IMPACT OF SOIL COMPACTION ON THE PRODUCTIVITY OF ONATTUKARA SOILS

By

SREELATHA, A.K.

THESIS
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Department of Soil Science and Agricultural Chemistry,
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2001

Dedicated

to my daughter

Anupama

DECLARATION

I hereby declare that this thesis entitled "**IMPACT OF SOIL COMPACTION ON THE PRODUCTIVITY OF *ONATTUKARA* SOILS**" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

Vellayani,
3-11-2001

Sreelatha A.K.
SREELATHA, A.K.

CERTIFICATE

Certified that this thesis entitled **"IMPACT OF SOIL COMPACTION ON THE PRODUCTIVITY OF *ONATTUKARA* SOILS"** is a record of research work done independently by Mrs. Sreelatha, A.K. under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

3/11/2001

Dr. S. Pushkala,
Chairman,
Advisory Committee,
Associate Professor,
Agronomic Research Station,
Chalakudy

Vellayani,
3-11-2001

APPROVED BY

CHAIRMAN

Dr. S. Pushkala
Associate Professor
Agronomic Research Station
Chalakudy

MEMBERS

1 **Dr. V.K. Venugopal**
Professor and Head
Department of Soil Science and Agricultural Chemistry
College of Agriculture, Vellayani.

2. **Dr. Muraleedharan Nair V.**
Professor and Head
Department of Agronomy
College of Agriculture, Vellayani.

3 **Dr. Vijayaraghava Kumar**
Associate Professor
Department of Agricultural Statistics
College of Agriculture, Vellayani.

4. **Dr. Sushma Kumari P.**
Assistant Professor
RRS, Kayamkulam

EXTERNAL EXAMINER.

Dr. K. Appavu,
Professor (Soil Science),
Tamilnadu Agricultural University,
Coimbatore

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SREELATHA, A .K.

Vellayani,
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List of abbreviations

@	at a rate of
c mol kg^{-1}	centimole per kilogram
Ca	calcium
cc	cubic centimeter
CD	critical difference
cm	centimeter
cm hr^{-1}	centimeter per hour
CPCRI	Central plantation crops research institute
DAS	days after sowing
^0c	degree Celsius
FYM	farm yard manure
g cc^{-1}	gram per cubic centimeter
g cm^{-1}	gram per centimeter
K	potassium
KAU	Kerala Agricultural University
kg	kilogram
kg ha^{-1}	kilogram per hectare
kg m^{-2}	kilogram per meter square
kPa	kilo Pascal
m Pa	mega Pascal
mg m^{-3}	mega gram per meter cube

mm^{-s}	micro meter per second
Mn	manganese
N	nitrogen
No_3	nitrate
P	phosphorus
SE	standard error
t ha^{-1}	tonnes per hectare
t m^{-3}	tonnes per meter cube
TNAU	Tamilnadu Agricultural University

INTRODUCTION

INTRODUCTION

Onattukara tract, spread over Kollam and Alappuzha districts is unique for the cropping system practiced there. The cropping intensity is very high i.e. 300 per cent. Three crops are raised in the kharif, rabi and summer seasons. Cropping system usually followed in *Onattukara* tract is Rice-Rice-Sesamum/Pulses/Vegetables. The soil in that area is coarse textured with low nutrient and water retention capacity. Because of their low water storage in the root zone and high susceptibility to leaching of mobile nutrients, crops on these soils are more prone to water and nutrient stresses. These stresses cause reduced plant growth and development and hence low crop yields. These observations imply that crop yield in sandy soils can be increased through a host of management practices, albeit with different modes of action.

Soil productivity is a complex phenomenon, governed by physical, chemical and biological characteristics, climatic conditions, management practices and other hazards such as pathogens and pests. *Onattukara* soils are coarse textured having lower specific surface areas and higher infiltration/percolation rates. Specific problems in the management of sandy soils include their excessive permeability and leaching of nutrients and their small soil moisture storage capacity in the profile.

Productivity of coarse textured sandy and loamy sand soils is relatively low due to its extreme permeability, which permits deep percolation of water and nutrients. For such soils of high infiltration rate, reduction of seepage losses by reducing the relative proportion of macro pores through compaction has an important beneficial effect on growth and yield of crops. Soil compaction increases soil strength and volumetric water content and decreases total porosity, air content, infiltration rate and saturated hydraulic conductivity. Along with compaction, application of coir pith and *kayal* silt, which are locally available, definitely improve the soil physical properties such as water retention and soil structure. Excessive permeability of *Onattukara* soil can be decreased to an extent by management practices such as soil compaction, application of organic manures and amendments such as coir pith and *kayal* silt.

Rice based cropping system is prevalent in *Onattukara* tract. Inclusion of legumes in the cropping system will definitely improve the soil health and consequently result in increasing the yields of subsequent crops in the sequence.

Thus in order to increase and stabilize the productivity of crops in *Onattukara* tract, suitable management practices such as soil compaction and application of amendments such as coir pith and *kayal* silt have to be adopted. Therefore the present investigation was undertaken with the following objectives.

1. To study the effect of soil compaction with organic manures and soil amendments on nutrient availability, rooting pattern, yield and quality of rice, sesamum, green gram and cowpea.
2. To find out the best amendment for increasing the soil moisture content and yield of crops.
3. To estimate the residual effect of compaction on rice based cropping system.
4. To assess the effect of compaction on soil physical and chemical properties.

REVIEW OF LITERATURE

Review of literature

Onattukara soils are predominantly loamy sand in texture. These soils retain only very little moisture and nutrients. The large pores in these soils enclosed by coarse soil fractions are drained at relatively low tension. Thus with increasing soil moisture tension, there is very fast initial release of water. Owing to high final infiltration rates up to 40 cm hr^{-1}, percolation losses are heavy. Because of the predominance of macrospores, these soils are excessively drained, have low plant available water reserves and are extremely susceptible to drought (Lal, 1995) In sandy soil, losses due to leaching particularly of soluble nutrients such as NO_3-N and potassium are considerably higher.

Compactibility of soil is dependent on the soil moisture content at the time of compaction and thrust of the roller. Almost all physico-chemical properties of coarse textured soils are affected by soil compaction. Studies relevant to compaction effects are reviewed for different parameters.

2.1 Treatment effects on physical properties of soil.

Compaction affects the soil physical properties like moisture content, water holding capacity, infiltration rate, hydraulic conductivity, porosity, aggregate stability, soil strength etc. The pore geometry of a soil is altered upon compaction and changes occur in the magnitude of aeration, mechanical impedence and moisture holding capacity. The plant response to soil compaction within a given bulk density range is the result of interaction of these factors. A study of these interactions would be helpful in understanding the behaviour of plant growth in compacted soils.

2.2 Effect of treatments on hydraulic conductivity of the soil

The effect of compaction on hydraulic conductivity of soil on which aeration and moisture availability can be predicted from the changes brought about in the size and geometry of voids, based on Poisseulli equation which states that the volume of water flowing through a tube per unit time is proportional to the fourth power of its radius.

Progressive decrease in saturated hydraulic conductivity with compaction was observed by various workers. Miller and Gardner (1962) showed that an impeding layer causes abrupt discontinuities in moisture content and hydraulic conductivity at the inter-layer boundaries and a pronounced reduction in infiltration.

Thus compaction by decreasing the larger voids had marked effect in decreasing water transmission in saturated soil (Warkentin, 1971).

Waldron *et al.* (1971) stated that compaction caused local shearing and particle rearrangement resulting in a greater reduction in hydraulic conductivity.

Greacen and Sands (1980) reported that soil compaction decreases saturated hydraulic conductivity. A slight increase in sub surface compaction of about 0.1 Mg m^{-3} reduced the saturated hydraulic conductivity (Agrawal, 1980, Agrawal *et al* 1987)

Sur *et al.* (1981) reported that puddling and soil submergence during rice growth decreased hydraulic conductivity in 5 – 25 cm. soil layer.

When compared to no till treatment and puddling, compaction treatment recorded lowest saturated hydraulic conductivity of 0.12 per μm s^{-1} in a sandy loam soil (aeric tropaquent) cultivated to low land rice in south west Nigeria. In puddled soil, hydraulic conductivity was 0.15 μm s-^{1}and in no till treatment it was 1.65- μm s^{-1}. This is because the undisturbed soil in the no till treatment, has greater porosity and a predominance of macropores or bio channels created by soil fauna and decayed roots. In contrast both puddling and compaction decreased the macropores and improved the soil structure (Ogunremi *et al.*1986).

Nimmo and Katherine (1988) reported that in sandy soils at low water content, soil compaction either by bringing the fine particles closer together or by altering their orientation in a way that affects pore size distribution could cause a decrease in hydraulic conductivity.

2.3. Effect of treatments on moisture content of soil

Compaction to a certain level brings about an increase in micropores at the expense of macropores resulting in an increase in available water content.

A slight increase in subsurface compaction of about 0.1 Mg m^{-3} increased the soil moisture retention (Agrawal, 1980, Agrawal *et al.* 1987)

Gupta and Abrol (1993) reported that the amount of water retained in the 0-10 cm loamy sand layer after 24 hours of irrigation was 21.5% higher in the soil compacted by 8 passes of 490 kg roller than in uncompacted soil. The available water storage capacity also increased.

Sharma *et al.* (1995) reported that in a loamy soil (aquic dystropept), the compacted plots had the greatest soil water after rice crop harvest. High soil moisture content after harvest is essential to increase cropping intensity through production of an upland crop after rice.

2.4 Effect of treatments on infiltration rate of soil

The effect of compaction on infiltration rate is similar to its effect on hydraulic conductivity. Compaction has been found to result in a decrease in infiltration rate, though the magnitude of decrease differs in different soil types depending upon the pore size distribution. The changes in infiltration rate as a result of compaction have been reported by several workers (Patel and Singh; 1981; Douglas and Mckyes, 1982).

An increase in subsurface compaction by 0.1 Mg. M^{-3} reduced the water infiltration rate (Agrawal, 1980 and Agrawal *et al* .1987).

Ogunremi *et al* .(1986) reported that in aeric tropaquent, the equilibrium infiltration rate in a compacted treatment was 0.12μmS^{-1} which was lower than the ploughed and no till treatments. The rate of infiltration decreased with soil compaction.

Agrawal (1991) reported that the average infiltration rate of subsurface compacted sandy soil is 25.3 cm hr^{-1} and that of surface compacted soil is 22.2 cm hr^{-1} against an infiltration rate of 32.7 cm hr^{-1} in non compacted soils.

The compaction of a loamy sand decreased the cumulative infiltration by 24.0%, 25.5%, 26.5% and 27.5% above the cumulative infiltration of 18.2 cm, 29.1 cm, 36.9 cm, and 43.3 cm in 30, 60, 90 and 120 minutes respectively (Gupta and Abrol, 1993)

The infiltration rate of compacted sandy soils cropped with ground nut decreased from 9.20 cm hr^{-1} (control) to 5.10 cm hr^{-1} (20 passes of roller) where as in the sorghum plots the infiltration rate reduced from 32.0 cm hr^{-1} (control) to 11.2 cm hr^{-1} (12 passes of roller) (TNAU, 1995)

2.5 Effect of treatments on porosity of soil

The moisture characteristics of the soil is a function of pore size distribution of soils. Compaction results in alteration of the pore size distribution, which in turn influences the plant growth through changed water relations of the soil. Greacan and Sands (1980) reported that soil compaction decreased total porosity.

Ogunremi *et al* (1986) reported that the total porosity of a compacted soil (aeric tropaquent) was less when compared to a no till treatment. Soil compaction compresses large pores into smaller ones favouring water retention over drainage (Gulati *et al,* 1985; Abo-Abda and Hussain, 1990).

Increased compaction of the soil caused an increase in the volume of storage pores, which is a common characteristic of applied stress (Gupta *et al.* 1989). Mc A Fee *et al.*

(1989) reported that presowing compaction on a clay soil reduced the total porosity of soil by 6% owing to loss of pores greater than 60 μm and water retention was increased.

Compaction interlocked the aggregates in such a way that it minimized the volume of macropores and reduced the percolation losses. The compacted treatments reduced the volume of transmission pores by 83 per cent, decreased the percolation losses by 30% where as the volume of storage pores (50 to 0.5 μm) increased with compaction. The number of large pores decreased sharply under compaction as the pores oriented themselves perpendicular to the action of load. Compaction interlocked the aggregates in such a way that it minimized the volume of macropores and reduced the percolation losses (Acharya and Sood, 1992).

2.6. Effect of treatments on mean weight diameter

The resistance of soil aggregates to the slaking and dispersive effects of water (aggregate stability) is important for maintaining of the porous structure of soil. The term mean weight diameter is used to quantify the aggregate stability. A mean weight diameter of 5 mm is considered to be optimum for seed beds (Larson, 1964).

Aggregate stability to wet sieving has been related to organic matter content (Chaney and Swift, 1984). Soil organic matter has a particularly important role in relation to aggregate stability because of its binding and cementing actions (Oades, 1984). A positive correlation of organic carbon and aggregate stability was reported by Sharma and Agrawal (1984) and Christensen (1986).

The larger mean weight diameter in the soils is primarily due to the occurrence of oxides of Fe, Al and Mn in these soils, which resisted break down. Hart *et al.* (1988) found that changes in macro aggregate stability was more closely related to decline in microbial bio mass carbon than to total organic carbon.

Increasing concentration of organic carbon at the soil surface may improve soil structure and aggregate stability depending on soil type (Carter *et al.*1990). Aggregate stability was significantly correlated with total soil organic matter content over a wide range, of cropping histories indicating that the binding action of humic substances were playing an important role in stabilizing aggregates (Haynes *et al.* 1991).

Carter (1991) reported that in a typic psammaquent, addition of farmyard manure to the river deposit improved its structure as significantly higher values of water stable aggregates and mean weight diameter were observed.

Acharya and Sood (1992) reported that compaction of soil interlocked the aggregates in such a way that it minimized the volume of macropores and reduced the percolation loss.

Horne *et al.* (1992) reported that the conservation tillage system are less damaging to soil aggregate stability than conventional tillage and continuous cropping caused a decline in aggregate stability compared with pasture.

Nicous *et al.* (1993) reported that plant roots particularly those of graminae improve the soil structure. Below the threshold clay content of 20% and especially when the clay fraction does not contain expanding lattice clay minerals, the soil is considered structurally inert. In these soils, plant roots cannot by themselves improve soil structure. In these soils tillage is necessary to help offset the inefficiency of natural factors in improving soil structure.

Kay *et al.* (1994) reported that wet aggregate stability is more responsive, to management than the tensile strength. The aggregate stability at 0-5 cm depth showed a positive correlation with organic carbon content.

Unger (1997) reported that mean weight diameter of water stable aggregates was related to soil organic matter or organic carbon concentration. Small aggregates reduced infiltration and there by the potential for soil water storage. Aggregate size differed due to cropping systems, rotation phase and crop but aggregate water stability and dry aggregation differences generally were not significant.

2.7 Effect of treatments on bulk density of soil

Bulk density is related to the total porosity of soil. Soil compaction increases the bulk density of the soil. Increasing the bulk density of a clay loam soil from 1.1 to 1.8 Mg. m^{-3} resulted in significantly greater root cation exchange capacity of several plant species (Kulkarni and Savant, 1977). Soil compaction is characterized by changes in bulk density (Cassel, 1982; Canarache *et al.* 1984)

The compaction of the sandy loam soil increased the bulk density, but the magnitude of increase in bulk density was within the optimum limits of loamy sand for sustainable crop production (Gupta *et al.*1984). Ogunremi *et al.* (1986) reported that in a sandy loam soil (aeric tropaquent), the compacted plots recorded highest bulk density than puddled and no-till treatments.

