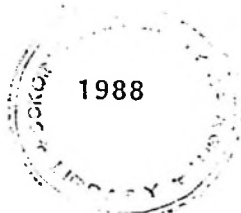


EFFECT OF TILLAGE, SOIL SURFACE MANAGEMENT AND CALCIUM PEROXIDE ON  
SOIL PROPERTIES AND PERFORMANCE OF SOME TROPICAL GRAIN CROPS



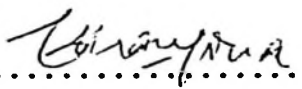
COSMAS MARKUS MAYONA, DIP. (AGRIC.), B.Sc. (AGRIC.)

A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS  
FOR THE DEGREE OF MASTER OF SCIENCE IN AGRICULTURE TO THE  
SOKOINE UNIVERSITY OF AGRICULTURE, FACULTY OF  
AGRICULTURE, MOROGORO, TANZANIA



i  
DECLARATION

I, Cosmas Markus Mayona, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation, which is solely the result of my own work, has not been submitted for a higher degree award in any other University.

Signature : .....  .....  
Date : ..... 4 / 5 / 88 .....  
i

i  
DECLARATION

I, Cosmas Markus Mayona, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation, which is solely the result of my own work, has not been submitted for a higher degree award in any other University.

Signature : ..... *Cosmas Markus Mayona* .....  
Date : ..... *4/5/88* .....

DEDICATION

To my mother, Colleta, who had always been an inspiring heart during my early ( primary and secondary ) education.

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## ABSTRACT

Two field experiments were conducted at two localities on the IITA farm to investigate the effects of tillage, residue management and soil surface manipulations; and oxygen supply on soil properties and the performance of some tropical grain crops. The localities were lowland planted with rice and upland planted with maize, soybeans and cowpeas.

The treatments for the lowland rice experiment were tillage operations (puddling and zero - tillage), residue management (with and without burning) and oxygen supply (with and without oxygen) using calcium peroxide. The experiment was a 2 x 2 x 2 factorial arranged in a randomized complete block design with three replications. Puddling resulted in higher grain yield than zero - tillage. However, all the other crop growth parameters were not influenced by the tillage operations. Burning the residues significantly improved the rate of seedling emergence, mean period to ultimate emergence and number of seedlings that attained ultimate establishment. However, it reduced plant height and the number of tillers per plant. Under both tillage systems oxygen supply did not affect the performance and yield of rice regardless of whether the residues were left on the soil surface unburnt or burnt.

The treatments for the upland crops experiment were oxygen supply and soil surface manipulations which included bare surface, mulch cover alone, or in combination with either chiselling or compaction. The experimental design was a split plot with three replications. Mulch in combination with compaction increased soil bulk density and reduced

total porosity at seedling emergence. It also reduced water infiltration before sowing and at harvest compared to the other soil surface manipulations. Oxygen supply alone generally had no significant effect on plant height and leaf production of maize, soybeans and cowpeas. However, it only enhanced percentage of seedling establishment and root growth of cowpeas, but suppressed root weight of maize. Reduction in growth of maize, soybeans and cowpeas was generally more marked when the soil was mulched and compacted. Mulching in combination with chiselling, on the other hand, improved the growth of the crops. Superimposing oxygen supply on soil surface manipulations significantly influenced seedling emergence and establishment, and root growth of soybeans and cowpeas. For example,  $O_2$  improved rate of seedling emergence and percentage of seedling establishment in soybeans across all the soil surface manipulations, except when mulch was combined with chiselling. However, oxygen supply delayed the mean period to ultimate seedling emergence in soybeans on the bare or compacted and mulched soil. While oxygen supply shortened mean period to ultimate emergence in cowpeas, when the surface was mulched, it prolonged it when the surface was mulched and compacted. The supply of oxygen also improved soybeans lateral root length and root density on the mulched and compacted soil. Cowpea tap root length was markedly enhanced by oxygen supply under mulch alone and mulch in combination with chiselling. On the other hand, cowpea root density was depressed by a mulch-chiselling combination. Grain yields of maize, soybeans and cowpeas were not affected by oxygen supply alone or in combination with any of the surface manipulations.

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## 1. INTRODUCTION

Tillage and other management practices in crop production (e.g. fertilizer use, residue management, etc.) are performed in order to create suitable soil conditions for crop growth. It is associated with seedbed preparation and weed control (Lal, 1979; Larson, 1980). Tillage and residue management practices affect germination, seedling emergence, growth and yield of a crop through their influence on the soil physical, chemical and biological properties. Tillage in general modifies soil structure which governs retention and movement of water, aeration and degree of compaction. However, repeated conventional cultivation (plowing and harrowing or puddling) of tropical soils causes rapid deterioration and degradation of the topsoil which results in poor rainfall acceptance, and make it prone to erosion (Grohman, 1960; Moura and Buol, 1972; Lal et al., 1981). These effects have been observed in both lowland and upland soils where conventional tillage has been shown to result in poor crop yields (Moura and Buol, 1972; De Datta, 1978; Rodriguez and Lal, 1985).

The adverse effects of conventional tillage on soil and crops have raised some concern to the farming community. As a result several options have been sought over the recent past in an attempt to provide alternatives. Among the options, zero - tillage system has received considerable attention by researchers. Zero - tillage plus proper management of crop residues appears to offer a possible solution to soil deterioration and degradation problems, especially to the fragile tropical soils. Zero - tillage crop production is a system that utilizes killed vegetation or previous crop residues as mulch. It is characterized

by an undisturbed soil profile and abundant plant residues on the soil surface which provides protective cover (Lal, 1983b; Hargrove et al., 1985). Seed is placed in a slot made at a desired depth without soil disturbance and weeds are commonly controlled by herbicides (Lal, 1983b).

Research experience in the tropics has shown that zero-tillage with mulch for both upland crops and lowland rice production can either replace or be used together with the conventional tillage system especially where weeds can effectively be controlled with appropriate herbicides (Mabbayad and Buencosa, 1967; Mitra and Pieris, 1968; Lal, 1979; Brown and Quantrill, 1973; Maurya and Lal, 1979a; Rodriguez and Lal, 1979; Ross and Cox, 1981). The merits of adopting zero-tillage for crop production have extensively been reviewed (Anon., 1976; De Datta, 1978; De Datta et al., 1979; Lal, 1974; Lal et al., 1980; Maurya and Lal, 1979b).

Although zero - tillage has gained popularity in crop production in the United States of America (Anon., 1985) and has also proved suitable for row crops in the humid and subhumid tropics, its adoption by farmers in the tropics has received little attention. Slow adoption rate of zero - tillage has been attributed to poor seedling establishment, reduced growth and low crop yields (Burrows and Larson, 1962; Gauer et al., 1982; Lal, 1983 b, 1985; Christian and Miller, 1984; Lindstrom, 1984). Prolonged use of zero-tillage performed by tractorized operations (e.g. planting, spraying, fertilizing, harvesting, etc.) has also been shown to lead to soil compaction and greater mechanical strength (Soane et al.,

1970; Gantzer and Blake, 1978; Lal et al., 1981, 1983b; Ross and Cox, 1981; Garman et al., 1981; Cannell, 1985), thus reducing growth and yield of most crops. Compaction results in reduction of soil macroporosity (Vomocil and Flocker, 1965) and water infiltration (Warketin, 1971). In addition to being more compact, the lower pore space and higher moisture content of soils managed with the zero-tillage system may lead to reduced gaseous exchange and bring about anaerobic conditions that may encourage the production of toxic substances (e.g. organic acids, ethylene, etc). Such conditions can restrict root elongation (Smith and Russell, 1969) and reduce stand establishment and crop yields (Norstadt and McCalla, 1968; Lynch et al., 1980). The presence of mulch commonly associated with zero-tillage may impede seedling emergence and encourage damage of seeds and emerging seedlings by pests like birds, rodents and insects (Kang, 1982; Lal, 1983b, 1985).

Several measures to minimize the adverse effects of mulch in zero - tillage have been suggested (Allmaras et al., 1977; Kang, 1982; Cannell, 1985; Lal, 1985). These include burning or incorporating the mulch into the soil (Cannell, 1985) and occasional chiselling to break the compacted zone (Allmaras et al., 1977). Recently the use of oxygen supplying chemicals to improve aeration and the effects of anaerobiosis in such conditions has been tried (Brandon et al., 1983; Leaver and Roberts, 1984; Kolotovskiy, 1985).

Burning and/or removing residues is part of seedbed preparation in traditional farming systems in the tropics. Such practice may eliminate excess residues that would otherwise decompose to produce

organic acids that are toxic plants. These decomposition products have been reported to cause poor seedling emergence, growth and yield of crops, particularly when they are grown in a wet soil or under zero - tillage with mulch system (Chandrasekeran and Yoshida, 1972; De Datta, 1978). Burning and/or removing the residues may also drive away rodents, birds and other pests that destroy seeds and young seedlings thus affecting crop stand (Kang, 1982; Lal, 1983 b. 1985). However, burning and/or removing residues in the tropics has to be done with caution as it may aggravate erosion and run-off problems (Lal, 1975, 1983 b).

Continuous use of zero - tillage particularly with heavy machinery commonly results in compaction of the soils below the surface. This brings about poor crop growth due to mechanical impedance to root elongation. Chiselling can be employed to break the surface seal and loosen the compacted zones and hence provide a corrective measure to the adverse effects of such continuous use of zero - tillage (Lal, 1983 b).

Under too wet soil conditions, where poor aeration may be a serious problem, the use of oxygenating compounds for alleviating the effects of poor aeration in the tropics could also be possible. Promising results on the use of such compounds have been reported from a few areas in the tropics, mainly West Africa (Ogunremi et al., 1981) and Asia (Yoshida and Parao, 1981; Leaver and Roberts, 1984). There is thus a need to demonstrate the possible benefits of such chemicals that can

overcome the adverse effects of lack of oxygen in poorly drained soils of the tropics.

Ample literature exists on conventional tillage and zero - tillage individually and their effects on soil properties and plant growth. However, information on zero - tillage in combination with various soil surface manipulations such as residue management, compaction, chiselling, etc. and their effects on soil properties and plant growth is scanty. Similarly, research on the use of oxygen to improve crop production is at its early stages. The work reported here was therefore designed to examine these aspects in two experiments with specific objectives as follows :

Experiment 1:

- 1) To evaluate the effects of tillage, residue management and calcium peroxide ( $\text{CaO}_2$ ) on the growth and yield of lowland rice.

Experiment 2 :

- 1) To evaluate the effects of soil surface management on soil properties, and performance and yield of selected upland crops.
- 2) To evaluate the effects of  $\text{CaO}_2$  on the emergence, growth and yield of selected upland crops grown under zero - tillage with various soil surface management practices.

## 2. LITERATURE REVIEW

### 2.1 Tillage in general

Tillage is defined as the physical, chemical or biological soil manipulations aimed at improving soil conditions for crop production (Lal, 1979). Traditionally, tillage is associated with seedbed preparation and weed control. Apart from weed control, tillage is also aimed at incorporating organic matter into the soil, improving soil structure and conservation of soil and water (Van Wambeke, 1974; Larson, 1980).

The type of tillage practice to be employed in a particular arable land depends on the crop to be raised and a number of environmental, edaphic and economic conditions. The fact that most crops are grown under either lowland (e.g. rice) or upland (e.g. maize, soybeans, cowpeas, etc.) conditions, means that their tillage requirements will also differ.

Tillage systems broadly encompass conventional (historical or traditional) and conservational (or minimum) tillage. Conventional tillage can either be a dry (e.g. for upland crops) or wet (e.g. for low land rice) tillage. In the dry tillage system land is plowed and harrowed several times to create a suitable tilth for seeding or transplanting before the onset of the rains. This tillage system is particularly used for rainfed crop production in which a whole range of tractor or animal drawn primary and secondary equipments and implements for land preparation are used. In this system, dry or pregerminated seed is sown directly

in banded or unbanded fields at the beginning of the rainy season or after irrigation (Ghose et al., 1960; Pendleton and Hartwig, 1973; Metcalfe and Elkins, 1980). Wetland preparation, on the other hand, is practised where there is an assured or adequate water supply. The system is used extensively for the production of lowland rice. It involves repeated and thorough wet plowings and harrowings or rotovating the soil at water saturation point with the ultimate goal of breaking down soil aggregates into a homogeneous mass of aggregates and textural separates, a process or practice known as puddling (Sanchez, 1973; De Datta, 1978). Immediately after transplanting or a few weeks after sowing, the land is flooded.

The conservational (or minimum) tillage system can also be used for both wetland and dryland preparation. In this system the number of field operations is reduced compared to that required in a conventional seedbed preparation. There are three main types of conservational tillage systems : reduced, mulch and zero - tillage. Reduced tillage system makes use of a moldboard or disc plow, but reduces or eliminates further secondary tillage with a harrow, etc. In the mulch tillage system, hoe, chisel, disc or rotary tillage equipments are used so that large amounts of previous crop residues are left on the soil surface. Zero-tillage system is an extreme case of conservation tillage which involves seeding or transplanting in relatively undisturbed seedbed. This system makes use of biological, organic and chemical means to kill the vegetation at planting (Pendleton and Hartwig, 1973; Metcalfe and Elkins, 1980; Lal, 1983b).

### 2.1.1 Tillage in lowland rice production

In lowland rice producing areas tillage commonly involves puddling and maintenance of standing water (De Datta and Kerim, 1974; Reddy and Hukkeri, 1983). Puddling changes the soil structure from granules to particles (Scheltema, 1974; De Datta and Kerim, 1974; Ghildyal, 1978). Sanchez (1973) listed several advantages of puddling as follows:

- a) increase in soil moisture content
- b) decrease in water loss by evaporation and percolation
- c) increase in soil aeration
- d) increase in mineralization of organic matter, and
- e) reduction in weed infestation.

During puddling weeds and weed seeds are buried. They therefore emerge after the establishment of the crop. In this way the crop gets the advantages of a head start and thus avoids competition from weeds at the early stages of establishment. Coupled with water economy and available nutrients from organic matter, puddling encourages seedling emergence and establishment, subsequently leading to higher crop yields (De Datta and Kerim, 1974; Scheltema, 1974).

It has been demonstrated that high yields in lowland rice can also be attained with the minimum disturbance of the soil (Mabbayad and Buencosa, 1967; Brown and Quantrill, 1973). The zero-tillage system, for example, is successfully replacing the conventional tillage system of land preparation for lowland rice production in tropical regions of Asia, Japan and Korea,

where herbicides are effectively employed to control weeds (Mabbayad and Buencosa, 1967; Mitra and Pieris, 1968). In Nigeria, Lal (1983b) pointed out a number of advantages of zero - tillage system in lowland rice production. They include savings in fuel and time needed for mechanical tillage (puddling), and more efficient utilization of labour, land and cultivation equipment.

#### 2.1.2 Tillage in upland crop production

Most upland crops are grown under the conventional tillage system of land preparation. This system consists of several plowings and harrowings followed by the planting operation. The significance of such a system of seedbed preparation has been well documented (Van Wambeke, 1974; Larson, 1980). Intensive use of the conventional tillage system, however, does not always lead to the expected soil improvements, especially with tropical soils because the system is incompatible with many aspects of soil and water conservation. For example, frequent use of conventional tillage operations in the tropics has been shown to expose the organic fraction of the soil to rapid oxidation at the generally high temperatures to the detriment of soil structure (Grohman, 1960; McCartney et al., 1971; Lal, 1983a). It also causes mechanical compaction, reduction in soil porosity and infiltration capacity, and it accelerates surface run - off and soil erosion (McCartney et al., 1971; Lal et al., 1981).

Water stability of soil aggregates, macroporosity and pore continuity are the soil characteristics most affected by the conventional tillage system. The magnitude of the effects on these properties, however, is dependent on soil type and organic matter content in the top layer of the soil. In Brazil, Grohman (1960) found that cultivation reduced the percentage of aggregates larger than 2 mm by half in Oxisols and Ultisols. Reduction in aggregate size was reflected in the uniform increase in the proportion of aggregates of small size ranges in the Oxisol and in a drastic increase of the aggregates smaller than 0.21 mm in the Ultisol. Reduction in mean size of water stable aggregates was responsible for clogging the soil pores between large aggregates thus reducing water infiltration rate and aeration. In another study, Moura and Buol (1972) compared the effects of 15 years of annual cropping on an Oxisol. They observed that infiltration rates decreased from 82 to 12 cm hr<sup>-1</sup> with intensive cropping. The decline in infiltration rate was associated with a sharp decrease in air porosity of the soil with small aggregates as compared to that with large aggregates. Soil compaction caused by mechanical farm operations under continued cultivation was cited as the cause of the decrease in macroporosity. The deterioration of soil structure has a great bearing on crop growth and on the ability of the land to sustain economic agricultural production (Lal, 1983b).

It is widely believed that both the frequency and intensity of primary tillage operations can be reduced in most soils without causing a serious decline in crop yield, provided that weeds are effectively controlled and that the crop stand is adequate (Lal, 1983b). The availability of herbicides and the development of appropriate seeding

equipment suitable for planting grain crops into untilled soils have enhanced the possibility of reducing the amount of tillage or eliminating it altogether (Soane and Pidgeon, 1975). Elimination of tillage operations maintains soil structure and favourable levels of organic matter (Lal, 1983b). In general, the problem of soil deterioration in the humid tropics can be minimized through application of zero-tillage practices provided that the use of zero-tillage system is combined with that of the crop residue mulch (Lal, 1983)

## 2.2 The concept of zero-tillage (no-tillage)

Bowen (1982) reported that an earlier attempt to use zero - tillage system was made by Garber in 1927. Garber successfully oversowed a legume into the grass sod without tillage using such simple techniques as close grazing or burning and heavy seed rate to manipulate the competition between the sward and the surface sown forage species. Hooves of animals were used to insert the seed into the soil and to improve the seed-soil contact. The introduction of herbicides such as dalapon, paraquat and glyphosate in the 1950s and 1970s, has revolutionized the zero-tillage farming practice (Baeumer and Bakermans, 1973). Basic concepts and definitions of zero-tillage (no-tillage) have been extensively reviewed (Baeumer and Bakermans, 1973; Unger and McCalla, 1980; Lal, 1983b).

The zero - tillage system developed in the USA for row crop production is now widely practised in the production of fodder, cereals and other row crops to minimize energy requirements and planting costs (Baeumer and Bakermans, 1973;Phillips and . . .

Young, 1973; Cannell, 1985). Traditionally, most farmers in the tropics use some form of zero-tillage (Karel and Ndunguru, 1980), hence the principles of zero-tillage system are not new in the tropics. Shifting cultivation practised by the small - holder farmers is often based on zero-tillage principles especially where labour is a major constraint. Under this traditional cultivation system, the soil is only slightly tilled with hand tools.

### 2.3 Effect of zero-tillage on soil physical properties in upland crops

Zero-tillage with mulch and other forms of reduced tillage systems affect the soil physical properties. Particularly affected are bulk density, porosity, mechanical impedance (or soil strength) and the soil water regime. Bulk density, total porosity and penetration resistance are indirectly related to soil compaction, soil water content and mechanical impedance (Larson, 1964; Lal, 1983a). Wheel - induced compaction also results in higher bulk density, greater mechanical strength and severe loss of macroporosity of the surface horizon (Ross and Cox, 1981).

Results of studies comparing the effects of zero-tillage and conventional tillage systems on soil physical properties have been extensively reviewed (Baeumer and Bakermans, 1973; Lal, 1983b). These studies indicate that continued use of zero-tillage may cause high soil bulk density, greater soil strength and slow water infiltration.

In a six year study, Gantzer and Blake (1978) showed that soil under zero-tillage system of land preparation had significantly greater bulk density and the surface soil had lower porosity than that under conventional tillage. Soil densities in zero-tillage ranged from 1.24 to 1.32 Mg m<sup>-3</sup> in contrast to those under conventional tillage which ranged from 1.05 to 1.12 Mg m<sup>-3</sup>. Low porosity and high bulk density under zero-tillage have also been reported by Baeauer and Kucera (1978). Other studies have indicated that bulk density and soil strength did not differ significantly between conventional and zero-tillage systems in non - wheel traffic areas (Nesmith et al., 1985; Anonymous, 1985). However, the bulk density and soil strength were greater in the top 15 cm of zero-tillage wheel traffic areas compared to similar areas under conventional tillage.

In contrast, Rao et al. (1960) have shown that zero-tillage resulted in lower bulk density, less compaction from tractor and implement traffic and less mechanical impedance to penetration than those from conventional tillage. Mannering et al. (1966) observed somewhat higher values of soil porosity in zero-tillage than in conventional tillage. However, Ley (1983) working on volcanic soils in South Western Tanzania observed non-significant difference in bulk density and porosity between conventional and zero-tillage systems from the early growth of maize up to silking. The greater bulk density and lower porosity recorded in conventionally tilled treatments after maize harvesting were attributed to raindrop impact and human traffic during sampling and other field operations.

Zero-tillage with liberal use of crop residue mulch on the soil surface can markedly influence the water regime of the soil. The magnitude and trends of such effects vary with soils, climate and soil, and crop management. However, Duin (1955) and Barnes and Bohrent (1958) have independently shown that zero-tillage results in a better water storage and increased rate of infiltration. Using high intensity simulated rainfall, Rao et al. (1960) found that zero-tillage in maize production resulted in higher rate of infiltration and water content than conventional tillage. Similarly, Kahnt (1969), Baeumer (1970), Cannell and Finney (1973), Gantzer and Blake (1978) and Nesmith et al. (1985) observed more volumetric water contents from a zero-tillage surface soil than from a plowed soil. The higher water contents in zero - tillage than cultivated plots were attributed to the high organic matter concentration near the soil surface while the increased water infiltration was ascribed to the presence of the mulch.

