the foreground maize was incorporated, in the background sunn hemp.

3.1.4 Results and Discussion

Figure 7 shows the mean daily carbon dioxide flux for the six treatments from August 1967 to May 1968 and each point represents the mean of five replicates.

Examination of the graph (Figure 7) shows the flux from the green manure treatments and the weed fallow almost invariably followed the same pattern. Also that there appeared to be an important factor(s) which influenced the treatments. This was soil moisture, as reference to Figure 8 shows that the periods of highest and lowest rainfall coincide with carbon dioxide flux in October/November and December/January respectively. It will also be seen that soil moisture status was more important than any effect incorporation of green plant material had on carbon dioxide flux. This is more important in the field than previous workers have shown, for where there are long dry periods, very little decomposition takes place. The influence of drying-out of soil on carbon dioxide flux can be more clearly demonstrated by examining the mean carbon dioxide flux, from the weed fallow from 29.11.67 to 25.1.68. Figure 9 shows the flux declining when plotted against the soil moisture status. This was calculated by subtracting the daily Penman E_t values (calculated according to Rijks and Walker, 1968) from the rainfall to obtain a 'running balance'

FIGURE 7 Mean carbon dioxide flux from green manure treatments from August 1967/May 1968



= Sunn hemp
= Sunn hemp + Irr.
= Maize
= Maize + N
= Maize + N + Irr.
= Weed fallow
Flux of Carbon dioxide gms/sq.m./day
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY

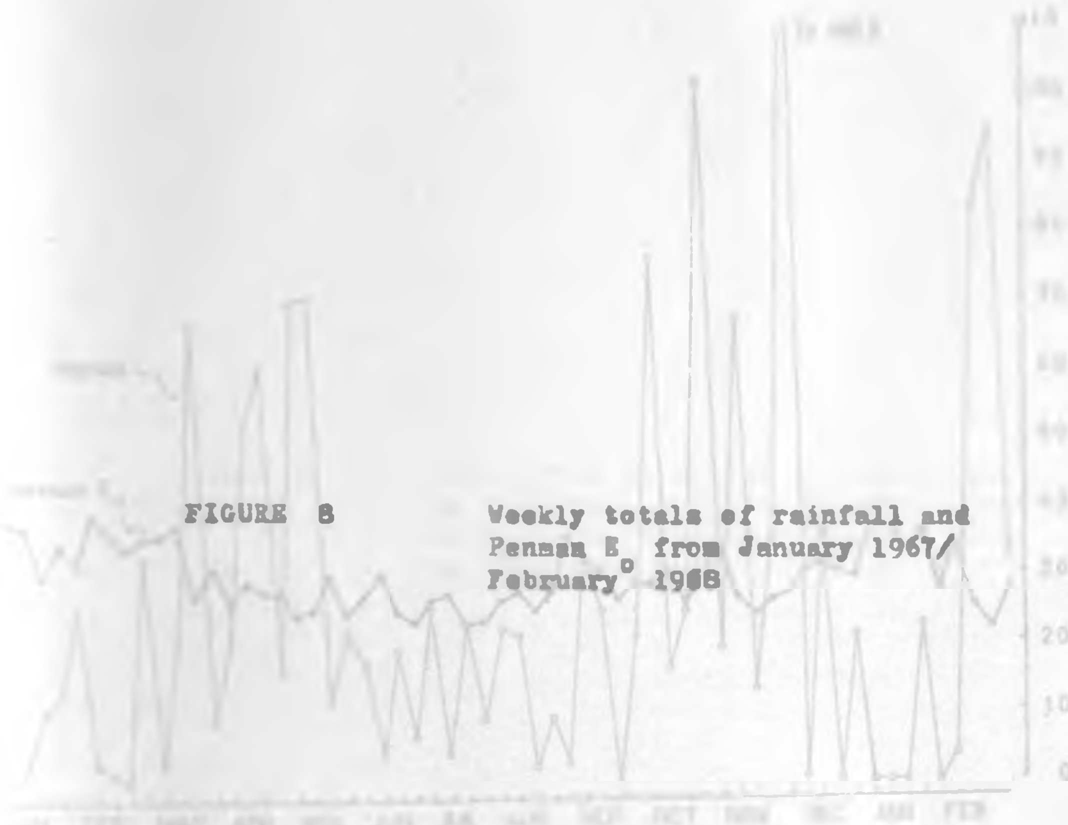
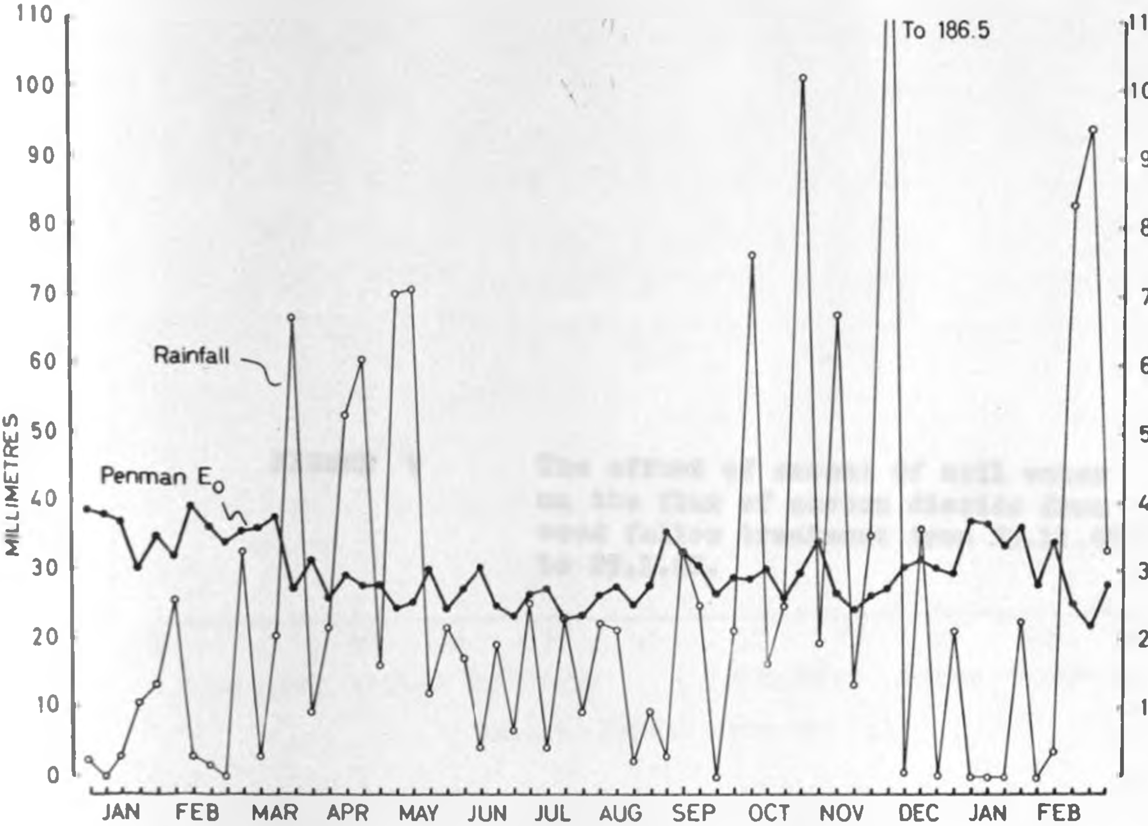


FIGURE 8 Weekly totals of rainfall and Penman E_o from January 1967/ February 1968



MILLIMETRES
0
10
20
30
40
50
60
70
80
90
100
110
Rainfall
Penman E_o
To 186.5
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB

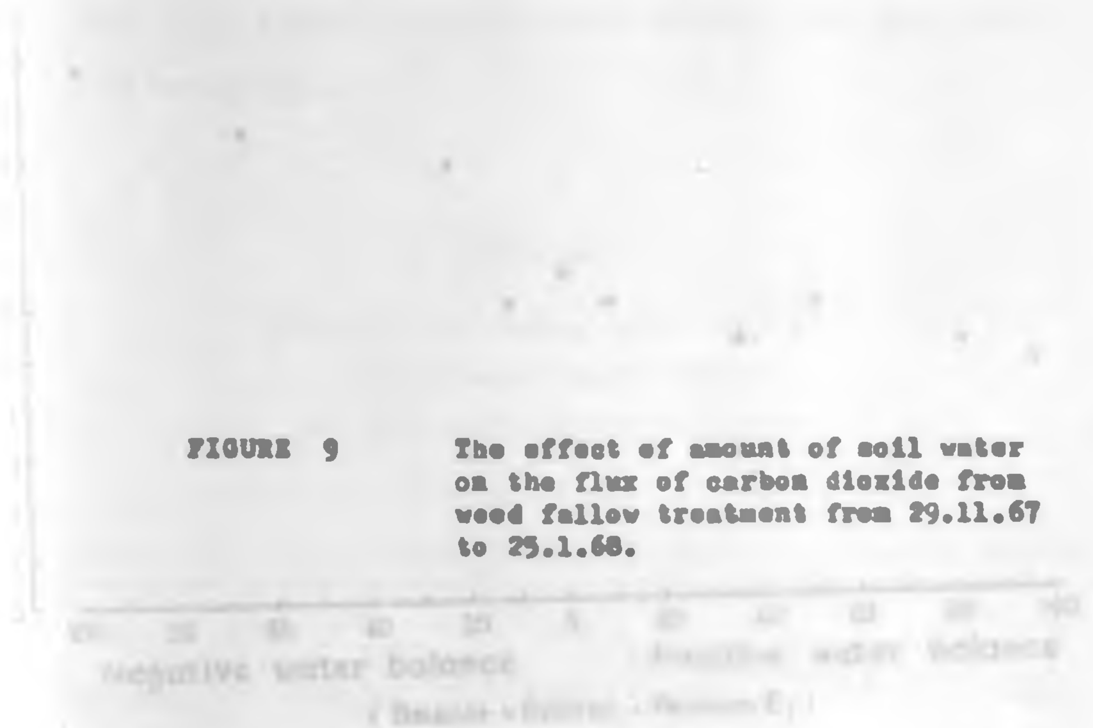
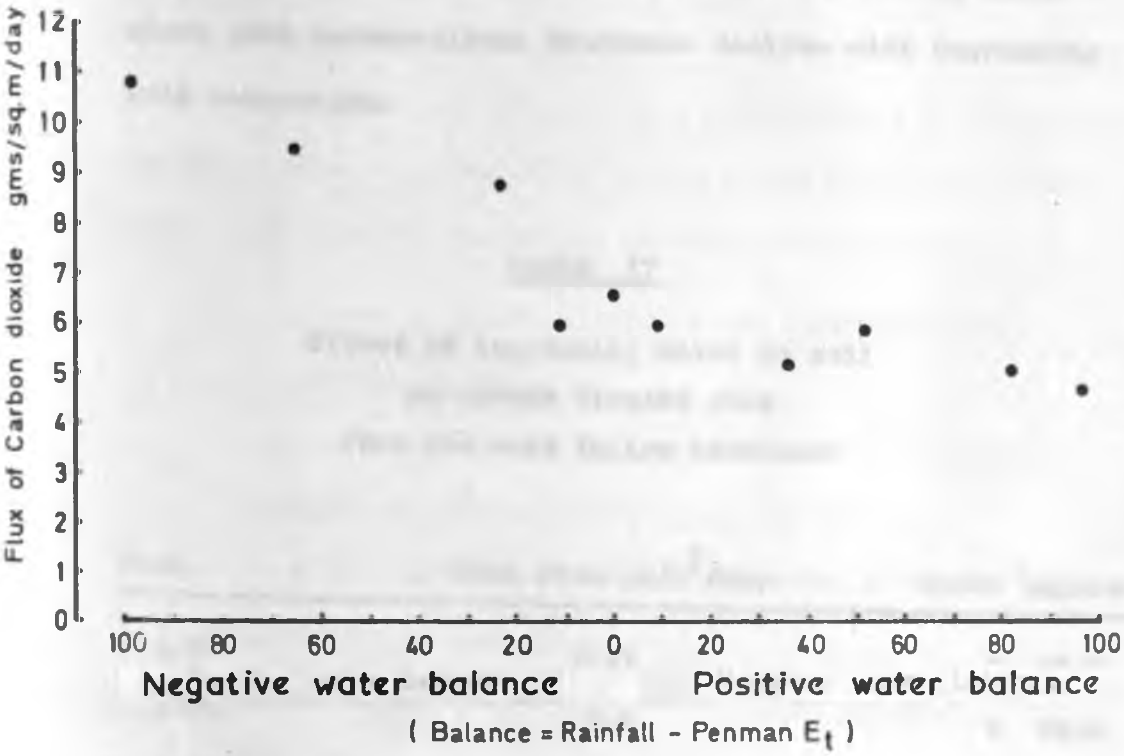


FIGURE 9 The effect of amount of soil water on the flux of carbon dioxide from weed fallow treatment from 29.11.67 to 25.1.68.



Flux of Carbon dioxide gms/sq.m/day
0
1
2
3
4
5
6
7
8
9
10
11
12
100
80
60
40
20
0
20
40
60
80
100
Negative water balance
Positive water balance
(Balance = Rainfall - Penman E_t)

of soil water. It will also be seen from Figure 7 that there was a reduction of carbon dioxide output at the end of February/beginning of March and during April. As there was the young test crop growing at the time, water was not removed and waterlogging occurred. The following table shows that decomposition processes decline with increasing soil saturation.

TABLE 17

Effect of increasing water in soil
on carbon dioxide flux
from the weed fallow treatment

Date	Mean Flux $gm/m^2/day$	Water balance mm
5.4.68	10.8	+ 19.2
11.4.68	9.0	+ 68.0
18.4.68	6.7	+ 84.5
22.4.68	6.4	+ 135.0

Later, with more intermittent rainfall, decomposition rose indicating more suitable conditions.

The flux figures, shown in Figure 7, for the sunn hemp and weed fallow treatments were rarely significantly different. The carbon dioxide released from the maize green manure treatments, however, were often 50 to 100% greater.

It appeared from the graph (Figure 7) that the flux from the maize treatments was declining with time, but not in the sunn hemp nor weed fallow.

The figures of carbon dioxide release from the green manure treatments were not solely due to the input of fresh organic matter, but probably compounded of four main factors:-

a) the normal decomposition of the 'native' soil organic matter;
b) the increase in overall activity of soil micro-organisms due to rotary cultivation;
c) the respiration of the living roots of the green manure crops;
d) the respiration of the fresh plant material.

Further calculations and experiments were then made to determine the approximate contribution of the above factors to the total carbon dioxide flux.

a) The normal decomposition processes

A week before removing the soda lime to the new site on the weed fallow treatments, a small area was cleared of weeds. This was to ensure that neither the living roots of the weeds nor the disturbance of soil should have any significant effect on carbon dioxide flux; but the decomposition of formerly living roots in the soil probably influenced the measurements.

For the period from August 1967 to May 1968 the mean carbon dioxide flux from the weed fallow was 7.6 $gm/m^2/day$ but, in the light of further experiments, this may have been one or two $gm/m^2/day$ too high as a measure of 'native' organic matter decomposition.

b) The effect of rotary cultivation

Attempts were made in the field to estimate the contribution of root respiration. Tanks with soda lime were placed within and between rows of plants at all stages of growth, but there were no significant results.

An experiment, to be described later, which was conducted in hydroponic beds, showed that both maize and sunn hemp roots produced significant quantities of carbon dioxide after the fifth to sixth week of growth. When this stage had been reached about 2.5 $gm/m^2/day$ of carbon dioxide were evolved.

d) <u>Respiration of fresh plant material</u>

If the decomposition of 'native' organic matter in the soil was say 7.5 and roots contributed say 2.5 $gm/m^2/day$ then the remainder will be due to the decomposition of the freshly incorporated material, except for short periods after rotary cultivation.

Examination of Table 18 and Figures 7 and 10 shows that, as a result of incorporating maize green manure, there was significant rise in decomposition over both sunn hemp and the weed fallow. It is also shown that there was no significant difference in flux of carbon dioxide between the maize green manure treatments. The difference between the sunn hemp and maize treatments could have been due to:-

1) the quantity of freshly incorporated material;
2) the quality of the material
3) the type of cultivation employed.

TABLE 18

Mean daily flux of carbon dioxide over a 10-month period
from green manure treatments
and the % increase over the weed fallow

	Sunn hemp	Sunn hemp + Irr	Maize	Maize + N	Maize + N + Irr	Weed fallow
Mean flux CO_2 gm/m^2/day	8.0	8.2	11.1	11.9	11.8	7.6
% increase of flux where weed fallow = 100	105.3	107.9	146.0	156.6	155.3	100.0