Pabin *et al.* (1991) reported that maximum sugar beet yield was obtained when the average soil bulk density was 1.64 g cm^{-3} in 0-60cm layer and 1.51 g cm^{-3} in 0-30 cm layer. Yield decreases when mean soil bulk density in the 0-60 cm layer was increased to more than 1.70 g cm^{-3}.

Gupta and Abrol (1993) reported that the compaction of loamy sand at Jobner, Rajasthan by eight passes of the 490 kg tractor drawn roller increased the bulk density by 0.140 t m^{-3}, 0.120 t m^{-3} and 0.100 tm^{-3} above the original bulk densities of 1.480 t m^{-3} 1.530 tm^{-3}, and 1.520 tm^{-3} in the 0-15, 15-30 and 30-45 cm layers respectively. The bulk density of 0-15 cm layer decreased during the sowing of pearl millet but that of the subsurface layer was not affected much. The effect of compaction on the bulk density of the subsurface layers persisted until the harvest of second crop.

2.8 Effect of treatments on soil strength

Soil strength is a composite property related to many factors such as size and continuity of pores, rigidity of soil, displaceability of particles, number of particle to particle contact etc. (Kaddah, 1971).

High soil strength without high bulk density could be associated to the rough surface of sand particles, which resist particle displacement by slippage (Cruse *et al.*1980).

Soil strength was related to pore size distribution especially the level of large soil pores which tend to decrease inter granular or effective stress (Byrd and Cassel, 1980, Vepraskas 1984). Reduction of soil strength to about 0.1 M.Pa to a depth of 40cm greatly increased root growth and penetration to deeper layers (Chaudhary *et al.* (1985). Soil compaction is characterised by changes in soil strength (Bauder *et al.* 1981; Swan *et al.* 1987)

The critical range for the maintenance of an optimum aerobic environment of 8-14% (v/v) for macropore volume for a Charlotte town fine sandy loam would be related to a concomitant range for bulk density, shear strength and field penetration resistance of 1.44 – 1.29 Mg m^{-3}, 3.2 – 1.8 k Pa and 1.50 – 0.90 M Pa respectively (Carter, 1988).

McAFee *et al.* (1989) reported that presowing compaction on a clay soil recorded a penetrometer resistance of 3.5 M Pa in the control plot and 4.5 M Pa in the compacted plot after sowing.

Comparisons of non volumetric indices of soil structure such as vane shear strength and penetrometer resistance with macropore volume indicated a relatively close relationship between the two parameters when the soil moisture potential was held constant. Regression equations between soil strength and macropore volume accounted for 50-67% of the variation in loamy sand to loam textured soils subjected to various degrees of tillage (Carter, 1990).

Nitant and Singh (1995) reported that soil strength decreases with an increase in soil water contents and organic matter content but increases with an increase in bulk density.

2.9.Effect of treatments on nutrient status of soil and plant.

Patel (1977) reported a higher tissue content of N, P, Mg and Mn in the compacted plots when compared with conventional tillage treatments. He attributed this increase in nutrient uptake is due to the reducing conditions caused by soil compaction. In addition, compaction of a permeable sandy soil decreases water percolation and thus curtails leaching loss.

In sandy soils, the losses due to leaching, particularly of soluble nutrients such as NO_3-N and potassium are considerable. Smika *et al.* (1977) showed that in a coarse textured soil from eastern Colorado, per centimeter of water percolating below crop root zone (150 cm) 10 kg ha^{-1} of NO_3-N was leached. The movement of water and NO_3-N in soil can be modified by compaction and puddling through changes in the volume of non-capillary water conducting pores. Cameron *et al.* (1978) reported for a well drained sandy soil , 0.65 and 1.45 kg N ha^{-1} day $^{-1}$ as average spring to fall rates of N losses. These losses were directly proportional to 120 and 255 kg N ha^{-1} respectively.

According to Mahajan *et al.* (1981) surface compaction in loamy sand resulted in greater retention of nutrients in the surface 30 cm soil layer as compared with no compaction. Reduced K uptake in compacted soil was mostly attributed to the decrease in root surface area. Greater K influx per unit root surface in compacted soil without K application was not sufficient to compensate for reduced K concentration due to restricted root growth of soybean seedling (Hallmark and Barber, 1981). In some sandy areas of Nebraska about 50 percent of N applied as fertilizer leached to ground water (Watts and Martin, 1981).

Restriction of root growth in compacted soil and the resulting drop in P uptake can be partially compensated for by greater uptake in nonstressed parts of soil. (Shierlaw and Alston, 1984)

Shierlaw and Alston (1984) using labelled P in a pot experiment containing three layer of soil with a compacted central layer, showed that the greater the compaction of the central layer the greater was the fraction of P in the plant tops which came from the surface soil. The ability to compensate was positively influenced by greater water supply in the non stressed soil layers.

The compacted treatment showed significantly higher N utilization at different growth stages over other treatments due to higher dry matter accumulation and increased concentration of nitrogen except in grain where it was at par. The compacted treatment showed higher uptake of N by 23%. Compaction of soils also increased the uptake of Mn and P (Ognuremi *et al.* 1986).

Since phosphorus is relatively immobile, the effect of soil compaction on P uptake is mostly related to the configuration of the root system. Generally a restricted root system and a low accessibility to soil P in compacted soil resulted in smaller amount of total P absorbed (Barraclough and Weir, 1988; Misra *et al*, 1988).

Agrawal and Jhorar (1989) concluded from a sandy soil column study that surface compaction reduced the leaching more than that of subsurface compaction. The average water infiltration rate decreased and in the 0-20 cm layer a greater amount of soil water and NO_3-N was retained. In the 0-20 cm layer of the surface compacted treatment NO_3 – N content was 10 times greater or even more than in the control. Subsurface compaction in the 10-20 cm layer was less effective than surface compaction in reducing NO_3 –N leaching in a field study on the same soil under cropped conditions. A higher soil moisture content in the 0-30 cm layer was observed under subsurface compaction than under no compaction. After irrigation, the NO_3 - N retained in the 0-30cm soil layer was 43.5% and 29.9% in subsurface compaction and no compaction treatments respectively.

Field studies with a relatively wide range of bulk densities showed a significant reduction in P uptake by spring barley in strongly compacted soil. Soil compaction reduced the phosphorus concentration much more in straw than in grain. This was attributed to greater diffusion of P to the roots greater uptake per unit length of root of maize grown in compacted unfertilized soil was accompanied by greater P concentration in the shoots and less of total P uptake (Wolkowskii 1990)

Compaction of sandy soils, which are conducive to leaching resulted in considerably greater nitrate retention in the top soil and in less leaching (Agrawal, 1991).

Wolkowskii (1991) reported that increased compactness resulted 4-11% reduced K concentration, which was accompanied by an increase in shoot growth of maize. The author indicated that this reduction was not large enough to result in reduced shoot growth. The above responses imply that in some cases soil compaction could be a desirable practice in regulating nutrient uptake and crop response. Additional K application increased the K concentration in the tissue of maize grown in compacted soil.

Subsoil compaction increased the Ca^{45} concentration in maize and caused a slight differentiation in the total uptake (Gediga, 1991).

Dolan *et al.* (1992) reported that surface compaction resulted in an enhancement of P and K uptake of corn when June and July precipitation was average or wetter than 30 year average.

In surface compacted sandy soils, the NO_3-N content was several times greater than in uncompacted soil. The reduction of NO_3-N and water losses resulted in higher productivity of sandy soils (Agrawal, 1992). Arvidsson (1993) reported that in a compacted soil P uptake was much reduced than N uptake.

Mathan *et al.* (1994) reported that as a result of sub soil compaction in sandy soil where the bulk density was maintained at 1.7 to 1.8 Mg m^{-3} there was significantly higher available N than in surface soils with bulk density of 1.5 to 1.6 Mg. m^{-3}. As the compaction of surface soil increased from 1.5 to 1.8 Mg m^{-3}, the available K content of the soil is also increased perhaps due to moisture retention and solubilisation.

Lipiec and Stepniewski (1995) reported that the effect of soil compaction on transport of nutrients to the roots depends on the amount of soil compaction and on water and nutrient supply. In well watered and high fertility conditions, moderate soil compaction may have a beneficial effect.

Westermann and Sojka (1996) reported that sub soil compaction of fine loamy soil reduced the P and K uptake by corn when rainfall was 25% low but enhanced when the rainfall was average or above average. Surface compaction affected P uptake than sub soil compaction.

2.9 Effect of treatments on biometric observations

Compacted treatments generally have greater root weight, number of leaves, leaf area and plant dry matter yield than the puddled or no till treatments. Better rice growth in a compacted sandy soil was also reported by Ghildyal (1978). Cruse *et al.* (1980) reported that rigidity of the soil pores plays an important role in root growth.

Increased root growth under compacted treatment could be ascribed to the increase in nutrient content per unit volume of soil (Ogunremi *et al.*1985). Hifiker and Lowery (1988) reported that the effect of tillage on root development is more obvious on heavier soils.

Kaselowsky *et al.* (1989) reported that there is no significant effect of soil compaction on total root length of sugar beet grown in a compacted soil. Kumar *et al* (1993) reported that bulk density affects root growth. The root penetration ratio has a significant and positive correlation with green pod yield of peas grown in a compacted typic udorthent soil.

The root is the main organ of plant which has to make contact with the soil to absorb nutrients and water but the quantum and rate of water and nutrient uptake by the plants depends mainly on the development of root system in spread, depth and density particularly under conditions of dry land agriculture (Nitant and Singh 1995).

Sharma *et al.* (1995) reported that in compacted plots, root mass density was greater in 0-10cm layer. About 98% of the total root length density was in 0-20cm layer in compacted plots. Root : shoot dry weight ratio was greatest in compacted plots. Sub soil compaction led to greater concentration of rice roots in plough layer above the compacted zone. Panicles emerged seven days earlier in sub soil compacted plots. Water stress delays panicle emergence and maturity in rice.

2.10 Effect of treatments on yield

Nair *et al.* (1976) reported that the compaction of soil increased the grain yield of rice remarkably. Even a slight increase in bulk density had a desirable effect on the upland rice in lateritic sandy loam soil. The rice yield in the rainfed marginal uplands could be increased substantially by applying 80 kg N ha^{-1} and compacting the soil to a bulk density of 1.318 g cc^{-1} after seeding. In sandy soils with high percolation losses, rice grain yield from soil compaction treatments were superior to that of dry or wet tillage treatments (Ghildyal, 1978).

Ogunremi (1986) reported that compacted treatment resulted in a significantly higher dry matter yield at the maximum tillering growth stage. Compacted soils produced the highest dry matter and grain yield following greater growth. Other soil physical and hydrological properties that are associated with low infiltration capacity therefore increased rice grain yield considerably under a continuously flood moisture regime.

Al-Janabi(1989) studied the effect of soil compaction on soil physical properties and wheat growth. The highest yield was obtained at a bulk density of 1.3 g cm^{-3} and at soil water potential of 0.05 M Pa. The effect of soil compaction on yield was greater in conditions of moisture stress.

Mathan and Natesan (1990) reported that in a compacted vertisol, the rice yield was enhanced by 18% over control and the residual effects of compaction persisted over five growing seasons.

The maize grain yield increased and dry matter content decreased with increasing sub soil bulk density by subsoil compaction (Gediga, 1991).

Pabin *et al.* (1991) reported that maximum sugar beet yield was obtained when the average soil bulk density was 1.64 g cm^{-3} in 0-60 cm layer and 1.51g cm^{-3} in the 0-30 cm layer. Maximum yields were obtained when the soil strength was 2.90 M Pa in the 0-60 cm, layer and 1.75 M Pa in the 0-30 cm layer. Significant yield decrease occurred when mean soil bulk density in the 0-60 cm layer increased to more than 1.70 g cm^{-3}.

Acharya and Sood (1992) reported that the compacted treatments significantly increased grain yield of 15.17% over other treatments in a typic hapludalf.

Gupta and Abrol (1993) reported that the compaction of the loamy sand significantly increased the grain yield of rain fed pearl millet and guar by 25.4% and 25.0% over the control yield of 1.26 and 1.00 t ha^{-1} respectively and that of irrigated pearl millet, wheat and barley by 16.4%, 17.0% and 14.5% over the control yield of 2.68, 2.41 and 2.28 t ha^{-1} respectively.

Sharma *et al.* (1995) reported that the grain yield and harvest index of rice crop were greatest in compacted treatment and were directly related to sub soil compaction. Sub soil compaction has the potential for increasing and stabilizing rice yield in coarse textured, rainfed low land soils.

2.11 Effect of farmyard manure and amendments on soil properties and crop growth.

In coarse textured soils incorporation of organic matter either in the form of crop residues or farmyard manure improves the structure, water retention capacity and nutrient values (Khanna *et al.* 1975).

Bhagat (1990) reported that addition of farmyard manure to a river deposit (typic psammaquent) improved its structure. Conventional tillage with farmyard manure produced significantly higher values of water stable aggregate, mean weight diameter and total porosity and significantly lower values of bulk density compared to all other treatments. The best soil structure under farmyard manure treatment was attributed to the incorporation of farmyard manure in soil. The lack of response of soil structure improvement to the incorporation of crop residue may be attributed to its slow decomposition under low soil temperature conditions. Farmyard manure applied plots retained higher water content at all suction values between 0 and 1000 K Pa. Total N uptake by wheat plants at all stages was highest under farmyard manure treated plots.

Yadav and Somani (1990) studied the effect of mixing of clayey soil and compaction to a sandy soil on the physical properties and yield of cluster bean (*Cyanopsis tetragonaloba*) and found that mixing of clayey soil had little effect on bulk density but both mixing clayey soil and compaction improved the moisture retaining power of soil especially when both techniques are combined. The yield of cluster bean also increased with compaction as well as with mixing of clayey soil and compaction had additive effect on soil properties and cluster bean yield.

Gupta and Abrol (1993) reported that the mixing of a fine textured soil having 37% clay into the loamy sand to increase its clay content by 1% and 2%, followed by 8 passes of 490 kg roller further reduced the cumulative 120 minute infiltration by 5% and 10% respectively. The effect of compaction and the addition of clay on infiltration rates persisted through the growth of a succeeding crop of wheat. The amount of water retained in the 0-10 cm loamy sand layer after 24 hour of irrigation was 2.15% higher in the soil compacted by 8 passes of 490 kg roller than in uncompacted soil. It was further increased by 0.50% and 1.05% with the addition of 1% and 2% clay respectively followed by compaction. The effect of compaction and addition of clay on water retention persisted through out the growth of a succeeding crop of wheat.

Gajri *et al.* (1994) observed that organic mulches conserve soil moisture, decrease soil temperature and improve root growth. Application of farmyard manure improves nutrition and yield. Hadas *et al.* (1994) reported that maintenance of a soil surface with stabilized structure requires addition of residues at a rather high frequency of 2 to 3 months.

Singh and Singh (1995) reported that straw application can replace fertilizer for rice grown under dry land condition in an inceptisol as it gives a yield response that did not differ statistically from that of chemical fertilizer application.

In order to initiate organic carbon build up in soil, organic carbon input must exceed 2.5 t ha^{-1} $year^{-1}$ (Sharma *et al.* 1995). Arunarajagopal *et al.* (1995) reported that application of coir waste in a sandy loam soil resulted in higher productivity, net returns and benefit cost ratio.

Durai *et al*. (1996) reported that irrespective of irrigation regime in a sandy loam soil, basal incorporation of coir waste at 25 t ha^{-1} recorded higher cane yield of 134.3 t ha^{-1} owing to more moisture retentive capacity than other amendments like farm yard manure, press mud and Jalasakthi. Cane yield was also higher in Jalasakthi (124.6 t ha^{-1}) than FYM (114.5 t ha^{-1}) and press mud (119.9 t ha^{-1}). Application of coir waste and Jalasakthi in treatments where water was applied once in 19 days resulted a net profit of Rs.21,674/- and Rs.16,248 respectively.