In the equatorial warm humid climate of Zanzibar, Tanzania, Khatibu et al. (1984) reported that mulch and zero-tillage treatments with maize and cowpeas had more soil moisture reserve than other treatments. However, the infiltration rate declined after two seasons as a result of continuous cropping. In a more or less similar climatic condition, Lal (1983a) reported that zero-tillage treatments in South Western Nigeria had high infiltration rates despite the relatively high bulk density. He attributed this to earthworm and root channels under the mulch which provided more pore continuity. Removal of the residues from zero-tillage plots lowered infiltration by approximately 18 percent.

In a two year study in the hilly regions of Northern India, Acharya and Bhagat (1984) showed that deep plowing in an Alfisol created more favourable conditions for water entry into the soil profile than reduced tillage systems. However, the infiltration rate decreased in the second year due to resettlement of the loosened soil. When mulch was added to conventionally plowed plots, the infiltration rate increased.

#### 2.4 Effect of zero-tillage on emergence, growth and yield of crops

##### 2.4.1 Lowland rice

The effects of zero-tillage on emergence, growth and yield of rice have not been studied extensively. In most of the studies conducted, the effect of zero-tillage on crop performance has either been equal to or slightly lower than that from conventional (puddling) tillage. For example, Maurya and Lal (1979a) and Rodriguez and Lal (1979) at IITA reported that days to maximum tillering, plant height, tiller number per hill, panicle length and grain yield were not affected by either zero-tillage or puddling methods of land preparation (Rodriguez and Lal, 1985).

In contrast, Pande and Bhan (1964) and De Datta et al. (1979) have shown that the zero-tillage system produced lower yields of rice than the conventional tillage system. The poor performance in zero-tillage has been attributed to phytotoxicity from the stubble/straw, poor aeration, nutrient imbalance and incidences of pests and diseases (Brown and Quantrill, 1975). In general, under wet or flooded

conditions, anaerobic decomposition of organic matter produces large quantities of organic acids such as acetic, propionic and butyric acids (Guenzi and McCalla, 1962; Cochran et al., 1977; Rao and Mikkelsen, 1977). The presence of these products may cause poor establishment and growth if seedlings come into contact with the straw (Chandrasekaran and Yoshida, 1972; Lynch et al., 1980). The highest levels of toxicity appear during the first 10 - 25 days of decomposition and decline after 5 - 7 weeks (Patrick and Toussoun, 1970; Patrick, 1971; Anon., 1985).

Zero-tillage particularly with mulch cover may also result in nutritional imbalance during the early days (10 - 25 days) of straw decomposition due to leaching of added inorganic fertilizers (Lal, 1985) and/or may enhance the problems of pests such as birds, rodents insects and of disease (Brown and Quantrill, 1979).

The adverse effects caused by the presence of mulch in a zero-tillage system may be minimized by incorporating the residue into the soil a few weeks before seeding or transplanting, or burning it. Although theoretically feasible and safe, these operations may have some practical problems associated with them. Straw incorporation may be expensive in terms of time, fuel, funds, labour and equipment, apart from the poor seedling establishment and crop growth (Oliphant, 1982) caused by poor seed placement, more pests (slugs, insects, mice) (Cannell, 1984) and diseases (Christian and Miller, 1984) and toxins from the decomposing straw (Harper and Lynch, 1981). Straw burning on the other hand, may present serious pollution and fire hazards.

However, when well carried out, these operations may result in improved crop growth and yields. For example, Acharya (1935) and Sircar et al. (1940) obtained significant increase in grain yield when straw was plowed into the soil a few weeks before sowing. These findings were later supported by Miranda (1960) who obtained high yield of rice when he incorporated the straw one month before sowing. Recently, however, Ogunremi (1983) observed a reduction in seedling emergence, plant height and grain yield of rice when mulch was applied before sowing while the converse was true when applied after seeding. The decline in yield due to incorporation of straw into the soil have been ascribed to N-immobilization (Jones, 1952).

In a ten - year study of rice straw management Williams et al. (1957) concluded that straw burning may cause significant rice yield reductions. Cagampang (1964) also obtained drastic rice yield reductions when straw was burnt in situ. It has been suggested that inavailability of mineral elements from the straw and soil were the major reasons for the decline in the yields.

#### 2.4.2 Upland crops

There is substantial evidence to support that continued use of zero - tillage system in upland crops can result in poor crop growth and yield (Cannell, 1983; 1985). Among the major reasons for the poor performance in zero - tillage especially with mulch include compaction, and it is associated with high soil strength, bulk density, and poor aeration. Wheel-traffic induced compaction can lead to high bulk density and thus impede seedling emergence

and early root development (Soane, 1985). Aljibury and Evans (1965) observed that in a compacted wet soil, poor seedling emergence could be associated with low aeration rather than high soil strength per se. Laboratory studies have indicated that raising the bulk density from 1.2 to 1.5 Mg m<sup>-3</sup> at 15 or 25% moisture content (v/v) can cause a delay in emergence and a decrease in percent emergence (Stibbe and Terpstra, 1982).

Garman et al. (1981) obtained poor stand establishment in zero-tillage plots which were continuously planted with maize. This was attributed to poor soil moisture content in the early part of the rainy season and highly compacted surface soil reflected in the high penetrometer resistance. Recent studies (Kayombo and Lal, 1986) demonstrated that soil compaction reduces percent emergence, plant height and the number of leaves in maize during the first cropping cycle. However, the difference in leaf number between compacted and uncompacted treatments increased considerably in both conventional and zero-tillage systems in the subsequent cropping cycle.

Probably the major effect of soil compaction under zero-tillage is on root development. Kohnke and Barber (1969), and Barber (1971) have shown that after 6 years of zero-tillage the weight of roots down to 60 cm was less than half of that obtained under conventional tillage at the same depth. In both cases, the roots were concentrated at the top 10 to 25 cm of the soil. Ellis et al. (1977) and Drew and Saker (1978) demonstrated slower rates of elongation of seminal roots in wheat and barley under zero - tillage

than under plowing, with a tendency for the roots to proliferate in the surface few centimetres of the soil. The proliferation of the roots in the surface layer of the zero-tillage soil was probably associated with nutrient accumulation, especially phosphate.

Lal (1974) noted that depth and lateral root spread of maize 45 days after sowing did not differ in plowed and unplowed mulched soils. However, four years later, the depth and lateral root spread of maize planted at the same site were lower in plowed than in unplowed-mulched soils. The highest concentration of roots was immediately beneath the mulch. More root density in the top layer of the soil with mulching has been ascribed to the lower and more favourable soil temperatures and reduced mechanical impedance due to greater moisture conservation (Chaudhary and Prihar, 1974).

Root growth in compacted soils is mainly dependent upon soil bulk density, soil strength and aeration status of the soil (Veihmeyer and Hendrickson, 1948; Taylor and Burnett, 1964). However, both soil water and bulk density are known to affect soil strength (Taylor and Bruce, 1968; Veen and Boone, 1981). Agrawal *et al.* (1975) reported that an increase in bulk density at the upper 10 to 20 cm of the soil from 1.5 to 1.7 Mg m<sup>-3</sup> increased the concentration of roots by 10% in the upper 10 cm layer and it declined to one-third at the deeper layers. Further increase in bulk density to 1.9 Mg m<sup>-3</sup> increased the concentration of roots to 30% in the upper 10 cm layer.

In a poorly aerated and compact soil root growth can also be inhibited by lack of oxygen and accumulation of respiratory by-products that are toxic to plant roots (Guenzi and McCalla, 1966; Lynch et al., 1980).

Depending on other soil parameters, crops react differently to soil compaction. The roots of some crops exhibit symptoms of mechanical impedance as usually shown by stunted tap root growth (e.g. cotton) or by profuse branching (e.g. wheat). Other plant roots grow down areas of weakness such as earthworm and dead root channels, and fissures between soil peds (Ellis and Barnes, 1980; Lal et al., 1980) thus offsetting the deleterious effects of soil compaction in a zero - tillage system.

The effects of soil compaction on crop growth and root development can be improved through periodic chiselling of the soil to break the compact layer and to improve water infiltration and aeration (Allmaras et al., 1977; Lal, 1983b; Wilcocks, 1984). Application of oxygen supplying compounds to the soil or seed can improve the soil aeration status of extensively wet (zero - tillage) soil, and thus alleviating the problems associated with soil compaction.

Yield response to tillage is difficult to generalize as it is highly dependent upon soil type, location and climate. Studies conducted both in the temperate (Amemiya, 1977; Papendick and Willer, 1977; Negi et al., 1982) and tropical (Kemper and Derpsch, 1981; Gazziero et al., 1983; Lal, 1984) regions have shown that there are some beneficial effects of zero-tillage compared to conventional tillage system. In maize, for example, grain yields have been shown

to be generally higher under zero - tillage than under conventional tillage (Jones et al., 1969; Triplett and Van Doren, 1969; Blevins et al., 1971). The higher grain yields in zero - tillage have been attributed to more efficient use of soil moisture from the crop residue and/or nutrients in the straw (Patterson, 1960).

Lal (1974) proposed that the higher yield of maize under zero - tillage with mulch than under conventional tillage is due to favourable soil temperature, more nutrients and more biological activity under the mulch. Mulch cover is thus an important component in the zero - tillage system. The absence of the mulch may not bring about the expected beneficial effects of the zero - tillage system, particularly under unfavourable weather conditions (Allmaras et al., 1973; Doran et al., 1984).

Some studies have also indicated yield reductions in zero-tillage compared with conventional tillage. Blake and Aldrich (1955), for example, obtained higher yields with maize under plowing than under zero - tillage. They proposed that the decrease in yield could be due to lower porosity and more bulk density of the zero - tillage silt loam soils. In a recent study, Acharya and Bhagat (1984), ascribed the increase in maize grain yield under the conventional plowing to better root growth. When evaluating the effects of dibbling, plow - planting and conventional method of soil manipulations, Pande and Bhan (1964) obtained significantly lower grain yield of upland rice in the zero - tillage than in the conventional - tillage method. Muzilli and Igue (1979) , however, have reported that yields of soybeans, wheat and maize

from zero - tillage plots are the same or sometimes higher than those from conventionally tilled plots. Similar results were also reported by Brar et al. (1982) and Franzen et al. (1984).

Soil compaction (or high bulk density) may affect the yield of crops. Samra and Goswami (1978) have observed yield reductions in wheat when the bulk density of an alluvial sandy loam soil at the upper 30 cm layer was more than  $1.6 \text{ Mg m}^{-3}$ . With other crops such as maize, pearl millet, sorghum, sunflower and pigeon peas yields can be reduced when the bulk density is above  $1.7 \text{ Mg m}^{-3}$  (Anon., 1977). Kayombo and Lal (1984) have shown that grain yields of maize, soybeans and cowpeas in both zero - tillage and plowed treatments in South Western Nigeria are highly correlated with bulk density, infiltration rate and porosity.

#### 2.5 Effect of oxygen on germination and growth of crops

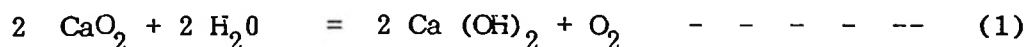
Germination, root development and growth are processes that require oxygen for oxidation. Crops vary widely in their oxygen requirements. Most root crops, for example, have relatively high oxygen demand (Baver and Farnsworth, 1941). Similarly, tomatoes need large quantities of oxygen for maximum growth (Clarke and Shive, 1936), whereas soybeans tolerate low oxygen supply (Allison and Shive, 1923).

In a well drained soil, oxygen is not limiting for optimum plant growth. However, inadequate supply of oxygen is common in wet or poorly drained soils as well as in soils under zero-tillage with mulch. Crops grown in such soils germinate and grow poorly

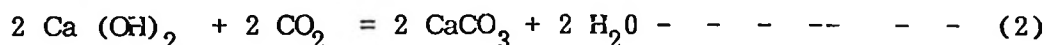
mainly due to oxygen deficiency and the presence of toxic organic acids from anaerobic decomposition of the mulch (Leaver and Roberts, 1984). Effects of anaerobiosis and the production of toxic compounds from the decomposing residue on such wet lands can be minimized by supplying sufficient oxygen to the seed or the soil (Ogunremi et al., 1981; Leaver and Roberts, 1984). Calcium peroxide is one of the sources of oxygen that can reduce the adverse effects of poor aeration (Leaver and Roberts, 1984).

To-date the use of peroxides as oxygen suppliers has gained some prominence in Japan, Korea, Philippines and the United States of America where they are used to improve seedling emergence, growth and yield of direct seeded rice, wheat and barley in wet and highly O<sub>2</sub> deficient soils. For example, about 1500 ha and 1200 ha of land were commercially planted to calcium peroxide - coated rice by 1982/83 in Japan and USA, respectively (Leaver and Roberts, 1984).

When calcium peroxide is applied to wet or moist soil it slowly breaks down and releases molecular oxygen and calcium hydroxide as end products. In the soil, calcium hydroxide may eventually combine with atmospheric carbon dioxide to form calcium carbonate (Yoshida and Parao, 1981; Ota, 1982) as shown below:



The O<sub>2</sub> is available to emerging seedling



The rate of oxygen release is pH - dependent; it is faster under acid than under alkaline conditions (Anon., 1981; Yoshida and Parao, 1981). The release of oxygen also occurs at a rate which decreases with time; this however, contrasts sharply with the maximum oxygen requirement by the plant which increases with time (Leaver and Roberts, 1984).

There are two common methods of applying calcium peroxide :

- 1) by soil application (Melsted et al., 1949; Ogunremi et al., 1981) mostly as granules through broadcasting, banding and spot application close to the planting hole and
- 2) by seed coating (Anonymous, 1983; Ota, 1982; Leaver and Roberts, 1984 ) in the form of a dust.

The latter method is currently the most widely used in the production of rice and other small cereals (e.g. wheat, barley, etc.) in Japan, Philippines, Korea and the USA (Leaver and Roberts, 1984).

#### 2.5.1 Effect of peroxide on germination and growth of crops

Probably the first attempt to use peroxide on crops was made in the USA during the late 1940s and early 1950s. Melsted et al. (1949), for example, recorded improved plant growth and increased yields of oats, maize and soybeans when hydrogen peroxide was applied to the soil as a fertilizer. Later, Wiersma and Wortland (1953) evaluated the responses of sugar beet (Beta vulgaris L.) grown on different soil types, and calcium peroxide as fertilizer. When yields of both tops and

beets were considered, there was no advantage of  $\text{CaO}_2$  on the clay loam soil whereas on the silty clay loam the peroxide treatment was of distinct advantage.

Recently, Yoshida and Parao (1981) at IRRI, found that the rate and percentage emergence and subsequent yield of lowland rice were greater in seeds coated with calcium peroxide than those from un-coated seeds. However, Brandon et al., (1983) in USA observed nonsignificant effect on stand density, shoot length, maturity, plant height or grain yield when they used calcium peroxide (61.5%  $\text{CaO}_2$ ) at the rate of 35% of seed dry weight.

Ogunremi et al. (1981) at IITA observed that calcium peroxide application in a poorly drained soil significantly improved percentage emergence, number of leaves, number of pods per plant and grain yield in soybeans and cowpeas. Similar observations were made in Russia with peroxides (barium and calcium) on potatoes grown in podzolic soils, especially during periods of excessive wetting when the soil oxygen regime was low (Kolotovskiy, 1985).

### 3. MATERIALS AND METHODS

#### 3.1 General

Two field experiments were conducted at the International Institute of Tropical Agricultural (IITA), Ibadan, Nigeria (Lat 7° 29'N and Long. 3° 54'E at an elevation between 185 - 240 m above sea level) during the 1985 growing season at two locations:

- a) on a lowland for a valley bottom soil which had been under rice cultivation for the previous several years (Block F-10 - Paddy) and
- b) on an upland which had been left fallow during the previous season (Block B 25).

At IITA, there are two growing seasons. The first season starts in April and extends to July; while the second, a short one covers August through early November. The lowland experiment was planted in January under flood irrigation while the upland one was planted during the main season (April to July) and extended to the short rainy season (August to early November) (Appendices 1 and 2). The details of each experiment at the two sites are outlined below.

#### 3.2 Experiment 1 : Effects of tillage, surface cover and calcium peroxide on the performance and yield of lowland rice (Oryza sativa L.)

The experiment was laid down in Block F-10 (Paddy) on a valley bottom soil under flood irrigation. The soil is classified as loamy, mixed, isohyperthermic Aeric Tropoqualf according to Soil Taxonomy (Soil Survey Staff, 1975). The general characteristics

of the soil at the experimental site are depicted in Table 1.

### 3.2.1 Treatments and experimental design

There were three treatments : tillage operations, residue management and oxygen supply (calcium peroxide application ). The details of each treatment were as follows :

- a) Tillage : Involved conventional tillage in which the land was rotovated using rotovator blades mounted on a power tiller (Land Master) at water saturation point, herein after referred to as puddled plot (T<sub>1</sub>). The zero-tilled land (T<sub>2</sub>) was treated with paraquat (1 - 1 dimethyl 4, 4' bipyridinium ion ) at 5 l ha<sup>-1</sup> in two splits before sowing (1 week and one day, respectively ).
- b) Residue management : This treatment was superimposed on the tilled and zero-tilled treatments (T<sub>1</sub> and T<sub>2</sub>, respectively ). Straw from the previous rice crop was spread over the entire experimental land. Residue management involved controlled burning of the straw on 12 plots (T<sub>1</sub>) while in the remaining 12 plots the straw was left unburnt (R<sub>2</sub>).
- c) Oxygen supply: Calcium peroxide (72% CaO<sub>2</sub>) was applied during sowing at the rates of 0 and 6 kg ha<sup>-1</sup>. The CaO<sub>2</sub> granules were placed 3 cm from the hill of rice seeds along the rows. The levels of oxygen are herein after referred to as O<sub>1</sub> and O<sub>2</sub>, respectively.

Table 1 : Some physical and chemical properties of the surface soil ( 0 - 15 cm ) of Block F -10 (1978)

Properties	Values
pH	5.9
Organic carbon (%)	0.64
Total nitrogen (%)	0.088
C/N ratio	7.3
Available P (Bray 1) mg kg <sup>-1</sup> soil	3.4
Exchangeable cation ( c mol (p <sup>+</sup> ) kg <sup>-1</sup> ):	
a) Calcium	7.82
b) Magnesium	3.39
c) Potassium	0.15
d) Sodium	1.14
Effective CEC ( c mol (p <sup>+</sup> ) kg <sup>-1</sup> )	13.03
Soil separates (%):	
a) Clay	30
b) Silt	29
c) Sand	41
Textural class	clay loam

Source : Rodriguez and Lal (1985)

The experiment was a 2 x 2 x 2 factorial arranged in a randomized complete block design with three replications. The plots ( 3 x 4.5 m) were separated by 1 m alley ways (Appendix 3 ).

### 3.2.2 Sowing and management of the trial

Rice seeds (CV ITA 306) previously soaked in water for 36 hours, were sown at a spacing of 20 x 25 cm. Four seeds per hill were dibbled on the top one centimeter of the wet and soft soil. The sowing operation was accomplished within two days (January 7 - 8, 1985). Flooding was withheld for three weeks until emergence was complete. Four weeks after emergence the seedlings were thinned to one plant per hill.

The compound fertilizer (Nitrophoska) 15 - 15 - 15 was hand broadcast on the soil surface at the rate of 400 kg ha<sup>-1</sup> at sowing. Additional 30 kg ha<sup>-1</sup> of nitrogen in the form of urea (46% N) was applied 40 days after emergence.

The experiment was flood irrigated and kept free of weeds and insect pests as recommended for IITA up to harvesting. There was no serious disease outbreak during the experimental period.

### 3.2.3 Data collection and analysis

Data were collected on seedling emergence, tiller number, plant height and grain yield. Seedling emergence was assessed using 1 m square quadrat randomly placed on each plot. Three counts were made on each plot daily and their average was recorded as

the number of seedlings emerged for the plot. This operation continued until no further emergence occurred. These counts were employed to arrive at the rate of emergence, mean period required for emergence and number of seedlings which attained ultimate establishment (Appendix 4).

Tiller number per plant was obtained from ten randomly selected plants from six rows at the centre of each plot at harvest. The average tiller number of the ten plants was taken as the number of tillers for the plot.

Plant height measurements were made up to the top of the tallest leaf or panicle in a hill. The same plants for which tiller number was recorded were used to obtain data for plant height. The average height of the ten plants was recorded as the plant height for the plot.

For grain yield, the central  $5.25 \text{ m}^2$  of each plot was harvested, threshed and fresh weight determined. Subsamples from each plot were oven dried at  $105^\circ\text{C}$  to constant weight. These were used to estimate yields per plot after being adjusted to 12% moisture content. Grain yield was expressed in  $\text{Mg ha}^{-1}$ .

The data were subjected to analysis of variance using the IITA GENSTAT computer programme.