S.E. for mean carbon dioxide flux = 1.0

LSD P = 0.05 = 2.1

P = 0.01 = 2.8

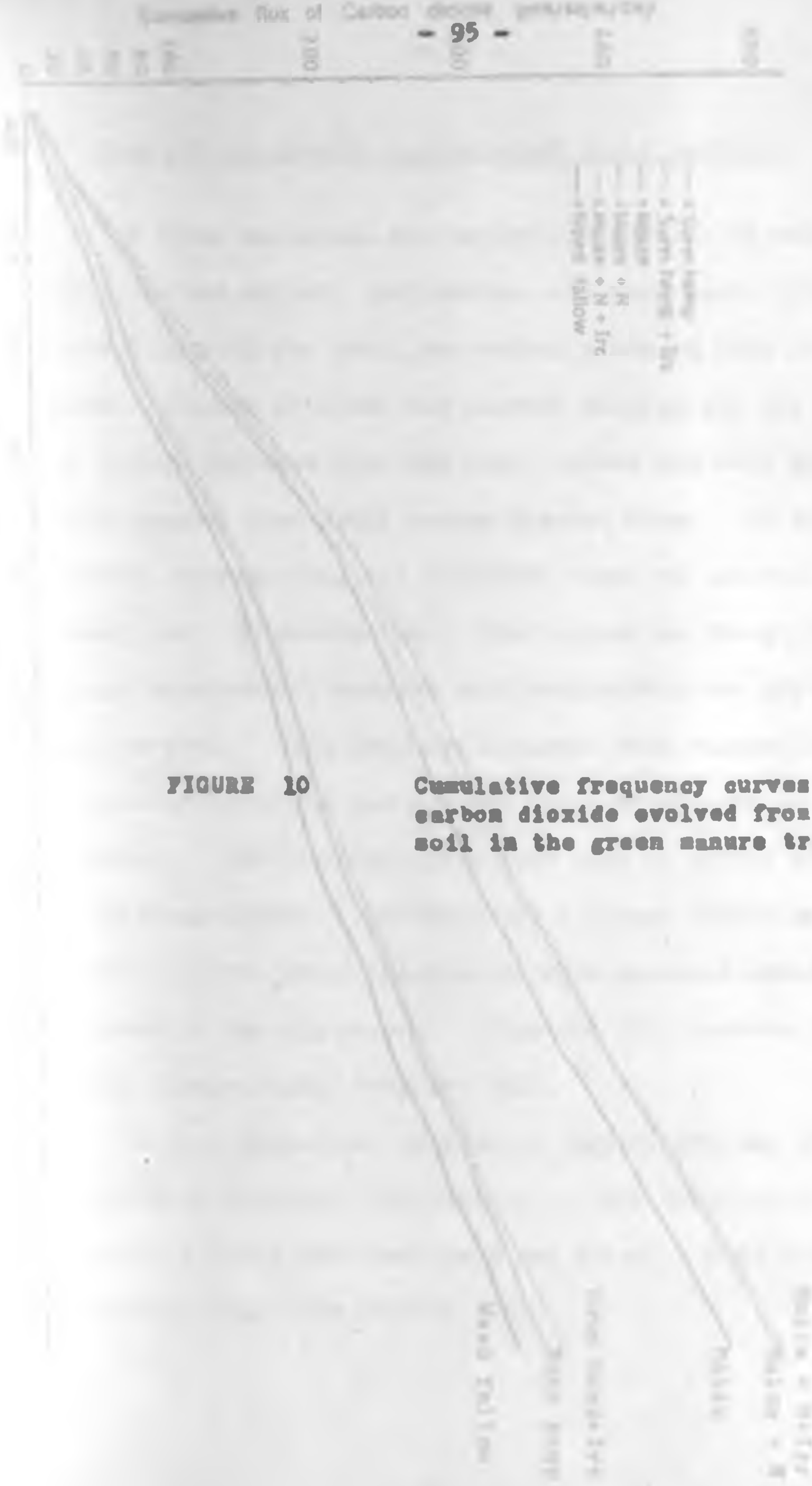
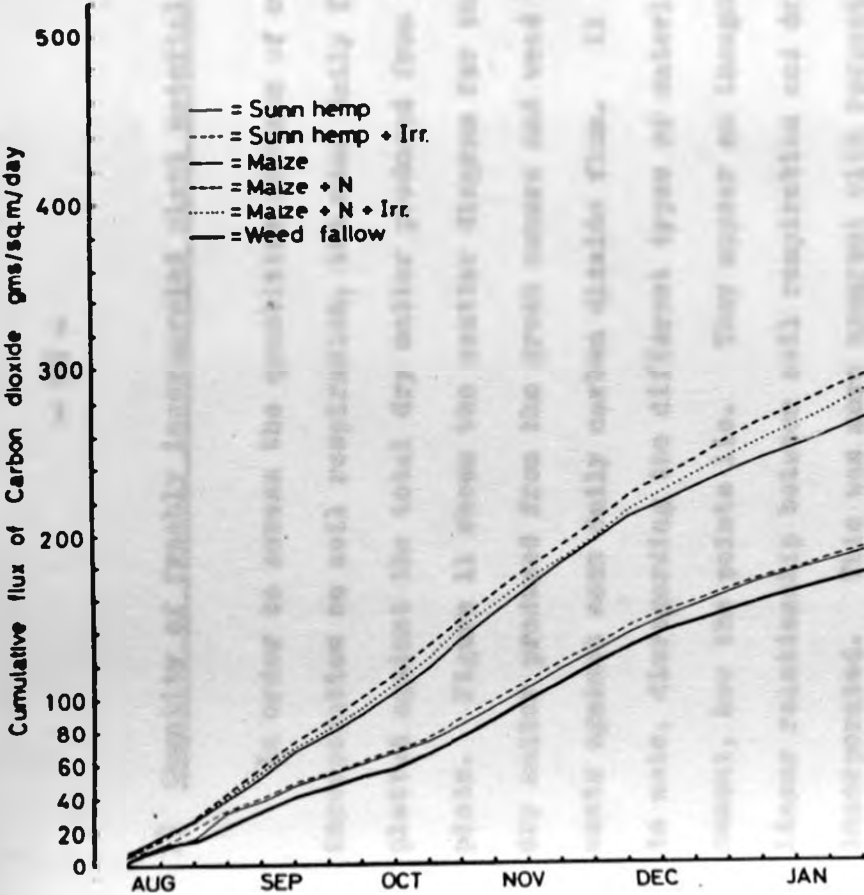
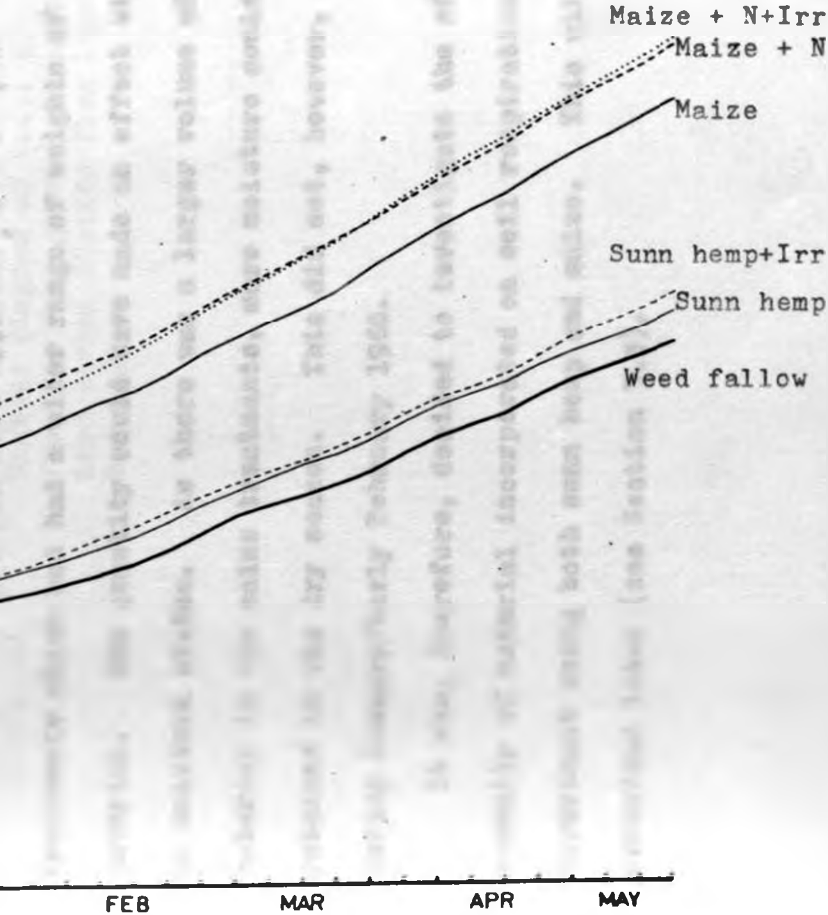


FIGURE 10 Cumulative frequency curves of carbon dioxide evolved from the soil in the green manure treatments



Cumulative flux of Carbon dioxide gms/sq.m/day
500
400
300
200
100
80
60
40
20
0
= Sunn hemp
= Sunn hemp + Irr.
= Maize
= Maize + N
= Maize + N + Irr.
= Weed fallow
AUG
SEP
OCT
NOV
DEC
JAN

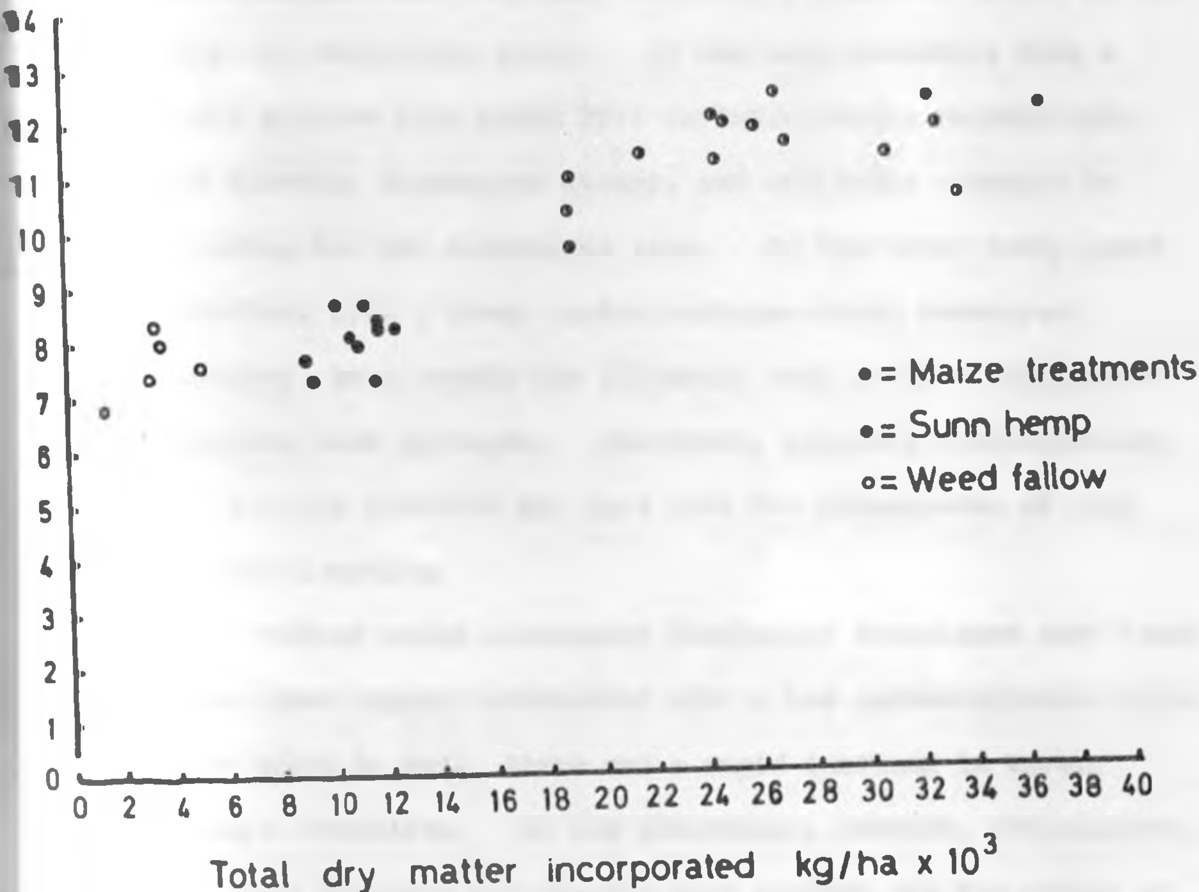

Maize + N+Irr
Maize + N
Maize
Sunn hemp+Irr
Sunn hemp
Weed fallow
FEB
MAR
APR
MAY

1) Quantity of freshly incorporated plant material

In order to assess the quantitive effects of organic matter incorporation on soil respiration, the mean daily flux was plotted against the total dry matter produced from the thirty plots. Figure 11 shows the scatter diagram for the total dry matter produced from the green manure and weed fallow treatments against mean daily carbon dioxide flux. It is of interest to note, disregarding the different types of material for the moment, how the points lie. They appear as though there was a linear relationship between soil respiration and dry matter incorporated. This was more apparent with respect to the maize treatments which had had a wider range of weights of incorporated material. The quantity could have made an effect with regard to moisture status. As there was a larger volume of plant material in the maize treatments, more moisture could have been retained in the dry season. This did not, however, hold true during January/early February 1968.

It was, therefore, decided to investigate the effects of quantity of material incorporated on soil respiration in an experiment using both sunn hemp and maize. This will be described later (see Section 3.3).

FIGURE 11 Scatter diagram of total dry matter from the four green manure crops against mean carbon dioxide flux August 1967/ May 1968


14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40
• = Maize treatments
• = Sunn hemp
o = Weed fallow
Total dry matter incorporated kg/ha x 10^3

2) Quality of freshly incorporated plant material

It is well known that the carbon:nitrogen ratio of incorporated plant material can have a dramatic effect on the soil and succeeding crops. If the crop materials have a ratio greater than about 25:1 carbon:nitrogen respectively, the material decomposes slowly, and available nitrogen is limiting for the succeeding crop. On the other hand, plant materials with a lower carbon:nitrogen ratio decompose rapidly; as a result the following crop is more adequately supplied with nitrogen. Sometimes, however, mineralization of nitrogen proceeds too fast with the consequence of loss through leaching.

Workers using laboratory incubation techniques have found that, when organic amendments with a low carbon:nitrogen ratio were added to soil, there was a rapid increase in carbon dioxide evolution. In the laboratory, however, temperatures and soil moisture are usually kept optimal and the mixing of soil and plant material more thorough than in the field.

The figures from Table 18 (page 94) seem to show results contrary to previous work. In the experiment the sunn hemp with a carbon:nitrogen ratio of 21.0 ± 1.7:1 appeared to decompose much more slowly than the maize with carbon:nitrogen of 54.2 ± 7.2:1.

The following table shows the analysis of the maize and sunn hemp.

TABLE 19

Analysis of maize and sunn hemp based on 100% dry matter

	% Ash	% N	% Ether Extract	% Crude Fibre
Maize	10.6	1.75	2.32	22.94
Sunn hemp	8.31	3.79	2.45	27.05

It will be seen that the protein and % crude fibre were higher for the sunn hemp. Therefore the greater proportion of lignins and cellulose in the sunn hemp may have accounted for its slower decomposition as it was more physiologically mature.

3) Type of cultivations

The action of the rotary cultivator on the soil is essentially one of chopping, digging and mixing. The plough, however, inverts the soil and vegetative material to a depth of say 20 - 25 cm, leaving a solid mat of vegetation below the soil layer containing micro-organisms. Thus, anaerobic conditions may prevail with the possible production of methane and fatty acids. The rotary cultivator mixes the green material with the soil in the top 15 cm or so, resulting in conditions suitable for aerobic decomposition. Where previous workers have found greater decomposition with leguminous compared with non-leguminous material, this may probably be explained in terms of aeration conditions and the surface areas of the vegetation and soil relative to one another. In the case where the rotary cultivator chops and therefore increases the surface area of the maize material, a much larger potentially decomposable surface is exposed.

The relationship between carbon dioxide flux and soil carbon loss

Although the measurements of carbon dioxide flux were primarily regarded as empirical, some cautious estimate of the annual loss of carbon can be made. In Table 20 mean daily fluxes have been converted to carbon loss kg/ha and are compared with the carbon inputs from the green manure crops.

TABLE 20

Rate of carbon loss from the green manure treatments
as calculated from carbon dioxide flux
compared to carbon incorporated from the green manures

Treatments	Mean daily flux CO_2 gm/m^2/day	Carbon loss kg/ha/year	Carbon loss less weed fallow kg/ha/year	Carbon incorporated from green manure kg/ha/year *
Sunn hemp	8.0	7963	395	5536
Sunn hemp + Irr	8.2	8162	594	5379
Maize	11.1	11050	3482	9960
Maize + N	11.9	11846	4278	13870
Maize + N + Irr	11.8	11746	4178	14410
Weed fallow	7.6	7560		1382

* Sunn hemp = 44.0 % Carbon
Maize = 42.6 % Carbon
Weeds = 40.0 % Carbon

Comparing the figures for carbon loss less weed fallow and the carbon incorporated, it appears as though the sunn hemp will remain in the soil for a much longer period than the maize. Of course, the figures are very approximate as both the flux and carbon percentages are only mean values, but there is an indication that, under the conditions imposed on the trial, organic matter derived from the leguminous material would have a larger residual effect than the maize.

The flux of carbon dioxide from the weed fallow can be used to make an estimation of the annual loss of carbon as a percentage of the total present in the soil.

Monteith _et al_ (1969) proposed the equation:

$$(2) \quad yX = F_b$$

where y = fraction of total carbon lost annually by decomposition

X = total carbon in the active layer

F_b = carbon equivalent of the annual carbon dioxide flux measured at the surface

Therefore substituting in equation (2)

$$y = \frac{.756}{7.02} = .108 = \underline{10.8\% \text{ per year}}$$

where weed fallow carbon dioxide loss = 7.6 gm/m^2/day = .756 carbon kg/m^2/year

and where X = 7.02 kg/m^2 in the top 27 cm layer with a total carbon percentage is 2.0 with a mean bulk density of 1.3 gm/cm^3.

Jenkinson (1963a) proposed the following equation relating carbon lost by decomposition and time:

$$(3) \quad \delta X/\delta t = A - \gamma X$$

where A = kg carbon returned m^2/year

Then where Xo = weight of carbon in the active layer at t = 0 then:

$$(4) \quad X = (X_o - \frac{A}{\gamma})e^{-t\gamma} \frac{A}{\gamma}$$

where symbols as in (2).

If A = 0 then the half-life of organic matter added to the soil is r = $0.69/\gamma$. Where γ = 0.108 as before, then the half-life of the organic matter in the weed fallow treatment is 6.4 years. At Rothamsted, England, Monteith et al (1964) found that the half-life of organic matter in soil under cultivation was 22 years. Jenkinson (1963a), quoting

Bartholomew and Kirkham's (1960) results stated that in North America the half-life of organic matter varied from 20 to 35 years. Therefore, even considering the uncertainty of the flux measurements, the soil organic matter at Kabanyolo decomposed about four times faster than in temperate areas. This emphasised the importance of building-up and maintaining organic matter under rotational systems in equatorial areas. Thus, unless systems of farming are employed where organic material is returned to the soil in reasonable quantities, 'run-down' of organic matter will occur in a short time, with a concomitant decline of soil fertility.

3.2 THE EFFECTS OF INCORPORATING MAIZE AND SUNN HEMP OF SIMILAR QUANTITIES ON THE SOIL CARBON DIOXIDE FLUX

3.2.1 Introduction

It was seen from Section 3.1.4 that there appeared to be a linear relationship between the carbon dioxide flux and the quantity of incorporated plant material. As the flux was determined within the green manure experiment, there may have been other factors which influenced the relationship. Therefore, an experiment was designed on similar soil nearby the green manuring trial, to answer a number of questions:

1. What increase of carbon dioxide flux would be found when a) maize and b) sunn hemp were incorporated into the soil in similar quantities ?

2. What was the carbon dioxide flux from soil which had been kept bare of plant growth for three months ?

3. What was the influence of rotary cultivations on the soil respiration ?

4. Was there a point when the flux ceased to increase with quantity of material incorporated ?

3.2.2 Treatment and Design

As large amounts of material were going to be incorporated and as the mechanical equipment available was limited in size, the maize and sunn hemp were cut into small pieces with a chaff-cutter.

The maize was cut twelve weeks after planting, passed through the chaff-cutter, and a sample was taken for moisture determination. The maize was then weighed out and spread evenly over the plots. After adjustments for moisture percentage the rates applied as kg/ha of dry matter were:

0; 2,570; 5,143; 10,286; 14,857; 20,571; 24,726; 29,714.

The sunn hemp was cut after thirteen weeks but due to its fibrous nature had to be cut by hand. The rates applied as kg/ha of dry matter were:

0; 1,028; 2,243; 4,571; 8,956; 13,632; 18,206; 27,352.

The plots were then rotary cultivated and the tanks with soda lime placed randomly on the plots.

There were eight treatments and five replications on each plot measuring 3 m by 1.74 m. The experiment was analysed as a randomized block design.

3.2.3 Results and Discussion

Two weeks before the plant material was incorporated, two series of samples of soda lime were placed on the plots. The carbon dioxide flux was remarkably evenly distributed over the plots and between the replicates with a mean of 5.2 $\pm$ 0.25 gm carbon dioxide/m^2/day. After rotary cultivation the flux rose to 8.1 $\pm$ 0.25 gm/m^2/day, an increase of 56%; also the standard error was reduced; two weeks later the flux had fallen back to a mean of 4.4 $\pm$ 0.20 gm/m^2/day.