Rasmussen and Collin (1996) reported that the type of organic residue applied is of less importance than its quantity. Trojan and Linden (1998) reported that steady state infiltration rates on a typic hapludoll were not different in tilled and non tilled soil with or without residues present but instantaneous infiltration rates and time required to reach steady state were significantly greater for soils retaining annual residues.

2.12 Significance of cropping system

Years of adverse drought have proved disastrous in mono cropped areas (Patnaik *et al.* 1971). Diversification of cropping provides an insurance against total crop failure. There is a need to develop efficient rice based cropping system such as intercropping for upland situations that can ensure stable optimal yield and maximum profit.

Pande *et al.* (1985) advocated the use of pigeon pea as an intercrop in rice fields. With the over all view of maintaining soil fertility and economizing fertilizer application it is beneficial to include legume as component of intensive cropping systems (Palaniappan, 1985). Legumes both as sole and as intercropping combination with cereals have been advocated not only for yield augmentation but also for maintenance of soil health.

Jadhav (1989) pointed out that inclusion of leguminous crop in the cropping sequence leads to an improvement in soil nutrients and consequently results in increasing the yield of succeeding crops in the sequence.

Srinivasan *et al.* (1991) studied the effect of summer legumes on the growth and productivity of succeeding Kharif maize. Summer pulses particularly cowpea significantly increased the productivity of the succeeding Kharif maize. Summer pulses contributed to an addition of 15 kg N ha^{-1} .

Kalarani (1995) reported that raising a summer crop resulted in saving of 25 per cent N for the succeeding rice crop. Mathew *et al* (1996) reported the influence of summer cropping on fertilizer use efficiency and productivity of rice. The cropping systems studied are Rice-Rice-Fallow (RRF), Rice-Rice-Daincha (RRD), and Rice-Rice-Sesamum (RRS) and Rice-Rice-cowpea (RRC). The highest yield was recorded by RRD followed by RRC and both were on par. This is due to addition of appreciable quantities of organic matter and fixation of N. The study revealed that chemical fertilizer application in rice can be reduced to 75 percent when an ideal cropping sequence is followed.

Bindhu (1999) reported that raising a sole crop of black gram in the rice fallows of *Onattukara* tract appears to be more profitable. Under the circumstances where an inter crop is desired for yield stability to reduce risk or for yield diversity, raising sesamum and black gram in 1:1 proportion can be recommended which is economically viable and biologically sustainable practice for the rice follows of *Onattukara* region during the summer season.

MATERIALS AND METHODS

MATERIALS AND METHODS

The present investigations was undertaken with the objective of studying the effect of soil compaction with organic manures and soil amendment on nutrient availability, rooting pattern, yield and quality of different crops under rice based cropping system of *Onattukara* tract of Kerala. The field experiment was conducted during the period from May 1998 to May 1999.The details of the materials used and methods adopted for the study are described below.

3.1 Materials.

3.1.1 Experimental site.

The experiment was conducted in the rice fields of Rice Research Station, Kayamkulam. The experiment field is located at 9° 80' N latitude and 76° 20'E longitude at an attitude of 3.05 m above mean sea level.

3.1.2 Soil

The soil of the experimental site is loamy sand and acidic in nature. The soil is classified as coarse loamy mixed isohyperthermic aquic ustipsamments. The physico-chemical properties of the soil are presented below.

Table 1. Mechanical composition of the soil of the experimental site.

Sl.No.	Fraction	Content in soil
A	Mechanical composition	
1	Coarse sand (%)	65.62
2	Fine sand (%)	17.20
3	Silt (%)	5.22
4	Clay (%)	10.20
5	Textural class	Loamy sand

Table 2. Physical constants of the soil of the experimental site

Sl.No.	Parameter	Observation
1	Soil Strength (kg m^{-2})	1.08
2	Bulk density (Mg m^{-3})	1.55
3	Particle density (Mg m^{-3})	2.41
4	Total porosity (%)	33.00
5	Macro porosity (%)	12.26
6	Micro porosity (%)	20.74
7	Water holding capacity (%)	18.73
8	Mean weight diameter	0.42
9	Field moisture content (%)	18.60
10	Hydraulic conductivity (cm hr^{-1})	21.35
11	Infiltration rate (cm hr^{-1})	36.35
12	Available water (%)	1.93

Table 3. Chemical properties of the experimental site

Sl.No	Parameter	Observation
1	Soil pH (ratio)	5.10
2	Organic Carbon (%)	0.48
3	Available N (kgha^{-1})	188.89
4	Available P (kg ha^{-1})	34.89
5	Available K (kg ha^{-1})	47.79
6	Exchangeable Ca (c mol kg^{-1})	1.70
7	Exchangeable Mg (c mol kg^{-1})	1.41

Before the starting of the experiment, the compaction treatment was given in an area near to the experimental plot. The profile was exposed and soil samples collected from different horizons were analysed for physical properties and the observations are presented below.

Table 4. Physical properties of soil as affected by compaction

Sl.No.	Parameter	Observation			
		0-20 cm	21-50 cm	51-90cm	91-150 cm
1	Soil Strength (kg m^{-2})	2.92	3.00	3.33	3.17
2	Bulk density (Mg m^{-3})	1.98	1.98	1.99	1.98
3	Particle density (Mg m^{-3})	2.56	2.47	2.41	2.38
4	Total porosity (%)	39.72	35.23	35.61	39.48
5	Macro porosity (%)	22.21	17.31	20.07	18.97
6	Micro porosity (%)	17.51	17.92	15.54	20.51
7	Water holding capacity (%)	16.67	17.61	21.49	20.46
8	Mean weight diameter	0.50	0.47	0.59	0.57
9	Field moisture content (%)	15.18	17.14	16.99	16.69
10	Hydraulic conductivity (cm hr^{-1})	10.75	11.49	10.59	9.79
11	Infiltration rate (cmhr^{-1})	25.44	25.77	23.47	23.94
12	Available water (%)	4.93	4.75	5.06	5.43

3.1.3 Cropping history of the field.

The experimental area was under bulk crop of sesamum during the previous season.

3.1.4 Season.

The experiment initiated during the Virippu season of May 1998 with the first crop of rice. The second crop of rice was transplanted during the Mundakan season of

September 1998. The third crops viz. sesamum, green gram and cowpea were raised during the summer season of February 1999 to May 1999.

3.1.5 Weather conditions.

The weekly averages of temperature, relative humidity, sunshine hours, rainfall and evaporation during the cropping period were collected from the observatory attached to CPCRI, Kayamkulam and the data are presented in Appendix I . The weather condition during the period was favourable for the satisfactory growth of the crop.

3.1.6 Crop characters and source of seed materials

Table 5. Crop characters and source of seed materials

Sl. No.	Crop	Variety	Duration (days)	Characteristics	Source of seed material
1	Rice	Bhagya	100	Suitable for first crop season in *Onattukara*. Drought resistant in early stages	RRS, Kayamkulam
2	Sesamum	Kayamkulam -1	70-75	It is a pure line selection from *Onattukara* local. Best suited to summer rice fallows of *Onattukara*	RRS, Kayamkulam
3	Green Gram	Pusa 8973	65-70	High yielding and locally adopted to summer rice fallows of *Onattukara*	RRS, Kayamkulam
4	Cowpea	Kanakamoni	90	Dual purpose variety	RRS, Kayamkulam

3.1.7 Manures and fertilizers.

Farmyard manure (0.4 per cent, 0.3 per cent, 0.2 per cent N, P_2O_5 and K_2O respectively) was used for the experiment. Urea (46 per cent N), Mussoriephos (20 per cent P_2O_5) and muriate of potash (60 per cent K_2O) were used as source of nitrogen (N), phosphorus (P) and potassium (K) respectively.

3.2 Methods.

3.2.1 Design and lay out.

The experiment was laid out in a factorial randomized block design. The experimental layout is given in figure 1. The experiment consisted of eighteen treatments with three replications.

Number of treatments	- 18
Number of replication	- 3
Total Number of plots	- 54
Plot size	- 6 x 6 m^2

3.2.2 Treatments.

1 $C_0F_0A_0$	10 $C_1F_0A_0$
2 $C_0F_0A_1$	11 $C_1F_0A_1$
3 $C_0F_0A_2$	12 $C_1F_0A_2$
4 $C_0F_1A_0$	13 $C_1F_1A_0$
5 $C_0F_1A_1$	14 $C_1F_1A_1$
6 $C_0F_1A_2$	15 $C_1F_1A_2$
7 $C_0F_2A_0$	16 $C_1F_2A_0$
8 $C_0F_2A_1$	17 $C_1F_2A_1$
9 $C_0F_2A_2$	18 $C_1F_2A_2$

C_0 – No compaction

C_1 – Compaction with 4 passes of 400 kg roller

F_0 – No farmyard manure

F_1 – 2.5 t farmyard manure ha^{-1}

F_2 – 5 t farmyard manure ha^{-1}

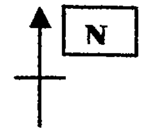
A_0 – No coir pith or *kayal* silt

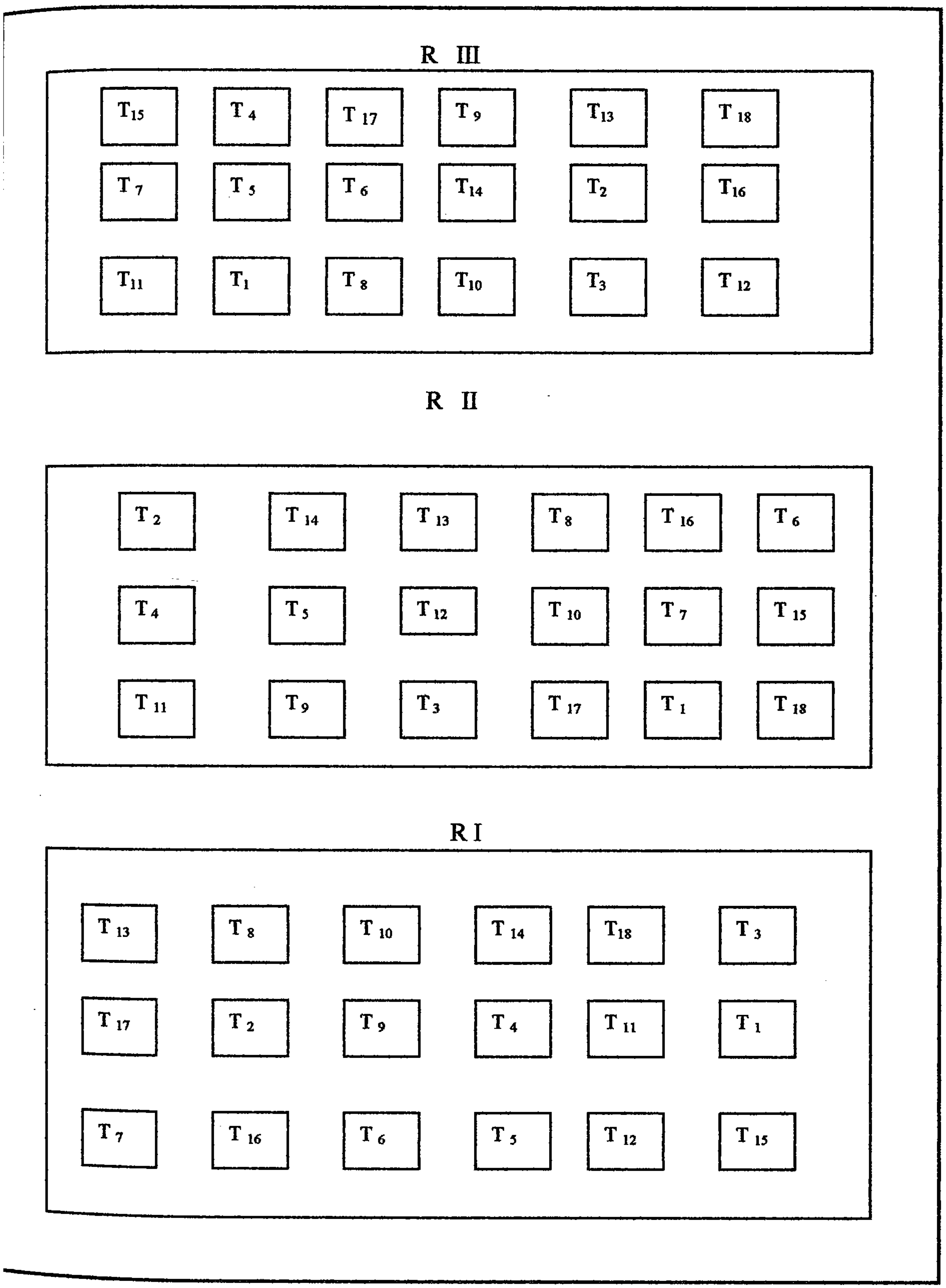
A_1 – 5 t coir pith ha^{-1}

A_2 – 5 t *kayal* silt ha^{-1}

Coir pith (0.27 percent, 0.02 per cent, 0.77 per cent N, P and K. respectively) and *kayal* silt (0.32, 0.12, 0.69 N, P and K respectively) were the amendment treatments. The compaction treatment was given only once before the sowing of first crop

FIGURE1. LAY OUT OF THE EXPERIMENT





of rice. After the harvest of first crop, second crop of rice was transplanted in the experimental plots with the same treatments without removing the stubbles. During the third crop season, each experimental plot was divided into three equal plots and sesamum (S_0) green gram (S_1) and cowpea (S_2) were sown in these plots respectively.

3.2.3 Land preparation

The experimental area was ploughed with a power tiller, clods broken and weeds and stubbles of previous crop were removed. The plots were laid out according to the design of the experiment. FYM, coir pith and *kayal* silt were applied according to the treatments and incorporated with the soil after levelling the plots. The compaction treatment was done by 4 passes of a 400 kg roller. After compacting the soil the surface soil is disturbed by light hoeing.

After the harvest of first crop the layout of the experiment was not disturbed. The plots were dug twice and all the cultivation practices and treatments were given to second and third crops similar to that of the first crop except the compaction treatment

3.2.4 Fertilizer application

The N, P and K were applied as urea, mussoriephos and muriate of potash as per the Package of Practices Recommendation (KAU,1996).The fertilizer doses, time and method of application are as follows. For the rice crop the fertilizer dose of 70:35:35 kg ha^{-1} NPK was applied. Half the dose of N and K and full dose of P was given as basal dressing at the time of final ploughing. Twenty five percent N was applied as top dressing 30 days after sowing and the remaining 25% N and 50% K was given as top dressing 45 days after sowing.

A fertilizer dose of 30:15:30 kg ha^{-1} NPK was applied for sesamum. At the time of land preparation, 75% N, full dose of P and K was applied as basal dressing. The remaining

25% N was applied 20 days after sowing. For green gram a fertilizer dose of 20:30:30 kg ha^{-1} NPK and for cowpea a fertilizer dose of 20:30:10 kg ha^{-1} NPK was applied. Half the dose of N, full P and K were applied as basal dressing and the remaining dose of N was applied 20 days after sowing for green gram and cowpea.

3.2.5 Seeds and sowing

Dry sowing of seeds of first crop of rice along lines was done on 22nd May 1998. The seeds were covered with soil after sowing. Nursery was raised for the second crop of rice and transplanted to the main field on 21st October 1998. Sowing of sesamum, green gram and cowpea along lines were done on 17th February 1999. After sowing, seeds were covered with soil and planking was done.