Table 2 : Some physical and chemical properties of the surface soil ( 0 - 5 cm ) of Block B 25, 1985\*

Properties	Values
pH	5.8
Organic carbon (%)	1.12
Total nitrogen (%)	0.15
C/N ratio	7.62
Available P (mg kg <sup>-1</sup> )	31.4
Exchangeable cation ( c mol (p <sup>+</sup> ) kg <sup>-1</sup> ):	
a) Calcium	0.51
b) Magnesium	0.67
c) Potassium	0.31
d) Sodium	0.18
Cation exchange capacity ( c mol (p <sup>+</sup> ) kg <sup>-1</sup> )	4.67
Soil separates (%) :	
a) Clay	19.4
b) Silt	8.6
c) Sand	72.0
Textural class	Sandy loam

\* Source : IITA Analytical Service Laboratory, 1985

3.3 Experiment 2 : Effect of zero-tillage and calcium peroxide on soil physical properties and performance and yield of some tropical crops

The experiment was conducted in Block B 25 on a soil derived from Basement complex rocks characterized by relatively sandy surface structure overlying a layer of angular to subangular quartz gravel which emerges into an argillic horizon. The soil is classified as an Oxic Paleustalf according to Soil Taxonomy (Soil Survey Staff, 1975). The clay fraction of the soil is dominated by Kaolinitic clay minerals and amorphous sesquioxides (Moormann *et al.*, 1975). The general properties of the surface soil ( 0 - 5 cm) at the experimental site before the experiment was laid out are depicted in Table 2.

3.3.1 Land preparation

One week before planting, the field was sprayed with paraquat ( 1 - 1 dimethyl - 4, 4' bipyridinium ion ) at 5 l ha<sup>-1</sup> to kill the vegetation and three days later the dead grass was slashed. The slashed grass was then spread evenly on the soil surface as mulch. The experimental land was then demarcated according to treatments.

3.3.2 Treatments and experimental design

The treatments involved oxygen supply (CaO<sub>2</sub> application) and zero-tillage operations which included bare surface, mulching, mulching plus strip chiselling and mulching plus compaction. These treatments were applied

to three selected crops (maize, cowpeas and soybeans) in a single experiment. The details of each treatment are outlined below:

- a) Oxygen supply: Granules of calcium peroxide (72%  $\text{CaO}_2$ ) were ground in a mortar to form a powder. The powder was carefully coated onto wet seeds at the rates of 0 and 10% (w/w). The coating procedure has successfully been employed in rice (Ota, 1982; Leaver and Roberts, 1984). The uncoated and coated treatments are herein after referred to as  $0_1$  and  $0_2$ , respectively.
  
- b) Zero - tillage operations (hereby to be known as soil surface management): In the bare plots the mulch was removed ( $T_1$ ). The mulched plots were left undisturbed ( $T_2$ ). In the chiselled - mulched plots a strip of 5 cm wide and 10 cm deep was made manually using machetes. The mulch on the remaining parts of the plots was left undisturbed ( $T_3$ ). In the compacted - mulched plots a tractor (Model DB 995) was run through the plots several times ( $T_4$ ).

The experiment was laid out in a split plot design with three replications (Appendix 5). The treatments were assigned to the plots as follows:

- i) without calcium peroxide ( $0_1$ )
- ii) with calcium peroxide ( $0_2$ )

Subplot treatments : Soil surface management

- 1) Soil surface management with bare surface ( $T_1$ )
- 2) Soil surface management with mulch cover ( $T_2$ )
- 3) Soil surface management with mulch plus chiselling ( $T_3$ )
- 4) Soil surface management with mulch plus compaction ( $T_4$ )

### 3.3.3 Sowing and management of the trial

The test crops (maize, cowpeas and soybeans) were sown using an IITA-made hand jab planter on May 9 and 10, 1985. The varieties and spacing used are shown in Table 3.

Table 3 : Varieties and spacings for the test crops

Crop	Variety	Distance between	
		Rows (cm)	Hills (cm)
Maize	TZB - GUSAU	75	25
Soybeans	TGx 536 - 02D	50	10
Cowpeas	TVx 3236	50	15

Maize received a split application (half at 4 weeks after sowing and half just before tasselling) of  $120 \text{ kg ha}^{-1}$  of nitrogen in the form of urea (46% N) and  $20 \text{ kg ha}^{-1}$  of phosphorus as single superphosphate (SSP) and  $30 \text{ kg ha}^{-1}$  of potassium in the form of muriate of potash, the latter two were applied at sowing. The legumes were supplied with  $20 \text{ kg P ha}^{-1}$  as SSP and  $30 \text{ kg K ha}^{-1}$  as muriate of potash at sowing. All the fertilizers were hand broadcasted on the soil surface.

Weeds were manually controlled during the entire experimental period. Pesticides were applied to control insect pests. Carbofuran (2 - 3 Dihydro 2, 2 - dimethyl - 7 - benzofuranyl methyl carbonate) granules (10% ai ) were applied to maize at  $2 \text{ kg ha}^{-1}$  three weeks after sowing to control insect pests. Starting from 5 weeks after sowing weekly sprayings of a mixture of deltamethrin ( 1 - d - cyano - 3 - benzyl d, cis - dibromochrynanthenates ) and dimethoate (0, 0 - Dimethyl s - (N - methyl - carbamyl - methyl ) phosphorodithiate at 2.5 and  $1.0 \text{ l ha}^{-1}$ , respectively, were applied to control leaf and postflowering insects in cowpeas. Soybeans were occasionally sprayed with the same mixture. No disease control measures were employed to either of the three test crops because they were all practically disease free.

#### 3.3.4 Data collection and analysis

Data collection and analysis of both agronomic and soil variables were conducted as detailed below :

##### 3.3.4.1 Agronomic variables

- a) Seedling emergence : seedling emergence was assessed as outlined in Experiment 1 above (section 3.2.3 ) except that percentage seedling establishment was recorded in the three crops instead of number of seedlings.
- b) Plant height: Plant height from five randomly selected plants was regularly determined, and the average height of the five plants was recorded as the plant height for the plot. The distance between the soil level and the tallest leaf was taken to be the plant height.

- c) Number of leaves : The number of leaves per plant in each plot was assessed from the same plants used for measuring plant height.
- d) Root growth: Seven weeks after sowing the root systems of five plants were excavated and washed. Tap and lateral root length was determined by taking the length between the part just below the soil surface and the tip of the roots. Root dry weight was recorded after the roots had been dried at 60°C for 24 hours to constant weight. At harvest samples were taken by the core method (Böhm, 1979) up to 10 cm depth for root density assessment. These samples were water saturated over night and then washed with a gentle spray of water over a 2 mm sieve. Washed roots were picked up with a pair of forceps and then dried at 60°C for 24 hours. Root density was expressed as the weight of dry roots per unit volume of soil ( $\text{mg cm}^{-3}$ ).
- e) Grain yield: The crops were harvested manually from the centre of each plot, shelled and their fresh weight was recorded. Subsamples from each plot were oven dried at 105°C to constant weight. These were used to estimate yield per plot after being adjusted to 12% moisture content. Grain yield was expressed in  $\text{Mg ha}^{-1}$ .

#### 3.3.4.2 Soil variables

- a) Bulk density and total porosity: Bulk density of the surface soil (0 - 5 cm) was determined according to the procedures outlined by Blake (1965) before sowing, at flowering and harvesting stages. Total porosity was calculated from the relationship between bulk density and particle density as follows:

$$f = 1 - ( D_b/D_p ) \quad \times 100 \quad - - - - - (3)$$

where ;

f = total porosity

$D_b$  = bulk density, and

$D_p$  = particle density

The particle density ( $D_p$ ) was taken as  $2.65 \text{ Mg m}^{-3}$ .

b) Infiltration and moisture content measurements : Field water infiltration capacity was determined using double ring infiltrometers prior to any treatment application and after harvesting the crops. The determination procedures are outlined below :

i) Infiltration

Two concentric metal cylinders of varying sizes were used in measuring infiltration (Plate 1). The small cylinder was 25 cm high and 25 cm internal diameter and the larger one was 30 cm high and 30 cm internal diameter. Each cylinder was driven into the soil to a depth of 8 cm. The space between the inner and outer cylinders ( 5 cm) was used as a buffer zone and was thus filled with water to a height of 15 cm. The water level was maintained approximately at the same height throughout the observation period. The inner cylinder was then filled to the desired depth and the starting time recorded. Using a short, pointed marker as a reference, the drop in water head was recorded at one minute intervals during a two - hour period of observations. The inner cylinder was refilled whenever the water level was too low for a reading.

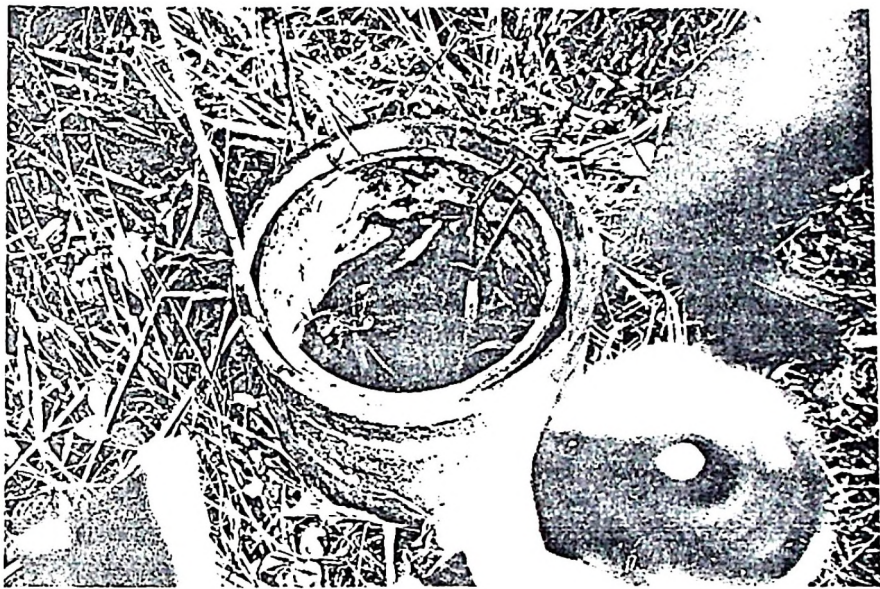


Plate 1 : Double ring infiltrometer

Infiltration equations are usually used to express cumulative infiltration, that is, total quantity of water infiltrated into the soil (I) or the infiltration rate (i) as a function of time (t).

Cumulative infiltration (I) was thus derived as follows:-

$$I = St^{\frac{1}{2}} + At + Bt^{3/2} + \dots \dots \dots (4)$$

Replacing all terms beyond  $St^{\frac{1}{2}}$  by  $Kt$ , I becomes :

$$I = St^{\frac{1}{2}} + Kt \dots \dots \dots (5)$$

where I = cumulative infiltration (cm)

t = time in minutes

S = "sorptivity" of the soil (also obtained by  $I/t^{\frac{1}{2}}$ )

K = "transmissivity" or hydraulic conductivity

ii) Soil moisture content

Soil moisture content of the surface soil ( 0- 15 cm) was determined gravimetrically at the time of monitoring infiltration and when taking samples for bulk density determination. Two soil samples were collected from each plot. The sampled soil was placed in moisture boxes which were then transferred to an oven and dried to constant weight at 105°C. The percent moisture content (Mc on w/w basis ) was calculated as :

$$\% MC = \frac{MS - DS}{DS} \times 100 \dots \dots \dots (6)$$

where % MC = moisture content %

MS =weight of moist soil (g)

DS = weight of dry soil (g)

Data collected, except infiltration data, were subjected to analysis of variance using the IITA GENSTAT computer programme. Data for each crop were analysed separately.

#### 4.0 RESULTS AND DISCUSSION

#### 4.1 Effects of tillage, surface cover and calcium peroxide on the performance and yield of lowland rice (Oryza sativa L)

##### 4.1.1 Seedling emergence

Data on the effect of tillage, residue management and oxygen supply on rice seedling emergence are presented in Tables 4, 5 and 6. Residue management significantly ( $P = 0.01$ ) affected the rate of emergence (Table 4) and period at which rice seedlings reached ultimate emergence Table 5 ( $P = 0.05$ ). The rate of seedling emergence was depressed by the presence of unburnt residues (mulch) irrespective of the tillage system and  $\text{CaO}_2$  application. Seedlings from the mulched plots were buckled and kinked indicating that the mulch was impeding their emergence. This might have led to the exhaustion of the cotyledons food reserves before the seedlings were able to photosynthesize (Rathore et al., 1983). It is also possible that the production of phytotoxic organic acids from the decomposing residue could have contributed to the slow rate of seedling emergence in the mulched plots (Rao and Mikkelsen, 1977; Lynch et al., 1980).

Burning the residue, however, resulted in a higher rate of seedling emergence than when the residue was unburnt (Table 4). This supports the earlier suggestion that seedling emergence in the mulched plots was depressed through mechanical impedance or through allelo - chemicals from the decomposing mulch (Lynch et al., 1980; Lal, 1985)

Table 4: Effect of tillage, residue management and oxygen supply on the rate of rice seedling emergence

CaO <sub>2</sub>	Mean numbers of seedlings day <sup>-1</sup>					
	0 kg ha <sup>-1</sup>			6 kg ha <sup>-1</sup>		
	Burnt	Unburnt (mulch)	Diff.	Burnt	Unburnt (Mulch)	Diff
Tillage						
Zero-tillage	11.3	6.4	4.9**	9.9	7.5	2.4 NS
Puddling	12.6	5.8	6.8**	11.2	4.4	6.8**
Difference	1.3 NS	0.6 NS		1.3 NS	3.1 NS	
CV, %	22					

\*\* Significant at P = 0.01; NS = Not significant at P = 0.05

CV = Coefficient of variation ;

F - values from the main table for:

$$\text{Tillage (1, 14) = 0.121}^{\text{NS}}$$

$$\text{Residue (1, 14) = 43.71; P = 0.01, LSD (0.01) = 3.27}$$

$$\text{CaO}_2 \text{ (1,14) = 1.046}^{\text{NS}}$$

$$\text{Tillage x Residue (1, 14) = 3.972}^{\text{NS}}$$

$$\text{Tillage x CaO}_2 \text{ (1, 14) = 0.625}^{\text{NS}}$$

$$\text{Tillage x Residue x CaO}_2 \text{ (1, 14) = 0.560}^{\text{NS}}$$

There was a significant interaction effect due to tillage, residue management and calcium peroxide (Table 5) on mean period to ultimate seedling emergence. Seedlings in zero-tillage plots took a significantly ( $P = 0.05$ ) longer time to ultimate emergence when the residue was left on the surface as compared to when the residue was burnt. In the zero-tillage plots, burning and oxygen supply significantly enhanced seedling emergence. In the puddled plots, however, neither burning nor oxygen supply affected the mean period to ultimate emergence to any significant level. However, when the residue was burnt,  $O_2$  supply significantly delayed the days to ultimate emergence in the puddled plots. The converse was true when the residue was unburnt.  $CaO_2$  (oxygen supply) main effects in the time to ultimate emergence suggest that the soil in this site could have been adequately aerated such that it did not require any external source of oxygen (Kolotovskiy, 1985).

The number of seedlings that attained ultimate establishment in all treatments was generally small (Table 6) . This was probably due to an unexpected early outbreak of insect pests which cut the seedlings at soil surface level. These were immediately controlled with  $2 \text{ kg ha}^{-1}$  of carbofuran ( 2 - 3 - Dihydro 2, 2 - dimethyl - 7 - benzofuranyl methyl carbomate ). However, none of the treatments (viz. tillage operation, residue management and oxygen supply ) affected the number of seedlings that eventually reached establishment to any significant extent.

Table 5 : Effect of tillage, residue management and oxygen supply on mean period to ultimate emergence

CaO <sub>2</sub>	Mean number of days					
	0 kg ha <sup>-1</sup>			6 kg ha <sup>-1</sup>		
	Burnt	Unburnt (Mulch)	Diff.	Burnt	Unburnt (Mulch)	Diff.
Residue						
Tillage						
Zero-tillage	4.3	5.0	0.7 NS	2.3	5.6	3.3*
Puddling	3.8	3.9	0.1 NS	4.5	3.6	0.9 NS
Difference	0.5 NS	1.1 NS		2.2*	2.0*	
CV, %	19					

\* significant at P = 0.05; NS = not significant at P = 0.05

CV = coefficient of variation;

F-values from the main table for:

Tillage (1, 14) = 0.97 NS

Residue (1, 14) = 6.47; P = 0.05; LSD (0.05) = 0.689

CaO<sub>2</sub> (1, 14) = 0.53 NS

Tillage x Residue (1, 14) = 14.76; P 0.01; LSD(0.01) = 0.97

Residue x CaO<sub>2</sub> (1, 14) = 1.69 NS

Tillage x CaO<sub>2</sub> (1, 14) = 1.97 NS

Tillage x Residue x CaO<sub>2</sub> (1, 14) = 7.86; P = 0.05; LSD (0.05) = 1.38

Table 6 : Effect of tillage, residue management and oxygen supply on the number of seedlings which attained ultimate establishment

CaO <sub>2</sub>	Mean number of seedlings m <sup>-2</sup>					
	0 kg ha <sup>-1</sup>			6 kg ha <sup>-1</sup>		
	Burnt	Unburnt (Mulch)	Diff.	Burnt	Unburnt (Mulch)	Diff.
Tillage						
Zero-tillage	76	64	12 NS	64	64	0 NS
Puddling	63	60	3 NS	68	67	1 NS
Difference	13 NS	4 NS		4 NS	4 NS	
CV, % 19						

NS = not significant at P = 0.05

CV = coefficient of variation;

F-values from the main table for :

Tillage (1, 14) = 0.287 NS

Residue (1, 14) = 0.542 NS

CaO<sub>2</sub> (1, 14) = 0.001 NS

Tillage x Residue (1, 14) = 0.161 NS

Tillage x CaO<sub>2</sub> (1, 14) = 1.373 NS

Residue x CaO<sub>2</sub> (1, 14) = 0.494 NS

Tillage x Residue x CaO<sub>2</sub> (1, 14) = 0.324 NS

Table 6 : Effect of tillage, residue management and oxygen supply on the number of seedlings which attained ultimate establishment

CaO <sub>2</sub>	Mean number of seedlings m <sup>-2</sup>					
	0 kg ha <sup>-1</sup>			6 kg ha <sup>-1</sup>		
	Residue	Burnt	Unburnt (mulch)	Diff.	Burnt	Unburnt (mulch)
Tillage						
Zero-tillage	76	64	12 NS	64	64	0 NS
Puddling	63	60	3 NS	68	67	1 NS
Difference	13 NS	4 NS		4 NS	4 NS	
CV, %	19					

NS = not significant at P = 0.05

CV = coefficient of variation;

F-values from the main table for :

Tillage (1, 14) = 0.287 NS

Residue (1, 14) = 0.542 NS

CaO<sub>2</sub> (1, 14) = 0.001 NS

Tillage x Residue (1, 14) = 0.161 NS

Tillage x CaO<sub>2</sub> (1, 14) = 1.373 NS

Residue x CaO<sub>2</sub> (1, 14) = 0.494 NS

Tillage x Residue x CaO<sub>2</sub> (1, 14) = 0.324 NS

## 4.1.2 Number of tillers per plant

The number of tillers per plant was not significantly influenced by the treatments before booting (Table 7).

Table 7 : Effect of tillage, residue management and  $\text{CaO}_2$  on number of tillers per plant before booting

$\text{CaO}_2$	Mean tiller number per plant					
	0 kg ha <sup>-1</sup>			6 kg ha <sup>-1</sup>		
	Burnt	Unburnt (Mulch)	Diff.	Burnt	Unburnt (Mulch)	Diff.
Tillage						
Zero-tillage	12.2	14.2	2.0 NS	14.2	13.4	0.8 NS
Puddling	14.8	13.4	1.4 NS	14.0	13.8	0.2 NS
Difference	2.6 NS	0.8 NS		0.2 NS	0.4 NS	
CV, %	15					

NS = not significant at  $P = 0.05$ ; CV = coefficient of variation.

F-values from the main table for :

Tillage (1, 14) = 0.396 NS

Residue (1, 14) = 0.019 NS

$\text{CaO}_2$  (1, 14) = 0.056 NS

Tillage x Residue (1, 14) = 0.683 NS

Tillage x  $\text{CaO}_2$  (1, 14) = 0.242 NS

Residue x  $\text{CaO}_2$  (1, 14) = 0.223 NS

Tillage x Residue x  $\text{CaO}_2$  (1, 14) = 1.348 NS

At harvest, however, the number of fertile tillers was significantly affected by the treatment combinations (Table 8). In the presence of  $\text{CaO}_2$ , residue management and tillage operations had significant effects on the number of tillers. When  $\text{CaO}_2$  was supplied, mulching produced significantly more tillers than when the residue was burnt in the zero-tillage system. In the puddled plots, however, the converse was true in that mulching depressed the number of tillers significantly ( $P = 0.05$ ). The higher number of tillers observed at harvest in the zero-tillage mulched plots could be due to the improvement in oxygen supply from the  $\text{CaO}_2$  which slowly releases oxygen to the plants at a later growth period when there is a higher demand for it (Yoshida and Parao, 1981; Leaver and Roberts, 1984). It has been reported that at high pH,  $\text{CaO}_2$  releases  $\text{O}_2$  at a slow rate (Yoshida and Rivera, 1978; Anon., 1981). The pH of the soils in the experimental plots was 6.5, which supports the suggestion that the  $\text{O}_2$  availability at the later growth stages of the plant was relatively higher than before booting. Also the leaching of phytotoxic organic acids from the decomposing mulch might have contributed to the large number of tillers in the zero-tillage mulched plots. Meanwhile, the lower number of tillers in the puddled and mulched plots could be attributed to the accumulation of phytotoxic organic acids produced from the straw (Lynch et al., 1980; De Datta, 1978) caused by the impermeable soil layer (that is a hard pan) formed just below the plow layer (De Datta, 1978) and this could not be improved with  $\text{O}_2$  availability.