Maize

The flux obtained from the treatments are shown in Table 21.

It will be seen from the table that the effect of rotary cultivation on soil respiration was a mean increase of about 60%.

The results for the first and fourth week after incorporation of the plant material are shown in Figure 12 where the range of observations is shown by vertical lines. It is of interest to note that during the first week the soil was wet throughout the profile but, during the fourth week, the soil was dry to 15 cm depth. No attempt was made to record the moisture content of the soil in the treatments.

Sunn Hemp

The flux obtained from the incorporated sunn hemp is shown in Table 22; the first measurements were not made until five weeks after the maize was incorporated.

During the third and fourth week the soil was dry and the figures were much lower than the first week which was a wet period. The results for the first week are most interesting for the relationship between rate of sunn hemp incorporated and carbon dioxide flux appeared to be curvi-linear (see

TABLE 21

Carbon dioxide flux from the soil at different times and quantities of material after incorporation of maize

Time	Incorporated maize as dry matter kg/ha x 10^3									LSD	
	None	2.5	5.1	10.3	14.8	20.6	24.8	29.7	SE of mean	P=.05	P=.01
Before cultivating and incorporation	5.0	4.7	4.4	6.1	4.7	5.2	5.1	4.6	.28	n.s	n.s
1 week after cultivating before incorporation	7.7	8.5	8.8	7.8	7.4	8.3	7.9	8.5	.25	n.s	n.s
2 weeks after cultivating before incorporation	4.4	4.5	4.4	4.5	3.9	4.6	4.7	4.7	.20	n.s	n.s
1 week after incorporation	4.4	10.0	13.0	20.4	24.4	33.0	42.1	43.2	2.5	7.5	10.4
2 weeks after incorporation	5.5	11.3	13.5	20.1	25.2	32.3	39.5	40.3	.86	3.3	4.4
4 weeks after incorporation	4.2	6.1	7.8	9.4	11.5	16.2	26.5	27.6	1.4	4.0	5.4

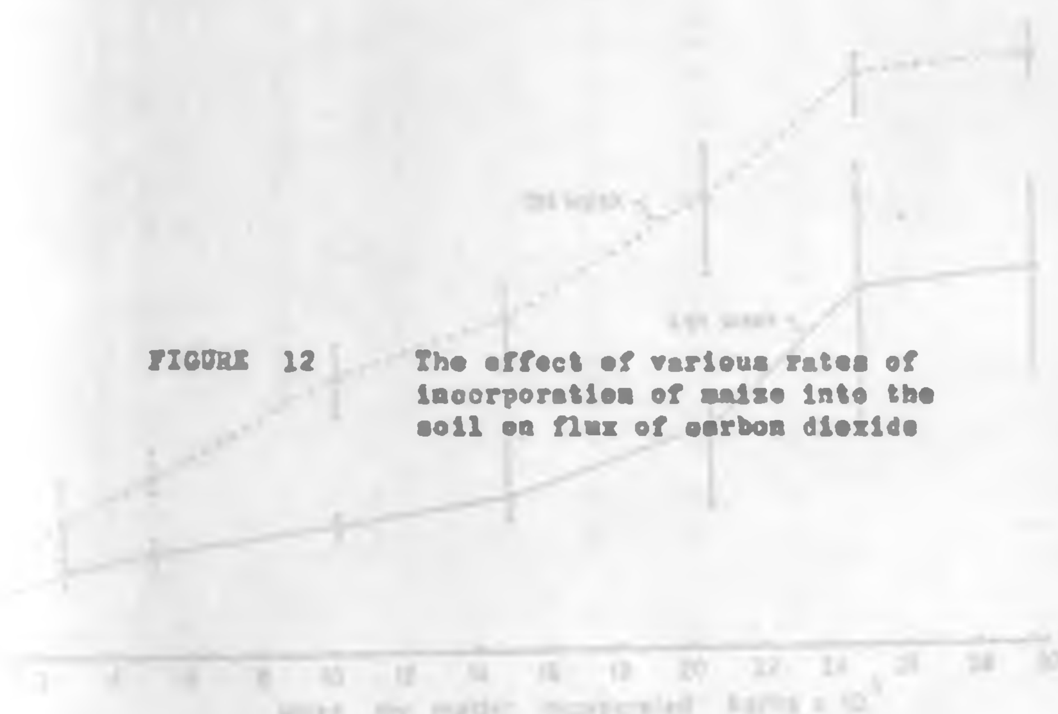


FIGURE 12 The effect of various rates of incorporation of maize into the soil on flux of carbon dioxide

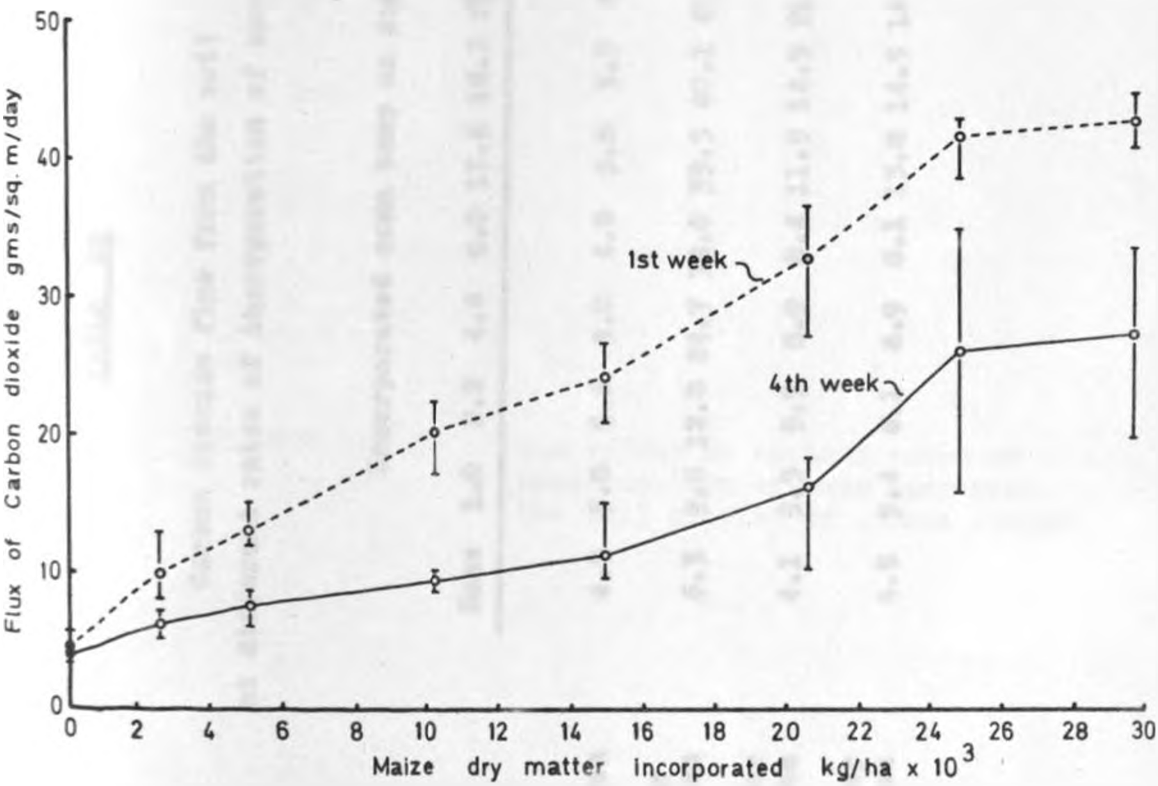

Flux of Carbon dioxide gms/sq. m/day
0
10
20
30
40
50
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
Maize dry matter incorporated kg/ha x 10^3
1st week
4th week

TABLE 22

Carbon dioxide flux from the soil
at different rates of incorporation of sunn hemp

Time	Incorporated sunn hemp as dry matter kg/ha x 10^3									LSD	
	None	1.0	2.2	4.6	9.0	13.6	18.2	27.3	SE of mean	P=.05	P=.01
Before incorporation	4.9	5.8	5.6	5.0	4.9	5.8	5.5	4.9	.22	n.s	n.s
1 week after incorporation	6.3	9.6	12.8	24.7	34.0	39.5	40.1	41.3	.97	2.8	3.8
3 weeks after incorporation	4.1	5.3	5.9	8.0	8.4	11.9	14.9	21.4	.94	2.7	3.4
4 weeks after incorporation	4.5	5.4	6.1	6.9	8.1	13.8	14.5	16.5	.86	2.5	3.3

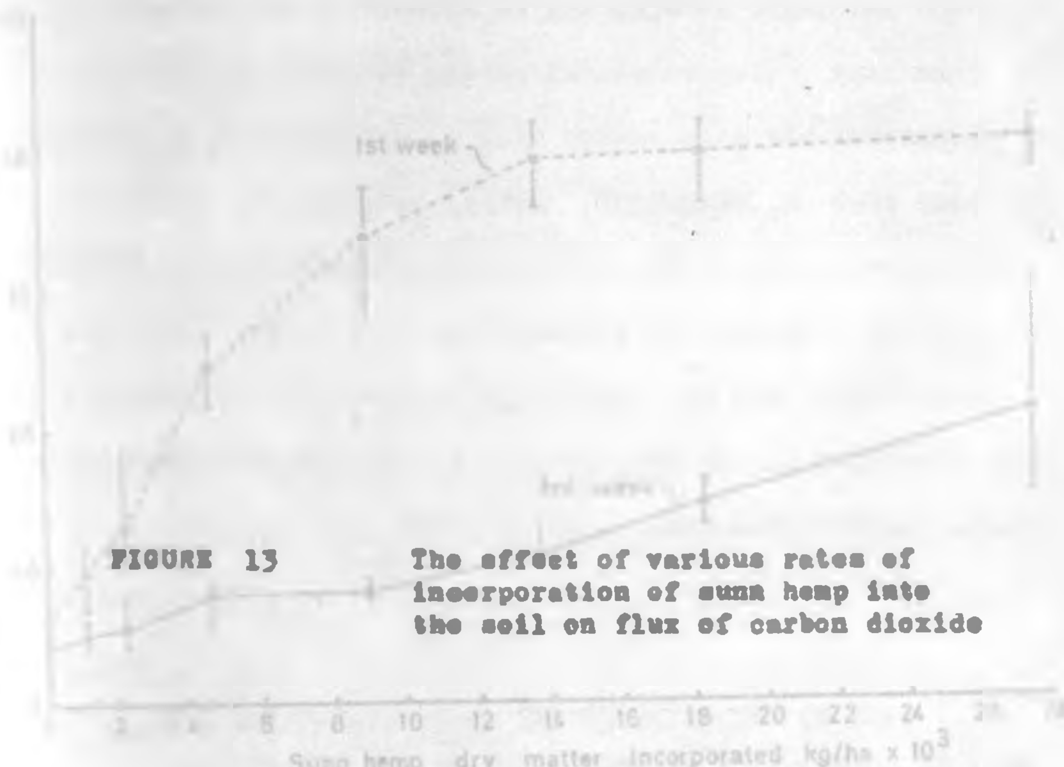
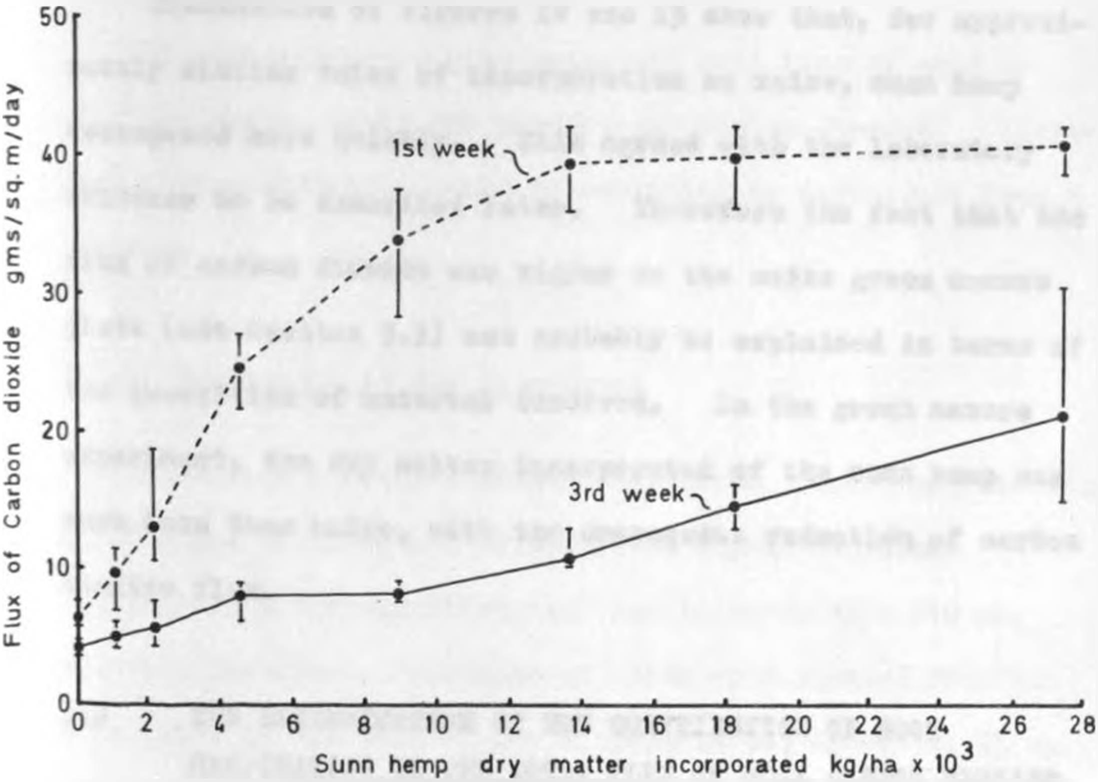


FIGURE 13 **The effect of various rates of incorporation of sunn hemp into the soil on flux of carbon dioxide**



Flux of Carbon dioxide gms/sq.m/day
1st week
3rd week
Sunn hemp dry matter incorporated kg/ha x 10^3

Figure 13). Therefore, there was a factor(s) limiting decomposition which may have been oxygen, for the absorption capacity of the soda lime was greater than 45 gm/day as found in other tests.

Examination of Figures 12 and 13 show that, for approximately similar rates of incorporation as maize, sunn hemp decomposed more quickly. This agreed with the laboratory evidence to be described later. Therefore the fact that the flux of carbon dioxide was higher on the maize green manure plots (see Section 3.1) can probably be explained in terms of the quantities of material involved. In the green manure experiment, the dry matter incorporated of the sunn hemp was much less than maize, with the consequent reduction of carbon dioxide flux.

3.3 THE DETERMINATION OF THE CONTRIBUTION OF ROOT RESPIRATION TO THE TOTAL FLUX OF SOIL CARBON DIOXIDE

3.3.1 Introduction

It was realised that, when measurements were being made of carbon dioxide flux in the green manuring experiment, the roots of the maize and sunn hemp were respiring, and probably contributing to the total flux. Attempts were made in the field to estimate root respiration by placing the tanks with soda lime within and between plant rows. There was, however, a very large variation between samples and there were no significant differences.

It was decided to grow maize and sunn hemp in sand so that the medium would not produce any carbon dioxide. Therefore root respiration could be estimated by difference from a control.

3.3.2 Treatments of the Experiment

Sand from a hydroponic bed was sieved, washed and sterilized at 82°C for two hours. After a week a soil sterilant 'Terrafume' (ethylene dibromide) was injected at 4 mls per planting station. Five rows of maize were planted fourteen days later in one half of the hydroponic bed spaced at 61 cm by 15 cm, the other half being a control. The sand in the two halves of the bed were separated by a double layer of 1000 gauge polyethylene sheeting. Five rows of sunn hemp were planted 61 cm apart in a second bed which was treated similarly to the first.

The plants were watered twice a day with a nutrient solution.

The tanks of soda lime were placed 10 cm from the base of the plants and there were four replicates to each half of a hydroponic bed.

Plates 3 and 4 show the maize and sunn hemp respectively growing in the hydroponic beds.

3.3.3 Results and Discussion

The flux of carbon dioxide evolved by the roots of maize and sunn hemp and their controls is shown in Figure 14 and Figure 15 respectively.

The mean differences of the carbon dioxide flux from maize roots and control was 3.3 ± 0.23 gms/m^2/day. The differences for the sunn hemp from the fourth week onwards was 3.4 ± 0.30 gms/m^2/day.

It will be seen from Figure 14 and Figure 15 that the control flux of carbon dioxide rose slowly with time which was probably due to microbial invasion. The flux from the roots of sunn hemp rose more rapidly than from the maize, and examination of the sunn hemp roots found that nodules appeared after four weeks.

After fourteen weeks' growth the sand was allowed to dry and five maize and five sunn hemp plants were carefully withdrawn. The roots and tops were dried and weighed separately.