3.2.6 After cultivation

Spraying of the herbicide butachlor was done on the third day after sowing for the first crop of rice. Two weedings at fort night interval were done for the first crop. For the second crop of rice, two hand weedings were done at fort night interval.

Thinning was done a fortnight after sowing of sesamum, green gram and cowpea plots, so as to maintain the spacing of 15x10 cm between the plants by working with *Kochuthumpa* a special type of implement prevalent in *Onattukara* tract. The second intercultural operations and weeding were done 25 days after sowing.

3.2.7 Plant protection

Ten per cent carbaryl was applied as spray to control the leaf and pod caterpillar during the flowering period of sesamum. Spraying of 0.03% quinalphos was also done for controlling pea aphids.

3.2.7 Harvesting

The first crop of rice was harvested on 27th August 1998 and the second crop of rice was harvested on 4th January 1999. The grain and straw yield of each plot were recorded separately. The grain yield from each plot was dried, cleaned, winnowed, weighed and expressed in t ha^{-1}. The straw from each plot was dried under sun and weight was expressed in t ha^{-1}

Sesamum and green gram were harvested on 28th April 1999 and cowpea was harvested on 17th May 1999 when the leaves turned yellow. Harvesting of sesamum was done by pulling out the plants, cutting out the root portion and stacking the plants in shade in bundles for 3 to 4 days. Later, the bundles were spread in the sun and beaten with sticks to break the capsules and seeds were collected. Drying and threshing were repeated for four more days. The pods of green gram and cowpea were picked by hands and beaten with sticks to separate the seeds.

3.3 Observations recorded

Observation on growth characters, yield and yield attributing characters of rice, sesamum, green gram and cowpea were recorded and the mean values were worked out.

3.3.1 Growth characters

Observations on the growth characters of number of leaves per plant were taken from 10 plants from each plot of rice at maximum tillering, panicle initiation and flowering stages. For the other three crops, the above observation was taken at 30 days after sowing (DAS), 60 days after sowing (60DAS) and at harvest. After elimination of border, 10 plants were selected randomly as observational plants. At harvest, five out of ten observational plants were used for dry matter estimation and chemical analysis.

3.3.1.1 Leaf area index (LAI)

Area of all leaves produced per plant was recorded by LICOR-3100 Leaf Area Meter and LAI was worked out using the formula suggested by William (1946)

LAI = Leaf area / Land area

Observation was recorded in five sample plants from each plot.

3.3.1.2 Days to maximum tillering

Number of days taken for maximum tillering of the two crops of rice in each treatment were noted and recorded

3.3.1.3 Days to 50 per cent flowering

The number of days taken by 50 per cent of plants for the emergence of flowers in each treatment of all the crops were recorded.

3.3.1.4 Root length, Root volume and Root density.

At the time of harvest the observational plants were carefully dug out without disturbing the roots. The roots were carefully washed and length of longest root was measured and recorded. The volume of roots was determined by water displacement method. Driving a metallic core collected the roots for root density determination. The roots were made free from soil by washing with water. The root mass was dried at 68^0 C followed by weighing and expressing results on unit soil volume basis.

3.3.1.5 Dry matter production

At the time of harvest, the observation plants were used for recording dry matter production. Five plants were uprooted from each plot carefully without damaging the roots. The plants were dried under shade and then oven dried at 65 ± 5^0 C till consecutive weights agreed. The dry weight of the plants were found out and expressed as t ha^{-1}

3.3.1.6 Carbohydrate content.

Sample lots of rice grain were drawn from the seed obtained from each treatment plot and the carbohydrate content was determined by anthrone method (Sadasivam and Manickam, 1992).

3.3.1.7 Crude protein content.

Nitrogen content in the seeds of all crops were analysed and percentage of protein in the seed was calculated by multiplying the percentage of nitrogen with the factor 6.25 (Simpson *et al.*, 1965).

3.3.1.8 Oil content

Sample lots of sesamum seeds were drawn from the seed obtained from each treatment plot and the oil content was estimated by cold percolation method (Kartha and Sethi, 1957).

3.3.2 Soil analysis

Soil samples collected from 0-15 cm (surface) and 15-30 cm (sub-surface) depths from each plot after the harvest of each crop were analysed for physico-chemical properties.

3.3.2.1 Physical Properties

Bulk density, particle density, porosity, water holding capacity and hydraulic conductivity were determined from undisturbed samples. *Insitu* determination of surface compaction and infiltration rate were recorded. Aggregate analysis and available water were also determined from the disturbed samples.

3.3.2.1.1 Bulk density, particle density, porosity, water holding capacity and hydraulic conductivity.

Core samples were collected from two depths of 0-15 cm and 15-30 cm and determined the bulk density, particle density, porosity, water holding capacity and hydraulic conductivity as described by Gupta and Dakshinamoorthi (1980)

3.3.2.1.2 Soil compaction

Using pocket penetrometer, the soil compaction of the surface soil was recorded for each treatment.

3.3.2.1.3 Infiltration rate

Infiltration rates were recorded using the double ring method (Gupta and Dakshinamoorthi, 1980) by nullifying angular effect.

3.3.2.1.4 Aggregate analysis.

Aggregate analysis was carried out by Yoder's wet sieving method (Yoder,1936). The samples were wetted slowly and using a set of sieves, water stable aggregates were determined. Mean weight diameter was taken as the structural index (Bavel, 1949).

3.3.2.1.5 Water retention characteristics.

The capacities of retention of soil moisture of the samples at 33 and 1500 KPa were determined by pressure plate and pressure membrane apparatus (Gupta and Dakshinamoorthi, 1980). From this available water for each treatment was calculated.

3.3.2.2 Chemical Properties

The soils collected from two depths of 0-15 cm (surface) and 15-30 cm (sub surface) were analysed for available nitrogen, phosphorus, potassium and exchangeable calcium and magnesium. The methods followed for the assay of various soil chemical parameters are given in table 6.

3.3.2.3 Plant analysis.

The plants of rice, sesamum, green gram and cowpea at harvest were analysed for nitrogen, phosphorus, potassium, calcium and magnesium. The samples were dried to constant weight in an electric oven at 70^{0}C, ground into fine powder and subjected to acid extraction for total nutrient analysis. The methods used for the determination of various nutrients are given in table 7.

Table 6. Chemical methods for soil analysis.

SL.NO	PARAMETER	METHOD	REFERENCE
1	Mechanical analysis	International pipette method	Piper, 1966
2	Soil pH	pH Meter with glass electrode	Jackson, 1973
3	Organic Carbon	Walkey and Black's rapid titration method	Jackson, 1973
4	Available Nitrogen	Alkaline Permanganate method	Subbiah and Asija, 1956
5	Available phosphorus	Bray and Kurtz colorimetric method	Jackson, 1973
6	Available potassium	Stanford and English Flame photometer method	Jackson, 1973
7	Exchangeable calcium	Stanford and English Flame photometer method	Jackson, 1973
8	Exchangeable magnesium	Atomic absorption spectro Photometer Model PE-3030 using ammonium acetate extract	Jackson, 1973

Table 7. Analytical Methods for Plant Parameters

SL. NO.	PARAMETER	METHOD	REFERENCE
1	Total Nitrogen	Modified microkjeldhal method	Jackson, 1973
2	Total Phosphorus	Vanado-Molybdo phosphoric yellow colour method	Jackson, 1973
3	Total potassium	Flame photometer method	Jackson, 1973
4	Total Calcium	Flame photometer method	Piper, 1966
5	Total Magnesium	Atomic absorption spectro photometer model PE-3030	Piper, 1966

3.4 Statistical analysis

Data relating to each character was analysed by applying the Analysis of variance technique (Gomez and Gomez, 1984). Wherever the effects were found to be significant, critical difference standard error were given for effecting comparisons among the mean.

RESULTS

RESULTS

Data generated through soil and plant analysis and observation on the yield of two crops of rice, summer crops of sesamum, green gram and cowpea were subjected to statistical analysis to study the effect of applied treatment on various parameters. Results are presented in this section for first, second and third crops.

4.1 First crop – Rice

4.1.1 Effect of treatments on moisture characteristics of soil

4.1.1.1 Field moisture content

The surface soils recorded a field moisture content ranging from17.56 percent to 27.12 percent (Table 8A). The main effect of coir pith and *kayal* silt treatments significantly influenced the moisture content of the soil (Table 9). Such differences were not seen in the case of C and F treatments. The interaction effects of treatments also did not significantly influence the moisture content of the soil.

The subsurface soils recorded a moisture content ranging from 16.54 percent to 24.88 percent (Table 8B). The subsurface soils also recorded a similar trend as that of surface soils except that the main effect of coir pith and *kayal* silt was not significant

4.1.1.2 Hydraulic conductivity

The hydraulic conductivity of the surface soils ranged from 9.79 cm hr^{-1} to 24.66 cm hr^{-1} (Table 8A). The hydraulic conductivity decreased in compacted treatments. The main effect of C and F and interaction effect of CF and FA significantly influenced the hydraulic conductivity (Table 10A). The main effect of coir pith and *kayal* silt and interaction effects except CA did not significantly influence the hydraulic conductivity of

Table:8A. Effect of treatments on moisture characteristics of surface soil

Treatment	Moisture Content (percent)	Hydraulic Conductivity (cm hr $^{-1}$)	Infiltration Rate (cm hr $^{-1}$)	Available Water (Percent)	Maximum Water Holding Capacity (Percent)
$C_0F_0A_0$	18.60	21.35	36.35	1.93	18.73
$C_0F_0A_1$	27.12	21.49	38.15	1.87	21.63
$C_0F_0A_2$	20.13	20.32	37.18	1.59	21.00
$C_0F_1A_0$	19.83	20.93	38.22	1.65	19.84
$C_0F_1A_1$	21.36	19.77	39.65	2.22	21.37
$C_0F_1A_2$	19.47	21.12	43.57	2.09	19.52
$C_0F_2A_0$	17.56	21.16	43.00	2.57	21.19
$C_0 F_2A_1$	21.32	23.13	44.45	2.08	22.59
$C_0F_2A_2$	19.24	24.66	38.96	2.87	19.34
$C_1F_0A_0$	21.79	11.41	33.26	3.47	21.87
$C_1F_0A_1$	20.07	11.73	30.57	4.30	20.48
$C_1F_0A_2$	21.29	10.75	31.21	3.76	21.43
$C_1F_1A_0$	20.81	11.49	26.99	4.11	20.81
$C_1F_1A_1$	23.56	10.59	25.44	4.93	20.26
$C_1F_1A_2$	18.17	09.79	25.77	4.75	18.14
$C_1F_2A_0$	22.20	10.70	23.47	5.06	22.21
$C_1F_2A_1$	25.96	10.16	23.94	5.43	24.83
$C_1F_2A_2$	21.12	10.11	25.68	5.46	19.47
CD	NS	NS	3.80	NS	NS
SE	2.19	0.66	1.32	0.45	1.82

Note : NS - Not Significant

CD - Critical Difference

SE - Standard Error

Table:8B. Effect of treatments on moisture characteristics of sub surface soil

Treatment	Moisture Content (percent)	Hydraulic Conductivity (cm hr $^{-1}$)	Available Water (Percent)	Maximum Water Holding Capacity (Percent)
$C_0F_0A_0$	21.40	17.54	1.43	21.42
$C_0F_0A_1$	16.54	16.81	1.49	16.65
$C_0F_0A_2$	18.71	16.49	1.60	18.76
$C_0F_1A_0$	17.24	17.35	1.72	17.30
$C_0F_1A_1$	17.75	17.29	2.45	17.83
$C_0F_1A_2$	16.77	16.33	1.73	17.44
$C_0F_2A_0$	24.88	15.55	2.31	19.80
$C_0 F_2A_1$	20.43	16.57	2.81	24.16
$C_0F_2A_2$	23.19	16.22	2.31	19.54
$C_1F_0A_0$	18.70	9.31	2.81	23.04
$C_1F_0A_1$	18.45	9.40	3.45	18.48
$C_1F_0A_2$	18.27	8.49	3.80	19.89
$C_1F_1A_0$	16.87	7.83	3.84	16.89
$C_1F_1A_1$	20.08	7.75	2.94	20.14
$C_1F_1A_2$	17.66	7.20	2.67	17.69
$C_1F_2A_0$	23.07	6.18	4.07	23.07
$C_1F_2A_1$	17.26	8.07	3.73	17.23
$C_1F_2A_2$	21.89	7.76	3.85	20.05
CD	NS	NS	NS	NS
SE	2.96	0.57	0.46	2.48

Table: 9 Main effect of treatments and two factor interactions on field moisture content (percent) of surface soil

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	18.66	23.27	19.61	21.95	20.22	19.37	20.05
C_1	21.05	20.85	23.09	21.60	23.20	20.19	21.66

	A_0	A_1	A_2	Mean
F_0	20.19	23.60	20.71	21.50
F_1	20.32	22.46	18.82	20.54
F_2	19.88	23.64	20.98	21.23
Mean	20.13	23.23	19.90	

	CD	SE		CD	SE
C	NS	0.62	CF	NS	1.24
F	NS	0.93	CA	NS	1.24
A	2.52	0.93	FA	NS	1.49

the soil. The subsurface soils recorded a hydraulic conductivity ranging from 6.18 cm hr^{-1} to 17.54 cm hr^{-1} (Table 8B). The subsurface soils recorded a similar trend as that of surface soils except that interaction effect were not significant (Table10B).

4.1.1.3 Infiltration rate

The infiltration rate ranged from 23.47 cm hr^{-1} to 44.45 cm hr^{-1} (Table 8A). The effect of treatments on infiltration rate was significant. The treatment $C_0F_2A_1$ recorded the highest infiltration rate of 44.45 cm hr^{-1} and the treatment $C_1F_2A_0$ recorded the lowest infiltration rate of 23.47 cm hr^{-1}. Considerable reduction in infiltration rate in compacted plots (27.37 cm hr^{-1}) compared to uncompacted plots (39.95 cm hr^{-1}) was noticed (Table 11).

4.1.1.4 Available water

The available water content of the surface soils ranged from 1.59 percent to 5.46 percent (Table 8A). The main effect of C and F were significant. The available water content increased in C_1 plots and F_1 and F_2 plots (Table12A). The subsurface soils recorded an available water content of 1.43 percent to 4.07 percent (Table 8B). The subsurface soils recorded a similar trend that of surface soils. The main effects of C and F were significant (Table 12B).