Table 8 : Effect of tillage, residue management and  $\text{CaO}_2$  on number of tillers per plant at harvest

$\text{CaO}_2$	Mean tiller number per plant					
	0 kg ha <sup>-1</sup>			6 kg ha <sup>-1</sup>		
	Burnt	Unburnt (Mulch)	Diff.	Burnt	Unburnt (Mulch)	Diff.
Tillage	<hr/>					
Zero-tillage	13.2	11.5	1.7 NS	11.4	13.6	2.2*
Puddling	12.8	12.1	0.7 NS	13.3	10.7	2.6*
Difference	0.4 NS	0.6 NS		1.9 NS	2.9*	
CV, %	13					

\* and \*\* significant at  $P = 0.05$  and  $P = 0.01$  levels, respectively;

NS = not significant ( $P = 0.05$ ); CV = coefficient of variation;

F-values from the main table for :

Tillage (1, 14) = 0.100 NS

Residue (1, 14) = 1.003 NS

$\text{CaO}_2$  (1, 14) = 0.058 NS

Tillage x Residue (1, 14) = 2.126 NS

Tillage x  $\text{CaO}_2$  (1, 14) = 0.197 NS

Residue x  $\text{CaO}_2$  (1, 14) = 0.560 NS

Tillage x Residue x  $\text{CaO}_2$  (1, 14) = 5.036,  $P = 0.05$ ,  $\text{LSD}(0.05) = 1.99$

## 4.1.3 Plant height

Plant height at early booting was significantly ( $P = 0.01$ ) affected only by residue management (Table 9).

Table 9 : Effect of tillage, residue management and oxygen supply on plant height at early booting

CaO <sub>2</sub>	Plant height, cm					
	0 kg ha <sup>-1</sup>			6 kg ha <sup>-1</sup>		
	Burnt	Unburnt (Mulch)	Diff.	Burnt	Unburnt (Mulch)	Diff.
Tillage						
Zero-tillage	82	94	12 **	88	95	7 **
Puddling	86	91	5 **	87	97	10 **
Difference	4 NS	3 NS		1 NS	2 NS	
CV, %	6					

\*\* significant at  $P = 0.01$ ; NS = not significant at  $P = 0.05$ ;

CV= coefficient of variation;

F-values from the main table for :

Tillage (1, 14) = 0.258 NS

Residue (1, 14) = 17.685,  $P = 0.01$ ; LSD (0.01) = 4.467

CaO<sub>2</sub> (1, 14) = 2.982 NS

Tillage x Residue (1, 14) = 0.301 NS

Tillage x CaO<sub>2</sub> (1, 14) = 0.000 NS

Residue x CaO<sub>2</sub> (1, 14) = 0.004 NS

Tillage x Residue x CaO<sub>2</sub> (1, 14) = 2.081 NS

It is interesting to note that although the rate of emergence was low in the unburnt residue (Table 4), the plants were generally taller than those from the plots with burnt residues (Table 9). The response to mulching could be ascribed to the adequate supply of nutrients from the decomposing straw (Lal, 1983b). On the other hand, the poor growth of plants in the burnt plots could probably be due to an inadequate nutrient supply, particularly nitrogen and sulfur which are known to be easily lost during burning (Biederbeck et al., 1980). These results are in contrast with those of Ogunremi et al., (1986), who reported a decrease in rice plant height in mulched plots and attributed it to competition for nutrients between the plants and microbes.

#### 4.1.4 Grain yield

Rice grain yield was not affected by either residue management,  $\text{CaO}_2$  application or by their combination. However, tillage operations resulted in significantly ( $P = 0.05$ ) higher yields compared to the other treatments (Table 10).

Puddling resulted in increased grain yield over the zero-tillage system, except in no oxygen supply mulched plots (Table 10). Despite the generally higher number of tillers in the zero-tillage plots (Table 8), yield in zero-tilled plots was much lower than that in the puddled plots. The tillers from the zero-tilled plots were slender and produced smaller panicles which suggest that the nutrients which were initially available at tillering were probably leached to deeper horizons beyond the

Table 10 : Effect of tillage, residue management and oxygen supply on the mean grain yield ( $\text{Mg ha}^{-1}$ ) of rice.

$\text{CaO}_2$	Yield, $\text{Mg ha}^{-1}$					
	0 $\text{kg ha}^{-1}$			6 $\text{kg ha}^{-1}$		
	Burnt	Unburnt (Mulch)	Diff.	Burnt	Unburnt (Mulch)	Diff.
Residue						
Tillage						
Zero-tillage	4.0	4.0	0 NS	3.4	3.5	0.1 NS
Puddling	3.3	5.2	1.9 NS	4.4	4.6	0.2 NS
Difference	0.7*	1.2*		1.0*	1.1*	
CV, %	17					

\* significant at  $P = 0.05$ ; NS = not significant at  $P = 0.05$ ,

CV = coefficient of variation;

F-values from the main table for:

Tillage (1, 14) = 5.225 ;  $P = 0.05$ ; LSD (0.05) = 0.616

Residue (1, 14) = 3.780 NS

$\text{CaO}_2$  (1, 14) = 0.445 NS

Tillage x Residue (1, 14) = 3.133 NS

Tillage x  $\text{CaO}_2$  (1, 14) = 1.860 NS

Residue x  $\text{CaO}_2$  (1, 14) = 2.022 NS

Tillage x Residue x  $\text{CaO}_2$  (1, 14) = 2.190 NS

reach of the rice roots (Thomas et al., 1973). Puddling such a sandy soil, on the other hand, resulted in a decrease in the loss of nutrients by leaching (Bodman et al., 1958; Anon., 1984). Similar higher rice grain yields with puddling have been reported (Pande and Bhan, 1964; Curfs, 1976; De Datta et al., 1979), although Rodriguez and Lal (1979), Maurya and Lal (1979a) and Ogunremi (1983) reported higher rice grain yields with zero-tillage. The latter workers attributed it to the availability of nutrients from the decomposing residue.

#### 4.2 Effect of soil surface management on the physical properties of soil sown with maize, soybean and cowpeas

##### 4.2.1 Bulk density

Data on bulk density for plots sown to maize, soybeans and cowpeas under various soil surface management practices are presented in Table 11. There were no significant ( $P = 0.05$ ) differences in bulk density at all growth stages of the test crops, except at emergence. At emergence, the bulk density was uniform in each crop for a particular surface management with compacted treatment registering significantly ( $P = 0.05$ ) higher bulk density ( $1.63 \text{ Mg m}^{-3}$ ) than any of the other treatments. There were no differences in bulk density between crop species at this growth stage; probably because the plants were still too small to exert any influence on the bulk density. The high bulk density value in compacted

Table 11 : Soil bulk density measured under maize, soybean and cowpeas at different growth stages

Treatment	Dry bulk density ( $\text{Mg cm}^{-3}$ )															
	Maize						Soybeans						Cowpeas			
	BS	EM	FLO	MAT	BS	EM	FLO	MAT	BS	EM	FLO	MAT	BS	EM	FLO	MAT
Bare	1.41	1.48	1.42	1.52	1.41	1.48	1.48	1.49	1.41	1.48	1.49	1.46	1.41	1.48	1.49	1.46
Mulch	1.47	1.43	1.43	1.50	1.48	1.43	1.37	1.45	1.48	1.43	1.41	1.48	1.48	1.43	1.41	1.48
Chisel+mulch	1.48	1.45	1.34	1.53	1.48	1.45	1.40	1.45	1.48	1.45	1.49	1.48	1.48	1.45	1.49	1.48
Compaction + mulch	1.52	1.63	1.59	1.56	1.52	1.63	1.52	1.61	1.52	1.63	1.58	1.51	1.52	1.63	1.58	1.51
Mean	1.48	1.50	1.45	1.53	1.47	1.50	1.44	1.50	1.47	1.50	1.50	1.48	1.47	1.50	1.50	1.48
LSD (5%)	NS	0.09	NS	NS	NS	0.09	NS	NS	NS	0.09	NS	NS	NS	0.09	NS	NS
CV, %	3	3	6	4	3	3	4	5	3	3	4	5	3	3	6	5

BS = Before sowing

EM = At emergence

FLO = At flowering

MAT = At maturity

LSD = Least significant difference

CV = Coefficient of variation

plots could be attributed to the high soil strength caused by soil compaction (Kayombo, 1986). Manipulation of the soil surface, however, did not seem to affect bulk density to any significant level after the crops had been well established. This could be due to the fracturing and aggregation (stabilizing) effect caused by plants root growth and organic matter (Phillips and Kirkham, 1962; Larson and Allmaras, 1971). The mulched and chiselled treatments registered low bulk density values possibly due to the biological activity in the former (Ehlers, 1979) plus the loosening of the soil in the latter treatment resulting in a porous soil surface. *The* observed slight differences in bulk density values at the different growth stages of three crops could have been caused by the differences in soil moisture content (Table 13). For example, there was low moisture content recorded at emergence and at maturity stages with corresponding high bulk density values. The converse was true at the tasseling - flowering stage of all crops when the soil was wet from the rain and the canopy. Curfs (1976) and Ley (1983) showed that an increase in moisture content can result in low bulk density values. The cumulative effect of trampling of the soil surface during sampling, data recording and chemical spraying might also be responsible for the generally high bulk density values registered at maturity (Ley, 1983). These results support an earlier conclusion that prolonged use of farm machinery and equipment as in a mechanized zero-tillage system, may result in soils of high bulk density caused by soil compaction (Ehlers, 1973; Douglas et al., 1980; Kayombo and Lal, 1983; Franzen et al., 1983 and Nesmith et al., 1985), although the presence of earthworms and root channels during the growing season and improve-

ment brought about by chiselling may offset the deleterious effects of compaction on a zero - tillage with mulch soil (Gantzer and Blake, 1978).

#### 4.2.2 Total porosity

Soil porosity was affected to a significant ( $P = 0.05$ ) level by surface management only at seedling emergence (Table 12). At this stage, compaction depressed the total porosity significantly ( $P = 0.05$ ). However, total porosity in the remaining surface manipulations in each crop did not differ from that in the control. At the other stages of crop growth the various treatments did not significantly influence total porosity, although compacted treatment still had the lowest values (Table 12). The results show that increase in bulk density (Table 11) after compacting a zero - tillage mulched soil resulted in a corresponding reduction in total porosity (Table 12). Soil compaction usually results in a decrease in the number and continuity of the large air - filled pores of the soil (Bodman et al., 1958 and Cannell, 1983). A reduction in total porosity from compacted surface soil in no - tilled plots has also been reported elsewhere (Pidgeon and Soane, 1977; Chopart, 1983; Kayombo and Lal, 1984; Hoefft and Randall, 1985). The relatively high total porosity values recorded in mulched and chiselled plots were probably due to the high biological activity and loosening action of the soil from the mulch and chiselling.

Table 12 : Total porosity measured under maize, soybean and cowpeas at different growth stages

Treatment	Total porosity ( % )																	
	Maize						Soybeans						Cowpeas					
	BS	EM	FLO	MAT	BS	EM	FLO	MAT	BS	EM	FLO	MAT	BS	EM	FLO	MAT		
Bare	46	44	47	42	47	44	47	44	46	44	44	44	46	44	44	45		
Mulch	45	46	45	42	44	46	48	45	44	46	48	45	44	46	47	44		
Chisel+mulch	44	45	49	42	43	45	47	44	44	45	47	44	44	45	44	44		
Compaction + mulch	41	39	40	40	42	39	44	39	42	39	44	39	42	39	41	43		
Mean	44	44	45	42	44	44	45	43	44	44	45	43	44	44	44	44		
LSD (5%)	NS	3.3	NS	NS	NS	3.14	NS	NS	NS	3.69	NS	NS	NS	NS	NS	NS		
CV, %	4	4	7	5	4	4	5	6	4	5	8	7	4	5	8	7		

BS = Before sowing

EM = At emergence

FLO = At flowering

MAT = At maturity

LSD = Least significant difference

CV = Coefficient of variation

#### 4.2.3 Infiltration

Initial cumulative infiltration data were collected for each surface management system before sowing. The measurements were taken for a period of 120 minutes. At this time the soil was still moist (Appendix 1). Chiselling in combination with mulch had the highest cumulative infiltration (207.3 cm) followed by mulched (148.2 cm) and bare (148.4 cm) surfaces, while the compacted - mulched plots had the lowest values (117.7 cm) (Fig. 1).

Data for cumulative infiltration at harvesting for the different crops are depicted in Figs. 2, 3 and 4. The measurements were taken during the wet spells (Appendix 1) when the soil was moist. Hence cumulative infiltration values were equally affected. The difference in infiltration data is therefore a reflection of the effects of the crops and treatments.

In general, cumulative infiltration was lowest in the compacted plots for all the crops (Figs. 2, 3 and 4). However, the infiltration values were highly dependent on the crop and surface manipulations. In the maize plots, for example, chiselling gave the highest infiltration data (Fig. 2) while in soybeans it was recorded from the mulched plots (Fig. 3). It is interesting to note that the bare plots planted with cowpeas had the highest infiltration (Fig. 4). Compaction is a common phenomenon in mechanized farming. The present data

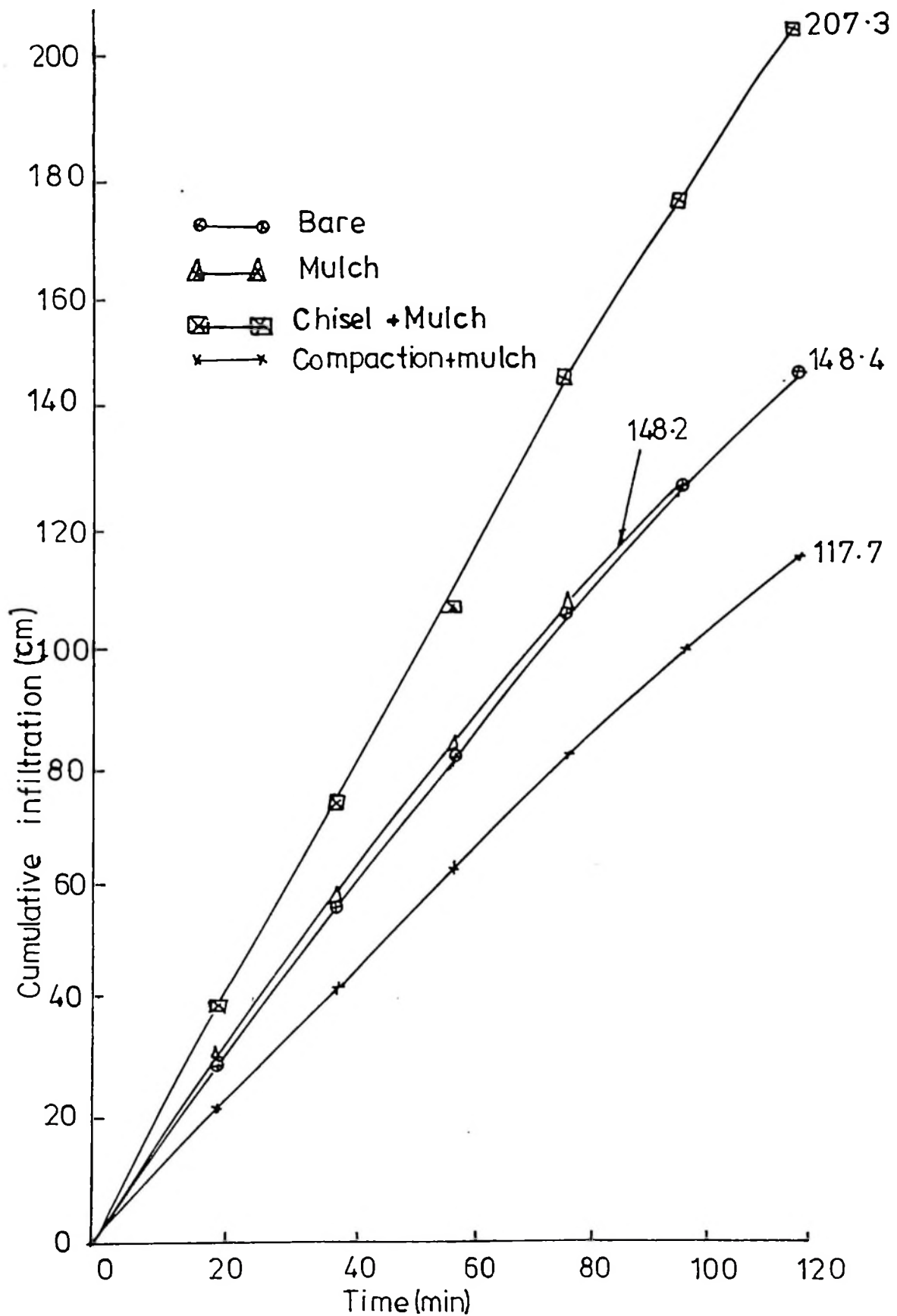


Fig 1. Effect of soil surface management on cumulative infiltration (cm) taken before sowing (may, 1985)

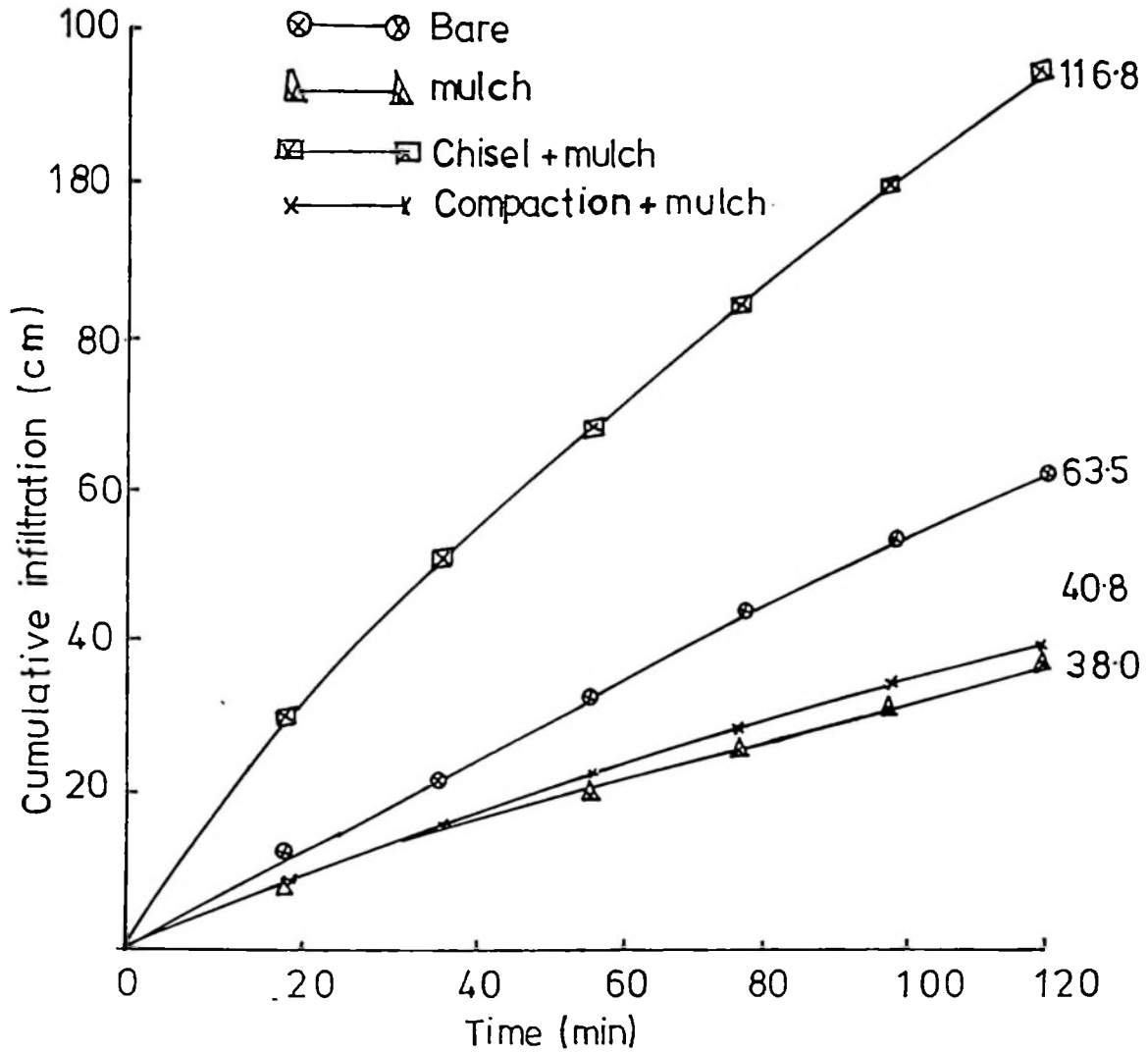


Fig 2 Effect of soil surface management on cumulative infiltration (cm) taken after maize harvest (sept, 1985)