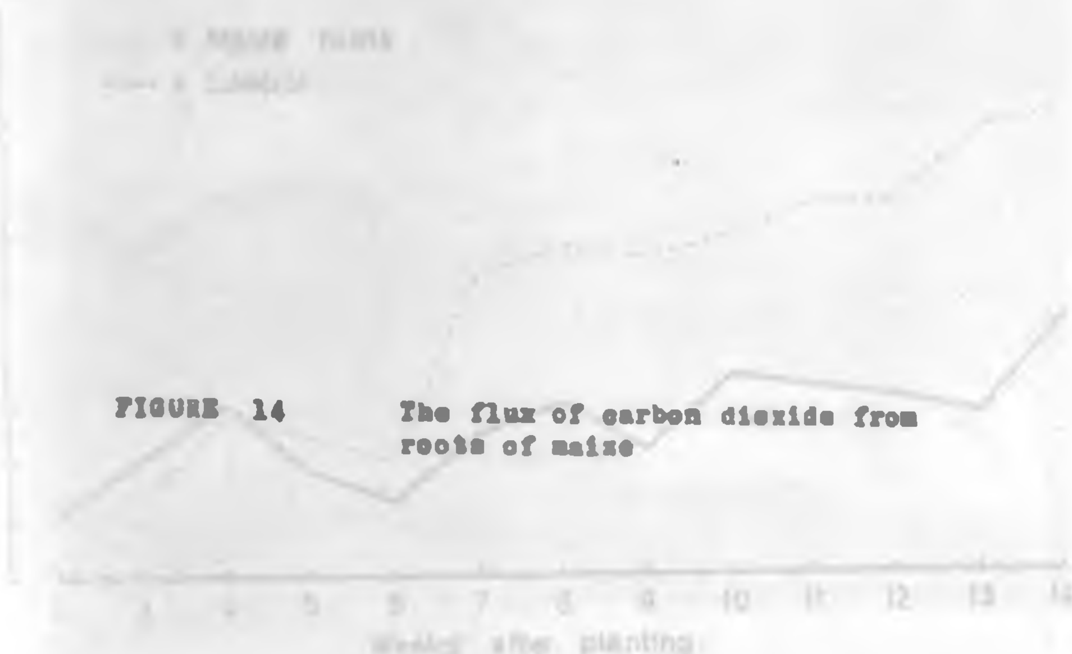
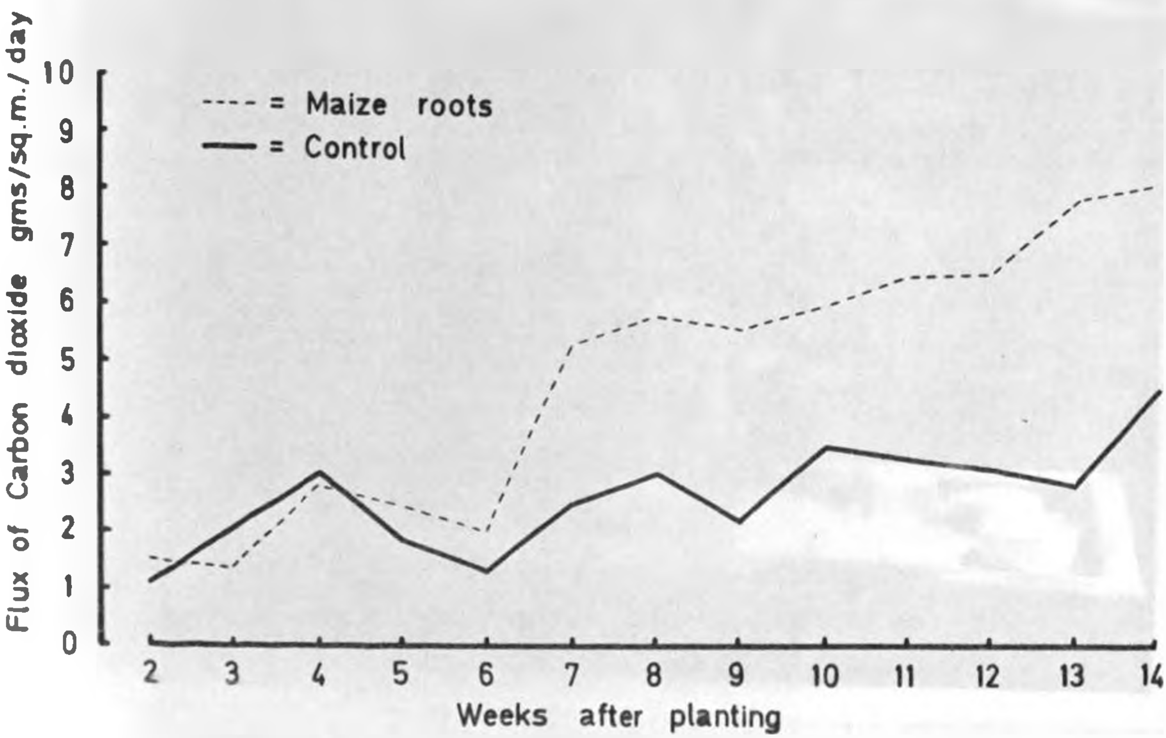


FIGURE 14 The flux of carbon dioxide from roots of maize



Flux of Carbon dioxide gms/sq.m./day
10
9
8
7
6
5
4
3
2
1
0
---- = Maize roots
—— = Control
2
3
4
5
6
7
8
9
10
11
12
13
14
Weeks after planting

PLATE 3 Maize growing in the hydroponic bed during measurement of evolution of carbon dioxide from roots.

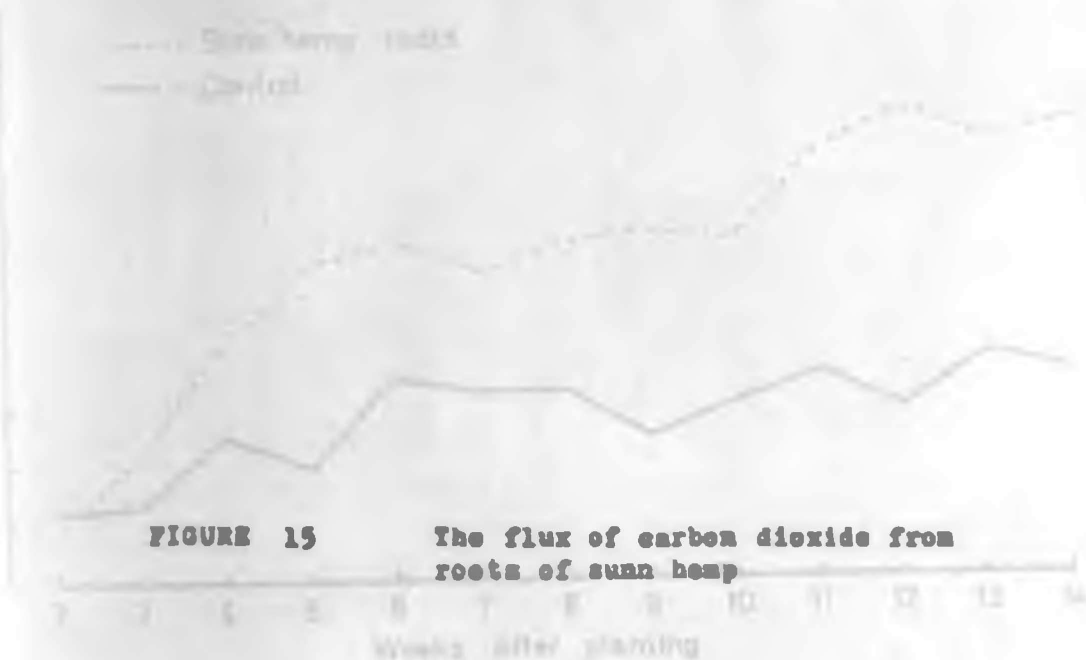
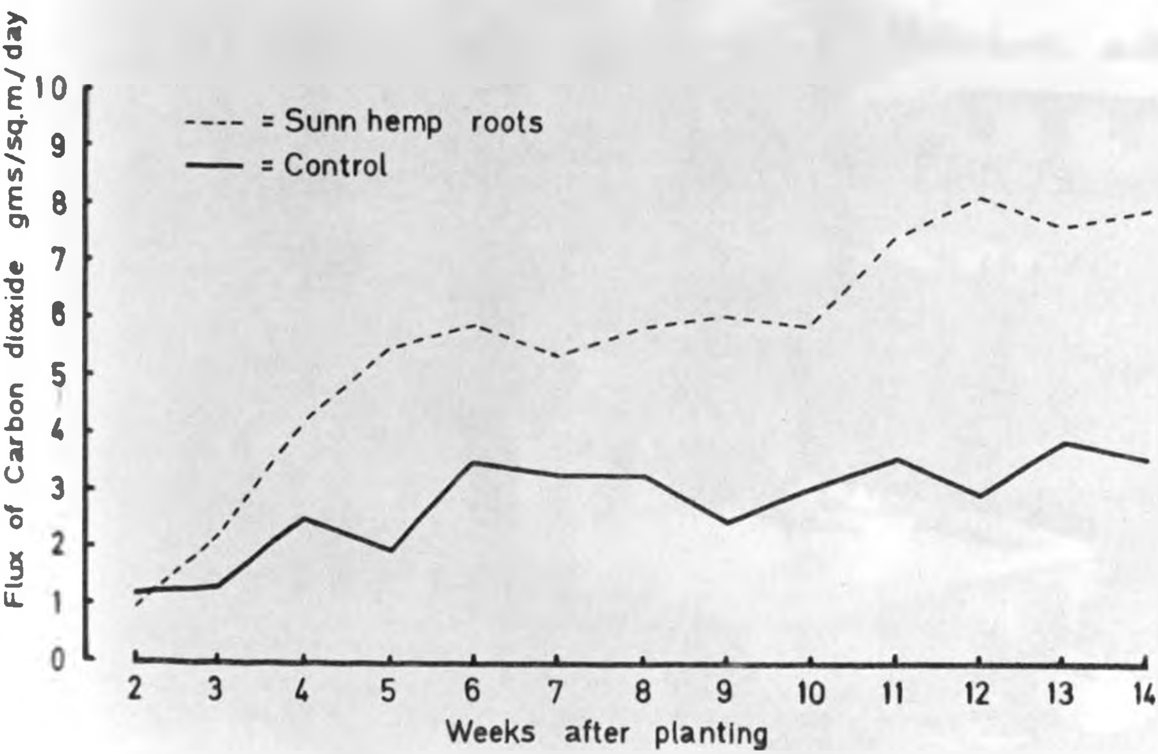


FIGURE 15 The flux of carbon dioxide from roots of sunn hemp



Flux of Carbon dioxide gms/sq.m/day
---- = Sunn hemp roots
— = Control
0
1
2
3
4
5
6
7
8
9
10
2
3
4
5
6
7
8
9
10
11
12
13
14
Weeks after planting

PLATE 4 Sunn hemp growing in the hydroponic bed during measurement of the evolution of carbon dioxide from roots.

The roots of the maize weighed 679 grams, 30% of the tops, and the sunn hemp roots 214 grams, 20% of the tops. The 'activity' of the root systems per se was not known, but a large proportion of the flux from the sunn hemp roots must have been derived from the nodule bacteria.

It was thought that the bacteria inhabiting the rhizosphere may have been making a significant contribution to the total flux. Therefore in the middle of the ninth week a 10% glucose solution was added to the roots and the controls. The graphs of the roots show very little response at ten weeks; the controls rose a little but not significantly. If there had been an increased response of carbon dioxide by the roots it would have probably been due to the micro-organisms in the rhizosphere.

The dry weight ratio of roots to tops from the plants in the hydroponic bed was greater than obtained in the field (see Table 15, Page 41). Therefore, the plants were growing in a medium more conducive to root development. As the root systems were larger in the hydroponic bed then presumably the respiratory activity was greater than in the field. Therefore, the figures for root activity cannot be taken as absolute but rather as an indication that, when soil carbon dioxide flux is measured in a growing crop, the roots may make a significant contribution to the total measurement.

CHAPTER 4

LABORATORY METHODS OF MEASUREMENT OF SOIL RESPIRATION

In a review of the decomposition of organic matter in soil, Jenkinson (1963b) stated that the results of laboratory experiments could rarely be applied to field practice. The field method and measurements have been described. In this Chapter the laboratory methods are described and a comparison with field data is made.

4.1 METHOD OF MEASUREMENT OF SOIL RESPIRATION WITH A RESPIROMETER

The respirometer has been described by Birch and Friend (1956a); see Figure 16 for diagram.

Exactly 50 gm of air-dried soil is passed through a 2 mm sieve and placed in the respiration jar. Distilled water is then added drop by drop while the soil is shaken. This is continued until the soil is at approximately field capacity. This was determined by passing a measured amount of water through the soil in a buchner flask until the soil held water against approximately one atmosphere.

A 2 molar solution of sodium hydroxide is made up carefully to ensure that it is not exposed to the atmosphere. This is to prevent CO_2 being absorbed which may bias the results. About 5 ml of this solution is placed in a weighing bottle and quickly put into the respiration jar containing the

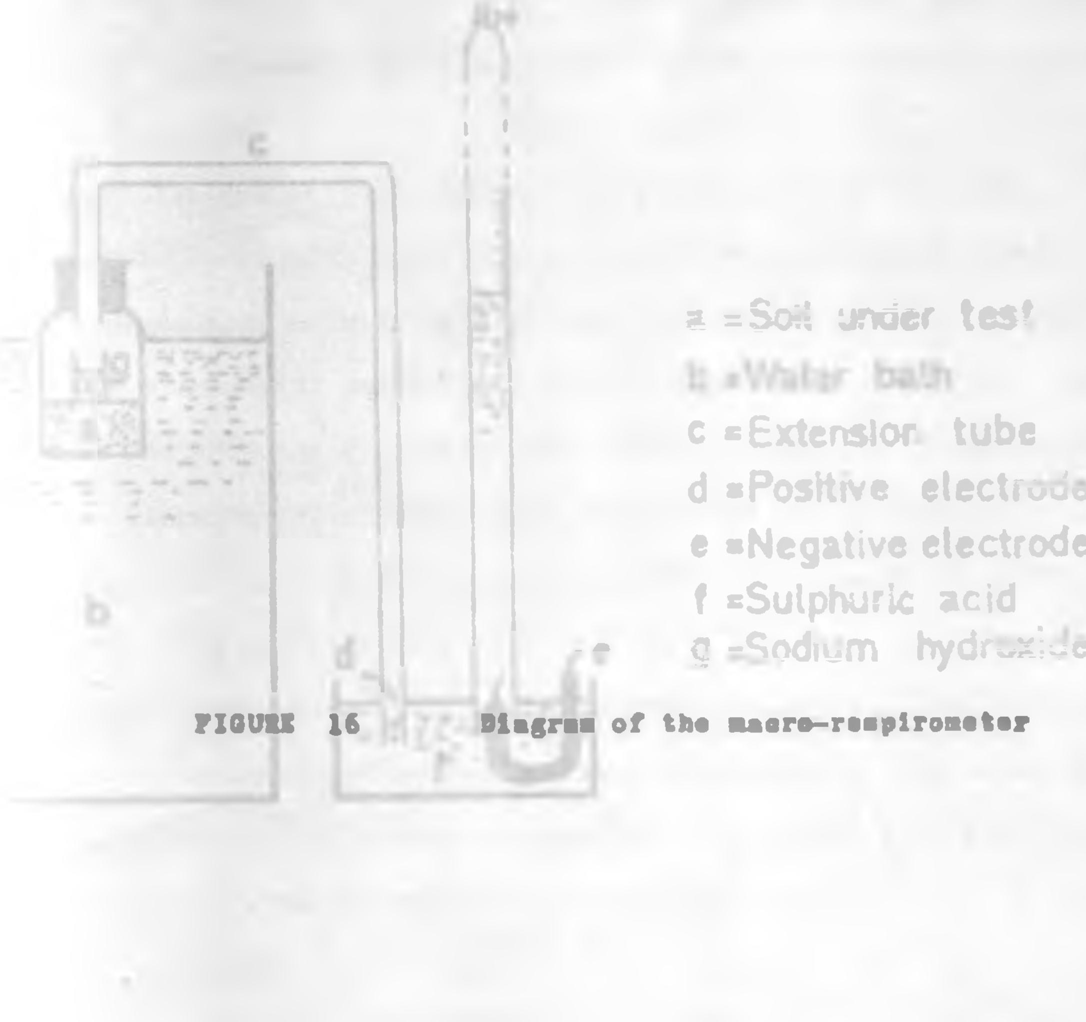
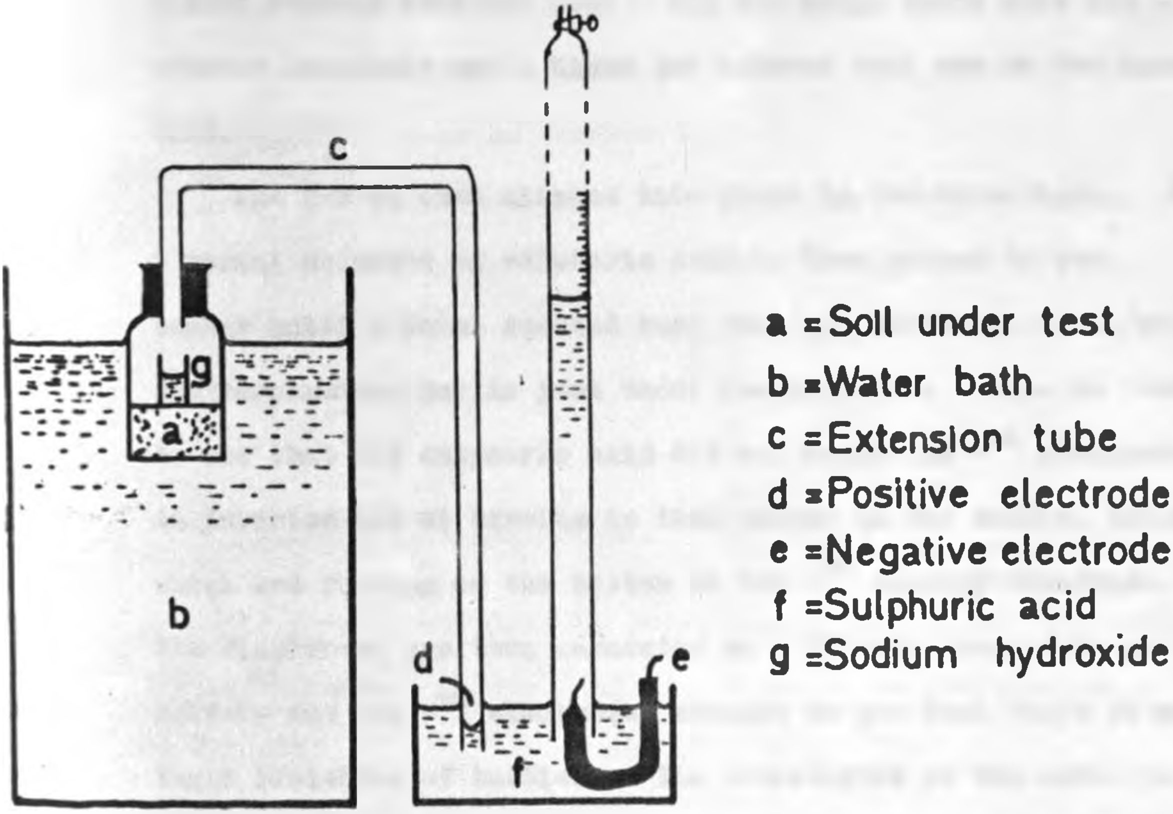


FIGURE 16 Diagram of the macro-respirometer


c
g
a
b
d
e
f
a = Soil under test
b = Water bath
c = Extension tube
d = Positive electrode
e = Negative electrode
f = Sulphuric acid
g = Sodium hydroxide

soil. The rubber bung with the extension tube attached is firmly screwed into the top. All the soils under test are treated similarly and a blank jar without soil run at the same time.

The jar is then clipped into place in the water tank. A 2 normal solution of sulphuric acid is then placed in the beaker until a level reached such that the extension tube from the respiration jar is just under the meniscus. Care is taken to see that the sulphuric acid did not reach the $+^{ve}$ electrode. An inverted 100 ml burette is then placed in the beaker, inside which and resting on the bottom is the $-^{ve}$ mercury electrode. The electrodes are then connected to a 12 volt heavy duty car battery and the $-^{ve}$ electrodes checked to see that there is no large evolution of bubbles. The temperature of the water is maintained at 28°C and readings of the hydrogen evolution within the burette are taken morning and night.

<u>Method for estimation of carbon dioxide</u>

The small weighing bottle is quickly withdrawn from the respiration jar and diluted with distilled water in a 100 ml volumetric flask. Then 5 ml is withdrawn by pipette and titrated against α/10 normal hydrochloric acid using methyl orange as indicator. Another 5 ml of the solution is withdrawn and titrated against 0.1N hydrochloric acid but this time 5 ml of 0.25 molar barium chloride is pipetted into the flask and phenolpthalein used as indicator.

The difference between the two titres is calculated and then multiplied by a correction factor of 22.4. The result expresses the number of ml of CO_2/50 gm of soil evolved by the soil micro-organisms.