4.1.1.5 Maximum water holding capacity

The maximum water holding capacity of the surface soils ranged from 18.14 percent to 24.83 percent (Table 8A). The subsurface soils recorded a maximum water holding capacity ranging from 16.65 percent to 24.16 percent (Table 8B). None of the

Table:10A Main effect of treatments and two factor interactions on hydraulic conductivity (cm hr^{-1}) of surface soil

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	21.05	20.61	22.98	21.15	21.47	22.03	21.55
C_1	11.30	10.62	10.32	11.20	10.83	10.22	10.75
	A_0	A_1	A_2	Mean	CD SE		CD SE
F_0	16.38	16.61	15.54	21.50	C 0.62 0.22		CF 1.08 0.38
F_1	16.21	15.18	15.45	20.54	F 0.76 0.27		CA NS 0.38
F_2	15.93	16.65	17.39	21.23	A NS 0.27		FA 1.32 0.46
Mean	20.13	23.23	19.90				

Table: 10 B Main effect of treatments and two factor interactions on hydraulic conductivity (cm hr^{-1}) of subsurface soil

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	16.95	16.99	16.11	16.81	16.89	16.35	16.68
C_1	9.07	7.59	7.34	7.77	8.40	7.82	8.00
	A_0	A_1	A_2	Mean	CD SE		CD SE
F_0	13.43	13.10	12.49	13.01	C 0.53 0.18		CF NS 0.32
F_1	12.59	12.52	11.77	12.29	F 0.65 0.23		CA NS 0.32
F_2	10.87	12.32	11.99	11.72	A NS 0.27		FA NS 0.38
Mean	12.29	12.65	12.08				

Table: 11 Main effect of treatments and two factor interactions on infiltration rate of soil

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	37.23	40.48	42.14	39.19	40.75	39.90	39.95
C_1	31.68	26.07	24.36	27.91	26.65	27.55	27.37
	A_0	A_1	A_2	Mean	CD SE		CD SE
F_0	34.81	34.36	34.20	34.46	C 1.27 0.44		CF 2.19 0.76
F_1	32.61	32.54	34.67	33.27	F NS 0.57		CA NS 0.76
F_2	33.24	34.20	32.32	33.25	A NS 0.57		FA NS 0.92
Mean	33.55	33.70	33.73				

Table: 12A Main effect of treatments and two factor interactions on available water content (percent) of surface soil

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	1.80	1.99	2.51	2.05	2.06	2.181	2.10
C_1	3.84	4.60	5.32	4.21	4.89	4.66	4.59
	A_0	A_1	A_2	Mean	CD SE		CD SE
F_0	2.70	3.09	2.68	2.82	C 0.48 0.17		CF NS 0.25
F_1	2.88	3.57	3.42	3.29	F 0.59 0.21		CA NS 0.25
F_2	3.82	3.75	4.17	3.91	A NS 0.21		FA NS 0.30
Mean	3.13	3.47	3.42				

Table: 12 B Main effect of treatments and two factor interactions on available water content (percent) of subsurface soil

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	1.51	1.97	2.48	1.82	2.25	1.88	1.98
C_1	3.35	3.15	3.90	3.58	3.37	3.45	3.47
	A_0	A_1	A_2	Mean	CD SE		CD SE
F_0	2.12	2.47	2.70	2.43	C 0.43 0.15		CF NS 0.26
F_1	2.78	2.69	2.20	2.56	F 0.53 0.18		CA NS 0.26
F_2	3.19	3.27	3.10	3.19	A NS 0.18		FA NS 0.31
Mean	2.70	2.81	2.66				

treatments or their interactions significantly influenced the maximum water holding capacity of surface and sub surface soils.

4.1.2. Effect of treatments on structural characteristics of soil

4.1.2.1 Mean weight diameter

The surface soils recorded a mean weight diameter ranging from 0.42 to 0.78 (Table 13A). There was no significant difference among treatments except the interaction effect of FA (Table 14A). The subsurface soils recorded a mean weight diameter ranging from 0.47 to 0.61 (Table 13B). The main effect of F significantly influenced the mean weight diameter (Table14B). The mean weight diameter increased with increasing doses of F.

4.1.2.2 Micro porosity

The micro porosity of the surface soils ranged from 17.93 percent to 31.79 percent (Table 13A). The treatment $C_1F_1A_1$ recorded the highest micro porosity of 31.79 percent. The main effect of C significantly influenced the micro porosity (Table 15A). The interaction effects of treatments except FA were not significant. The subsurface soils recorded a micro porosity ranging from 17.53 percent to 27.51 percent (Table 13B). The main effect of compaction increased the micro porosity of subsurface soil (Table15B). The subsurface soils recorded a similar trend that of surface soils.

4.1.2.3 Macro porosity

The macro porosity of surface soils ranged from 10.23 percent to 26.89 percent (Table 13A). None of treatments or their interaction significantly influenced the macro porosity of the soil. The macro porosity of sub surface soils ranged from 7.49 percent to 22.17 percent (Table13B). The main effects of compaction significantly influenced the

Table:13 A. Effect of treatments on structural characteristics of surface soil

Treatment	Mean weight diameter	Micro porosity (Percent)	Macro porosity (Percent)	Total Porosity (Percent)	Bulk Density (Mg m^{-3})	Particle Density (Mg m^{-3})	Soil Strength (Kg m^{-2})
$C_0F_0A_0$	0.42	19.73	19.66	39.39	1.46	2.41	1.08
$C_0F_0A_1$	0.78	20.74	12.26	37.15	1.55	2.38	1.17
$C_0F_0A_2$	0.57	23.33	23.35	46.78	1.48	2.69	1.50
$C_0F_1A_0$	0.46	18.84	17.32	36.16	1.57	2.45	1.25
$C_0F_1A_1$	0.49	20.62	25.44	46.06	1.37	2.45	1.75
$C_0F_1A_2$	0.47	19.18	16.75	35.67	1.60	2.51	1.00
$C_0F_2A_0$	0.56	18.27	26.89	45.17	1.59	2.41	1.42
$C_0F_2A_1$	0.52	23.96	17.21	41.17	1.44	2.45	1.58
$C_0F_2A_2$	0.59	23.49	24.62	48.01	1.50	2.59	1.50
$C_1F_0A_0$	0.57	23.39	13.30	33.68	1.51	2.35	2.83
$C_1F_0A_1$	0.49	17.93	16.89	38.91	1.49	2.39	2.92
$C_1F_0A_2$	0.51	29.48	19.50	40.02	1.52	2.48	3.00
$C_1F_1A_0$	0.47	27.48	17.02	36.87	1.54	2.46	3.33
$C_1F_1A_1$	0.54	31.79	10.23	40.47	1.53	2.36	3.17
$C_1F_1A_2$	0.48	21.25	18.54	39.45	1.52	2.35	3.17
$C_1F_2A_0$	0.67	23.55	17.90	40.89	1.51	2.44	3.17
$C_1F_2A_1$	0.47	30.41	25.29	39.77	1.46	2.45	2.92
$C_1F_2A_2$	0.50	21.62	15.16	37.55	1.49	2.54	3.33
CD	NS	NS	NS	NS	NS	NS	NS
SE	0.06	2.45	5.72	4.48	0.05	0.08	0.13

Table:13 B. Effect of treatments on structural characteristics of sub surface soil

Treatment	Mean weight diameter	Micro porosity (Percent)	Macro porosity (Percent)	Total Porosity (Percent)	Bulk Density (Mg m^{-3})	Particle Density (Mg m^{-3})
$C_0F_0A_0$	0.51	20.27	22.17	39.86	1.54	2.56
$C_0F_0A_1$	0.49	19.81	19.32	32.10	1.66	2.47
$C_0F_0A_2$	0.48	18.29	20.25	43.19	1.62	2.41
$C_0F_1A_0$	0.51	18.60	16.16	36.48	1.64	2.38
$C_0F_1A_1$	0.52	17.53	20.89	40.45	1.51	2.46
$C_0F_1A_2$	0.54	18.63	11.25	33.07	1.60	2.29
$C_0F_2A_0$	0.58	19.65	09.91	45.82	1.62	2.37
$C_0F_2A_1$	0.61	24.61	19.89	43.90	1.38	2.42
$C_0F_2A_2$	0.50	18.40	19.64	38.93	1.57	2.46
$C_1F_0A_0$	0.47	26.49	15.08	37.62	1.52	2.46
$C_1F_0A_1$	0.49	26.26	07.49	35.89	1.58	2.51
$C_1F_0A_2$	0.55	25.77	15.28	37.36	1.64	2.65
$C_1F_1A_0$	0.50	21.39	12.76	33.58	1.68	2.44
$C_1F_1A_1$	0.59	25.26	14.46	41.96	1.55	2.58
$C_1F_1A_2$	0.57	22.85	12.26	36.73	1.60	2.52
$C_1F_2A_0$	0.58	24.88	10.22	38.18	1.62	2.37
$C_1F_2A_1$	0.56	22.75	10.85	39.53	1.64	2.45
$C_1F_2A_2$	0.56	27.51	12.52	39.00	1.72	2.63
CD	NS	NS	NS	NS	NS	NS
SE	0.04	2.39	3.71	4.32	0.07	0.09

Table: 14A Main effect of treatments and two factor interactions on mean weight diameter of surface soil

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	0.59	0.47	0.56	0.48	0.59	0.54	0.54
C_1	0.50	0.49	0.55	0.55	0.50	0.50	0.51
	A_0	A_1	A_2	Mean			
F_0	0.46	0.64	0.54	0.55			
F_1	0.47	0.51	0.47	0.48			
F_2	0.62	0.49	0.55	0.55			
Mean	0.51	0.55	0.52				

	CD	SE		CD	SE
C	NS	0.02	CF	NS	0.04
F	NS	0.03	CA	NS	0.04
A	NS	0.03	FA	0.13	0.04

Table: 14B Main effect of treatments and two factor interactions on mean weight diameter of sub surface soil

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	0.49	0.53	0.56	0.53	0.54	0.51	0.53
C_1	0.50	0.55	0.57	052	0.55	0.56	0.54
	A_0	A_1	A_2	Mean			
F_0	0.49	0.49	0.51	0.50			
F_1	0.51	0.56	0.56	0.54			
F_1	0.58	0.59	0.56	0.57			
Mean	0.53	0.54	0.53				

	CD	SE		CD	SE
C	NS	0.01	CF	NS	0.03
F	0.05	0.02	CA	NS	0.03
A	NS	0.02	FA	NS	0.03

Table:15A Main effect of treatments and two factor interactions on micro porosity (percent) of surface soil

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	21.27	19.55	21.91	18.95	21.77	22.00	20.91
C_1	23.60	26.84	25.20	24.81	26.71	24.12	25.21
	A_0	A_1	A_2	Mean	CD SE	CD SE	
F_0	21.56	19.33	26.40	22.43	C 2.30 0.80	CF NS 1.39	
F_1	23.16	26.20	20.22	23.20	F NS 1.04	CA NS 1.39	
F_2	20.19	27.19	22.56	23.55	A NS 1.05	FA 4.88 1.70	
Mean	21.88	24.24	23.06				

Table: 15B Main effect of treatments and two factor interactions on micro porosity (percent) of sub surface soil

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	19.46	18.19	20.89	19.44	20.65	18.44	19.51
C_1	26.17	23.17	25.05	24.25	24.76	25.38	24.80
	A_0	A_1	A_2	Mean	CD SE	CD SE	
F_0	23.38	23.04	22.03	22.81	C 2.30 0.78	CF NS 1.35	
F_1	19.89	21.44	20.74	20.68	F NS 1.01	CA NS 1.35	
F_2	22.27	23.68	22.96	22.97	A NS 1.01	FA 4.88 1.62	
Mean	21.85	22.71	21.91				

Table: 16 Main effect of treatments and two factor interactions on macro porosity (percent) of sub surface soil

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	20.58	16.10	16.48	16.08	20.03	17.05	17.72
C_1	12.62	13.16	11.20	12.69	10.93	13.35	12.32
	A_0	A_1	A_2	Mean	CD SE	CD SE	
F_0	18.63	13.41	17.76	16.60	C 3.48 1.26	CF NS 2.09	
F_1	14.46	17.67	11.76	14.63	F NS 1.57	CA NS 2.09	
F_2	10.06	15.37	16.08	13.84	A NS 1.57	FA NS 2.52	
Mean	14.38	15.48	15.20				

macro porosity of the sub surface soil (Table16). The macro porosity decreased significantly in compacted plots. Other treatments and their interaction did not significantly influence the macro porosity

4.1.2.4 Total porosity

The total porosity of the soils ranged from 33.68 percent to 48.01 percent (Table 13A). None of the treatments or their interactions significantly influenced the treatments. The subsurface soils recorded a total porosity ranging from 32.10 percent to 45.82 percent (Table 13B). The subsurface soils showed the same trend as surface soils.

4.1.2.5 Bulk Density

The bulk density of surface soils ranged from 1.37 Mg m^{-3} to 1.60 Mg m^{-3} (Table 13A). None of treatments or their interactions significantly influenced the bulk density. The bulk density of the subsurface soils ranged from 1.38 Mg m^{-3} to 1.72 Mg m^{-3} (Table13B). The bulk density of the soil was not significantly influenced by any of the treatments either alone or in combination.

4.1.2.6 Particle density

The particle density of the surface soil ranged from 2.35 Mg m^{-3} to 2.69 Mg m^{-3} (Table13A). None of the treatments or their interactions significantly influenced the particle density except the main effect of A (Table 17A). The particle density increased significantly in A_2 plots compared to A_0 and A_1 plots. The subsurface soils recorded a particle density ranging from 2.29 Mg m^{-3} to 2.65 Mg m^{-3} (Table 13B) .The main effect of compaction significantly influenced the particle density (Table 17B). The particle density significantly increased in compacted plots. Other main effects or interaction effects of treatments did not significantly affect the particle density.

Table:17A Main effect of treatments and two factor interactions on particle density (Mg m^{-3}) of surface soil

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	2.50	2.47	2.48	2.42	2.43	2.60	2.48
C_1	2.41	2.39	2.48	2.42	2.40	2.46	2.43
	A_0	A_1	A_2	Mean	CD SE		CD SE
F_0	2.38	2.39	2.59	2.45	C NS 0.03		CF NS 0.05
F_1	2.45	2.41	2.43	2.43	F NS 0.03		CA NS 0.05
F_2	2.43	2.45	2.56	2.48	A 0.09 0.03		FA NS 0.05
Mean	2.42	2.41	2.53				

Table:17B Main effect of treatments and two factor interactions on particle density (Mg m^{-3}) of sub surface soil

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	2.48	2.38	2.42	2.44	2.45	2.38	2.42
C_1	2.55	2.51	2.48	2.42	2.51	2.61	2.51
	A_0	A_1	A_2	Mean	CD SE		CD SE
F_0	2.51	2.49	2.54	2.51	C 0.08 0.03		CF NS 0.05
F_1	2.41	2.52	2.40	2.44	F NS 0.04		CA NS 0.05
F_2	2.37	2.44	2.55	2.45	A NS 0.04		FA NS 0.05
Mean	2.43	2.48	2.50				

Table: 18 Main effect of treatments and two factor interactions on strength of soil (kg m^{-2})

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	1.25	1.33	.50	1.25	1.50	1.33	1.36
C_1	2.92	3.22	3.14	3.11	3.00	3.17	3.09
	A_0	A_1	A_2	Mean	CD SE		CD SE
F_0	1.96	2.14	2.25	2.08	C 0.12 0.04		CF NS 0.07
F_1	2.29	2.46	2.08	2.28	F 0.15 0.05		CA 0.21 0.07
F_2	2.29	2.25	2.42	2.32	A NS 0.05		FA 0.26 0.09
Mean	2.18	2.25	2.25				

4.1.2.7 Soil strength

The strength of the surface soil ranged from 1.00 kg m^{-2} to 3.33 kg m^{-2} (Table13A). The main effect of C and F significantly affected the soil strength (Table 18). The soil strength increased significantly in compacted and in F_1 and F_2 plots. All other interaction effects except CF were significant.

4.1.3 Effect of treatments on chemical characteristics of soil

4.1.3.1 Soil reaction

The surface soils recorded a soil pH ranging from 4.87 to 5.30 (Table 19A). The treatments significantly influenced the pH of surface soil. The treatment $C_1F_1A_2$ recorded the highest pH of 5.30 and treatment $C_0F_1A_2$ recorded the lowest pH of 4.87. The main effect of the treatments and their two factor interactions did not significantly influence the soil pH. The pH of subsurface soil ranged from 4.90 to 5.13 (Table 19B). The pH was higher in A_1 plots compared to A_0 and A_2 plots. None of the treatments or their interactions did not significantly affect the soil pH.

4.1.3.2 Organic carbon

The organic carbon content of the surface soil was not significantly affected by the treatments alone or their combinations. The organic carbon content ranged from 0.53 percent to 0.73 percent (Table 19A). The organic carbon content of subsurface soil ranged from 0.50 percent to 0.69 percent (Table 19B). The treatments significantly influenced the organic carbon content of the subsurface soil. The treatment $C_0F_2A_0$ recorded the highest organic carbon content of 0.69 percent and the treatment $C_1F_0A_1$ recorded the lowest organic carbon content of 0.50 percent. None of the main effect or the two factor interactions did significantly affect the organic carbon content .