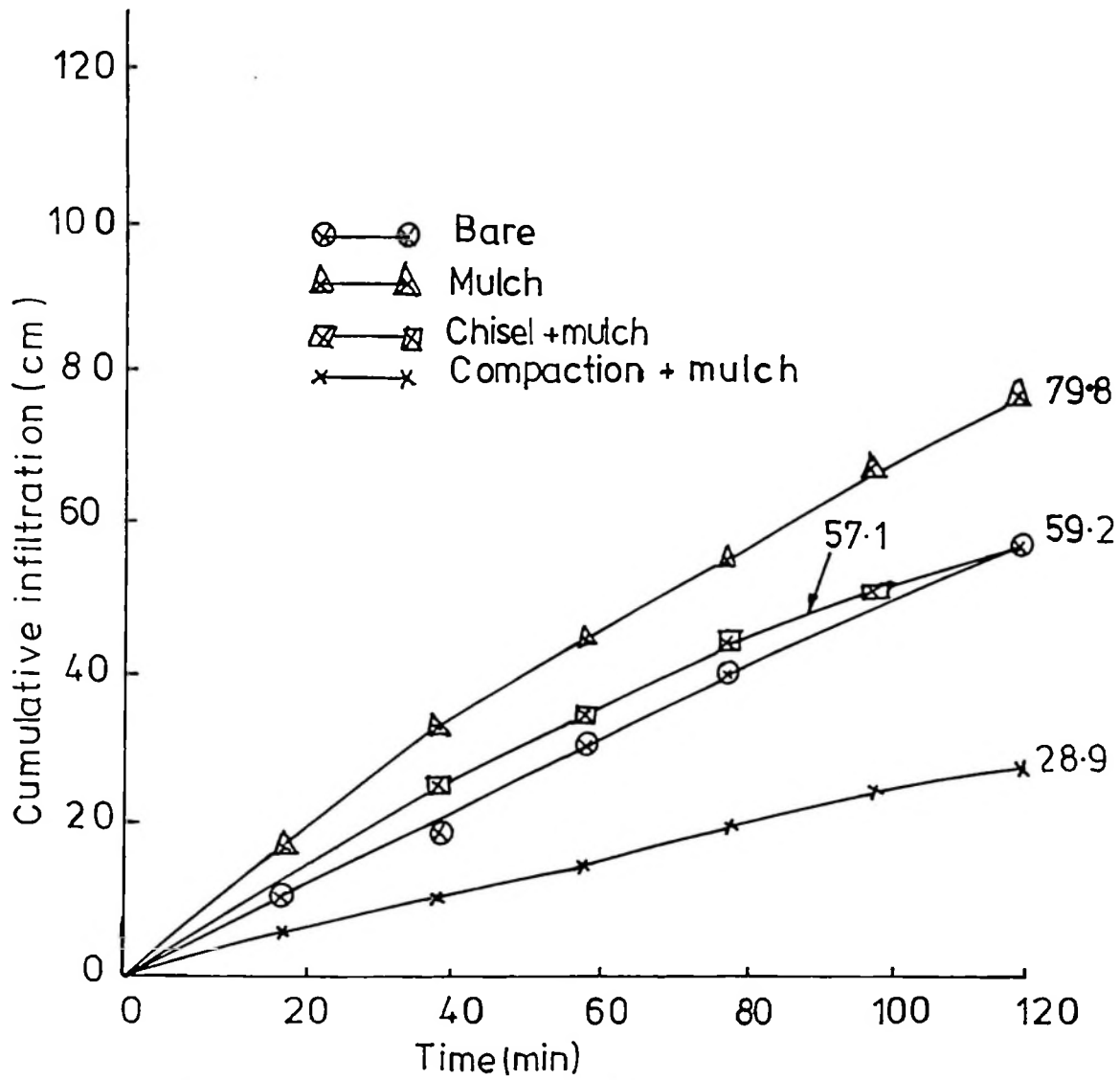


Fig 3. Effect of soil surface management on cumulative infiltration (cm) taken after soybean harvest (sept 1985)

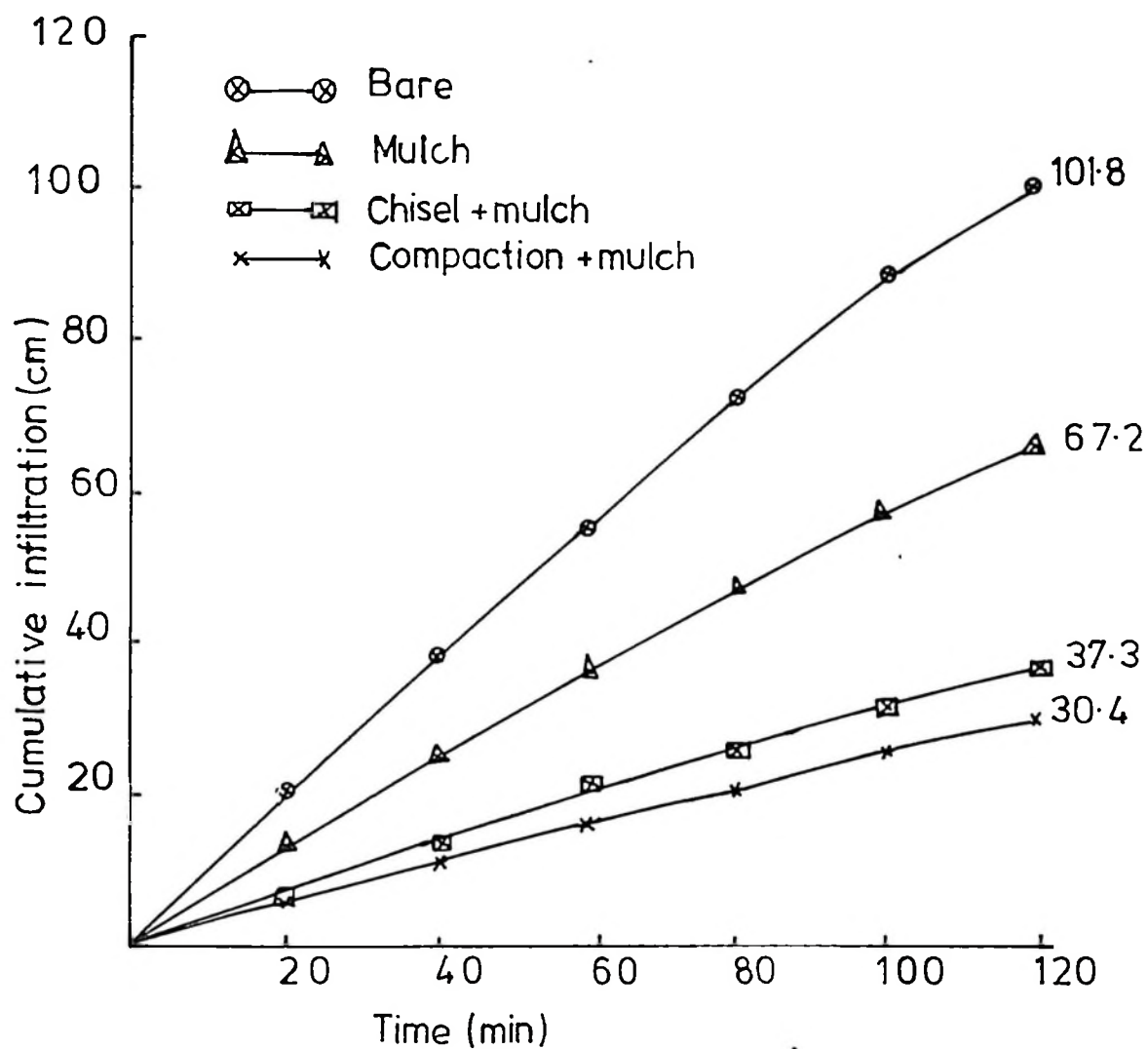


Fig 4. Effect of soil surface management on cumulative infiltration (cm) taken after cowpea harvest (1985)

reveal drastic reduction in cumulative infiltration over the experimental period. Generally compacted mulched soils have less "transmission" pores (for gas and water movement) (Cannell, 1985; Lal, 1985) and hence low total porosity values (Table 12). Thus infiltration values in compacted soils are low. Similar results were earlier reported from the same soil type (Kayombo and Lal, 1983; Kayombo, 1986).

Chiselling and mulching improve the soil structure substantially (Campbell et al., 1974; Barnes and Ellis, 1979). Chiselling loosens the soil and hence enhances total porosity (Table 12), while mulch, especially after decomposition, contributes to organic matter content of the top soil and thus increases infiltration values (Larson and Allmaras, 1971). The present data, however, reveal that only in maize did chiselling enhance infiltration (Fig. 2). while in soybeans it was mulch (Fig. 3). Similar high water infiltration values under mulch as observed for soybeans have been attributed to the presence of earthworm and root channels which provide pore continuity for water movement (Douglas et al., 1980). The high infiltration values recorded in maize at maturity when compared with soybeans and cowpeas could be ascribed to the large mass of root material on the surface soil (0 - 10 cm) which created pores for water movement. The root mass from the legumes was too small to have a marked effect on infiltration. The experimental site was fallow in the previous season hence dead roots could attribute to the high infiltration values obtained from the bare plots especially in the cowpea plots (Fig. 4).

#### 4.2.4 Soil moisture

The different soil surface manipulation regimes did not affect the moisture contents significantly at any growth stage of the crops (Table 13). However, for any crop, there was a general tendency for the moisture content to decline at emergence for each of the surface manipulations. Before emergence water loss occurs mainly through surface evaporation. But with seedling emergence loss of water occurs through evapotranspiration. The differences in soil water content among the crops at later stages of growth and development is thus a function of the surface exposure to evapotranspiration. Planophillic canopy (e.g. of legumes) could be expected to have more moisture content than erectophillic canopy regardless of the surface management. Hence, within a particular crop, the lack of difference in moisture content at a given growth stage among the different surface management schemes is a reflection of canopy cover (Table 13).

### 4.3 Effect of CaO<sub>2</sub> and soil surface management on the growth and development of maize, soybeans and cowpeas

#### 4.3.1 Seedling emergence

Data on seedling emergence of maize, soybeans and cowpeas are depicted in Tables 14, 15 and 16. While only surface manipulations influenced the rate of seedling emergence in maize and cowpeas to any significant level ( $P=0.05$ ), soybean rate of seedling emergence was responsive

Table 13 : Effect of soil surface management on soil moisture content at different maize, soybean and cowpeas growth stages

Treatment	Moisture content ( % ) by weight															
	Maize						Soybeans				Cowpea					
	BS	EM	FLO	MAT	BS	EM	FLO	MAT	BS	EM	FLO	MAT	BS	EM	FLO	MAT
Bare	9.5	5.5	12.3	9.3	9.5	5.3	12.0	7.9	9.5	5.3	13.8	9.3				
Mulch	8.5	6.3	11.5	10.5	8.5	6.3	12.3	7.5	8.5	6.3	13.8	10.2				
Chisel+mulch	9.6	6.4	13.5	9.8	9.6	6.4	11.1	8.3	9.6	6.4	13.1	9.6				
Compaction + mulch	10.8	6.8	10.2	10.8	10.8	6.8	12.1	10.1	10.8	6.8	12.2	9.6				
Mean	9.6	6.2	11.9	10.1	9.6	6.2	11.9	8.4	9.6	6.2	13.2	9.7				
LSD (5%)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV, %	10	16	15	9	11	14	10	15	11	14	10	14	10	14	10	14

BS = Before sowing

EM = At emergence

FLO = At flowering

MAT = At maturity

LSD = Least significant difference

CV = Coefficient of variation

to both oxygen supply and surface management (Table 14). In maize, the rate of seedling emergence was highest in the bare plots at both levels of oxygen supply. However, mulching alone and in combination with chiselling and compaction did not differ in their effect on maize seedling emergence. It seems that the presence of mulch impeded the emergence of maize seedlings (Rathore et al., 1983).

In the case of soybeans, rate of seedling emergence was significantly ( $P=0.05$ ) affected by both oxygen supply and surface manipulations (Table 14). Except for the chisel - mulched plots, supply of oxygen enhanced seedling emergence significantly ( $P = 0.05$ ). At any oxygen level, mulching alone and in combination with surface compaction tended to depress the rate of seedling emergence (Table 14). It is interesting that soybean seedling emergence was markedly high in the bare and chisel - mulched plots. The two surface manipulations must have been operating differently in influencing soybean seedling emergence. The bare surface plots favoured seedling emergence because there was no impedance to their extension into the surface (Plates 2 and 3). The chisel - mulched plots, however, had more moisture content (Table 13) and the soil was soft and well aerated compared to the compacted or mulched plots.

In cowpeas, the rate of seedling emergence was highest in the plots with mulch alone or in combination with chiselling irrespective of oxygen supply (Table 14). Adequate aeration, the softness of the soil and possibly higher moisture content in the mulch - chiselled plots could have favoured the fast rate of seedling emergence in cowpeas.

Table 14 : Effect of CaO<sub>2</sub> and soil surface management on the rate (plants per day) of emergence of maize, soybean and cowpea seedlings

Crop	Maize				Soybeans			Cowpeas				
	0%	10%	Mean	LSD(5%)	0%	10%	Mean	LSD(5%)	0%	10%	Mean	LSD(5%)
Surface management												
Bare	1.5	1.6	1.6	2.9	4.0	3.5	1.08	2.4	2.8	2.6		
Mulch	0.9	0.8	0.9	2.0	3.6	2.8	0.55	2.2	3.3	2.8		
Chisel + mulch	1.1	1.2	1.2	3.1	3.3	3.2	NS	3.1	3.4	3.3		
Compaction + mulch	0.9	0.8	0.9	1.2	2.8	2.0	0.11	2.0	2.8	2.4		
Mean	1.1	1.1	1.1	2.3	3.4	2.9	0.17	2.4	3.1	2.8	NS	
LSD (5%)			0.27	0.85	0.36	0.28	0.57			0.60		
CV, % (1)					3				7			
(2)					6				12			

LSD = Least significant difference  
CV = Coefficient of variation

- 1) For main plots (oxygen supply)
- 2) For subplots (surface management)

From the main Table, F - values for :

	Maize	Soybeans	Cowpeas
CaO <sub>2</sub> (1, 2)	0.068 NS	328.51; P=0.05; LSD(0.05)=0.55	16.74 NS
Surface management (3, 12)	29.28; P=0.05; LSD(0.05)=0.27	95.57; P=0.05; LSD(0.05)=0.28	7.94; P=0.05; LSD(0.05)=0.60
CaO <sub>2</sub> x surface management(3,12)	1.436 NS	26.92; P=0.05; LSD(0.05)=0.57	1.77 NS

Plate 2

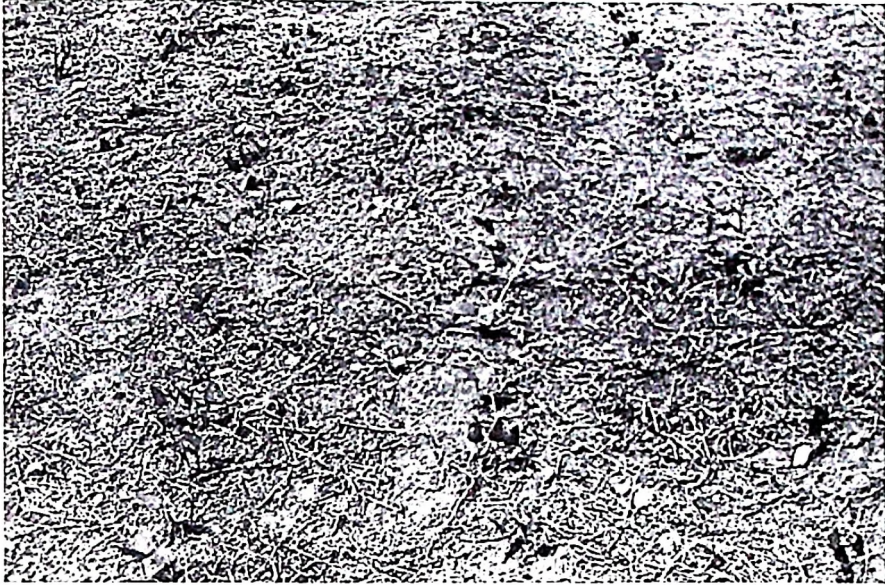


Plate 3

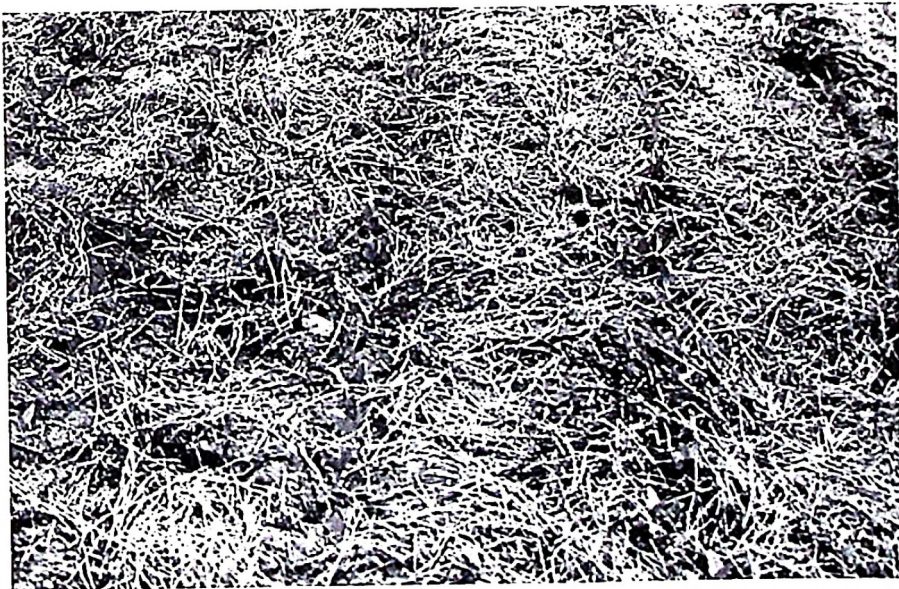


Plate 4 : soybeans emerging on a bare plot

PLATE 4 (1914) 2 side

In maize, mean period (that is, number of days) to maximum seedling emergence was influenced by soil surface manipulations, and oxygen supply had no effect at all. Mulching delayed seedling emergence markedly (Table 15). This is in complete agreement with the observations on the rate of maize seedling emergence (Table 14). The rate of seedling emergence was highest in the bare plots while in the treatments containing mulch the rates were low. Buckling and kinking of the seedlings from the mulched plots were observed suggesting that the mulch impeded seedling emergence. This extended the period taken to attain ultimate emergence (Table 15). However, mulch in combination with either chiselling or soil compaction had shortened the period for the seedlings to reach maximum emergence. In the chiselled plots, for example, aeration might have enhanced seedling emergence and thus shortened the period to maximum emergence. In the compacted plots on the other hand, high bulk density of the soil could have lowered the rate of emergence (Table 14) and prolonged the period to maximum emergence (Table 15) because of mechanical impedance to seedling emergence, low moisture availability and poor aeration (Varade and Ghildyal, 1968; Stibbe and Terpstra, 1982).

The period to maximum seedling emergence in soybeans and cowpeas was highly dependent upon oxygen supply and soil surface manipulations and there was an interaction between them. In soybeans, supply of oxygen delayed significantly ( $P = 0.05$ ) the time to maximum seedling emergence in the bare and compacted treatments (Table 15). However, effect of mulching alone or in combination with chiselling was not influenced by oxygen supply. On the other hand, mulch in combination with soil compaction significantly ( $P = 0.05$ ) reduced the period to maximum

Table 15 : Effect of CaO<sub>2</sub> and soil surface management on mean period (days) to ultimate emergence of maize, soybean and cowpea seedlings

Crop	Maize			Soybeans			Cowpeas					
	0%	10%	Mean	LSD(5%)	0%	10%	Mean	LSD(5%)	0%	10%	Mean	LSD(5%)
Surface management												
Bare	3.1	2.5	2.8		2.8	3.9	3.3	0.52	2.9	3.2	3.0	NS
Mulch	3.5	2.6	3.1		3.7	3.9	3.8	NS	4.2	3.2	3.7	0.16
Chisel + mulch	2.9	2.2	2.6		3.1	3.0	3.1	NS	3.7	3.9	3.8	NS
Compaction + mulch	2.2	1.9	2.1		1.2	2.4	1.8	0.71	2.4	3.1	2.7	0.43
Mean	2.9	2.3	2.7	NS	2.7	3.3	3.0	0.37	3.3	3.3	3.3	NS
LSD (5%)			0.73		0.44	0.32	0.54	0.71	0.30	NS	0.70	1.15
CV, % (1)		9			3					9		
(2)		16			7					12		

LSD = Least significant difference

CV = Coefficient of variation

1) For main plots (oxygen supply)

2) For subplots (surface management)

From the main Table, F - values for :

	Maize	Soybeans	Cowpeas
CaO <sub>2</sub> (1, 2)	11.24 NS	106.74; P=0.05; LSD(0.05) = 0.54	0.042
Surface management (3,12)	6.39; P=0.05; LSD(0.05)=0.73	102.36; P=0.05; LSD(0.05) = 0.37	10.80; P=0.05; LSD(0.05) = 0.70
CaO <sub>2</sub> x surface management (3,12)	0.43 NS	15.86; P=0.05; LSD(0.05)= 0.71	4.94; P=0.05; LSD(0.05) = 1.15

seedling emergence when compared with the other surface manipulations including leaving the soil surface bare (Table 15). This was unexpected because the high bulk density (Table 11) and mechanical impedance by the mulch (Rathore et al., 1983) to seedling emergence were expected to prolong emergence.

In cowpeas, oxygen supply shortened the period to maximum emergence under mulch alone and prolonged that under compact - mulched plots (Table 15). However, the period to maximum seedling emergence followed the same trend as that shown by the rate of seedling emergence (Tables 14 and 15). At any oxygen level, mulching alone and in combination with chiselling prolonged period to maximum emergence significantly ( $P = 0.05$ ).

Soil surface manipulations alone significantly ( $P = 0.05$ ) influenced percentage seedling establishment in maize in which bare soil produced the highest percentage of seedlings finally established (Table 16). This could probably be due to no or little impedance from the mulch and adequate aeration of the soil from earthworm and root activity from the previous fallow. Compaction in combination with mulch, on the other hand, significantly reduced the percentage seedling establishment, probably attributable to impedance by the mulch and soil hardness.