4.1.2 Results and Discussion

At first, unreplicated soil samples were taken from under different crops and the following table shows the results obtained:

TABLE 23

Evolution of carbon dioxide and absorption of oxygen from different soils

Soil	Mls CO_2 evolved/50 gm soil	Mls O_2 absorbed/50 gm soil
Under bananas	109.8	20.0
Under coffee	73.9	22.2
Under grass	69.4	13.9
Under chillies	22.4	16.0
Blank	29.1	49.3

The respiration processes of soil micro-organisms involve the release of carbon dioxide and absorption of oxygen in approximately equal proportions (Equation 1). The table, however, shows the disparity between the gases. The measurement of hydrogen evolved was taken at twelve hourly intervals but the quantity evolved at night was significantly higher than during the daytime. After testing it was found that there was a 10°C daily variation in the extension tube. This was probably sufficient to draw the acid up the side-arm a millimetre or so, to connect with the +ve electrode - thus at night giving a high oxygen content within the respiration jar. Attempts to reduce the temperature fluctuation with air-conditioning proved unsuccessful.

When duplicate samples were tested there was reasonable agreement but in the following table the continuing disparity between oxygen and carbon dioxide is shown.

The partial pressure of both carbon dioxide and oxygen within the respiration jar must have varied greatly through the day and night due to temperature. As it was not possible to construct a constant temperature room, the use of the respirometer was discontinued.

TABLE 24

Carbon dioxide evolved and oxygen absorbed from duplicate soils

Soil	Mls CO_2 evolved/50 gm soil	Mls O_2 absorbed/50 gm soil
Under grass	17.9	19.9
Under grass	15.6	36.7
Under sweet potatoes	7.8	26.9
Under sweet potatoes	8.9	28.0
Under bananas	15.6	40.2
Under bananas	19.3	18.5
Blank	4.3	7.7

4.2 METHOD OF MEASUREMENT OF SOIL RESPIRATION USING A TEST TUBE AND BARIUM PEROXIDE

The method used has been described by Cornfield (1961), in which the soil environment is kept at a constant temperature and the partial pressure of oxygen is kept virtually constant and of carbon dioxide virtually zero, by using barium peroxide which in solution absorbs carbon dioxide and evolves oxygen in equal proportions.

Soil taken from the weed fallow treatment was air-dried and passed through a 2 mm sieve. Then 10 gm were weighed out dried and ground and the maize or sunn hemp was mixed with the soil and placed in a boiling tube 15 cm by 2.7 cm diameter. Distilled water in which nitrogen, as potassium nitrate, was dissolved so that 14 mg was given to each sample, was slowly added to bring the soil to field capacity. About 0.2 gm of barium peroxide was weighed into a vial 5 cm by 1.5 cm diameter and 1 ml of distilled water added. The barium peroxide was placed in the boiling tube and sealed with a thermo plastic 'Parafilm'. The tube was then placed in an incubator at 25°C. After a few days the vial was removed and placed in a Collins calcimeter (see Figure 17). The reaction which takes place in the tube proceeds to form the carbonate as follows:

$$(5) \qquad 2\ Ba\,O_2 + CO_2 \longrightarrow 2\ Ba\,CO_3 \downarrow$$

In the calcimeter 2 Normal Hydrochloric acid is added to liberate the carbon dioxide.

The carbon dioxide evolved is forced into the inverted burette and measured in millimetres.

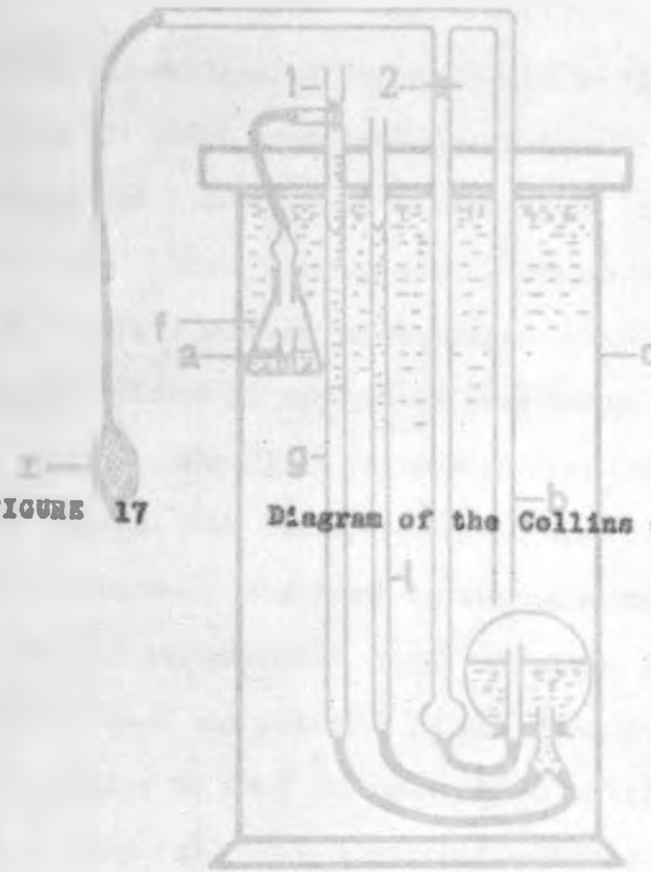
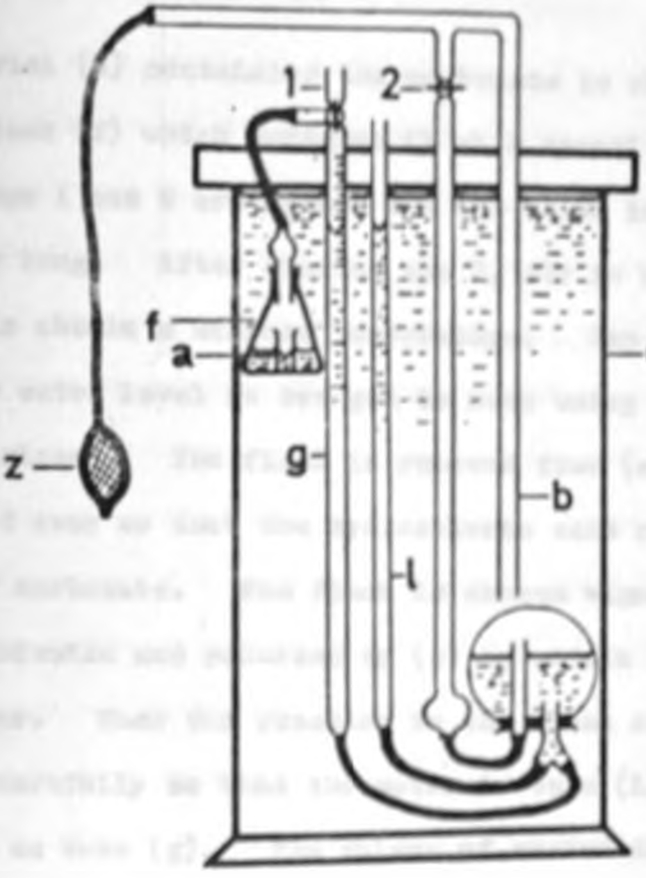


FIGURE 17 Diagram of the Collins Calcimeter


1
2
f
a
c
z
g
b
l

Determination of carbon dioxide

The calcimeter, described by Knowles and Watkin (1946), consists of a water jacket (c) in which the working parts are enclosed.

The vial (a) containing the carbonate is placed in a conical flask (f) which contains 15 ml 2 normal hydrochloric acid. Taps 1 and 2 are opened and the flask is closed with the rubber bung. After closing tap 2, air is blown through tube (b) to obtain a uniform temperature. Tap 2 is opened again, the water level is brought to zero using the bulb (x) and tap 1 closed. The flask is removed from (c) and the vial tipped over so that the hydrochloric acid reacts with the barium carbonate. The flask is shaken vigorously for about two minutes and returned to (c) to attain the temperature of the water. When the reaction in the flask subsides tap 2 is opened carefully so that the water in tube (l) is at the same level as tube (g). The volume of carbon dioxide is read off from tube (g) and the temperature noted.

The calcimeter was calibrated before and after barium carbonate determinations were made with test samples of analar calcium carbonate. This was done to check for leaks in the apparatus.

4.2.1 Results and Discussion

Figure 18 shows the results obtained where the maize and sunn hemp were mixed with soil at 1% by dry weight, which was equivalent to 20 metric tons/ha of dry matter. Each point represents a mean of three replicates. It will be seen that during the first week in the incubator the sunn hemp decomposed more rapidly than the maize or soil alone. This was probably due to conditions where the soil micro-organisms were able to make use of the more nitrogenous material. Figure 19 shows the carbon recovered when 2% by dry weight of maize and sunn hemp were mixed with the soil. As before, the sunn hemp decomposed more quickly than the maize. There was in both cases a lag-period followed by a rise in respiratory activity which later declined, probably due to the reduction of substrate carbon and bacterial population.

Comparison of Figure 18 with Figure 19 shows that, when the quantity of dry matter mixed with the soil was doubled, the carbon recovered during the first ten days was also doubled. Therefore there was a linear relationship between quantity of material incorporated and the production of carbon dioxide. This agreed with measurements made in the field (Section 3.2.3).

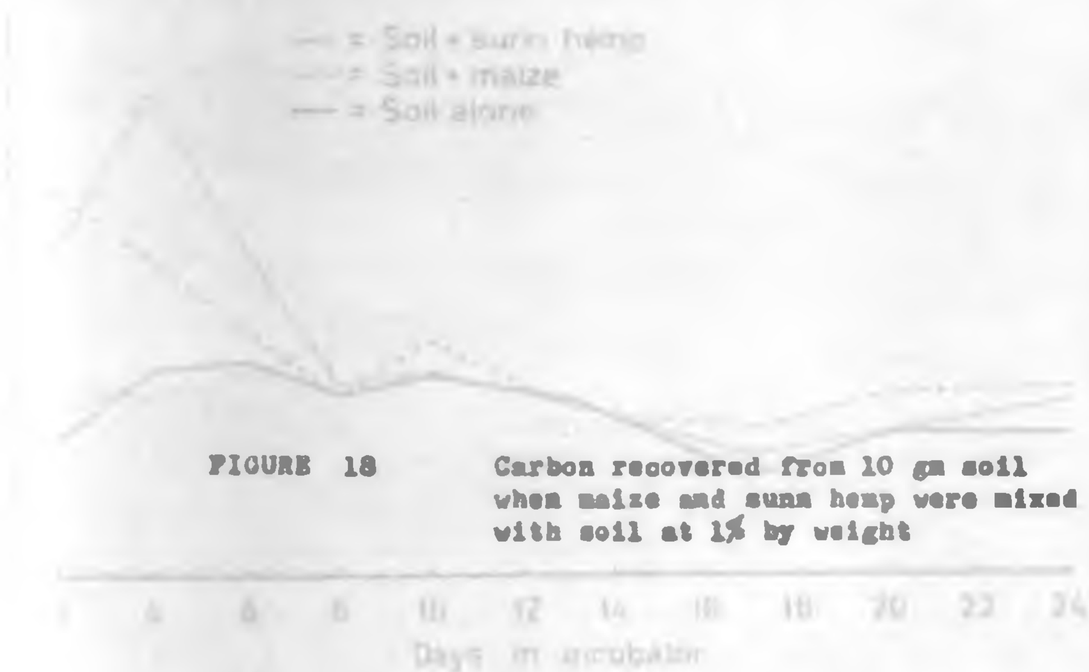
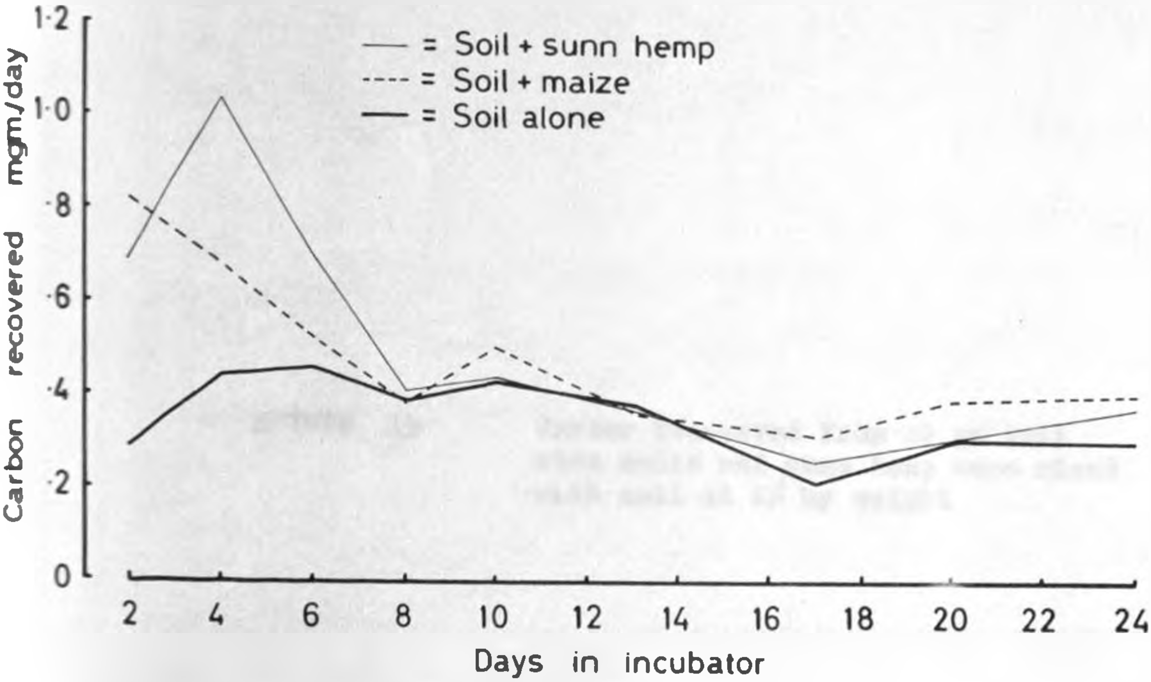


FIGURE 18 Carbon recovered from 10 gm soil when maize and sunn hemp were mixed with soil at 1% by weight



= Soil + sunn hemp
= Soil + maize
= Soil alone
Carbon recovered mgm/day
1·2
1·0
·8
·6
·4
·2
0
2
4
6
8
10
12
14
16
18
20
22
24
Days in incubator

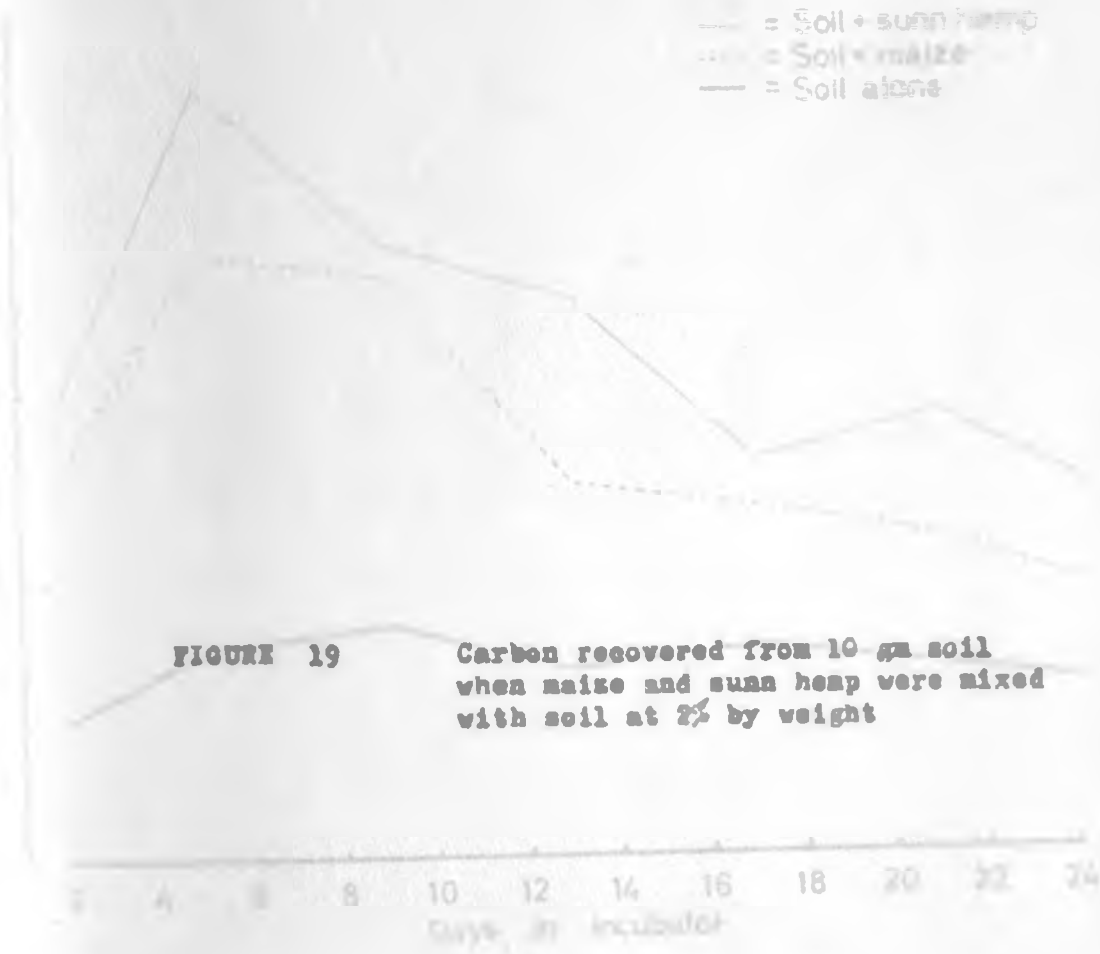
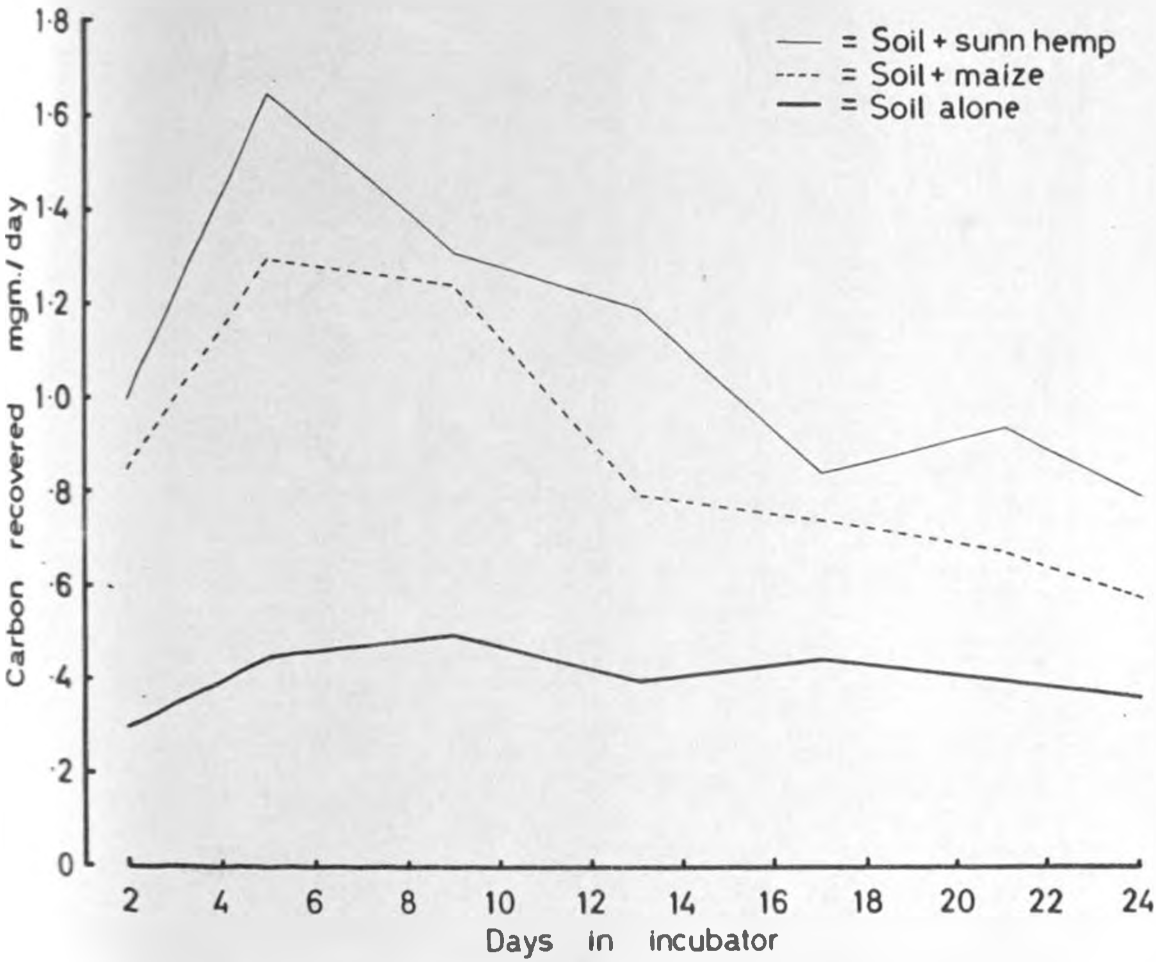


FIGURE 19 Carbon recovered from 10 gm soil when maize and sunn hemp were mixed with soil at 2% by weight



1·8
1·6
1·4
1·2
1·0
·8
·6
·4
·2
0
Carbon recovered mgm./ day
= Soil + sunn hemp
= Soil + maize
= Soil alone
2
4
6
8
10
12
14
16
18
20
22
24
Days in incubator

Table 25 shows the rate of carbon loss from the soil alone, soil-plus-sunn hemp, and soil-plus-maize measured in the laboratory. These values are compared with field data from plots with approximately similar quantities of dry matter, assuming one hectare of soil to 15 cm depth weighs 2,000 metric tons.