Table:19A Effect of treatments on chemical characteristics of surface soil

Treatment	Soil pH	Organic carbon (Percent)
$C_0F_0A_0$	5.07	0.67
$C_0F_0A_1$	5.23	0.63
$C_0F_0A_2$	4.90	0.53
$C_0F_1A_0$	5.13	0.58
$C_0F_1A_1$	4.97	0.62
$C_0F_1A_2$	4.87	0.57
$C_0F_2A_0$	5.07	0.57
$C_0 F_2A_1$	4.97	0.67
$C_0F_2A_2$	4.97	0.68
$C_1F_0A_0$	5.20	0.64
$C_1F_0A_1$	5.03	0.59
$C_1F_0A_2$	5.00	0.63
$C_1F_1A_0$	4.97	0.62
$C_1F_1A_1$	5.00	0.60
$C_1F_1A_2$	5.30	0.59
$C_1F_2A_0$	5.13	0.73
$C_1F_2A_1$	4.90	0.70
$C_1F_2A_2$	4.97	0.62
CD	0.21	NS
SE	0.07	0.07

Table:19B Effect of treatments on chemical characteristics of sub surface soil

Treatment	Soil pH	Organic carbon (Percent)
$C_0F_0A_0$	5.13	0.53
$C_0F_0A_1$	5.03	0.63
$C_0F_0A_2$	4.90	0.52
$C_0F_1A_0$	4.93	0.54
$C_0F_1A_1$	5.00	0.60
$C_0F_1A_2$	4.97	0.60
$C_0F_2A_0$	4.97	0.69
$C_0F_2A_1$	5.07	0.58
$C_0F_2A_2$	5.03	0.57
$C_1F_0A_0$	5.00	0.54
$C_1F_0A_1$	5.13	0.50
$C_1F_0A_2$	4.90	0.66
$C_1F_1A_0$	4.93	0.55
$C_1F_1A_1$	4.97	0.59
$C_1F_1A_2$	5.10	0.52
$C_1F_2A_0$	5.13	0.52
$C_1F_2A_1$	5.10	0.51
$C_1F_2A_2$	5.07	0.64
CD	NS	0.13
SE	0.07	0.06

4.1.3.3 Available nitrogen

The surface soils recorded an available nitrogen content ranging from 186.03 kg ha^{-1} to 289.07 kg ha^{-1} (Table 20A). None of treatments or their interactions significantly affected the available nitrogen content of the surface and subsurface soils. The subsurface soils recorded an available nitrogen content ranging from 186.00 kg ha^{-1} to 260.30 kg ha^{-1} (Table 20B).

4.1.3.4 Available phosphorus.

The surface soil recorded available phosphorus content ranging from 14.53 kg ha^{-1} to 32.83 kg ha^{-1} (Table 20A) and that of sub surface soils ranged from 15.47 kg ha^{-1} to 28.33 kg ha^{-1} (Table 20B). The main effects of C significantly influenced the phosphorous content of the surface and subsurface soil (Tables 21A and 21B). The available phosphorous content of surface and subsurface soils significantly increased in the compacted plots. Other treatments alone or in combination did not significantly affect the available phosphorous content of soil.

4.1.3.5 Available potassium.

The available potassium content of the surface soil ranged from 41.21 kg ha^{-1} to 73.94 kg ha^{-1} (Table 20A). The main effects of C, F and A significantly influenced the available potassium content of surface soil (Table 22A). The available potassium content significantly increased in the C_1, F_1 and A_1 plots. The subsurface soils recorded an available potassium content ranging from 46.43 kg ha^{-1} to 73.90 kg ha^{-1} (Table 20B). The main effect of C and F significantly influenced available potassium content of the sub surface soils (Table 22B). The available potassium content of sub surface soils increased significantly in the C_1 and F_1 plots.

Table:20A Effect of treatments on available N, P, K and exchangeable Ca and Mg content of surface soil

Treatment	Available N (kg ha $^{-1}$)	Available P (kg ha $^{-1}$)	Available K (kg ha $^{-1}$)	Exchangeable Ca (c mol kg $^{-1}$)	Exchangeable Mg (c mol kg $^{-1}$)
$C_0F_0A_0$	220.55	23.91	41.21	1.72	1.39
$C_0F_0A_1$	186.03	19.30	56.41	1.70	1.39
$C_0F_0A_2$	214.04	15.87	52.40	1.71	1.41
$C_0F_1A_0$	232.06	12.33	51.49	1.70	1.39
$C_0F_1A_1$	247.44	22.43	59.76	1.71	1.39
$C_0F_1A_2$	225.74	21.43	66.48	1.70	1.41
$C_0F_2A_0$	225.74	19.10	51.50	1.70	1.41
$C_0 F_2A_1$	196.50	14.53	49.77	1.71	1.39
$C_0F_2A_2$	211.14	21.40	54.37	1.74	1.41
$C_1F_0A_0$	187.87	23.70	53.73	1.71	1.41
$C_1F_0A_1$	254.00	18.17	62.67	1.73	1.44
$C_1F_0A_2$	201.67	22.13	56.50	1.75	1.43
$C_1F_1A_0$	191.40	23.90	58.93	1.78	1.42
$C_1F_1A_1$	190.23	23.47	73.94	1.81	1.42
$C_1F_1A_2$	210.14	32.83	70.90	1.78	1.44
$C_1F_2A_0$	253.17	27.00	48.83	1.73	1.47
$C_1F_2A_1$	266.54	26.77	66.40	1.75	1.46
$C_1F_2A_2$	289.07	25.73	51.83	1.75	1.46
CD	NS	NS	NS	NS	NS
SE	2.51	3.78	5.93	0.02	0.01

Table:20B Effect of treatments on available N, P, K and exchangeable Ca and Mg content of sub surface soil

Treatment	**Available N (kg ha $^{-1}$)**	**Available P (kg ha $^{-1}$)**	**Available K (kg ha $^{-1}$)**	**Exchangeable Ca (c mol kg $^{-1}$)**	**Exchangeable Mg (c mol kg $^{-1}$)**
$C_0F_0A_0$	251.20	20.00	46.43	1.68	1.35
$C_0F_0A_1$	186.00	18.03	48.33	1.68	1.33
$C_0F_0A_2$	243.33	15.73	48.39	1.69	1.33
$C_0F_1A_0$	230.97	22.47	52.63	1.68	1.32
$C_0F_1A_1$	215.13	15.47	54.13	1.72	1.37
$C_0F_1A_2$	245.63	17.47	59.77	1.68	1.37
$C_0F_2A_0$	220.50	18.37	50.77	1.72	1.34
$C_0 F_2A_1$	204.57	18.57	48.90	1.74	1.34
$C_0F_2A_2$	196.47	18.30	53.00	1.75	1.32
$C_1F_0A_0$	224.40	26.53	62.33	1.73	1.34
$C_1F_0A_1$	225.73	26.63	55.97	1.76	1.33
$C_1F_0A_2$	223.67	24.30	62.23	1.79	1.35
$C_1F_1A_0$	213.20	25.67	59.30	1.75	1.36
$C_1F_1A_1$	260.30	28.33	73.90	1.77	1.36
$C_1F_1A_2$	220.60	26.40	62.67	1.72	1.35
$C_1F_2A_0$	195.50	25.03	48.10	1.79	1.37
$C_1F_2A_1$	209.97	23.67	54.87	1.78	1.37
$C_1F_2A_2$	246.90	26.97	57.77	1.81	1.37
CD	NS	NS	NS	NS	NS
SE	1.61	2.03	4.28	0.02	0.01

Table:21A Main effect of treatments and two factor interactions on available phosphorus (kg ha^{-1}) content of surface soil

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	19.69	18.73	18.24	18.45	18.76	19.57	18.26
C_1	21.33	26.73	26.50	24.87	22.80	26.90	25.95
	A_0	A_1	A_2	Mean	CD SE		CD SE
F_0	23.81	18.73	19.00	21.87	C 3.56 1.24		CF NS 2.15
F_1	18.12	22.95	27.13	22.63	F NS 1.61		CA NS 2.15
F_2	23.05	20.65	23.57	21.82	A NS 1.61		FA NS 2.58
Mean	23.01	21.78	21.52				

Table:21B Main effect of treatments and two factor interactions on available phosphorus (kg ha^{-1}) content of sub surface soil

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	17.92	18.46	18.41	20.28	17.36	17.16	18.92
C_1	25.82	26.80	25.22	25.74	26.21	25.89	24.86
	A_0	A_1	A_2	Mean	CD SE		CD SE
F_0	23.27	22.33	20.02	20.51	C 1.91 0.67		CF NS 1.15
F_1	24.07	21.90	21.92	22.73	F NS 0.87		CA NS 1.15
F_2	21.70	21.12	22.63	22.42	A NS 0.87		FA NS 1.38
Mean	21.66	20.78	23.23				

Table: 22A Main effect of treatments and two factor interactions on available potassium content (kg ha^{-1}) of surface soil

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	50.01	59.24	51.88	48.07	55.31	57.75	53.71
C_1	57.63	67.92	55.69	53.83	67.67	59.74	60.42
	A_0	A_1	A_2	Mean	CD SE	CD SE	
F_0	47.47	59.54	54.45	53.82	C 5.57 1.94	CF NS 3.36	
F_1	55.21	66.85	68.69	63.58	F 6.83 2.38	CA NS 3.36	
F_2	50.17	58.08	53.10	53.78	A 6.83 2.38	FA NS 4.03	
Mean	50.95	61.49	58.75				

Table: 22B Main effect of treatments and two-factor interactions available potassium content (kg ha^{-1}) of sub surface soil

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	47.72	55.51	50.89	49.94	50.46	53.72	51.37
C_1	60.18	65.29	53.58	56.58	61.58	60.89	59.68
	A_0	A_1	A_2	Mean	CD SE	CD SE	
F_0	54.38	52.15	55.31	53.95	C 4.02 1.40	CF NS 2.43	
F_1	55.97	64.02	61.22	60.40	F 4.93 1.72	CA NS 2.43	
F_2	49.43	51.88	55.38	52.23	A -NS 1.72	FA NS 2.91	
Mean	53.26	56.02	57.30				

4.1.3.6 Exchangeable calcium .

The surface soil recorded an exchangeable calcium content ranging from 1.70 c mol kg^{-1} to 1.81 c mol kg^{-1} (Table 20A). The main effects of C and F significantly affected exchangeable calcium content of the surface and subsurface soil. The exchangeable calcium content of subsurface soils ranged from 1.68 c mol kg^{-1} to 1.81 c mol kg^{-1} (Table 20B). The exchangeable calcium content increased in C_1 plots of both surface and subsurface soils (Tables 23A and 23B). In F_1 plots of sub surface soils, the exchangeable calcium content increased significantly, where as in subsurface soils F_2 plots recorded the highest exchangeable calcium content. The interaction effect of CF also significantly influenced the exchangeable calcium content of surface soils.

4.1.3.7 Exchangeable magnesium.

The exchangeable magnesium content of the surface soils ranged from 1.39 c mol kg^{-1} to 1.47 c mol kg^{-1} (Table 20A). The main effect of C and A significantly influenced the exchangeable magnesium content (Table 24A). Exchangeable magnesium content of the surface soils increased significantly in C_1 and A_2 plots compared to other levels of respective factors. The interaction effect of CF also differed significantly among the plots. The subsurface soils recorded an exchangeable magnesium content ranging from 1.32 c mol kg^{-1} to 1.37 c mol kg^{-1} (Table 20B). The interaction effect of CF significantly influenced the exchangeable magnesium content of the soil. Other treatments or interaction effects of treatments did not significantly affect the exchangeable magnesium content of the soil (Table 24B).

Table: 23A Main effect of treatments and two factor interactions on exchangeable calcium content (c mol kg^{-1}) of surface soil

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	1.71	1.70	1.72	1.71	1.71	1.72	1.71
C_1	1.71	1.79	1.74	1.73	1.79	1.74	1.75
	A_0	A_1	A_2	Mean	CD SE	CD SE	
F_0	1.71	1.71	1.72	1.72	C 0.02 0.01	CF 0.03 0.01	
F_1	1.74	1.76	1.74	1.75	F 0.02 0.01	CA NS 0.01	
F_2	1.72	1.73	1.74	1.73	A NS 0.01	FA NS 0.01	
Mean	1.72	1.73	1.74				

Table: 23B Main effect of treatments and two factor interactions on exchangeable calcium (c mol kg^{-1}) content of sub surface soil

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	1.68	1.70	1.73	1.69	1.71	1.71	1.70
C_1	1.76	1.75	1.79	1.76	1.77	1.77	1.77
	A_0	A_1	A_2	Mean	CD SE	CD SE	
F_0	1.71	1.72	1.74	1.72	C 0.02 0.01	CF NS 0.01	
F_1	1.72	1.74	1.70	1.72	F 0.02 0.01	CA NS 0.01	
F_2	1.76	1.76	1.78	1.76	A NS 0.01	FA NS 0.01	
Mean	1.73	1.74	1.74				

Table:24A Main effect of treatments and two factor interactions on exchangeable magnesium content (c mol kg^{-1}) content of surface soil

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	1.40	1.40	1.40	1.40	1.39	1.44	1.40
C_1	1.42	1.43	1.46	1.43	1.44	1.44	1.44
	A_0	A_1	A_2	Mean	CD SE		CD SE
F_0	1.40	1.42	1.42	1.41	C 0.01 0.003		CF 0.01 0.01
F_1	1.41	1.40	1.43	1.41	F NS 0.004		CA NS 0.01
F_2	1.44	1.42	1.44	1.41	A 0.01 0.004		FA NS 0.008
Mean	1.41	1.41	1.43				

Table:24B Main effect of treatments and two factor interactions on exchangeable magnesium content (c mol kg^{-1}) of sub surface soil

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	1.34	1.36	1.33	1.34	1.35	1.34	1.34
C_1	1.34	1.35	1.36	1.35	1.35	1.36	1.35
	A_0	A_1	A_2	Mean	CD SE		CD SE
F_0	1.34	1.33	1.34	1.34	C NS 0.004		CF 0.02 0.01
F_1	1.34	1.37	1.36	1.36	F NS 0.006		CA NS 0.01
F_2	1.36	1.35	1.34	1.35	A NS 0.006		FA NS 0.008
Mean	1.35	1.35	1.35				

4.1.4 Effect of treatments on biometric observations

4.1.4.1 Leaf area index

The leaf area index at maximum tillering stage ranged from 1.18 to 1.50, where as the leaf area index at panicle initiation stage ranged from 4.14 to 4.77 (Table 25). The treatments alone or in combination did not significantly affect the leaf area index at these stages. At flowering stage, the leaf area index ranged from 4.62 to 4.94 with a mean of 4.79. The main effect of C and F and the interaction effect of CF and FA significantly affected the treatments. Leaf area index significantly increased in compacted plots (Table 27).

4.1.4.2 Time taken for maximum tillering

The time taken for maximum tillering ranged from 22.00 to 23.67 days (Table 26). None of the treatments alone or in combination significantly affected the time taken for maximum tillering except the main effect of C (Table 28). The C_1 treatment significantly reduced the time taken for maximum tillering.

4.1.4.3 Time taken for 50 percent flowering

The time taken for 50 percent flowering ranged from 61.33 days to 62.00 days (Table 26). The treatments alone or in combination did not significantly affect the above observations.