In soybeans, the percentage of seedlings that attained ultimate establishment was significantly higher in the mulch - compacted soil when oxygen was supplied than in the rest of the soil surface manipulations (Table 16), suggesting that oxygen supply could probably be used to reduce impedance to seedling emergence caused by mulch - compaction

Table 16 : Effect of CaO<sub>2</sub> and soil surface management on percentage seedling establishment in maize, soybean and cowpeas

Crop	Maize				Soybeans				Cowpeas			
	0%	10%	Mean	LSD(5%)	0%	10%	Mean	LSD(5%)	0%	10%	Mean	LSD (5%)
Surface management												
Bare	90.2	84.3	87.3		79.8	87.9	83.9	NS	62.6	66.0	64.3	
Mulch	78.0	82.0	80.0		66.7	81.3	74.0	NS	65.1	65.8	65.4	
Chisel + mulch	66.7	72.6	69.6		81.6	78.8	80.2	NS	72.3	83.7	78.0	
Compaction + mulch	57.7	62.2	59.9		59.3	88.0	73.7	12.0	70.8	77.5	74.1	
Mean	73.2	75.3		NS	71.9	84.0		4.8	67.7	73.2		1.45
LSD 5%			11.5		6.8	6.7	6.0	16.2			7.70	
CV, % (1)			3			4				1		
(2)			9			4				6		

LSD = Least significant difference ; NS = not significant at P = 0.05  
 CV = Coefficient of variation

- 1) For main plots (oxygen supply)
- 2) For subplots' (surface manipulations)

From the main table, F values for:

	Maize	Soybeans	Cowpeas
CaO <sub>2</sub> (1, 2)	14.05 NS	20.06; P=0.05; LSD(0.05)=4.8	69.19; P=0.05; LSD(0.05) = 1.45
Surface management (3, 12)	20.66; P=0.05; LSD(0.05)=11.50	12.98; P=0.05; LSD(0.05)=6.0	14.52; P=0.05; LSD(0.05) = 7.70
CaO <sub>2</sub> x surface management(3,12)	1.16 NS	22.90; P=0.05; LSD(0.05)=16.2	1.70 NS

treatments (Schumacher and Smucker, 1981).

In the case of cowpeas, however, soil surface management and oxygen supply individually increased the percentage of seedlings established (Table 16). Mulching in combination with chiselling resulted in a much higher percentage of seedlings than in any of the bare, mulched or compacted treatments. The improvement in seedling establishment achieved through chiselling could be ascribed to better water infiltration and storage and aeration (Campbell et al., 1974; Doty et al., 1975). It is also interesting to note that compaction did not affect the percentage of seedlings that attained ultimate establishment in cowpeas as opposed to its effect in maize and soybeans. It has been reported by Maurya and Lal (1979b) and Babalola (1980) that cowpeas can tolerate soil compaction because their roots are able to penetrate soils of high strength and high bulk density.

#### 4.3.2 Plant height

Data on plant height for maize, soybeans and cowpeas at different stages of growth are depicted in Tables 17, 18, 19 and 20, respectively. In general, plant height increased with time and there was no indication of the growth reaching a plateau in any of the treatments. While the growth rate in maize was fastest over the 7<sup>th</sup> and 9<sup>th</sup> weeks after sowing the rate of growth in soybeans and cowpeas was rather gradual during the entire growth period (Tables 17, 18, 19 and 20). Oxygen supply did not affect plant height in any crop at any surface management system (Tables 17, 18, 19 and 20).

Table 17 : Effect of  $\text{CaO}_2$  and soil surface management in maize, soybean and cowpea plant height (cm) at 4 WAS

Crop	Maize			Soybeans			Cowpeas					
	0%	10%	Mean	LSD (5%)	0%	10%	Mean	LSD (5%)	0%	10%	Mean	LSD (5%)
Surface management												
Bare	38.9	30.6	34.8		14.0	13.6	13.8		12.2	11.1	11.6	
Mulch	30.5	38.9	34.7		14.6	14.3	14.5		12.8	14.3	13.5	
Chisel + mulch	41.9	39.6	40.7		15.7	16.0	15.9		13.3	14.5	13.9	
Compaction + mulch	26.9	30.4	28.6		11.4	12.9	12.1		10.5	11.1	10.8	
Mean	34.5	34.9		NS	13.9	14.2		NS	12.2	12.8		NS
LSD (5%)			10.56				2.53				NS	
CV, % (1)	4				6				1			
(2)	13				10				2			

WAS = weeks after sowing

NS = not significant at  $P = 0.05$

LSD = least significant difference

CV = coefficient of variation

1) for main plots (oxygen supply)

2) for subplots (surface management)

F - values for :

	Maize	Soybean	Cowpea
$\text{CaO}_2$ ( 1, 2)	0.08 NS	0.16 NS	0.75 NS
Surface management ( 3, 12)	4.154; $P=0.05$ ; $\text{LSD}(0.05) = 10.56$	7.131; $P=0.05$ ; $\text{LSD}(0.05)=2.53$	3.45 NS
$\text{CaO}_2 \times$ surface management ( 3, 12)	2.25 NS	0.53 NS	0.54 NS



Table 19 : Effect of CaO<sub>2</sub> and soil surface management in maize, soybean and cowpea plant height (cm) at 7 WAS

Crop	Maize				Soybeans				Cowpeas			
	0%	10%	Mean	LSD (5%)	0%	10%	Mean	LSD (5%)	0%	10%	Mean	LSD (5%)
Surface management												
Bare	86.1	78.9	82.5		32.1	34.5	33.3		22.3	19.9	21.1	
Mulch	74.7	93.4	84.0		29.6	31.9	30.8		20.7	29.4	25.0	
Chisel + mulch	76.6	92.3	84.5		33.7	35.9	34.8		23.4	29.0	26.2	
Compaction + mulch	67.3	80.2	73.7		27.7	30.3	29.0		18.6	20.7	19.6	
Mean	76.2	86.2		NS				NS				NS
LSD (5%)				NS								NS
CV, % (1)	8				9				9			
(2)	13				12				19			

75

WAS = weeks after sowing  
 NS = not significant at P = 0.05  
 LSD = least significant difference  
 CV = coefficient of variation

F - values for :

	Maize	Soybeans	Cowpeas
CaO <sub>2</sub> ( 1, 2)	3.97 NS	1.13 NS	4.52 NS
Surface management ( 3, 12)	1.45 NS	2.80 NS	3.09 NS
CaO <sub>2</sub> x surface management ( 3, 12)	1.97 NS	0.002 NS	1.79 NS

At 4 week stage the height of maize plants was greatly influenced by surface manipulations (Table 17). Chiselling in combination with mulching greatly enhanced plant height while mulching in combination with compaction seemed to depress it. Mulching alone did not have any effect on plant height.

At 5 week stage, maize plant height was influenced only by surface manipulations with mulch alone and in combination with chiselling enhancing plant height. However, the increase in height was significant ( $P = 0.05$ ) only when compared to that in mulching in combination with compaction which was markedly depressed (Table 18; Plate 4). This showed that mulching alone or in combination with chiselling did not affect maize plant height to any greater extent compared to when the surface was left bare.

At 7 and 9 weeks after sowing, neither oxygen supply nor surface manipulation had any effect on plant height (Tables 19 and 20). The differential response during these stages of maize growth appears to be inconsistent and does not lend itself to any explanation.

The height of soybean plants was not affected by oxygen supply at any of the growth stages (Tables 17, 18, 19 and 20). However, surface manipulations influenced plant height only during the 4<sup>th</sup> and 5<sup>th</sup> week (Tables 17 and 18). During the 4<sup>th</sup> week, only mulch in combination with chiselling enhanced plant height (Table 17) while at week 5, maize plant height was significantly ( $P = 0.05$ ) higher in the bare, mulched and mulched in combination with chiselling than in the compacted plots (Table 18; Plate 5). At both stages of growth mulching and chiselling

Table 20 : Effect of CaO<sub>2</sub> and soil surface management on maize and soybean plant height (cm) at 9 WAS

Crop	Maize				Soybeans				
	CaO <sub>2</sub>	0%	10%	Mean	LSD (5%)	0%	10%	Mean	LSD (5%)
Surface management									
Bare		187.3	170.9	179.1		52.0	52.5	52.3	
Mulch		182.5	205.3	193.9		50.9	59.5	55.2	
Chisel + mulch		187.1	193.4	190.3		53.1	52.9	53.0	
Compaction + mulch		151.8	167.2	159.5		50.2	51.1	50.7	
Mean		177.2	184.2		NS	51.5	54.0		NS
LSD (5%)					NS				NS
CV, % (1)		8				7			
(2)		6				8			

WAS = weeks after sowing;

NS = not significant at P = 0.05

LSD = least significant difference

CV = coefficient of variation

1) for main plots (oxygen supply)

2) for sub plots (surface management)

F - values for :

	<u>Maize</u>	<u>Soybeans</u>
CaO <sub>2</sub> ( 1, 2)	0.41 NS	0.75 NS
Surface management (3, 12)	2.50 NS	1.08 NS
CaO <sub>2</sub> x surface management ( 3, 12)	0.75 NS	1.30 NS



Plate 4 : Maize plant showing plant size between mulched-  
chiselled (left) and mulched - compacted (right)  
plots



Plate 5 : Soybean plant grown on mulched - ~~mis~~elled (left)  
and mulched - compacted (right) plots

appeared to improve water infiltration and storage, and aeration which might have encouraged vigorous root and plant growth (Campbell et al., 1974; Doty et al., 1975). However, in subsequent stages of growth (7 and 9 WAS ) plant height did not respond to either oxygen supply or surface manipulations (Table 19 and 20 ) implying that their effects might have been diluted over time.

The height of cowpea plants was also not affected by the supply of oxygen at any stage of growth (Tables 17, 18 and 19). But, surface manipulations had an effect on cowpea height only during the 5<sup>th</sup> week (Table 18). During this stage, mulch alone and in combination with chiselling significantly ( $P = 0.05$ ) enhanced the height of cowpea plants. It seems that leaving the plots bare or mulching in combination with compaction inhibit cowpea growth. The mature crop was harvested during the 9<sup>th</sup> week.

It is evident from this study that oxygen supply did not affect plant height of the crops tested. This could be due to the fact that oxygen usually affects early stages of growth (e.g. emergence) and that little change occurs on plant growth at the later stages (e.g. plant height, etc) (Anon., 1981). Ogunremi et al. (1981), reported improved emergence, number of leaves, pods and grain yield of soybeans and cowpeas on a poorly drained soil. It could also be that the soil at the site of the present study was well aerated because of root channels from the previous fallow, and that the supply of oxygen under such conditions will have no effect on crop growth (Wiersma and Mortland, 1953; Kolotovskiy, 1985). Surface manipulations, on the other hand, invariably affected plant growth nearly at all growth stages, except

at 7 and 9 weeks after sowing, with mulching alone or in combination with chiselling enhancing plant height, and compaction depressing it. Mulching and chiselling appeared to have improved water infiltration and storage, and aeration, while high bulk density (Table 12) and lack of adequate aeration (Table 13) together in the mulch-compacted plots could have contributed to the decline in growth of the three crops at their different stages of growth (Gupta and Abrol, 1970; Raghavan et al., 1978; Maurya and Lal, 1979b). Contrary to this, Stibbe and Terpstra (1982) reported a linear increase in plant height with increasing soil strength probably because nutrients were not limiting (Brar et al., 1982; Nogueira et al., 1983).

#### 4.3.3 Number of leaves

The number of leaves per plant for maize, soybeans and cowpeas at different stages of growth are presented in Tables 21, 22, 23 and 24. In general, the number of leaves per plant was influenced by surface management and oxygen supply did not seem to have any effect. At 4 week stage surface manipulations did not affect the number of leaves per plant in maize. However, the number of maize leaves was significantly dependent upon surface manipulations from the 5<sup>th</sup> week after sowing to harvest (Tables 22, 23 and 24). At week 5, for example, mulch alone and in combination with chiselling enhanced leaf production while compaction or to some extent leaving the soil surface bare depressed leaf production (Table 22). Only mulch in combination with chiselling enhanced maize leaf production to any significant ( $P = 0.05$ ) level during the 7<sup>th</sup> week after sowing (Table 23).

Table 21 : Effect of CaO<sub>2</sub> and soil surface management on the number of leaves per plant of maize, soybeans and cowpeas at 4 WAS

Crop	Maize			Soybeans			Cowpeas					
	0%	10%	Mean	LSD (5%)	0%	10%	Mean	LSD (5%)	0%	10%	Mean	LSD (5%)
Surface management												
Bare	7.7	6.5	7.1		16.1	15.2	15.6		28.5	33.9	31.2	
Mulch	7.1	7.6	7.4		17.5	15.1	16.3		33.3	42.3	37.8	
Chisel + mulch	6.9	7.3	7.1		19.1	16.6	17.9		36.4	36.6	36.5	
Compaction + mulch	6.5	6.5	6.5		14.2	13.3	13.7		24.4	33.9	29.1	
Mean	7.1	7.0	NS	NS	16.7	15.1	2.03	NS	30.7	36.7	6.39	NS
LSD (5%)												
CV, % (1)	7				5				12			
(2)	9				11				13			

WAS = weeks after sowing  
 NS = not significant at P = 0.05  
 LSD = least significant difference  
 CV = coefficient of variation  
 1) for main plots ( oxygen supply)  
 2) for subplots ( surface management)

F - values for :

	Maize	Soybeans	Cowpeas
CaO <sub>2</sub> ( 1, 2 )	0.025 NS	7.435 NS	3.184 NS
Surface management ( 3, 12 )	1.813 NS	5.391; P=0.05; LSD(0.05) = 2.03	5.051; P=0.05; LSD(0.05) = 6.39
CaO <sub>2</sub> x surface management ( 3, 12 )	2.039 NS	0.377 NS	1.340 NS

Table 22 : Effect of CaO<sub>2</sub> and soil surface management on the number of leaves per plant of maize, soybeans and cowpeas at 5 WAS

Crop	Maize			Soybeans			Cowpeas		
	0%	10%	Mean LSD (5%)	0%	10%	Mean LSD (5%)	0%	10%	Mean LSD (5%)
Surface management									
Bare	8.3	8.3	8.3	20.1	21.1	20.6	72.3	76.9	74.6
Mulch	9.0	9.1	9.1	23.6	22.5	23.1	88.7	82.5	85.6
Chisel + mulch	8.5	9.5	9.0	22.8	21.1	22.0	78.8	83.5	81.1
Compaction + mulch	7.6	8.4	8.0	20.6	20.7	20.6	61.5	66.7	64.1
Mean	8.4	8.8	NS	21.8	21.4	NS	75.3	77.4	NS
LSD (5%)	0.996			NS			NS		
CV, % (1)	5			7			4		
(2)	6			14			16		

83

WAS = weeks after sowing

NS = not significant at P = 0.05

LSD = least significant difference

CV = coefficient of variation

- 1) for main plots (oxygen supply)
- 2) for subplots (surface management)

F - values for :

	Maize	Soybeans	Cowpeas
CaO <sub>2</sub> ( 1, 2)	1.693 NS	0.104 NS	0.896 NS
Surface management ( 3, 12)	4.978; P = 0.05; LSD (0.05) = 0.996	0.985 NS	3.489 NS
CaO <sub>2</sub> x surface management ( 3, 12)	1.279 NS	0.258 NS	0.309 NS

Table 23 : Effect of CaO<sub>2</sub> and soil surface management on the number of leaves per plant of maize, soybeans and cowpeas at 7 WAS

Crop	Maize			Soybeans			Cowpeas					
	0%	10%	Mean	LSD (5%)	0%	10%	Mean	LSD (5%)	0%	10%	Mean	LSD (5%)
Surface management												
Bare	9.7	9.8	9.8		32.1	34.5	33.3		100.1	107.6	103.8	
Mulch	9.2	10.7	9.9		29.6	31.9	30.8		105.7	102.0	103.8	
Chisel + mulch	10.7	10.9	10.8		33.7	35.9	34.8		108.0	109.7	108.8	
Compaction + mulch	8.5	9.9	9.2		27.8	30.3	29.0		90.4	111.1	100.7	
Mean	8.5	10.3	0.97	NS	30.8	33.1	NS	NS	101.0	107.6	NS	NS
LSD (5%)												
CV, % (1)	6				9				9			
(2)	9				12				10			

WAS = weeks after sowing

NS = not significant at P = 0.05

LSD = least significant difference

CV = coefficient of variation

- 1) for main plots (oxygen supply)
- 2) for subplots (surface management)

F- values for :

	Maize	Soybeans	Cowpeas
CaO <sub>2</sub> ( 1, 2)	2.373 NS		0.760 NS
Surface management ( 3, 12)	3.492; P=0.05; LSD (0.05) = 0.97	2.770 NS	0.573 NS
CaO <sub>2</sub> x surface management ( 3, 12)	1.240 NS	0.001 NS	1.398 NS

Table 24 : Effect of  $\text{CaO}_2$  and soil surface management on the number of leaves per plant of maize and soybeans at 9 WAS

Crop	Maize				Soybeans				
	$\text{CaO}_2$	0%	10%	Mean	LSD (5%)	0%	10%	Mean	LSD (5%)
Surface management									
Bare		11.5	12.0	11.8		78.1	89.7	83.9	
Mulch		12.3	13.5	12.9		88.8	96.8	92.8	
Chisel + mulch		12.9	12.7	12.8		79.0	89.4	84.2	
Compaction + mulch		12.3	12.6	12.5		76.5	82.0	79.3	
Mean		12.3	12.7		NS	80.6	89.3		NS
LSD (5%)				0.8					NS
CV, % (1)		7				5			
(2)		5				18			

WAS = weeks after sowing

NS = not significant at  $P = 0.05$

LSD = least significant difference

CV = coefficient of variation

1) for main plots (oxygen supply)

2) for sub plots (surface management)

F-values for :

	<u>Maize</u>	<u>Soybeans</u>
$\text{CaO}_2$ ( 1, 2)	0.318 NS	6.869 NS
Surface management (3, 12)	4.597; $P=0.05$ ; $\text{LSD}(0.05)=0.8$	0.866 NS
$\text{CaO}_2 \times$ surface management(3, 12)	1.376 NS	0.050 NS

The effect of mulching on the number of leaves was also evident during the 9<sup>th</sup> week after sowing (Table 24). At this stage, mulching alone or in combination with either chiselling or compaction had significantly ( $P = 0.05$ ) more leaves compared to when the surface was left bare.

Soybeans and cowpeas responded to oxygen supply and soil surface manipulations in the same manner (Tables 21, 22, 23 and 24). While oxygen supply did not affect leaf production in either crop at any of the growth stages, surface manipulations affected leaf production only during the 4<sup>th</sup> week after sowing. In both crops, mulch alone and in combination with chiselling favoured leaf production while compaction or to some extent bare surface seemed to depress leaf production (Table 21). Chiselling increases soil aeration through soil loosening while mulching conserves soil moisture. Hence the good aeration and possibly more moisture content could have attributed to the high leaf production under these treatments (Doty *et al.*, 1975). On the other hand, compacting the soil or leaving it bare usually results in increased soil strength and hence low moisture conservation and poor aeration. High soil strength and low moisture conservation and poor aeration in such a soil might have contributed to the low number of leaves produced by these crops (Kayombo, 1986 ; Ogunremi *et al.*, 1986:b).

Soybeans and cowpeas, however differ in the trend at which leaves are produced. In soybeans, the number of leaves per plant increases gradually for the first 7 weeks after sowing (Tables 21, 22 and 23). However, after the 7<sup>th</sup> week, there is a rapid leaf production

possibly reaching the maximum on week 9 after sowing (Table 24). In cowpeas, on the other hand, most leaves are produced during the first 5 weeks after sowing beyond which the rate declines (Tables, 21, 22 and 23). This could be ascribed to the difference in the phenology of the two crops. The cowpea cultivar (TVx 3236) takes about 75 to 80 days to mature as opposed to 110 to 120 days in soybeans (TGx 536 - 02 D). As such maximum leaf production in cowpea has to be attained before pod formation sets in, 5 weeks after sowing. The difference in leaf production in the two crops may also be attributed to the differential utilization of soil and other environmental resources (e.g. water, light, etc.) (Sheriff and Muchow, 1984).

#### 4.3.4 Root growth

Data on root growth was based on length (cm), density ( $\text{mg cm}^{-3}$ ) and root weight (g per plant). In maize, oxygen supply tended to depress root growth (Table 25) with mean root weight being depressed significantly ( $P = 0.05$ ). Hence maize root growth was mainly influenced by surface manipulations (Table 25). Maize roots were longest under mulch in combination with chiselling and shortest in the compacted plots.