TABLE 25

The effect of incorporating plant material with soil on mean carbon lost as $gm/m^2/day$ measured by different methods

	Treatments					
Method	Soil alone	Weed fallow	Soil + Sunn hemp	Sunn hemp + Irr	Soil + Maize	Maize + N
Lab.	9.0	-	15.8	-	13.4	-
Field	-	2.1	-	2.2	-	3.2

It will be seen from the above table that the laboratory method measured rates of carbon loss about four times greater than in the field. This elevation was probably due to more suitable conditions for decomposition existing in the incubator.

The results therefore demonstrate the fact that laboratory methods can rarely make any quantitive estimation of soil respiration, as conditions in the field are constantly changing; in particular, soil moisture. Therefore, if the decomposition of plant material in the soil is measured by laboratory techniques, then it is not surprising that green manuring has been found to be of little value in maintaining soil organic matter (Broadbent and Bartholemew, 1948).

CHAPTER 5

THE CALORIFIC VALUES OF THE GREEN MANURES AND POTENTIAL FLUX OF CARBON DIOXIDE

5.1 INTRODUCTION

The degradation of organic matter in the soil involves the evolution of heat, according to equation (1), and the calorific value of the organic matter can be related to the output of carbon dioxide. Macfadyen (1968) has proposed the use of the conversion factor E_c so that an estimate of the accuracy of the field method of measuring soil carbon dioxide can be made where:

$$(7) \quad E_c = \frac{H}{C} \text{ kcals}$$

where E_c = energy content of organic matter per gm of carbon

H = heat of combustion per gm organic matter in kcal

C = carbon content of organic matter (expressed as a decimal)

Then E_c is substituted into an equation:

$$(8) \quad E_{CO_2} = E_c \times \frac{12}{22.4} \text{ kcals}$$

where E_{CO_2} = energy liberated in the evolution of 1 litre of carbon dioxide

E_c = as before

and 22.4 litres of carbon dioxide is equivalent to 12 gms of carbon at N.T.P

The measurements made of the plant material were the carbon contents by the Metson (1956) method and heats of combustion with a ballistic bomb calorimeter.

5.2 METHOD OF DETERMINATION OF CARBON CONTENT AND HEAT OF COMBUSTION OF PLANT MATERIAL

a) Carbon content

The method was that of Metson (1956) where an EEL absorptiometer was used after reduction of chromic acid to measure the intensity of the green colour.

Exactly .02 gm of the ground plant material is placed in a 250 ml flask and 10 ml normal potassium dichromate added. After shaking, 20 ml of concentrated sulphuric acid is added and left for 10 minutes. Exactly 100 ml of de-mineralized water is added and the mixture left for 3 - 4 hours. A portion of the supernatant fluid is decanted into a centrifuge tube and spun for 15 minutes. The EEL spectra-photometer is calibrated, using a red filter, with a chromic acid blank from plant material whose percentage carbon has been determined by the titration method. The optical density of the green colour of the plant extract is read and the percentage carbon determined from a graph.

b) Heats of combustion

In the Gallenkamp ballistic bomb calorimeter a known weight of the sample is ignited electrically and burned in excess oxygen. The maximum temperature of the bomb is measured with a thermocouple and spot galvanometer system. A sample of known calorific value is burnt to obtain a heat release value and the sample temperature is compared to obtain the calorific value of the sample.

Firstly the apparatus has to be calibrated to establish the relationship between the galvanometer deflection and the amount of heat released by combustion of the sample. In this case thermochemical grade benzoic acid, calorific value 6.32 kcals/gm was used.

About one gram of benzoic acid is pelleted in which a standard 5 cm length of sewing cotton is embedded. A stainless steel crucible is then carefully weighed with and without the benzoic acid whose weight is obtained by difference. The crucible containing the benzoic acid is placed on the support pillar in the base of the bomb and the cotton clipped to the coils of the firing wire. The body of the bomb is then lowered and firmly screwed into place. The thermocouple is then plugged into the top of the bomb and, having closed the pressure release valve, the oxygen valve is opened, the pressure allowed to rise to 25 atmospheres and the valve closed. The light spot index of the galvanometer is brought to zero and left for 30 seconds to check temperature stability. The firing button is then pressed and after about 30 seconds the maximum deflection on the galvanometer is noted. The gases are then released and the body of the bomb cooled with water and dried.

As there is a small amount of heat released in the bomb by the firing current and cotton, a test is carried out without the benzoic acid and the deflection noted. For the calibration with benzoic acid, five repeat tests were made with a standard deviation of 0.9% of the mean.

When the apparatus was calibrated, the plant materials were then tested. A 10 kg bulk sample of wet plant material was dried for 72 hours at 60°C, then ground to a powder. The powder was then thoroughly mixed and a 20 gm working sample obtained, from which the material was pelleted and fired in the bomb as described, and also used for the carbon determinations.

5.3 RESULTS AND DISCUSSION

The following table shows the results obtained.

TABLE 26

The carbon percentage and heat of combustion of maize, sunn hemp and weed green manure

	Carbon %	Heat of combustion kcals/gm dry matter
Maize	43.0 ± 1.6	4.10 ± 0.035
Sunn hemp	42.6 ± 2.0	4.57 ± 0.041
Weeds	39.2 ± 1.4	4.00 ± 0.038

The higher energy value of the sunn hemp was probably due to its higher ether extract value (Page 99) and the values obtained agree with other data available for calorific values of plant constituents (Ovington and Lawrence, 1967).

The values of carbon content can now be substituted in equation (7) so that:

$$E_c \text{ (maize)} = \frac{4.10}{.430} = 9.53 \text{ kcals}$$

$$E_c \text{ (sunn hemp)} = \frac{4.57}{.426} = 10.73 \text{ kcals}$$

$$E_c \text{ (weeds)} = \frac{4.00}{.393} = 10.20 \text{ kcals}$$

The mean daily soil temperature at 5 cm was 23.5°C at 660 mm atmospheric pressure. Therefore 28.0 litres of carbon dioxide are equivalent to 12 gm of carbon and substituting in equation (8):

$$E_{CO_2} \text{ (maize)} \quad 9.53 \times \frac{12}{28} = 4.08 \text{ kcals}$$

$$E_{CO_2} \text{ (sunn hemp)} \quad 10.73 \times \frac{12}{28} = 4.59 \text{ kcals}$$

$$E_{CO_2} \text{ (weeds)} \quad 10.20 \times \frac{12}{28} = 4.36 \text{ kcals}$$

In order to relate dry matter incorporated with the evolution of carbon dioxide, the dry matter is multiplied by the calorific value. The energy value is then divided by the E_{CO_2} to obtain the theoretical evolution of carbon dioxide in litres. The converse is applied if dry matter values are required from carbon dioxide figures.

If the weights of dry matter incorporated are taken from Table 7 (Page 42), then the theoretical carbon dioxide flux from the soil can be calculated as in the following tables.

TABLE 27

Calculated evolution of carbon dioxide from measured quantities of dry green manure incorporated into the soil

	Green manure treatments					
	Sunn hemp	Sunn hemp + Irr	Maize	Maize + N	Maize + Irr + N	Weed fallow
Measured dry matter incorporated $gm/m^2/year$	1258	1222	2338	3256	3383	387
Energy value $kcals/m^2$	5749	5584	9586	13350	13570	1548
Calculated carbon dioxide evolution $litres/m^2/year$	1252	1216	2349	3272	3394	335
Measured carbon dioxide evolution	1860	1906	2580	2766	2744	1766

The converse relationship can be calculated by taking the figures for carbon dioxide flux from Table 20 and expressing them as litres carbon dioxide/m^2/year. This is done by multiplying gm/m^2/day by the factor 365 x 28/44 as in the following table:

TABLE 28

Calculated dry green manure material incorporated into the soil from field measured evolution of carbon dioxide

Green Manure Treatments

	Sunn hemp	Sunn hemp + Irr	Maize	Maize + N	Maize + N + Irr	Weed fallow
Measured mean carbon dioxide evolution litres/m^2/year	1860	1906	2580	2766	2744	1766
Energy value kcals/m^2	8533	8748	10526	11285	11195	7700
Calculated dry matter gm/m^2/year	1867	1914	2567	2752	2730	1925
Measured dry matter	1258	1222	2338	3256	3383	387

Examination of the two tables shows that the calculated and measured carbon dioxide fluxes compare favourably with the exception of the weed fallow. The latter is probably accounted for by the decomposition of the 'native' organic matter in the calculated carbon dioxide, which is not taken into consideration.

The difference between the calculated and measured carbon dioxide flux of the sunn hemp may have been due to root and nodule bacteria respiration. The measured maize respiration was rather lower than calculated, which may have been partially due to the fact that available nitrogen was a limiting factor for the soil micro-organisms at the higher levels of organic matter incorporation.

The fact that the calculated and measured figures compare favourably indicates that the soda-lime method is reasonably accurate for the determination of soil respiration. Also it appears as though in this environment, carbon dioxide is not carried down the profile by leaching as suggested by Hofmann and Hoffman (1962).

PART III

DISCUSSION OF SOME ASPECTS OF THE EXPERIMENTS

1. GREEN MANURING EXPERIMENT

Four green manure crops cycles were completed in one year; as was shown in Section 1.2.4., however, the green manures had no effect on the yield of the test crop. It was thought that the build-up of organic matter and return to the soil of available plant nutrients would have had an appreciable effect on soil fertility, for a degree of success had been obtained in Nigeria (Vine, 1953) and Rhodesia (Rattray and Ellis, 1956), (Von Burkersroda, 1964). There are two possible explanations.

The first is that the soil at Kabanyolo has a relatively high level of inherent fertility. It would seem that when the soil chemical analysis is compared to other soils in East Africa, all the available nutrients were at a high level. Therefore, as there was no response to green manuring, then the soils in other areas of Africa must have been much poorer in nutrient status.

The second explanation could be that in the past not only were investigators working with partially failed crops, but also their standards of husbandry were not so high as today's. Therefore once better varieties of crops are planted early at the correct spacing and more advanced techniques are employed, then the most significant responses in yield will be obtained by supplying the nutrients the plant needs in the form of inorganic fertilizers. Once a good rotational system is established then soil fertility will be self-perpetuating. The reason why the green manures were not successful can probably be explained by combination of the two above, for as Burkersroda pointed out, the practice of green manuring was dying out after the introduction of hybrid maize varieties and when larger quantities of fertilizers were applied.

Foliar analysis of the maize test crop leaves showed that, by American standards, nitrogen, phosphorus and potassium levels were not low. However the crop showed signs of both a nitrogen and potassium deficiency which was most noticeable on the weed fallow and sunn hemp green manure treatments. The symptoms were less marked on the maize green manure treatments where larger quantities of organic material had been incorporated. No attempt was made to score the experiment on this basis for the symptoms often occurred on the same leaf. It will be necessary to establish critical levels of nutrients in leaves of maize for East African conditions and varieties.

2. CARBON DIOXIDE EVOLUTION

A most interesting aspect of the studies on soil carbon dioxide flux was that of the decrease of carbon dioxide flux with increased soil saturation (Section 3.1.4., Page 86). As the soil micro-organisms respire so they need oxygen; therefore, as the soil becomes wetter, so the soil air volume decreases. Now this is probably intimately connected with the 'early planting' phenomenon. The earlier the crop is planted so the young roots, which are very sensitive to aeration conditions, can make use of the available oxygen. As the planting continues into the rainy season, so the soil air may have a higher carbon dioxide concentration and lower oxygen concentration. Since these measurements and observations were made, preliminary results from experiments by Allan (1968) show that maize yield declines with increasing water saturation at early stages of growth. Therefore, in all probability, the 'early planting' phenomenon is directly associated with soil air and the availability of oxygen, at least in part.

The rates of loss of organic matter (Section 3.1.4., Page 103), as measured by the field method, were not so high as anticipated, for Martin (1944) had stated that in Uganda the oxidation of organic material was so high that little ever reached colloidal dimensions. It was shown that the half life of the weed fallow was 6.4 years which had had six rotary cultivations. If the figure of 5.2 gm carbon dioxide/m^2/day is taken from Section 3.2.3, Page 106, where the soil had not been cultivated for six months, then the annual loss of organic matter is 7% with a half life of 9.8 years. These figures show that incorporated organic material has enough time to become humified.

A direct correlation was found between the quantity of material incorporated and its rate of decomposition (see Figures 11, 12 and 13). This was found with both the field and laboratory methods of measuring carbon dioxide output, which is in agreement with the findings of Stozky and Mortensen (1958) and Jenkinson (1963a); for both Broadbent and Bartholemew (1948) and Hallam and Bartholemew (1953) had found that decomposition proceeded faster with smaller additions of organic matter to soil than larger ones. Jenkinson found a non-linear relationship where wheat straw was incubated without additional nitrogen; the only non-linear relationship found in the field studies, however, was where sunn hemp was incorporated. This was probably due not to the lack of nitrogen, but to the lack of available oxygen in the soil at the higher rates of incorporation.

APPENDIX I.

A P P E N D I C E S

[illegible]

APPENDIX I

SOIL MOISTURE DATA ON THE GREEN MANURE TREATMENTS

1.1 INTRODUCTION

It was not known whether four green manure crops could be grown in one year without water becoming a limiting factor. Therefore, a treatment was introduced into the green manuring trial where water was to be applied when the soil was drying out. However, the timing of planting and incorporation of the green manure was planned so that the crops could derive, as much as possible, their water from rainfall.

Adequate soil moisture data was needed to monitor the amount of water in the rooting zones, and the effects of incorporation of organic matter on soil water content could be determined.

1.2 METHOD AND TREATMENTS

Nylon/stainless steel electrical resistance units jacketed in Plaster of Paris were used (Farbrother and Harrisson, 1957). Initially the units were read with a Bouyoucos Moisture Meter but when its performance became unsatisfactory, a Sciex Moisture Meter incorporating a small dynamo and calibrated in log-ohms was used.

The resistance units when placed in the ground and after an equilibrium period, enable measurement of the soil moisture status. When soil, and therefore the units, are dry there is a very high resistant between the electrodes. The reverse occurs when the soil is wet. Gravimetric determination of the moisture content of the fallow soil at 'wilting point' and 'field capacity' was 10.2 $\pm$ 2.1% and 22.0 $\pm$ 3.5% respectively. The figures derived by Hearn (1967) relating resistance to soil moisture content on similar soil was used. Thus, when the resistance was 2.0 - 3.0 log-ohms, the soil was assumed to be wet, 4.0 - 5.0 log-ohms, dry, and 3.0 - 4.0 log-ohms drying or wetting.

The holes for the moisture units were made with a modified 'Jarrett' auger (Farbrother and Harrisson, 1957). Before placement, the blocks were rubbed with a wet slurry of the soil type in which they were to be embedded. Then, when the block was suspended in the hole, the wet slurry was poured carefully around it, taking care not to entrap air. The top-soil was then replaced and half a gallon of water sprayed on to the spot.

In the plots to be irrigated two resistance blocks were placed at 15 cm and 30 cm depth. As the growth period was only ten weeks and, therefore, the rooting depth shallow, deeper placement of the units was not considered. From figures given by Harrop (1967) the water retention of the top 30 cm of the soil was assumed to be 4.5 cm.

When the resistance at 30 cm increased to 3.5 log-ohms 4.5 cm of water was applied at the rate of 2 cm per hour with a rotary sprinkler.

1.3 RESULTS AND DISCUSSION

The resistance pattern of the moisture units in maize and sunn hemp is shown in Figures A.1 and A.2 respectively. In the graphs each point represents a 10-day mean of five moisture unit readings, otherwise the mass of data becomes unwieldy. The 10-day totals of rainfall and irrigation in millimetres has been imposed on the figures for comparison.

Examination of the two figures shows that the 15 cm soil layer in the maize green manure plots dried out more quickly than in the sunn hemp plots. This was probably due to the larger exposed surface area caused by the greater amounts of incorporated maize material. The 30 cm soil layer in the two treatments followed a similar pattern.