4.1.4.4 Root length

The length of root ranged from 15.67 cm to 25.33 cm (Table 29). The main effects or the interaction effects of treatments did not significantly influence the root length

Table: 25. Effect of treatments on leaf area index at maximum tillering, panicle initiation and flowering stage.

Treatment	Maximum Tillering	Panicle Initiation	Flowering
$C_0F_0A_0$	1.36	4.20	4. 71
$C_0F_0A_1$	1.18	4.17	4. 76
$C_0F_0A_2$	1.18	4.14	4. 76
$C_0F_1A_0$	1.44	4.15	4. 70
$C_0F_1A_1$	1.29	4.15	4. 81
$C_0F_1A_2$	1.27	4.16	4. 70
$C_0F_2A_0$	1.29	4.17	4. 65
$C_0F_2A_1$	1.28	4.26	4. 64
$C_0F_2A_2$	1.40	4.42	4. 62
$C_1F_0A_0$	1.50	4.62	4. 75
$C_1F_0A_1$	1.25.	4.73	4. 80
$C_1F_0A_2$	1.39	4.77	4. 83
$C_1F_1A_0$	1.38	4.74	4. 87
$C_1F_1A_1$	1.38	4.74	4. 89
$C_1F_1A_2$	1.34	4.73	4. 92
$C_1F_2A_0$	1.29	4.77	4. 94
$C_1F_2A_1$	1.35	4.69	4. 87
$C_1F_2A_2$	1.33	4.74	4. 90
CD	NS	NS	NS
SE	0.10	0.10	0.03

Table: 26. Effect of treatments on time taken for maximum tillering and fifty percent flowering

Treatment	Maximum Tillering (days)	Fifty percent Flowering (days)
$C_0F_0A_0$	23.67	62.00
$C_0F_0A_1$	22.67	62.00
$C_0F_0A_2$	23.33	62.00
$C_0F_1A_0$	23.33	61.67
$C_0F_1A_1$	22.67	61.67
$C_0F_1A_2$	23.00	61.67
$C_0F_2A_0$	23.33	61.67
$C_0F_2A_1$	23.33	62.00
$C_0F_2A_2$	23.67	62.00
$C_1F_0A_0$	23.00	61.67
$C_1F_0A_1$	22.67	61.33
$C_1F_0A_2$	22.33	62.00
$C_1F_1A_0$	22.33	61.33
$C_1F_1A_1$	22.33	62.00
$C_1F_1A_2$	22.67	62.00
$C_1F_2A_0$	22.00	61.67
$C_1F_2A_1$	23.00	62.00
$C_1F_2A_2$	22.67	61.33
CD	NS	NS
SE	0.44	0.10

Table: 27 Main effect of treatments and two factor interactions on leaf area index at flowering stage

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	4.74	4.74	4.64	4.69	4.73	4.69	4.71
C_1	4.79	4.89	4.91	4.85	4.85	4.89	4.86
	A_0	A_1	A_2	Mean	CD SE		CD SE
F_0	4.73	4.78	4.79	4.77	C 0.02 0.01		CF 0.04 0.01
F_1	4.79	4.85	4.81	4.82	F 0.03 0.01		CA NS 0.01
F_2	4.80	4.76	4.76	4.77	A NS 0.01		FA 0.05 0.02
Mean	4.77	4.79	4.79				

Table:28 Main effect of treatments and two factor interactions on time taken for maximum tillering (days)

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	23.22	23.00	23.44	23.44	22.89	23.33	23.22
C_1	22.67	22.44	22.56	22.44	22.67	22.58	22.56
	A_0	A_1	A_2	Mean	CD SE		CD SE
F_0	23.33	22.67	22.83	22.94	C 0.42 0.14		CF NS 0.25
F_1	22.83	22.50	22.83	22.72	F NS 0.19		CA NS 0.25
F_2	22.67	23.17	23.17	23.00	A NS 0.19		FA NS 0.30
Mean	22.94	22.78	22.94				

4.1.4.5 Root volume

The volume of roots ranged from 16.00 cc to 35.33 cc (Table 29). The root volume differed significantly with regard to C, F, and A effects and also with CF interactions (Table 30).

4.1.4.6 Root density

The root density ranged from 1.28 Mg $m^{-3} \times 10^{-6}$ to 1.81 Mg $m^{-3} \times 10^{-6}$ (Table 29). The main effects and the interaction effects of CF significantly influenced the root density (Table 31). The root density significantly increased in C_1 , F_2, and A_2 plots.

4.1.4.7 Grain yield

The grain yield ranged from 1.33 t ha^{-1} to 3.15 t ha^{-1} (Table 32). All effects and interactions except A differed significantly (Table 33). The grain yield significantly increased in C_1 and F_1 plots.

4.1.4.8 Straw yield

The straw yield ranged from 1.75 t ha^{-1} to 2.96 t ha^{-1} (Table 32). None of the factors significantly influenced the straw yield except CF (Table 33).

4.1.4.9 Dry matter production

The dry matter production ranged from 3.07 t ha^{-1} to 6.11 t ha-^{1} (Table 32). The main effect of the compaction and the interaction effects of the CF significantly influenced the dry matter production (Table 35). The dry matter production significantly increased in compacted plots.

Table: 29. Effect of treatments on root length, root volume, and root density

Treatment	Root length (cm)	Root volume (cc)	Root density ($Mg\ m^{-3} \times 10^{-6}$)
$C_0F_0A_0$	24.33	16.33	1.28
$C_0F_0A_1$	22.00	16.00	1.29
$C_0F_0A_2$	25.33	19.67	1.38
$C_0F_1A_0$	15.67	18.33	1.35
$C_0F_1A_1$	18.00	28.33	1.36
$C_0F_1A_2$	21.33	33.33	1.42
$C_0F_2A_0$	21.00	27.00	1.46
$C_0F_2A_1$	16.33	28.00	1.51
$C_0F_2A_2$	21.33	27.33	1.52
$C_1F_0A_0$	21.33	21.00	1.71
$C_1F_0A_1$	22.33	35.00	1.78
$C_1F_0A_2$	19.33	28.67	1.81
$C_1F_1A_0$	18.67	28.67	1.77
$C_1F_1A_1$	20.00	27.33	1.81
$C_1F_1A_2$	23.33	30.33	1.73
$C_1F_2A_0$	19.67	34.00	1.80
$C_1F_2A_1$	21.67	31.67	1.80
$C_1F_2A_2$	24.67	35.33	1.80
CD	NS	NS	NS
SE	2.78	2.82	0.03

Table: 30 Main effect of treatments and two factor interactions on root volume (cc)

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	17.33	26.67	27.44	20.56	24.11	26.78	23.81
C_1	29.89	28.78	33.67	29.56	31.33	31.44	30.78
	A_0	A_1	A_2	Mean	CD SE		CD SE
F_0	21.17	25.50	24.17	23.61	C 2.65 0.92		CF 4.59 1.60
F_1	23.50	27.83	31.83	27.72	F 3.25 1.13		CA NS 1.60
F_2	30.50	29.83	31.33	30.56	A 3.25 1.13		FA NS 1.92
Mean	25.06	27.72	29.11				

Table: 31 Main effect of treatments and two factor interactions on root density (Mg m^{-3} x 10^{-3})

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	1.32	1.38	1.50	1.36	1.39	1.44	1.40
C_1	1.77	1.77	1.80	1.76	1.80	1.78	1.78
	A_0	A_1	A_2	Mean	CD SE		CD SE
F_0	1.49	1.54	1.59	1.54	C 0.03 0.01		CF 0.03 0.02
F_1	1.56	1.59	1.58	1.58	F 0.03 0.01		CA NS 0.02
F_2	1.63	1.66	1.66	1.65	A 0.03 0.01		FA NS 0.02
Mean	1.56	1.59	1.61				

Table: 32 Effect of treatments on grain yield, straw yield, and dry matter production

Treatment	Grain Yield (t ha^{-1})	Straw Yield (t ha^{-1})	Dry Matter Production (t ha^{-1})
$C_0F_0A_0$	1.63	2.04	3.67
$C_0F_0A_1$	1.58	2.34	3.92
$C_0F_0A_2$	1.33	1.75	3.07
$C_0F_1A_0$	1.61	2.01	3.62
$C_0F_1A_1$	1.60	1.75	3.35
$C_0F_1A_2$	1.49	1.96	3.45
$C_0F_2A_0$	1.59	2.38	3.97
$C_0F_2A_1$	1.67	2.35	4.20
$C_0F_2A_2$	1.65	2.78	4.43
$C_1F_0A_0$	2.06	2.47	4.53
$C_1F_0A_1$	1.94	2.20	4.78
$C_1F_0A_2$	2.67	2.11	4.79
$C_1F_1A_0$	2.33	2.19	4.52
$C_1F_1A_1$	3.15	2.96	6.11
$C_1F_1A_2$	2.39	2.35	4.75
$C_1F_2A_0$	2.43	2.35	4.78
$C_1F_2A_1$	2.18	2.17	4.35
$C_1F_2A_2$	2.28	2.37	4.65
CD	0.28	0.53	0.70
SE	0.10	0.19	0.24

Table: 33 Main effect of treatments and two factor interactions on grain yield (t ha^{-1})

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	1.51	1.57	1.64	1.61	1.62	1.49	1.57
C_1	2.23	2.62	2.30	2.27	2.42	2.45	2.38
	A_0	A_1	A_2	Mean	CD	SE	CD SE
F_0	1.85	1.76	2.00	1.87	C 0.09	0.03	CF 0.16
F_1	1.97	2.38	1.94	2.10	F 0.11	0.03	CA 0.16
F_2	2.01	1.93	1.97	1.97	A NS	0.03	FA 0.20
Mean	1.94	2.02	1.97				

Table: 34 Main effect of treatments and two factor interactions on straw yield (t ha^{-1})

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	2.04	1.91	2.50	2.14	2.15	2.16	2.15
C_1	2.26	2.50	2.30	2.34	2.45	2.28	2.35
	A_0	A_1	A_2	Mean	CD	SE	CD SE
F_0	2.26	2.27	1.93	2.15	C NS	0.06	CF 0.31 0.11
F_1	2.10	2.36	2.16	2.21	F NS	0.08	CA NS 0.11
F_2	2.36	2.26	2.57	2.40	A NS	0.08	FA NS 0.13
Mean	2.24	2.30	2.22				

Table:35 Main effect of treatments and two factor interactions on dry matter content (t ha^{-1})

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	3.55	3.47	4.20	3.75	3.82	3.65	3.74
C_1	4.70	5.13	4.59	4.61	5.08	4.73	4.81
	A_0	A_1	A_2	Mean	CD	SE	CD SE
F_0	4.10	4.35	3.93	4.13	C 0.23	0.08	CF 0.41 0.14
F_1	4.07	4.73	4.10	4.30	F NS	0.11	CA NS 0.14
F_2	4.38	4.28	4.54	4.40	A NS	0.11	FA NS 0.17
Mean	4.18	4.45	4.19				

4.1.4.10 Carbohydrate content

The carbohydrate content ranged from 67.43 percent to 71.19 percent (Table 46). The main effects of treatments or their interactions did not significantly influence the carbohydrate content.

4.1.4.11 Crude protein content

The crude protein content ranged from 4.79 percent to 8.65 percent (Table 36). The main effects of C and A and the interaction effects of the CF and FA significantly influenced the crude protein content (Table 37). The crude protein content significantly increased in C_1 and A_2 plots.

4.1.4.12 Total nitrogen content

The total nitrogen content of the plant ranged from 1.23 to 2.04 percent (Table 38).The main effects of C, F and A and the interaction effects of CF and FA significantly influenced the N content (Table 39). The N content increased significantly in C_1, F_2 and A_2 plots.

4.1.4.13 Total phosphorus content.

The total phosphorus content of the plant ranged from 0.13 percent to 0.29 percent (Table 38). The main effects of C and F significantly influenced the P content (Table 40).

4.1.4.14. Total potassium content

The total potassium content of the plant ranged from 1.69 to 2.21 percent (Table 38). The main effect of C, F and A significantly affected the potassium content of the (Table 41).

Table: 36 Effect of treatments on quality characteristics

Treatment	Carbohydrate content (percent)	Crude protein content (percent)
$C_0F_0A_0$	70.10	4.79
$C_0F_0A_1$	70.24	5.29
$C_0F_0A_2$	69.73	5.49
$C_0F_1A_0$	69.60	5.61
$C_0F_1A_1$	70.81	5.36
$C_0F_1A_2$	70.77	6.06
$C_0F_2A_0$	67.43	5.83
$C_0F_2A_1$	70.48	6.43
$C_0F_2A_2$	70.17	7.25
$C_1F_0A_0$	69.98	7.13
$C_1F_0A_1$	69.72	7.00
$C_1F_0A_2$	70.43	8.65
$C_1F_1A_0$	70.61	7.25
$C_1F_1A_1$	70.37	7.94
$C_1F_1A_2$	70.12	6.65
$C_1F_2A_0$	70.60	5.73
$C_1F_2A_1$	71.19	7.25
$C_1F_2A_2$	70.59	8.17
CD	NS	0.91
SE	0.90	0.30

Table:37 Main effect of treatments and two factor interactions on protein content (percent)

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	5.18	5.68	6.50	5.41	5.68	6.27	5.78
C_1	7.59	7.28	7.05	6.70	7.40	7.82	7.31
	A_0	A_1	A_2	Mean	CD SE	CD SE	
F_0	5.96	6.12	7.07	6.38	C 0.30 0.11	CF 0.53 0.18	
F_1	6.43	6.65	6.35	6.48	F NS 0.13	CA NS 0.18	
F_2	5.78	6.84	7.71	6.78	A 0.37 0.13	FA 0.65 0.23	
Mean	6.06	6.54	7.04				

Table: 38 Effect of treatments on total N, P, K, Ca and Mg content in the plant.

Treatment	N (percent)	P (percent)	K (percent)	Ca (percent)	Mg (percent
$C_0F_0A_0$	1.23	0.13	1.69	0.46	0.23
$C_0F_0A_1$	1.34	0.17	1.80	0.47	0.23
$C_0F_0A_2$	1.38	0.20	1.78	0.47	0.23
$C_0F_1A_0$	1.46	0.21	1.84	0.47	0.23
$C_0F_1A_1$	1.49	0.22	1.81	0.47	0.23
$C_0F_1A_2$	1.53	0.21	1.80	0.47	0.23
$C_0F_2A_0$	1.45	0.24	1.77	0.47	0.22
$C_0F_2A_1$	1.57	0.24	1.81	0.47	0.22
$C_0F_2A_2$	1.78	0.26	1.93	0.48	0.22
$C_1F_0A_0$	1.83	0.20	2.05	0.47	0.23
$C_1F_0A_1$	1.76	0.25	2.09	0.48	0.23
$C_1F_0A_2$	2.04	0.22	2.08	0.49	0.24
$C_1F_1A_0$	1.79	0.24	2.09	0.48	0.24
$C_1F_1A_1$	1.98	0.26	2.14	0.48	0.23
$C_1F_1A_2$	1.72	0.23	2.15	0.48	0.23
$C_1F_2A_0$	1.59	0.28	2.15	0.48	0.23
$C_1F_2A_1$	1.81	0.29	2.21	0.49	0.24
$C_1F_2A_2$	2.01	0.25	2.21	0.49	0.24
CD	0.15	NS	NS	NS	NS
SE	0.05	0.01	0.03	0.003	0.01

Table:39 Main effect of treatments and two factor interactions on total nitrogen content (percent) in the plant

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	1.32	1.49	1.60	1.38	1.47	1.56	1.47
C_1	1.87	1.83	1.80	1.74	1.85	1.92	1.84
	A_0	A_1	A_2	Mean	CD SE	CD SE	
F_0	1.53	1.55	1.71	1.60	C 0.05 0.02	CF 0.08 0.03	
F_1	1.62	1.74	1.62	1.66	F 0.06 0.02	CA NS 0.03	
F_2	1.52	1.69	1.89	1.70	A 0.06 0.02	FA 0.10 0.04	
Mean	1.56	1.66	1.74				

Table:40 Main effect of treatments and two factor interactions on total phosphorus content (percent) in the plant

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	0.17	0.22	0.25	0.20	0.21	0.23	0.21
C_1	0.22	0.24	0.27	0.24	0.26	0.23	0.25
	A_0	A_1	A_2	Mean	CD SE	CD SE	
F_0	0.17	0.21	0.21	0.19	C 0.03 0.04	CF NS 0.008	
F_1	0.23	0.24	0.22	0.23	F 0.04 0.01	CA NS 0.008	
F_2	0.26	0.26	0.26	0.26	A NS 0.01	FA NS 0.01	
Mean	0.22	0.23	0.23				

Table: 41 Main effect of treatments and two factor interactions on total potassium content (percent) in the plant

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	1.76	1.82	1.84	1.76	1.81	1.84	1.80
C_1	2.07	2.13	2.19	2.10	2.15	2.15	2.13
	A_0	A_1	A_2	Mean	CD SE	CD SE	
F_0	1.87	1.94	1.93	1.91	C 0.03 0.01	CF NS 0.02	
F_1	1.97	1.98	1.98	1.97	F 0.04 0.01	CA NS 0.02	
F_2	1.96	2.01	2.07	2.01	A-0.04 0.01	FA NS 0.02	
Mean	1.93	1.98	1.99				

4.1.4.15 Total calcium content

The total calcium content of the plant ranged from 0.46 to 0.49 percent (Table 38). The main effects of treatments or their interactions except CF did not significantly influence the calcium content (Table 42).