Table 25 : Effect of CaO<sub>2</sub> and soil surface management on root growth of maize

CaO <sub>2</sub> Surface management	Length (cm)			Weight (g)			Density (mg cm <sup>-3</sup> )					
	0%	10%	Mean	LSD (5%)	0%	10%	Mean	LSD (5%)	0%	10%	Mean	LSD (5%)
Bare	16.5	14.3	15.4		12.6	6.8	9.7		0.74	0.51	0.63	
Mulch	15.0	13.8	14.4		20.5	14.2	17.4		1.94	1.97	1.96	
Chisel + mulch	26.0	22.0	24.0		19.4	12.7	16.1		2.55	1.70	2.13	
Compaction + mulch	12.8	11.7	12.3		12.5	10.0	11.2		2.14	2.29	2.21	
Mean	17.6	15.5		NS	16.3	10.9		4.1	1.84	1.62		NS
LSD (5%)			9.7				3.9				1.1	
CV, % (1)	6				4				15			
(2)	16				16				36			

LSD = least significant difference  
 NS = not significant at P = 0.05  
 CV = coefficient of variation

- 1) for main plots (oxygen supply)
- 2) for sub plots (surface management)

From the main table , F - values for :

	Length	Weight	Density
CaO <sub>2</sub> ( 1, 2)	7.41 NS	128.44; P=0.05; LSD(0.05)=4.1	1.17 NS
Surface management ( 3, 12)	23.96; P=0.05; LSD 0.05) = 9.7	16.85; P=0.05; LSD(0.05)=3.9	8.74; P=0.05; LSD(0.05)=1.1
CaO <sub>2</sub> x surface management (2,12)	0.40 NS	1.18 NS	0.79 NS

Root weight, was enhanced by mulch alone or in combination with chiselling (Table 25). Once again, compaction and bare surface significantly depressed root weight. Supply of oxygen depressed maize root weight by about 33%. While the results of soil manipulations can be explained by bulk density, aeration and moisture content, it is difficult to explain the depressive effect of oxygen on root growth. It becomes even more difficult when decrease in weight varies with surface manipulations. For example, in the bare surface the decrease is over 46% while in the compacted mulched soils it was only about 20% (Table 25).

The effect of mulching on root growth is more evident in root density (Table 25). The maize root density under mulch alone or in combination with either chiselling or compaction is more than three-fold that obtained from the bare soil (Table 25). Low moisture reserves due to evaporation from the bare soil could account for the poor root growth. While the high root density in mulch alone or in combination with chiselling could be explained by the adequate water infiltration and storage, and aeration; that in the mulch - compacted soil could be ascribed to mechanical impedance in the deeper layers which resulted in most roots growing in the surface layers of the soil. Agrawal et al. (1975), Nogueira et al. (1983), Agnew and Carrow (1985) and Bauder et al. (1985) have reported increased concentration of crop roots in the upper soil layers (0-10 cm) due to mechanical impedance on root growth to deeper layers. Insufficient oxygen in the lower soil layers may also have reduced root growth especially when the moisture content is high .

Data on root growth in soybeans are depicted in Table 26. Lateral root length and root density were significantly ( $P = 0.05$ ) affected by both oxygen supply and soil surface manipulations. Oxygen supply markedly enhanced soybean lateral root length (Table 26) in the mulch compacted soil. The supply of oxygen might have improved aeration in the compacted soil. Length of soybean tap root and root weight, on the other hand, were significantly ( $P = 0.05$ ) affected by surface manipulations in which mulch in combination with chiselling produced the highest root length and weight (Table 26). Improved aeration, high moisture and nutrient reserves from the mulch could have attributed to the good root growth in these plots. It is interesting to note that growth of tap root in the compacted soil was completely inhibited at both levels of oxygen supply, suggesting that the layer just beneath the soil surface might have provided high resistance to downward (vertical) growth of the soybean tap roots (Barley and Greacen, 1967). Voorhees (1977) also recorded a total absence of soybean roots in the 0 - 25 cm layer of a compacted soil.

Data on root growth in cowpeas are presented in Table 27. Root growth was significantly ( $P = 0.05$ ) influenced by both oxygen supply and surface manipulations (Table 27). The length of tap roots was significantly ( $P = 0.05$ ) enhanced by oxygen supply under mulch alone and in combination with chiselling. Lateral roots, however, did not respond to oxygen supply. In the absence of external supply of oxygen, surface manipulations did not have a marked effect on the length of tap root in cowpeas (Table 27).

Table 26 : Effect of CaO<sub>2</sub> and soil surface management on root growth of soybeans

CaO <sub>2</sub> Surface management	Length ( cm )												Density (mg cm <sup>-3</sup> )			
	Lateral root				Tap root				Weight (g)				Density			
	0%	10%	Mean	LSD (5%)	0%	10%	Mean	LSD (5%)	0%	10%	Mean	LSD (5%)	0%	10%	Mean	LSD (5%)
Bare	12.3	18.2	15.3	NS	8.5	7.3	7.9		0.63	0.60	0.62		0.67	1.19	0.93	0.30
Mulch	20.2	18.7	19.5	NS	8.7	8.9	8.8		0.77	0.87	0.82		1.43	1.08	1.26	NS
Chisel + mulch	31.0	32.2	31.6	NS	7.5	11.1	9.3		1.23	1.17	1.20		1.08	0.71	0.90	NS
Compaction + mulch	8.0	19.0	13.5	6.6	0	0	0		0.50	0.90	0.70		0.97	0.86	0.82	NS
Mean	17.9	22.0		NS	5.9	6.6		NS	0.78	0.88		NS	1.04	0.92		NS
LSD (5%)	7.1	6.3	6.0		2.1	2.3	1.9				0.27		0.29	0.38	0.30	
CV, % (1)	13				11				4				10			
(2)	17				17				19				17			

LSD = least significant difference

NS = not significant at P = 0.05

CV = coefficient of variation

1) for main plots (oxygen supply)

2) for sub plots (surface management)

From the main table, F - values for :

CaO<sub>2</sub> ( 1, 2)  $\frac{LRL^*}{TRL^+}$  3.86 NS  $\frac{TRL^+}{Weight}$  1.48 NS  $\frac{Density}{Weight}$  2.26 NS

Surface management (3,12) 34.68;P=0.05;LSD(0.05)=6.0 119.91;P=0.05;LSD(0.05)=1.9 16.80;P=0.05;LSD(0.05)=0.27 7.68;P=0.05;LSD(0.05)=0.30

CaO<sub>2</sub> x surface management 3.97;P=0.05;LSD(0.05)=7.5 5.41;P=0.05;LSD(0.05) =2.99 2.85 NS 9.46;P=0.05;LSD(0.05)=0.80 ( 3, 12 )

\* LRL = lateral root length

+ TRL = tap root length

Table 27 : Effect of CaO<sub>2</sub> and soil surface management on root growth of cowpeas

CaO <sub>2</sub>	Length (cm)												Weight (g)			Density (mg cm <sup>-3</sup> )					
	Lateral root				Tap root																
	0%	10%	Mean	LSD (5%)	0%	10%	Mean	LSD (5%)	0%	10%	Mean	LSD (5%)	0%	10%	Mean	LSD (5%)	0%	10%	Mean	LSD (5%)	
Surface management																					
Bare	13.7	11.3	12.5	NS	13.7	17.0	15.3	NS	0.80	1.07	0.93		0.71	0.56	0.64	NS					
Mulch	20.0	29.7	24.8	10.5	13.3	25.8	19.6	10.5	0.97	1.23	1.10		0.48	0.57	0.53	NS					
Chisel + mulch	27.8	31.0	29.4	3.8	15.7	21.5	18.6	3.8	1.10	1.93	1.52		1.72	0.76	1.24	0.39					
Compection + mulch	10.8	14.9	12.9	NS	9.2	10.5	9.8	NS	0.50	0.63	0.57		0.23	0.34	0.29	0.02					
Mean	18.1	21.7	6.1	NS	13.0	18.7	4.8	2.5	0.84	1.22	0.38		0.21	0.20	0.17	NS					
LSD (5%)	5				5			7					10								
CV, % (1)	17				7			21					15								

LSD = least significant difference

NS = not significant at P = 0.05

CV = coefficient of variation

1) for main plots (oxygen supply)

2) for sub plots ( surface management)

From the main table F - values for :

CaO <sub>2</sub>	LRL*	TRL <sup>+</sup>	Weight	Density
CaO <sub>2</sub> ( 1, 2)	18.38 NS	67.82; P=0.05; LSD(0.05)=1.5	42.19; P=0.05; LSD(0.05)=0.13	16.02 NS
Surface management (3,12)	37.20; P=0.05; LSD(0.05)=6.1	15.86; P=0.05; LSD(0.05)=4.8	20.32; P=0.05; LSD(0.05)=0.38	103.81; P=0.05; LSD(0.05)=0.1
CaO <sub>2</sub> x surface management ( 3, 12 )	3.08 NS	4.82; P=0.05; LSD(0.05)=6.5	3.19 NS	40.28; P=0.05; LSD(0.05)=0.5

\* LRL = lateral root length

+ TRL = tap root length

However, when oxygen was supplied (10% w/w), mulching alone and in combination with chiselling, the length of tap root was more or less doubled when compared to those obtained from the compacted plots. Root weight was also influenced by both oxygen supply and surface manipulations (Table 27). Supply of oxygen favoured mean root dry matter production. Once again mulching in combination with chiselling produced the largest root weight. Bare surface and mulch in combination with compaction significantly ( $P = 0.01$ ) depressed root dry matter production. Root density was mainly influenced by surface manipulations and their interactions with oxygen supply (Table 27). Oxygen seemed to depress root density under mulch - chiselling plots while the reverse was true when mulch was combined with compaction. These results suggest that the poor response to oxygen in the mulch chiselled soil can not be explained by inadequate aeration but probably by a complexity of other factors.

#### 4.3.5 Grain yield

##### 4.3.5.1 Maize

Maize grain yield as influenced by oxygen supply and soil surface management is depicted in Table 28. Neither oxygen supply nor surface management influenced maize grain yield to any significant level. In general, supply of oxygen tended to increase maize yield with a narrow margin (2.86 to 3.08 Mg ha<sup>-1</sup>). The effect of surface management was not influenced by oxygen supply; hence the yields were comparable in both 0% and 10% oxygen supply. However, when the surface was

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Table 28 : Effect of CaO<sub>2</sub> and soil surface management on grain yield (Mg ha<sup>-1</sup>) of maize, soybeans and cowpeas

Crop	Yield (Mg ha <sup>-1</sup> )											
	Maize				Soybeans				Cowpeas			
	0%	10%	Mean	LSD (5%)	0%	10%	Mean	LSD (5%)	0%	10%	Mean	LSD (5%)
Bare	2.99	2.62	2.81		2.04	1.98	2.01		1.15	1.26	1.21	
Mulch	2.42	3.96	3.19		1.54	1.78	1.66		1.33	1.29	1.26	
Chisel + mulch	3.42	3.03	3.23		2.00	1.89	1.95		1.10	1.38	1.24	
Compaction + mulch	2.60	2.70	2.66		1.29	1.90	1.60		1.03	1.10	1.10	
Mean	2.86	3.08	2.97	NS	1.72	1.89	1.81	NS	1.13	1.26	1.20	NS
LSD (0.05)			NS				NS				NS	
CV, % (1)	11				7				9			
(2)	19				18				15			

NS = not significant at P = 0.05  
 LSD = least significant difference  
 CV = coefficient of variation

- 1) for main plots (oxygen supply)
- 2) for sub plots (surface management)

F - values for :

	Maize	Soybeans	Cowpeas
CaO <sub>2</sub> (1, 2)	0.79 NS	0.41 NS	2.25 NS
Surface management ( 3, 12)	0.98 NS	1.70 NS	1.55 NS
CaO <sub>2</sub> x surface management ( 3, 12 )	2.57 NS	0.54 NS	0.29 NS

left bare or compacted and mulched the yields were lower ( 2.81 and 2.66 Mg ha<sup>-1</sup>, respectively) than when it was mulched or chiselled and mulched (3.19 and 3.23 Mg ha<sup>-1</sup>, respectively ).

That maize grain yield was not influenced by oxygen supply is not surprising. Grain yield is dependent upon the factors governing all the processes of plant growth right from establishment. In this case, oxygen supply had no effect on seedling establishment (Section 4.3.1), plant height (section 4.3.2), number of leaves per plant (section 4.3.3) and root growth, except root dry weight (section 4.3.4). The lack of response to oxygen supply could be ascribed to a number of factors. In this particular case, the experimental site was a fallow during the previous season and the soil could have been well aerated. Such aeration might have been due to channels from earthworms and roots of vegetation that existed on the experimental site prior to establishment of the experiment (Lal, 1985). It has been reported that a crop like potato in a well aerated soil will not respond to oxygen supply (Kolotovskiy, 1985). It would appear that such crops would benefit from oxygen supply only in poorly aerated soils (Ogunremi et al., 1981; Kolotovskiy, 1985).

Soil surface management, on the other hand, had marked effects on seedling emergence (section 4.3.1), plant height (section 4.3.2), number of leaves per plant (section 4.3.3) and root growth (section 4.3.4). However, maize grain yield was not affected by soil surface management (Table 28). In all these parameters, mulching or in combination with chiselling favoured the growth of maize (Appendix 6 ).

Although the differences were not significant, grain yields obtained from these surface management systems were relatively higher than those obtained from bare and compacted soil surface (Table 28). This suggests that the grain yield data followed the same general pattern as that obtained from the vegetative growth phase of maize. Under IITA conditions maize variety TZB - GUSAU yields between 3.0 and 5.0 Mg ha<sup>-1</sup> (Anon., 1982, 1984) which is comparable to the grain yield data under mulch alone and in combination with chiselling in the present experiment. Similar results have also been reported by Lal (1974) and Huxley (1979), under mulch conditions and by Doty et al. (1975) and Doty and Reicosky (1978) under chiselling alone.

Several factors contribute to improved maize yields under mulch conditions. Such factors include : favourable soil structure, temperature, greater water retention capacity, higher microbial activity and higher organic matter content (Patterson, 1960; Nangju, 1979; Power et al., 1986). Improved maize grain yields in the chiselled plots could be attributed to such factors as reduced impedance to root growth, increased water infiltration and storage, which result in more water and nutrient extraction from the deeper soil horizons (Campbell et al., 1974).

Yield reductions from the bare soils could be attributed to excessive evapotranspiration which could possibly be compounded by excessive surface soil temperature (Doran et al., 1984 ). Compaction, on the other hand, could reduce maize grain yield through high soil strength (or bulk density). Generally high bulk density influences the crop at various stages of development including seedling emergence,

vegetative and root growth, and eventually yield (Taylor et al., 1986; Varade and Ghildyal, 1968). In the present study, bulk density was highest in the compacted soil and particularly so at seedling emergency (Table 11). The present study has also shown that bulk density was negatively correlated with several growth parameters (Appendices 7, 8 and 9). Similar observations were made by Raghavan et al. (1978); Canarache et al (1984) and Kayombo and Lal (1986).

#### 4.3.5.2 Soybeans

Data on soybean grain yield as influenced by oxygen supply and soil surface management are depicted in Table 28. Similar results as those obtained with maize (section 4.3.5.1) were observed with soybeans, and that neither oxygen supply nor soil surface management affected the yield of soybeans to any significant level. However, there was a general tendency for the yield to increase slightly with supply of oxygen (1.72 to 1.89 Mg ha<sup>-1</sup>). As in the case of maize, effects of soil surface management were not influenced by the 10% oxygen supply.

However, supply of oxygen had some stimulating effect only on seedling establishment (section 4.3.1) and root density (section 4.3.4; Appendix 6). The lack of response of soybeans to oxygen at the advanced stages of development including grain yield could be indicative of adequate soil aeration (Lal, 1985).

Soil surface management influenced soybean growth and development so that after seedling establishment mulching alone or in combination with chiselling enhanced plant height (section 4.3.1) and root development (section 4.3.4). However, these advantages were not translated to grain yields (Table 28). Conversely, grain yield was relatively higher in the bare ( $2.01 \text{ Mg ha}^{-1}$ ) and chiselled ( $1.95 \text{ Mg ha}^{-1}$ ) soils than in the mulched ( $1.65 \text{ Mg ha}^{-1}$ ) and compacted ( $1.60 \text{ Mg ha}^{-1}$ ) soils. As the crop grows, the canopy cover modifies the effect of surface management treatment such that their initial effects become masked. The effect of mulching in water conservation, for example, can easily be masked by crop canopy so that its effect will not be observed at maturity of the crop. Similar results have been shown for soybeans (Kayombo, 1986).

#### 4.3.5.3 Cowpeas

The grain yield data for cowpeas as influenced by oxygen supply and soil surface management are presented in Table 28. The results follow the same general pattern as those observed for maize and soybeans and that neither oxygen supply nor soil surface manipulations influenced cowpea grain yield to any significant extent. The supply of 10% oxygen resulted in marginal ( $0.13 \text{ Mg ha}^{-1}$ ) increase in grain yield. This is consistent with the results of the vegetative growth data in which oxygen supply had marked effect only on cowpea root growth (section 4.3.4 ).

The effect of surface management on the early vegetative growth phase was significant only in seedling establishment (section 4.3.1), early shoot growth (sections 4.3.2 and 4.3.3) and root growth and development (section 4.3.4). However, these early effects of soil surface manipulations were not reflected in the grain yield of cowpeas. But grain yield was much higher in the mulched ( $1.26 \text{ Mg ha}^{-1}$ ) and chiselled ( $1.24 \text{ Mg ha}^{-1}$ ) soils than in the bare ( $1.21 \text{ Mg ha}^{-1}$ ) and compacted ( $1.10 \text{ Mg ha}^{-1}$ ) soils. As in the case of maize and soybeans, improved cowpea grain yield in the mulched and chiselled plots could be attributed to biological activity and the loosening action of the soil by the mulch and by chiselling (Lal 1974; Doty and Reicosky, 1978). The marginal yield difference between bare, mulched and chiselled plots appear to emphasize the masking effect of the canopy at the later growth stages of the cowpea crop (Kayombo, 1986).

## 5.0 SUMMARY AND CONCLUSIONS

Two field experiments were conducted at the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria during the 1985 season. The two experiments were located at two different ecologies on the IITA farm i.e. on a lowland (for paddy - Oryza sativa L.), Experiment 1 and on an upland (for Zea mays L., Glycine max L. and Vigna unguiculata Walp), Experiment 2.

### 5.1 Experiment 1

The lowland rice experiment was initiated with the objective of evaluating the effects of tillage systems and residue management on the establishment of rice, its growth and yield. The study also examined the effect of oxygen supply on the amelioration of soils with poor aeration commonly met with in rice cultivation. The main findings of these investigations are presented below:

- 1) Tillage alone did not influence early growth (section 4.1.1), number of tillers per plant (section 4.1.2) and rice plant height (section 4.1.3). However, tillage had a significant effect on grain yield, in which puddling resulted in higher yield than zero-tillage system (section 4.1.4).
- 2) Among the residue management systems, mulching reduced the rate of seedling emergence, mean period to ultimate emergence and number of seedlings that attained ultimate establishment (section 4.1.1).

- 3) Burning the residue increased the rate of seedling emergence, mean period to ultimate emergence and number of seedlings that attained ultimate emergence (section 4.1.1). However, burning reduced the number of tillers per plant (section 4.1.2) and plant height (section 4.1.3); but it did not affect grain yield to any significant level (section 4.1.4).
- 4) Supply of oxygen along did not seem to improve the performance of rice under either puddling or zero-tillage system (sections 4.1.1, 4.1.2, 4.1.3 and 4.1.4).
- 5) The combination of tillage and residue management markedly delayed the mean period to ultimate seedling emergence. Zero-tilled plots with unburnt mulch suffered more delay than puddled plots with unburnt mulch (section 4.1.1 ).
- 6) Oxygen supply enhanced mean period to ultimate seedling emergence (section 4.1.1 ) and production of tillers at harvest (section 4.1.2 ) more when the residue was unburnt under zero-tillage than when burnt under the same system.

## 5.2 Experiment 2

The objectives of the upland crops experiment were to evaluate :

- 1) The effects of soil surface manipulations (management) on soil properties, and the performance and yield of some selected upland crops.
- 2) The effects of oxygen supply ( $\text{CaO}_2$ ) on emergence, growth and yield of some upland crops under zero-tillage system.

The findings of the investigations are presented below :

- 1) Supply of oxygen alone did not influence maize, soybean and cowpea seedling emergence. However, oxygen supply enhanced percentage seedling establishment in cowpeas (section 4.3.1 ).
- 2) Supply of oxygen alone enhanced root weight of cowpeas significantly and suppressed that of maize (section 4.3.4).
- 3) Soil surface manipulations alone significantly influenced soil bulk density and total porosity at the emergence stage of the crops. Mulching in combination with compaction, for example, increased soil bulk density (section 4.2.1) and reduced total porosity (Section 4.2.2 ). Mulching in combination with compaction also reduced water infiltration before sowing the crops and at harvest (section 4.2.3) compared to other surface manipulations.
- 4) Soil surface manipulations on the other hand had a marked influence on seedling emergence of the three crops. Leaving the soil bare, for instance, improved the rate of seedling emergence and percentage of seedling establishment in maize, while mulching combined with chiselling improved seedling emergence and establishment in cowpeas. Mean period to ultimate emergence in maize and cowpeas was markedly prolonged when the soil was mulched, but it was shortened in maize when mulch was combined with either chiselling or compaction (section 4.3.1 ).

- 5) Mulch combined with chiselling generally enhanced plant height in maize, soybean and cowpeas during the initial five weeks after sowing. Conversely, mulch in combination with compaction invariably depressed plant height of the three crops at all developmental stages (section 4.3.2 ).
- 6) Mulch alone and in combination with chiselling enhanced leaf production in soybeans and cowpeas only during the early growth phase (up to 4 weeks after sowing). In maize, however, the same treatments enhanced leaf production later and for a prolonged period (from the 5<sup>th</sup> to the 9<sup>th</sup> week after sowing ). Mulch in combination with compaction on the other hand depressed leaf production in the three crops at the same durations (section 4.3.3 ).
- 7) Mulch in combination with chiselling influenced root growth in the three crops differently. In maize and cowpeas root weight was enhanced, while in soybeans and cowpeas root length was favoured. In maize alone, root density was highest in the compacted and mulched soils.
- 8) With any soil surface manipulation, except mulch in combination with chiselling, oxygen supply improved rate of seedling emergence and percentage of seedling establishment in soybeans. However, oxygen supply delayed the mean period to ultimate seedling emergence in soybeans when the surface was left bare or compacted and mulched. On the other hand, oxygen supply shortened the mean period to ultimate emergence in cowpeas when the surface was mulched

and prolonged it under mulch-compacted surface. Maize seedling emergence and establishment were not influenced by oxygen supply in any of the surface manipulations (section 4.3.1).