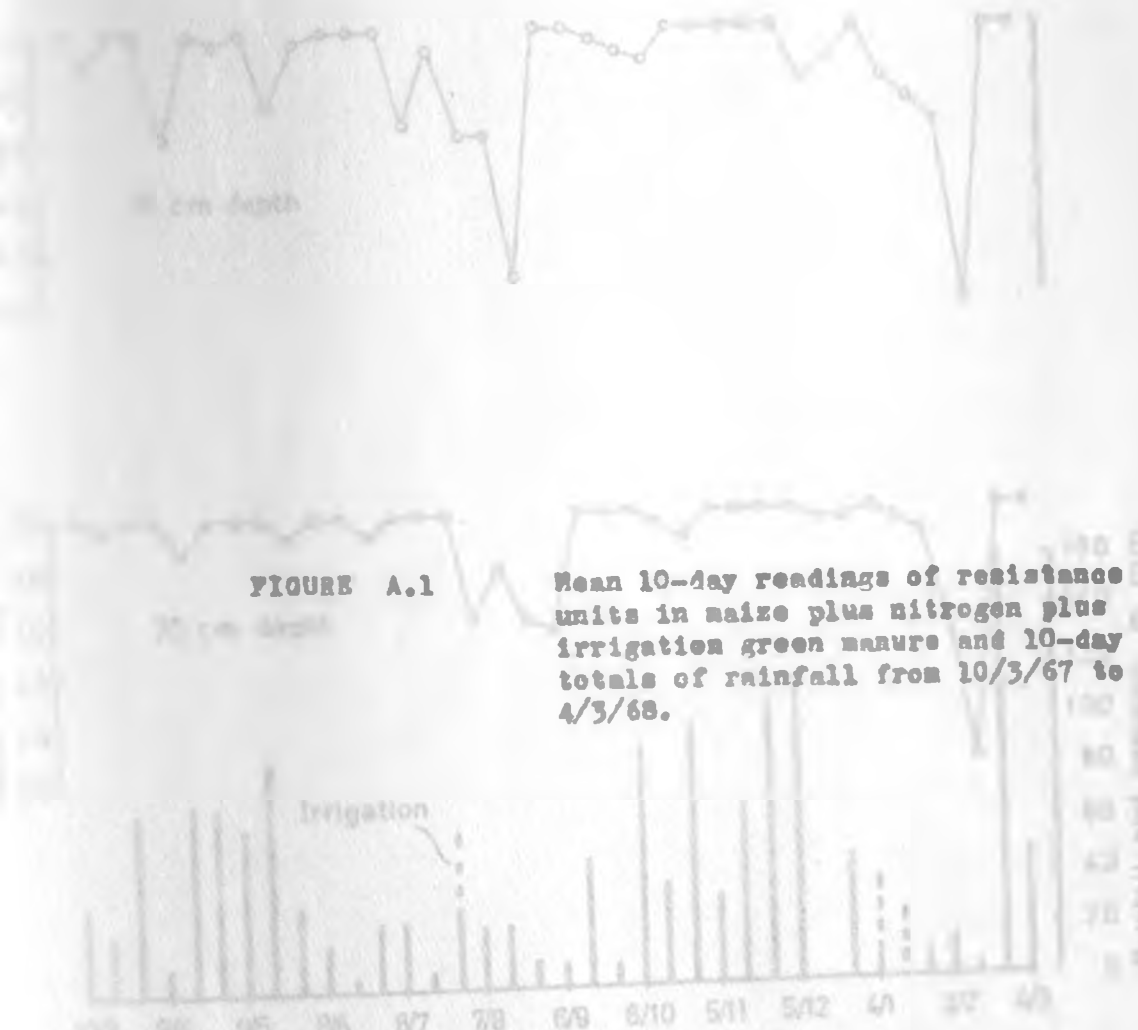
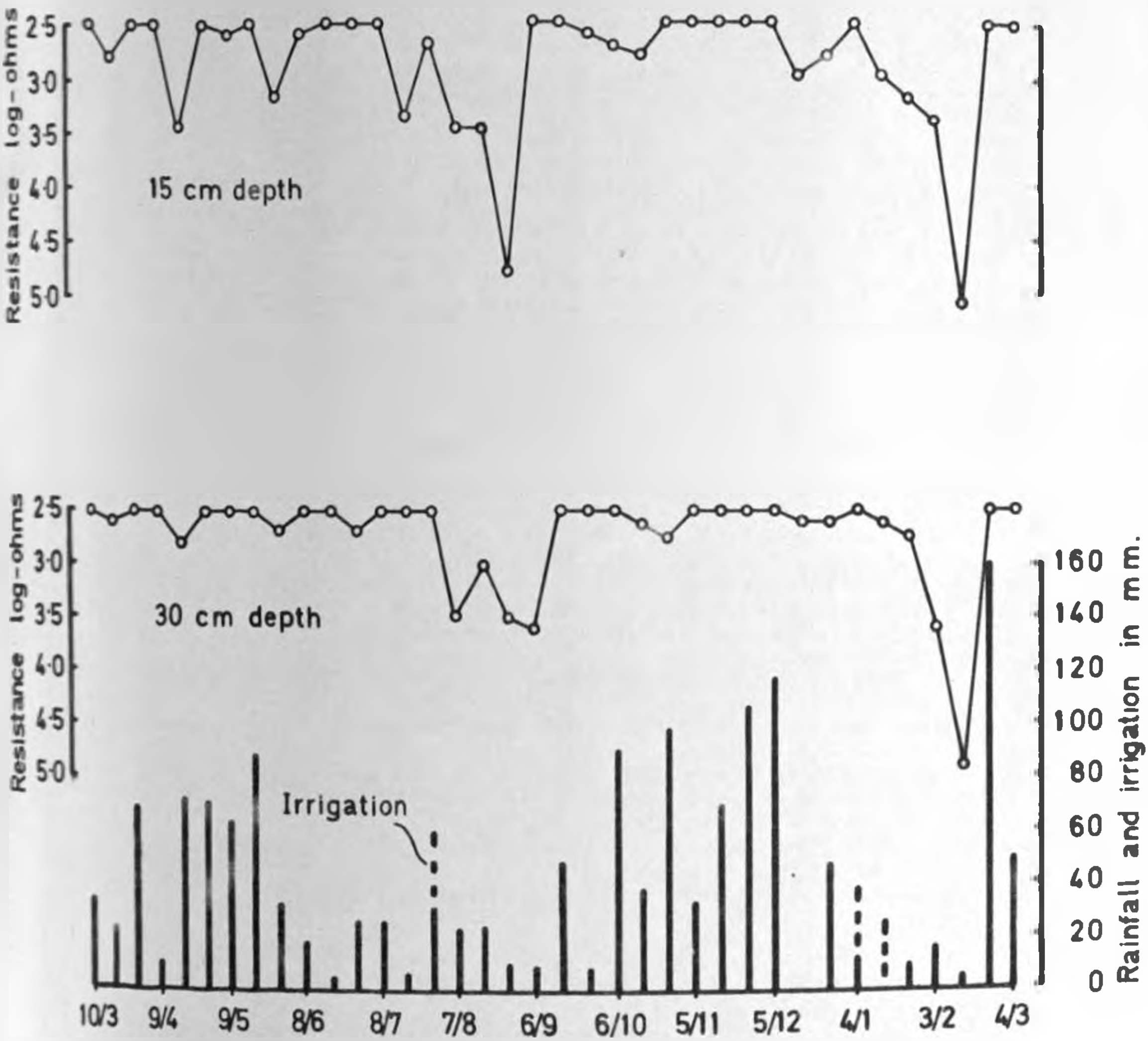


FIGURE A.1 Mean 10-day readings of resistance units in maize plus nitrogen plus irrigation green manure and 10-day totals of rainfall from 10/3/67 to 4/3/68.



Resistance log-ohms
2·5
3·0
3·5
4·0
4·5
5·0
15 cm depth
30 cm depth
Irrigation
160
140
120
100
80
60
40
20
0
Rainfall and irrigation in mm.
10/3
9/4
9/5
8/6
8/7
7/8
6/9
6/10
5/11
5/12
4/1
3/2
4/3

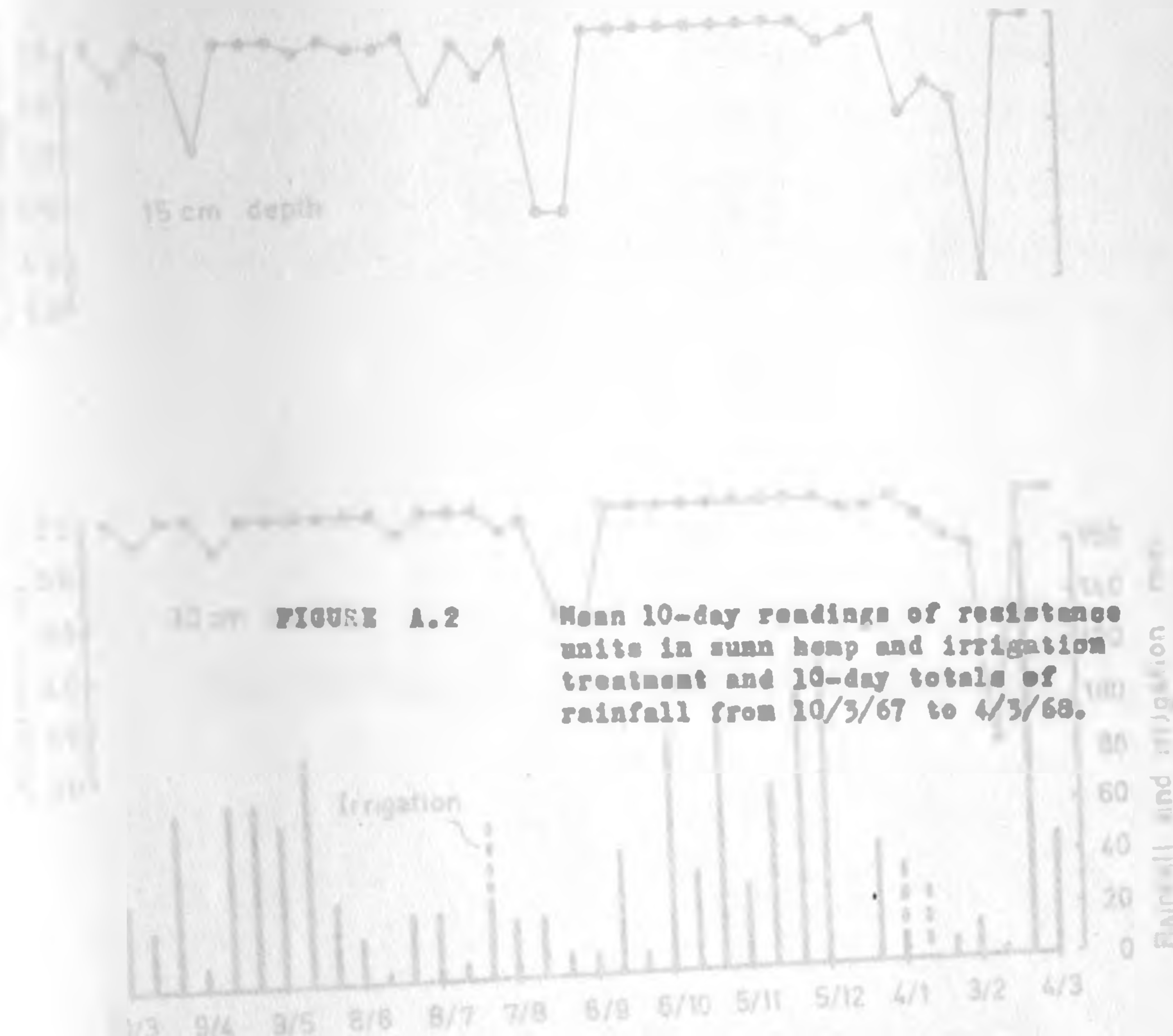
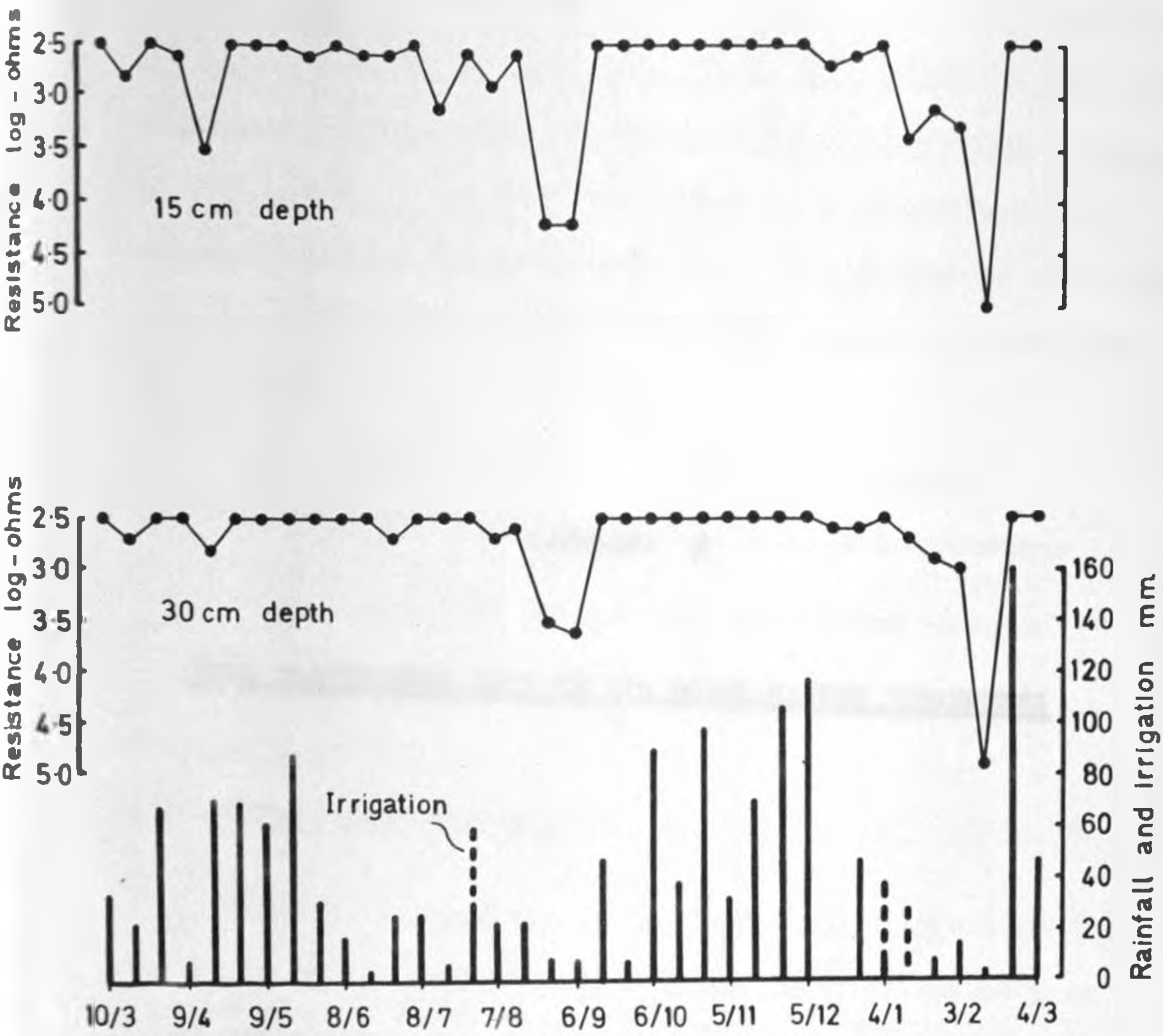


FIGURE A.2 Mean 10-day readings of resistance units in sunn hemp and irrigation treatment and 10-day totals of rainfall from 10/3/67 to 4/3/68.



Resistance log - ohms
2·5
3·0
3·5
4·0
4·5
5·0
15 cm depth
Resistance log - ohms
2·5
3·0
3·5
4·0
4·5
5·0
30 cm depth
Irrigation
Rainfall and irrigation mm
0
20
40
60
80
100
120
140
160
10/3
9/4
9/5
8/6
8/7
7/8
6/9
6/10
5/11
5/12
4/1
3/2
4/3

APPENDIX 2

SOIL TEMPERATURE DATA ON THE GREEN MANURE TREATMENTS

2.1 INTRODUCTION

In temperate areas the diurnal range of soil temperature in the top soil is far more pronounced than in the tropics and equatorial regions where the temperature range is much smaller. In all climates, however, soil temperature is influenced by moisture, chroma and organic matter. The purpose of examining soil temperatures under different green manure treatments was to determine:

a) whether the organic matter from the green manures had any influence on soil temperature;

b) whether soil respiration was related to soil temperature.

2.2 METHOD AND TREATMENTS

Mercury thermometers of the right-angled type were used. The bulbs of the thermometers were carefully placed at 5 cm depth and a litre of water sprayed on the thermometer. This was to compress the soil around the bulb and to equilibrate the moisture content of the surrounding soil.

Nine thermometers were obtained, with three replicates in a maize green manure treatment, three in sunn hemp and three in the weed fallow. The soil temperatures were read to within

$0.25^{\circ}C$ at 0900 hrs and 1500 hrs daily.

2.3 RESULTS AND DISCUSSION

The soil temperatures at 0900 and 1500 hrs are shown for the three treatments in Figure A.3. These are shown as 10-day means for the period 14th September to 3rd December, 1967. The green manure treatments were planted on the 9th September and the general decline of the afternoon temperatures was caused by shading. Throughout the period the same degree of shading was given to all the replicate thermometers.

Table A.1 shows the mean soil temperature at 5 cm depth for the treatments.

The only significant difference was between the afternoon temperatures of the maize and weed fallow plots. This was most probably due to the organic matter from the maize forming an insulated air layer.

The soil temperatures were analyzed during another period but no correlation was found with the flux of carbon dioxide. It is therefore probable that soil temperatures in the area of Uganda in question do not become sufficiently low or high to affect soil micro-organism respiratory activity.

TABLE A.1

Mean daily soil temperatures in °Centigrade
at 0900 hrs and 1500 hrs
for maize, sunn hemp and weed fallow treatments

	Time	
	0900 hrs	1500 hrs
Maize	21.9 ± .13	25.51 ± .74
Sunn hemp	21.0 ± .17	27.19 ± 1.00
Weed fallow	21.3 ± .12	28.51 ± .68

Differences at 0900 hrs not significant

Differences at 1500 hrs:		
	Maize and Sunn hemp	n.s
	Maize and Weed fallow	Sig. Diff. at 5%
	Sunn hemp and weed fallow	n.s

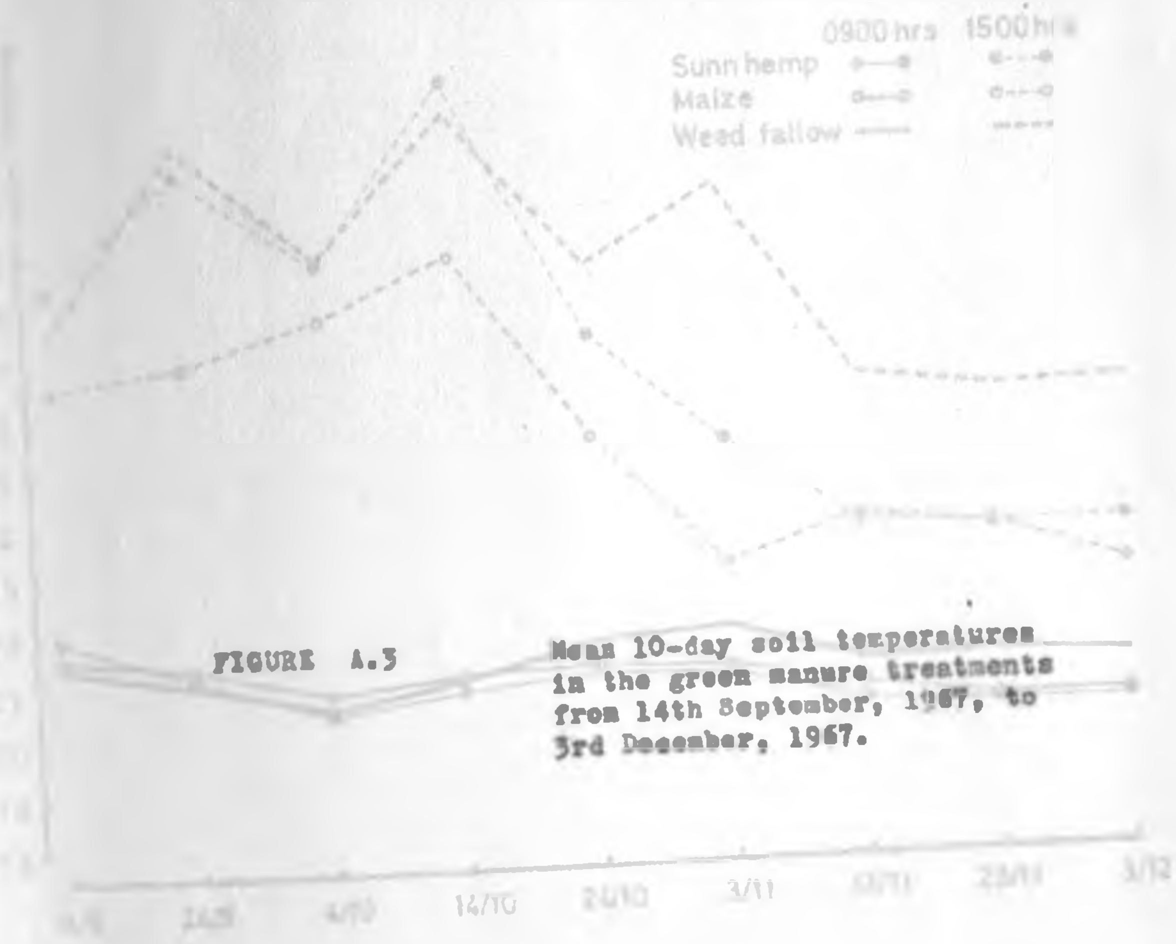
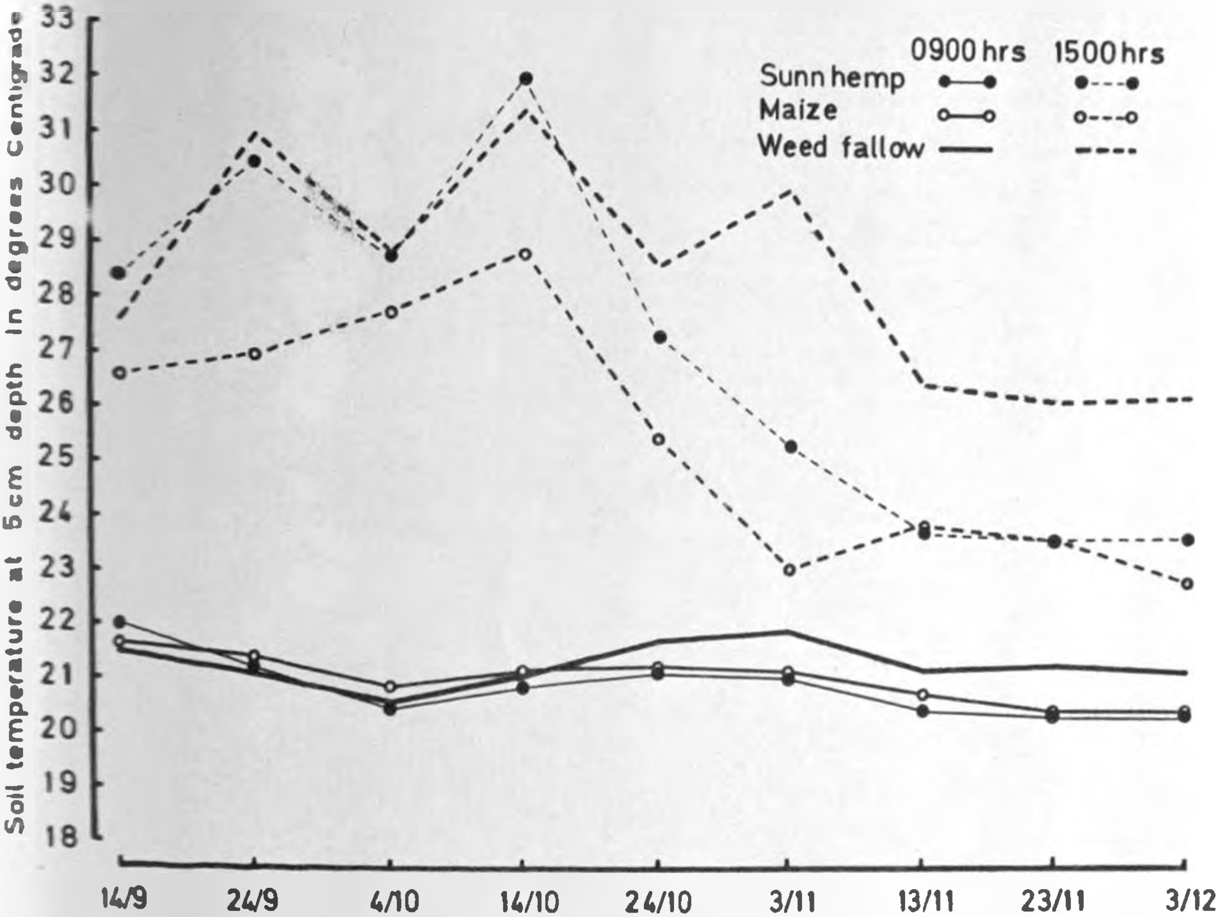


FIGURE A.3 Mean 10-day soil temperatures in the green manure treatments from 14th September, 1967, to 3rd December, 1967.



0900 hrs
1500 hrs
Sunn hemp
Maize
Weed fallow
Soil temperature at 5 cm depth in degrees Centigrade
33
32
31
30
29
28
27
26
25
24
23
22
21
20
19
18
14/9
24/9
4/10
14/10
24/10
3/11
13/11
23/11
3/12

APPENDIX 3

METHODS OF FOODSTUFF ANALYSIS OF MAIZE AND SUNN HEMP

METHODS OF FOODSTUFF ANALYSIS OF MAIZE AND SUNN HEMP

Ash

Exactly 2 gm of the ground plant material is weighed into an ignited, cooled crucible of known weight. The crucible and its contents are then inserted into a muffle furnace which is heated to 600°C and left overnight. After cooling in a dessicator, the crucible and contents are re-weighed and the percentage ash found by difference.

Nitrogen

The method is described in Appendix 4.1.

Ether Extract

Exactly 3 gm of the ground material is weighed into an extraction thimble lined with filter paper. An extraction flask is then accurately weighed having been heated to 100°C and cooled in a dessicator. The thimble is placed in the extraction flask and 30 ml of petroleum ether added. The flask is then fitted with a reflex condenser and the apparatus placed on a water bath. The solvent is boiled until it has cleared. After boiling off the solvent, the extract and extraction flask is heated, cooled and accurately re-weighed. The difference in weight of the extraction flask gives the ether extract of the sample.

Crude Fibre

The dried residue in the thimble from the ether extraction is transferred to a 1-litre conical flask. The flask is fitted with a cold-finger condenser and the water turned on. When 200 ml of 1.25% sulphuric acid has come to the boil, it is transferred to the conical flask which is boiled for exactly 30 minutes, while the contents are gently rotated.

A filter cloth is fitted to a Buchner funnel and placed in a filtration flask. Before actual filtration, boiling water is poured into the flask to heat it. After boiling the contents of the conical flask for 30 minutes, they are poured into the funnel and filtered rapidly. The residues are transformed back to the conical flask, 200 ml of hot 1.25% sodium hydroxide is added, the cold-finger condenser fitted and the whole gently heated for exactly 30 minutes. Filtration is then carried out, as before, with the same filter cloth. The residues are washed further with boiling water and two 5 ml volumes of ethyl alcohol then two 5 ml volumes of ether.

The residue is then transferred to a weighed, ashless filter paper, dried at 100°C and re-weighed. The filter paper plus fibre is then transferred to a crucible which has been ignited and weighed. The organic material is ashed until a white residue remains and after cooling the crucible is re-weighed.

The weight of crude fibre is given by the weight of filter paper plus dried fibre less the weight of filter paper and weight of ash. At Kampala the weight of fibre is multiplied by 0.98 to give the percentage crude fibre to allow for altitude effects on the boiling point of reagents.

APPENDIX 4

METHODS USED FOR FOLIAR AND SOIL ANALYSIS

4.1 FOLIAR ANALYSIS METHODS

Nitrogen

Total nitrogen was determined by a semi-micro Kjeldahl method to express percentage nitrogen of total dry weight.

Exactly 0.1 gm of the plant material is weighed into a semi-micro Kjeldahl flask, to which is added about 0.8 gm potassium sulphate catalyst and 2 ml of concentrated sulphuric acid. The flask is then placed on a digestion rack and heated for about two and a half hours to obtain a clear solution. After allowing the flask to cool, a little de-mineralized water is added and the contents transferred to a Markham still. In the receiver 25 ml of a boric acid/bromocresol green indicator solution is placed, and 15 ml of a sodium hydroxide is poured into the mixture, which is steam distilled vigorously for five minutes. The distillate is then titrated with a N/50 standard sulphuric acid solution. The blank titration is subtracted from the actual titration and multiplied by 0.28, which gives the percentage of nitrogen in the plant material.

Phosphorus

The method used was to prepare a plant extract which was then placed in a calibrated Spekker absorptiometer and the percentage phosphorus read from a graph.

To 0.2 gm of the plant material in a 50 ml beaker, 2 ml of concentrated nitric acid is added, covered with a watch glass and left overnight. Then 2 ml magnesium nitrate solution is added to the washings and evaporated to dryness on a steam bath. The beaker is then placed in a furnace and heated overnight at 450°C. After cooling, 5 ml 25% nitric acid is added and transferred to a 50 ml volumetric flask. This is made up to volume with de-mineralized water and filtered. The Spekker absorptiometer is calibrated with a standard phosphorus solution to which a vandomolybdate reagent is added. Fifteen ml of the filtrate is pipetted into a wide-necked flask and 5 ml of the vandomolybdate solution added. After fifteen minutes the intensity of the yellow colour which develops is measured against water in a Spekker absorptiometer using No. 1 filter and the apparent percentage of phosphorus read. The density of the reagent blank is obtained and, when subtracted from the apparent phosphorus percentage, gives the true percentage.

Calcium, Potassium and Magnesium

The bases were liberated by ashing and a portion of the extractant then placed in an EEL flame photometer. Calcium and potassium are measured by the photometer and magnesium by titration.

Into a porcelain crucible, 2 gm of the plant material are weighed out and then slowly heated to 500°C overnight. After cooling, 4 ml of 50% hydrochloric acid are added and evaporated to complete dryness. To the residue 5 ml of 0.5 N nitric acid is added and filtered with the washings into a 100 ml flask and made up to the volume with distilled water.

The EEL flame photometer is calibrated by making up standards of calcium and potassium solutions with a 2% solution of lanthanum chloride. A 5 ml aliquot of the plant extractant is placed in a 50 ml volumetric flask, to which is added 10 ml of lanthanum chloride solution, which prevents interference of phosphate and aluminium, and made to volume with water. The solution is sprayed in the photometer and the concentrations of calcium and potassium are read from calibration curves.

To determine calcium-plus-magnesium about 10 ml of the plant extract are pipetted into a 250 ml conical flask and diluted to about 150 ml with water. Then 15 ml of a buffer solution is added to bring the pH to 10. About 10 drops each of potassium cyanide, potassium ferro-cyanide, hydroxylamine hydrochloride and triethanolomine screening reagents are added, followed by 15 drops of Erichrome black T indicator. The solution is then titrated with 0.005 molar EDTA solution until a blue end-point is reached. The magnesium content can then be calculated by subtraction from the sum of calcium and magnesium.

4.2 SOIL ANALYSIS METHODS

Nitrogen

A macro-Kjeldahl technique was employed and the method similar to that for plant material.

Exactly 5 gm of soil is placed in a 300 ml Kjeldahl flask to which is added 2.5 gm of the catalyst and 7.5 gm potassium sulphate. Then 25 ml of concentrated sulphuric acid is added and the mixture heated. After transfer to the still, 70 ml of the 50% sodium hydroxide solution is added and the mixture steam distilled. After titration with N/20 sulphuric acid, the corrected titre is multiplied by 0.014 to give the percentage of nitrogen in the soil.

Carbon

The method used was that of Metson (1956) which has been described in Section 5.2, but exactly 2 gm of the ground soil was weighed out into the 250 ml flask instead of 0.02 gm.

Phosphorus

The method adopted was with the use of Truog extraction solution buffered at pH 3. The extracted phosphate was then measured by chlorostannous reduced molybdophosphoric blue-colour method.

Exactly 2 gm of the soil was placed in a shaking bottle with 400 ml of N/10 sulphuric acid and ammonium sulphate solution and then shaken for one hour. The mixture is filtered and to 50 ml of the filtrate, 2 ml of 2.5% ammonium molybdate in 10 N sulphuric acid solution is added and shaken. Then 1 ml of a 40% stannous chloride solution is added and after exactly five minutes the blue colour is measured with an EEL absorptiometer. The absorptiometer is calibrated with standard phosphate solution and the p.p.m P_2O_5 in soil is read from a graph.

Calcium, Potassium and Magnesium

The exchangeable bases are displaced from the soil by leaching with normal ammonium acetate solution.

Magnesium can then be determined by complexometric titration and calcium and potassium by flame photometry.

Filter paper is macerated and plugged in the bottom of a leaching tube. Then 20 gm of soil is placed on top and a polyethylene bottle containing 195 ml of Normal ammonium acetate is inverted over the tube. The tube at the bottom is closed when the soil is wetted and left for two hours to equilibrate. The solution is allowed to pass slowly through the soil for not more than twelve hours. The leachate is collected in a 200 ml volumetric flask and made to volume with water.

A 10 - 50 ml aliquot of the leachate is then pipetted into a 250 ml flask and diluted to about 150 ml with water. The method is then followed as for plant extracts previously described.

pH

The paste method was employed and pH determined by a pH meter.

A 50 ml beaker is half-filled with soil and de-mineralised water is poured down the side until the soil is just wetted. The mass is stirred with a glass rod and a little more water added until the moisture saturation point is reached. A 'spear' type glass electrode is inserted into the soil paste and the pH read from a compensated and calibrated pH meter.

Soil particle size analysis

The soil was dispersed with sodium hexameta phosphate and Bouyoucos hydrometer readings taken after four minutes, and after two hours.

Into a shaking bottle, 50 gm of the sieved soil is weighed and 100 ml water and 5 ml of sodium hexameta phosphate solution are added. The mixture is shaken overnight. All the soil and suspension is transferred to a polythene cylinder. The hydrometer is floated in the cylinder and the suspension is made up to 1130 ml with water. The hydrometer is removed and the cylinder is shaken thoroughly. The suspension is left for about three and a half minutes then the hydrometer and thermometer carefully inserted. After exactly four minutes the hydrometer and thermometer are read and removed. About two hours later the readings are taken again.

The percentage of silt plus clay is read off from tables for the four-minute readings, the percentage clay alone is found using the two-hour readings. Percentage silt is found by difference.

APPENDIX 5

ANALYSIS OF VARIANCE OF THE YIELD OF THE MAIZE TEST CROP

The analysis of variance for the maize test crop plot yield was as follows:-

Main plots	Degrees of freedom	Sums of squares	Mean square	F.
Blocks	4	149.7959	37.45	10.92 **
Treatments	5	48.4094	9.68	2.82 *
Error	20	117.7416	5.89	
Sub Total	29	315.9469		
Sub-plots				
Fertilizers	1	503.1507	503.15	146.69 **
Interaction				
Fertilizers and Treatments	5	38.0676	7.61	2.22
Error	24	82.3130	3.43	
Total	59	939.4782		

Significance P = 0.05 = *

P = 0.01 = **

This analysis showed no significant interaction between fertilizers and treatments. The analysis was continued of the treatment combinations by asymmetrical comparison. The analysis of variance was as follows:-

Main plot

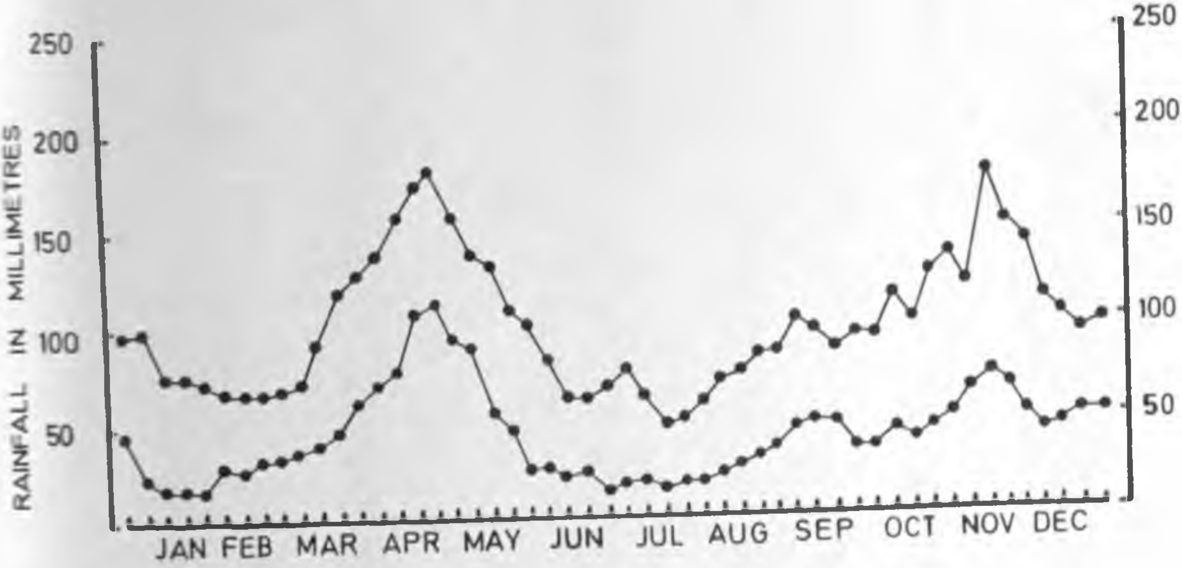
	Degrees of freedom	Sums of squares	Mean square	F.	
Green manure vs. weed fallow	1	1.8019	1.8	0.30	n.s
Within green manures	4	46.6075	11.65	1.97	n.s
Total treatment combinations	5	48.494			

Therefore it will be seen that there was no significant difference between the weed fallow treatment and the five green manures, nor within the green manure treatments. Even by separation of the interaction, the variance ratio could not be raised to significance.

APPENDIX 6

GRAPH OF RAINFALL CONFIDENCE LIMITS AT KA[redacted].

1:1 CONFIDENCE LIMITS OF THREE WEEKS MOVING TOTALS OF RAINFALL AT KABANYOLO FARM 1955-1965
ANNUAL MEAN 1335 mm.



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