- 9) Soybeans lateral root length and root density were improved by oxygen supply only when the surface was compacted and mulched. In cowpeas, however, oxygen supply enhanced tap root length under mulch alone and in combination with chiselling. On the other hand, cowpea root density was depressed by mulch - chiselling combination (section 4.3.4).
- 10) Grain yields of maize, soybeans and cowpeas were not influenced by oxygen supply alone or in combination with any of the surface manipulations ( section 4.3.5).

### 5.3 Suggestions for future research

- 1) For conclusive inferences ,tillage and soil surface manipulation experiments need to be repeated for several seasons. The experiments reported here were carried out for only one season and the data collected during such a short time are not adequate for firm conclusions.
- 2) Burning and/or removing crop residues and other plant materials from the soil surface can improve growth of crops under both conventional and zero-tillage systems particularly on soils with less erosion hazards. Since tropical soils are known to have highly variable properties within short distances, further studies are needed to evaluate the effects of burning and/or removing plant residues on the various soil types and

crops. The present studies were based only on one soil type (Alfisol) and only a few selected crops.

- 3) Various soil surface manipulations such as mulching, have been employed to alleviate the setbacks of zero - tillage. More work is therefore required on the type of mulch materials and their methods of placements in various cropping systems in the tropics.
- 4) Work on the use of oxygen to correct for oxygen deficiencies particularly in the tropical oxygen - deficient soils is limited. Currently only the peroxides of calcium, zinc, barium and hydrogen have been employed as oxygen supplying agents in cropping systems. More work is thus required to identify other oxygen supplying agents, their rates and methods of application, and their effects on the soil properties and growth of crop plants.

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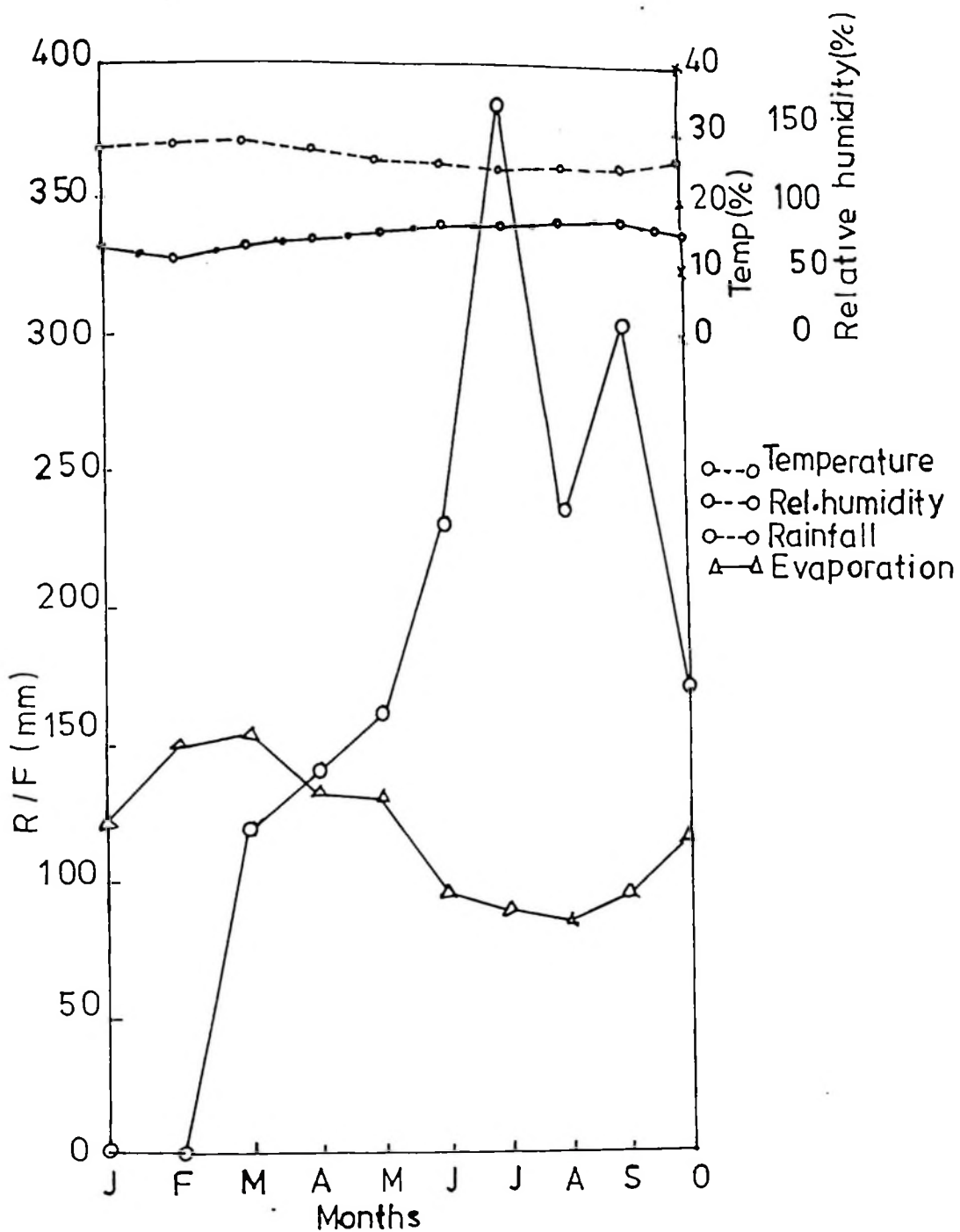
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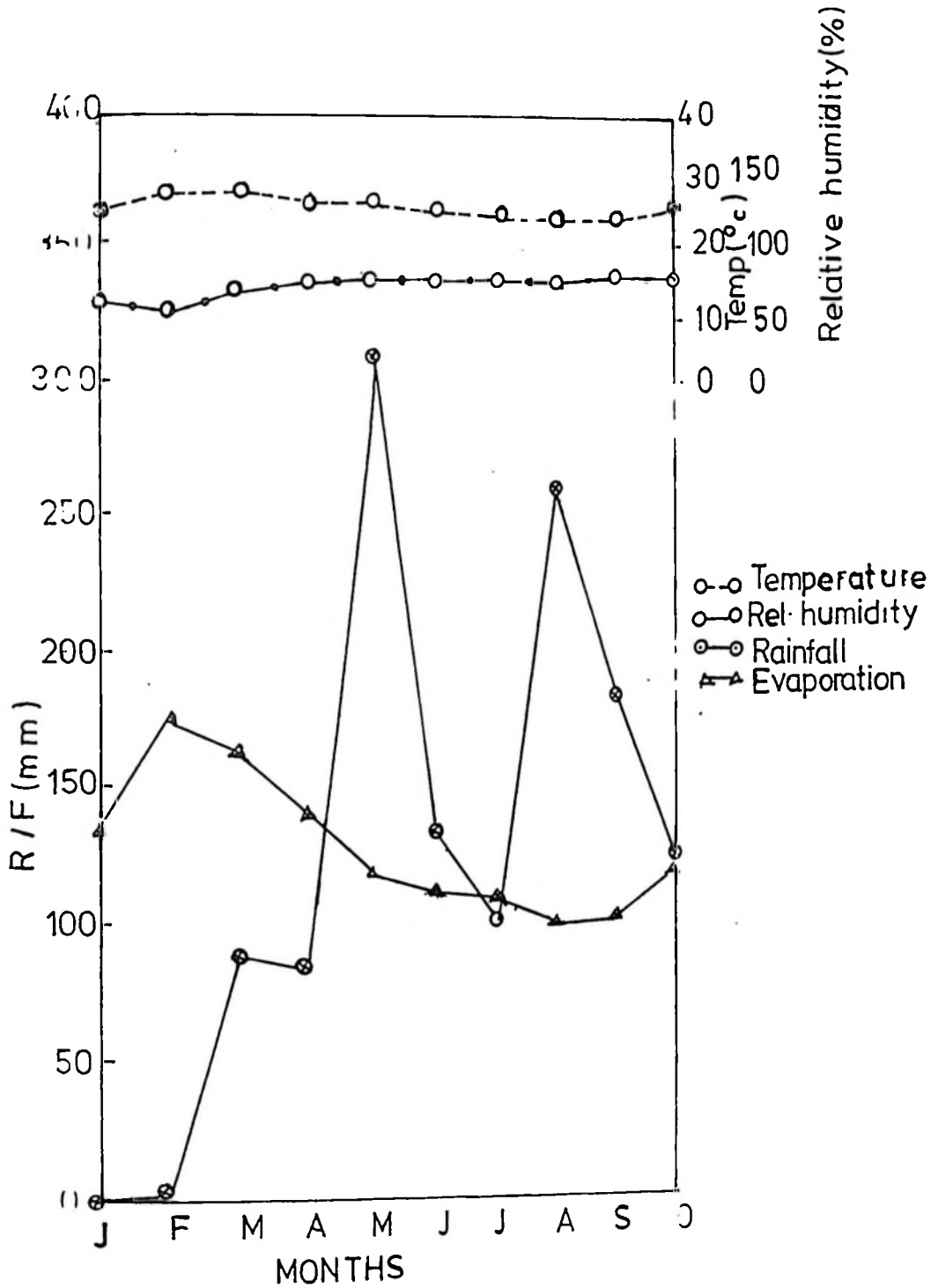
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Mean temperature, rainfall, evaporation and relative humidity at IITA, Jan-Oct, 1985

Source: IITA weather station records

APPENDIX 2



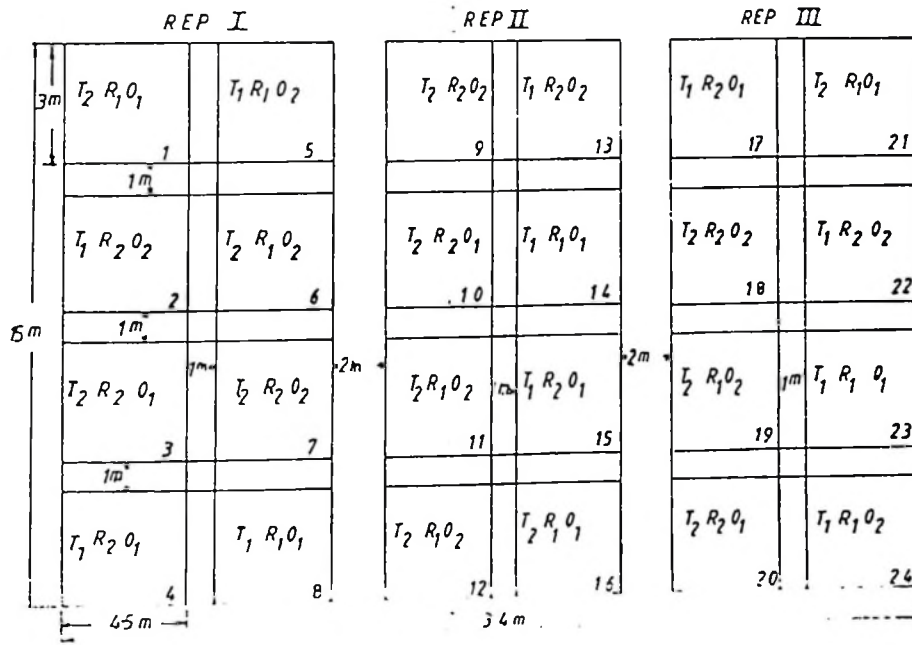
Mean temperature, rainfall, evaporation and relative humidity at IITA Jan-Oct, 1984

Source: IITA Annual report, 1984

APPENDIX 3

FIELD LAYOUT, EXP 1 • 2<sup>3</sup> FACTORIAL

SITE : F 10- (PADDY)



Gross area

Plot 45 × 3m 13.5m<sup>2</sup>  
 Whole exp: 34 × 15 = 510m<sup>2</sup>  
 Spacing : 25 × 20 cm (12 rows/plot)

Treatments :

- T<sub>1</sub> = Puddling
- T<sub>2</sub> = zero-tillage
- R<sub>1</sub> = residue burnt
- R<sub>2</sub> = residue unburnt
- O<sub>1</sub> = no oxygen
- O<sub>2</sub> = with oxygen

## APPENDIX 4

DEFINITIONS OF SEEDLING EMERGENCE TERMSRate of seedling emergence :

The sum of the values of daily increase in seedling number divided by the number of days from sowing.

Mean period to ultimate seedling emergence :

The sum products of the daily increase in seedling number and the number of days from sowing divided by ultimate emergence.

Ultimate seedling establishment :

Total number of seedlings established during the experiment.

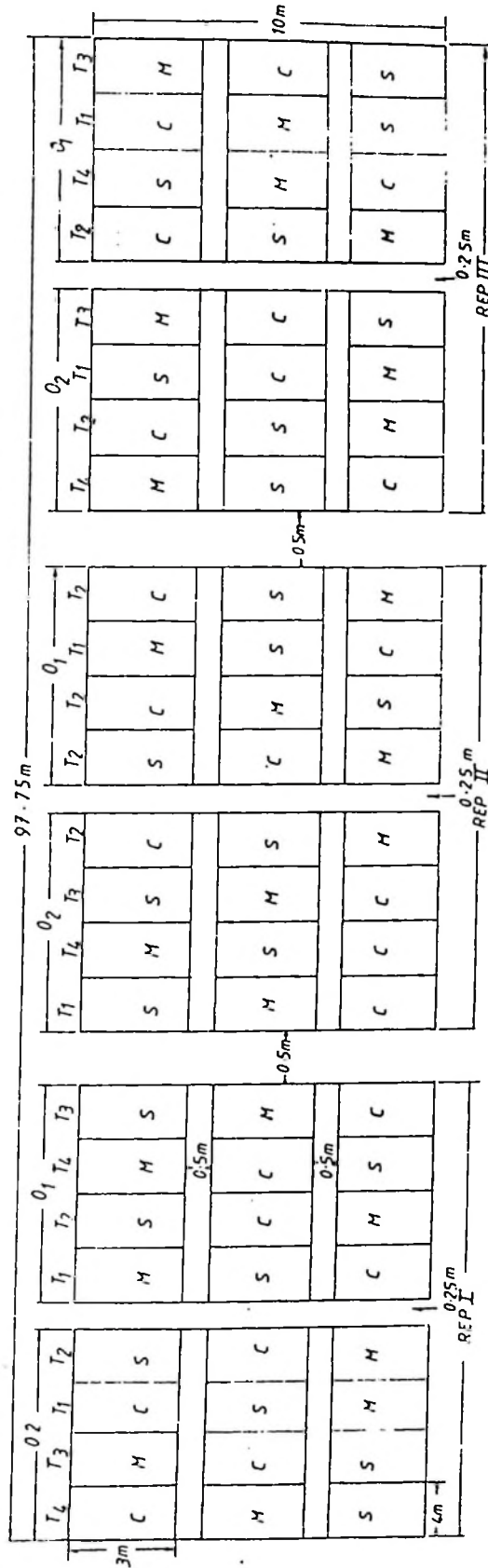
Percentage seedling establishment :

Total number of seedlings established during the experiment expressed as a percentage of expected total number of seedlings to establish.

APPENDIX . 5

FIELD LAYOUT, EXP 2. SPLIT PLOT DESIGN

SITE : BLOCK B 25



Gross area :  
 Plot:  $4 \times 3m = 12m^2$   
 Whole exp. =  $9775 \times 10m^2 = 9775m^2$

Treatments:  
 T<sub>1</sub> = bare  
 T<sub>2</sub> = mulch  
 T<sub>3</sub> = mulch + chisel  
 T<sub>4</sub> = mulch + compaction



APPENDIX 7

Relationships between soil properties and some growth parameters of maize

Correlation/properties	Bulk density ( $Mg\ m^{-3}$ )		Porosity (%)		Cumulative infiltration (cm)		Moistures content (%)	
	Regression equation	Correlation coefficient (r)	Regression equation	Correlation coefficient (r)	Regression equation	Correlation coefficient (r)	Regression equation	Correlation coefficient (r)
Seedling rate	$Y=1.58-0.09x$	- 0.47	$Y=40.9+3.38x$	0.49	$Y=13.5+44.59x$	0.41	$Y=9.7-0.34x$	- 0.20
Number of seedling	$Y=1.71-0.003x$	- 0.68	$Y=36.2+0.12x$	0.69	$Y=27.32+0.52x$	0.16	$Y=9.6-0.004x$	- 0.10
Plant height	$Y=1.90-0.05x$	- 0.75*	$Y=8.73+0.47x$	0.28	$Y=136.0+2.28$	0.52	$Y=9.29+0.001x$	0.01
Root length	$Y=10.57-0.51x$	- 0.75*	$Y=42.3+0.14x$	0.30	$Y=55.85+7.38x$	0.97*	$Y=9.8-0.03x$	- 0.27
Root weight	$Y=1.45+0.02x$	0.15	$Y=37.0+0.19x$	0.06	$Y=90.95-1.67x$	-0.51	$Y=9.95-0.04x$	- 0.38
Root density	$Y=1.42+0.04x$	0.47	$Y=46.32+1.062$	0.38	$Y=60.28+2.59x$	0.053	$Y=9.28+0.04x$	0.06
Grain yield	$Y=7.60\ 3.13x$	- 0.36	$Y=0.01+0.07x$	0.30	$Y=2.72+0.04x$	0.50	$Y=3.29-0.03x$	- 0.04

\*= significant at 5% level of probability

df (n-2) = 6 for bulk density, porosity and moisture content; df (n - 2) = 2 for cumulative infiltration

APPENDIX 8

Relationships between soil properties and some growth parameters of soybeans

Growth/properties	Bulk density (Mg m <sup>-3</sup> )		Porosity ( % )		Cumulative infiltration (cm)		Moisture content (%)	
	Regression equation	Correlation coefficient (r)	Regression equation	Correlation coefficient (r)	Regression equation	Correlation coefficient (r)	Regression equation	Correlation coefficient (r)
Seedling emergence rate	Y=1.65-0.06x	- 0.82*	Y=37.59+2.59x	0.89**	Y=0.05+19.51x	0.60	Y=9.69-0.22x	- 0.32
Number of seedlings	Y=1.59-0.06x	- 0.15	Y=32.40+0.16x	0.62	Y=17.82+0.49x	0.12	Y=8.97+0.001x	0.01
Plant height	Y=2.43-0.03x	- 0.85**	Y=9.03+1.18x	0.85**	Y=226.85+9.30x	0.77	Y=14.59-0.18x	- 0.56
Root length	Y=7.79-0.40x	- 0.60	Y=41.17+0.29x	0.61	Y=28.53+2.08x	0.56	Y=9.79-0.06x	- 0.53
Root weight	Y=1.53-0.08x	- 0.29	Y=42.65+2.81x	0.29	Y=36.23+123.41x	0.29	Y=9.24-0.27	- 0.12
Root density	Y=1.55-0.08x	- 0.31	Y=42.28+2.76x	0.28	Y=31.79+88.13x	0.86	Y=9.82-0.82	- 0.35
Grain yield	Y=2.67-0.55x	- 0.77*	Y=-0.81+0.58x	0.58	Y=1.66+0.003x	0.31	Y=2.75-0.11x	- 0.25

\* and \*\* = significant at 5% and 1% levels of probability, respectively  
df (n-2) = 6 for bulk density, porosity and moisture content; df (n-2) = 2 for cumulative infiltration

Relationships between soil properties and some growth parameters of cowpeas

Growth/properties	Bulk density		Porosity		Cumulative infiltration		Moisture content	
	Regression equation	Correlation coefficient (r)	Regression equation	Correlation coefficient (r)	Regression equation	Correlation coefficient (r)	Regression equation	Correlation coefficient (r)
Seedling emergence rate	Y=1.69-0.07x	- 0.67	Y=36.13+2.91x	0.71*	Y=108.49-17.77x	- 0.21	Y=7.25+0.88	0.65
Number of seedlings	Y=1.40-0.001x	- 0.15	Y= 47.7 + 0.05	0.18	Y=377.04-4.48x	- 0.89	Y=83.48-1.05	-0.95***
Plant height	Y=1.75-4.02x	- 0.66	Y=34.59+0.55x	0.65	Y=89.73-1.75x	- 0.12	Y=8.27+0.08	0.29
Root length	Y=14.04-0.55x	- 0.49	Y=40.2+0.22x	0.70	Y=70.3-0.68x	- 0.13	Y=9.05+0.04x	0.33
Root weight	Y=1.58-0.09x	- 0.69	Y=41.01+3.03x	0.63	Y=60.9-1.63x	- 0.02	Y=9.23+0.44x	0.28
Root density	Y=1.50-0.03x	- 0.21	Y=43.4+1.13x	0.25	Y=64.60-8.04	- 0.10	Y=9.93-0.38x	-0.25
Grain yield	Y=3.82-1.77x	- 0.85**	Y=0.75+0.044x	0.79*	Y=1.12+0.001x	0.50	Y=0.55+0.066x	0.40

\* and \*\* = significant at 5% and 1% levels of probability, respectively  
of (n-2) = 6 for bulk density, porosity and moisture content; df (n-2) = 2 for cumulative infiltration