4.1.3.16 Total magnesium content

The total magnesium content of the plant ranged from 0.22 to 0.24 percent (Table 38). Neither the main effect nor the interaction effect significantly influenced the magnesium content except main effect of C (Table 43).

Table: 42 Main effect of treatments and two factor interactions on total calcium content (percent) in the plant

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	0.46	0.47	0.48	0.47	0.47	0.47	0.47
C_1	0.48	0.48	0.49	0.48	0.48	0.48	0.48
	A_0	A_1	A_2	Mean	CD SE		CD SE
F_0	0.47	0.47	0.48	0.47	C 0.01 0.001		CF NS 0.002
F_1	0.48	0.47	0.48	0.47	F NS 0.001		CA NS 0.002
F_2	0.48	0.48	0.48	0.48	A NS 0.001		FA NS 0.002
Mean	0.47	0.47	0.48				

Table: 43 Main effect of treatments and two factor interactions on total magnesium content (percent) in the plant

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	0.23	0.23	0.22	0.23	0.23	0.23	0.23
C_1	0.23	0.23	0.24	0.23	0.23	0.24	0.23
	A_0	A_1	A_2	Mean	CD SE		CD SE
F_0	0.23	0.23	0.23	0.23	C NS 0.004		CF 0.01 0.007
F_1	0.23	0.23	0.23	0.23	F NS 0.005		CA NS 0.007
F_2	0.23	0.23	0.23	0.23	A NS 0.005		FA NS 0.007
Mean	0.23	0.23	0.23				

4.2 SECOND CROP – RICE.

4.2.1 Effect of treatments on moisture characteristics of soil

4.2.1.1 Field Moisture Content

The surface soils recorded a field moisture content ranging from 15.93 to 24.58 percent (Table 44A). The subsurface soils recorded a field moisture content ranging from 14.17 to 24.44 percent (Table 44B). None of the treatments or their interactions significantly influenced the moisture content of surface and sub surface soils.

4.2.1.2 Hydraulic conductivity

The hydraulic conductivity of surface soils ranged from 10.03 (C_1FoA_1) to 22.34 cm hr^{-1} (C_1FoA_2) (Table 44A). The hydraulic conductivity showed a significant decrease in compacted plots. The main effect of compaction significantly influenced the hydraulic conductivity (Table 45A). The sub surface soils recorded a hydraulic conductivity ranging from 7.68 to 19.01 cm hr^{-1} (Table 44B). Sub surface soils showed a significant decrease in hydraulic conductivity in the compacted plots. The main effects of C and F significantly influenced the hydraulic conductivity (Table 45B).

4.2.1.3. Available water content

The available water content of the surface soils ranged from 1.58 to 5.18 percent (Table 44A). The available water content showed a significant increase in compacted plots. The $C_1F_1A_o$ plot recorded the highest available water content. The main effects of C and F significantly influenced the available water content (Table 46A). The sub surface soils recorded an available water content of 1.56 to7.00 percent (Table 44B). The sub surface soils showed the similar trend that of surface soils (Table 46B).

Table: 44A Effect of treatments on moisture characteristics of surface soil

Treatment	Moisture Content (percent)	Hydraulic Conductivity (cm hr $^{-1}$)	Available Water (percent)	Maximum Water holding Capacity (Percent)
$C_0F_0A_0$	24.58	20.52	1.58	31.75
$C_0F_0A_1$	19.66	21.83	1.73	27.04
$C_0F_0A_2$	15.93	22.34	1.58	23.02
$C_0F_1A_0$	17.94	22.09	2.04	22.75
$C_0F_1A_1$	19.42	21.05	2.33	25.02
$C_0F_1A_2$	20.41	22.00	2.15	30.38
$C_0F_2A_0$	18.61	20.87	1.77	26.46
$C_0F_2A_1$	18.24	21.86	2.01	26.49
$C_0F_2A_2$	18.06	19.94	2.44	25.01
$C_1F_0A_0$	19.75	11.43	3.64	30.37
$C_1F_0A_1$	22.24	10.03	3.55	29.62
$C_1F_0A_2$	19.14	10.32	3.80	27.37
$C_1F_1A_0$	17.18	10.46	5.18	22.45
$C_1F_1A_1$	16.82	11.53	4.38	22.65
$C_1F_1A_2$	22.27	11.35	3.57	30.14
$C_1F_2A_0$	20.54	10.19	2.95	28.67
$C_1F_2A_1$	20.69	11.01	4.72	25.69
$C_1F_2A_2$	24.10	10.74	3.84	27.39
CD	NS	NS	NS	NS
SE	2.18	0.58	0.38	3.52

Table: 44 B Effect of treatments on moisture characteristics of sub surface soil

Treatment	Moisture Content (percent)	Hydraulic Conductivity (cm hr $^{-1}$)	Available Water (percent)	Maximum Water Holding Capacity (Percent)
$C_0F_0A_0$	16.79	16.70	2.50	25.21
$C_0F_0A_1$	19.54	17.64	1.63	23.29
$C_0F_0A_2$	24.44	17.02	2.21	18.11
$C_0F_1A_0$	18.30	19.01	2.56	19.04
$C_0F_1A_1$	16.89	17.68	2.49	22.42
$C_0F_1A_2$	15.80	17.48	1.56	18.90
$C_0F_2A_0$	19.59	18.37	3.42	25.02
$C F_2A_1$	17.92	17.74	2.03	23.05.
$C_0F_2A_2$	19.70	18.89	2.36	23.20
$C_1F_1A_0$	16.34	8.03	4.60	27.71
$C_1F_0A_1$	19.35	8.16	4.61	33.26
$C_1F_0A_2$	15.43	7.68	5.43	18.65
$C_1F_0A_0$	14.17	8.10	5.04	33.51
$C_1F_1A_1$	15.38	7.99	7.00	18.81
$C_1F_1A_2$	17.77	8.62	5.97	24.23
$C_1F_2A_0$	16.22	8.21	6.54	19.06
$C_1F_2A_1$	17.47	.85	6.22	24.87
$C_1F_2A_2$	17.44	8.71	6.98	20.01
CD	NS	NS	NS	NS
SE	2.87	0.56	0.36	2.46

Table: 45A Main effect of treatments and two factor interactions on hydraulic conductivity (cm hr^{-1}) of surface soil

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	21.56	21.72	20.76	21.16	21.45	21.43	21.34
C_1	10.59	11.11	10.65	10.69	10.86	10.80	10.78
	A_0	A_1	A_2	Mean	CD	SE	CD SE
F_0	15.98	15.93	16.33	16.08	C 0.55	0.20	CF NS 0.33
F_1	16.28	16.29	16.67	16.41	F NS	0.25	CA NS 0.33
F_2	15.53	16.24	15.34	15.70	A NS	0.25	FA NS 0.39
Mean	15.931	16.15	16.12				

Table: 45B Main effect of treatments and two factor interactions on hydraulic conductivity (cm hr^{-1}) of sub surface soil

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	17.12	18.05	18.33	17.12	18.05	18.33	17.84
C_1	7.96	8.24	8.59	7.96	8.24	8.59	8.26
	A_0	A_1	A_2	Mean	CD	SE	CD SE
F_0	12.36	12.90	12.35	12.04	C 0.55	0.19	CF NS 0.32
F_1	13.55	12.83	13.05	13.15	F 0.65	0.24	CA NS 0.32
F_2	13.29	13.29	13.80	13.46	A NS	0.24	FA NS 0.38
Mean	13.07	13.01	13.07				

4.2.1.4 Maximum water holding capacity

Maximum water holding capacity of the surface soils ranged from 22.45 to 31.75 percent (Table 44A). None of the treatments or their interactions except FA significantly affected the maximum water holding capacity of the soil (Table 47A). The subsurface soils recorded the maximum water holding capacity ranging from 18.11 to 33.51 (Table 44B). The subsurface soils recorded a similar trend that of surface soils. None of the treatments or their interactions significantly affected the maximum water holding capacity of the soil.

4.2.2.Effect of treatments on structural characteristics of soil.

4.2.2.1 Mean weight diameter

The mean weight diameter of the surface soils ranged from 0.50 to 0.65 (Table 48A). The main effect of F significantly affected the mean weight diameter (Table 49A). Other treatments or their interactions did not significantly affected the mean weight diameter of the soil. The subsurface soils recorded a mean weight diameter ranging from 0.54 to 0.67 (Table 48B). None of the treatments or their interactions did not significantly affect the mean weight diameter of the soil.

4.2.2.2 Microporosity

The microporosity of the surface soils ranged from 15.90 to 36.00 percent (Table 48A). The main effect of compaction significantly increased the microporosity of surface soils (Table 50A). The subsurface soils recorded a microporosity ranging from 17.05 to 37.63 percent (Table 48B). The main effect of C and F significantly influenced the microporosiy of sub surface soils (Table 50B). The other treatments or their interactions did not significantly influence the microporosity of subsurface soils

Table: 46A Effect of treatments and two factor interactions on available water content (percent) of surface soil

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	1.63	2.17	2.17	1.80	2.02	2.05	1.90
C_1	3.66	4.38	3.84	3.92	4.22	3.74	3.90
	A_0	A_1	A_2	Mean	CD SE	CD SE	
F_0	2.61	2.64	2.69	2.65	C 0.35 0.12	CF NS 0.21	
F_1	3.61	3.36	2.86	3.28	F 0.43 0.15	CA NS 0.21	
F_2	2.36	3.36	3.14	2.95	A NS 0.15	FA 0.75 0.26	
Mean	2.86	3.42	2.90				

Table: 46B Effect of treatments and two factor interactions on available water content (percent) of sub surface soil

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	2.11	2.20	2.61	2.83	2.05	2.04	2.31
C_1	4.88	6.00	6.58	5.40	5.94	6.13	5.82
	A_0	A_1	A_2	Mean	CD SE	CD SE	
F_0	3.55	3.12	3.82	3.53	C 0.34 0.12	CF 0.58 0.20	
F_1	3.80	4.74	3.76	4.10	F 0.41 0.14	CA 0.58 0.20	
F_2	4.98	4.13	4.67	4.59	A NS 0.14	FA 0.71 0.25	
Mean	4.10	4.00	4.09	.			

Table: 47 Main effect of treatments and two factor interactions on water holding capacity (percent)of surface soil

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	27.27	26.05	25.91	26.99	26.18	26.14	26.54
C_1	29.12	25.08	27.25	27.16	25.99	28.30	27.15
	A_0	A_1	A_2	Mean	CD SE	CD SE	
F_0	31.06	28.33	25.19	28.19	C NS 0.84	CF NS 1.39	
F_1	22.10	23.83	30.26	25.57	F NS 1.05	CA NS 1.39	
F_2	27.56	26.09	26.20	26.62	A NS 1.05	FA 4.90 1.71	
Mean	27.07	26.08	27.22				

Table: 48A Effect of treatments on structural characteristics of surface soil

Treatment	Mean weight diameter	Micro porosity (Percent)	Macro porosity (Percent)	Total Porosity (Percent)	Bulk Density (Mg m^{-3})	Particle Density (Mg m^{-3})	Soil Strength (kg m^{-2})
$C_0F_0A_0$	0.52	19.83	21.23	45.89	1.61	2.58	1.00
$C_0F_0A_1$	0.50	16.46	33.60	48.91	1.70	2.60	1.00
$C_0F_0A_2$	0.54	17.52	29.05	42.91	1.56	2.70	1.00
$C_0F_1A_0$	0.59	17.06	22.57	37.93	1.63	2.50	1.33
$C_0F_1A_1$	0.58	15.90	29.38	39.62	1.56	2.52	1.33
$C_0F_1A_2$	0.58	17.67	29.16	48.44	1.74	2.65	1.33
$C_0F_2A_0$	0.62	22.30	23.87	45.87	1.60	2.46	1.33
$C_0F_2A_1$	0.64	20.90	20.96	39.48	1.67	2.60	1.33
$C_0F_2A_2$	0.61	17.87	27.13	39.36	1.55	2.55	2.58
$C_1F_0A_0$	0.56	24.35	18.50	45.63	1.61	2.59	3.00
$C_1F_0A_1$	0.50	16.91	34.80	51.33	1.43	2.51	3.00
$C_1F_0A_2$	0.51	28.23	15.39	43.01	1.77	2.59	3.17
$C_1F_1A_0$	0.59	27.49	19.77	41.07	1.50	2.65	3.08
$C_1F_1A_1$	0.57	36.00	16.30	37.12	2.02	2.57	3.00
$C_1F_1A_2$	0.58	20.80	28.85	45.92	1.49	2.55	3.42
$C_1F_2A_0$	0.65	24.01	21.33	46.62	1.76	2.64	3.00
$C_1F_2A_1$	0.61	31.21	15..78	39.08	1.57	2.58	3.00
$C_1F_2A_2$	0.62	23.09	23.39	46.60	1.73	2.59	3.00
CD	NS	NS	NS	NS	0.35	NS	0.45
SE	0.03	3.83	4.25	3.85	0.12	0.006	0.16

Table: 48B Effect of treatments on structural characteristics of sub surface soil

Treatment	Mean weight diameter	Micro porosity (Percent)	Macro porosity (Percent)	Total Porosity (Percent)	Bulk Density (Mg m-^{3})	Particle Density (Mg m^{-3})
$C_0F_0A_0$	0.57	25.30	13.57	38.87	1.61	2.63
$C_0F_0A_1$	0.54	22.72	22.02	34.74	1.83	2.60
$C_0F_0A_2$	0.56	18.68	24.62	39.97	1.56	2.60
$C_0F_1A_0$	0.62	21.32	21.22	35.01	1.63	2.51
$C_0F_1A_1$	0.66	24.32	21.67	39.32	1.72	2.56
$C_0F_1A_2$	0.65	17.05	15.77	29.49	1.74	2.47
$C_0F_2A_0$	0.62	23.65	21.11	38.09	1.67	2.55
$C_0F_2A_1$	0.63	21.58	18.89	33.94	1.67	2.53
$C_0F_2A_2$	0.64	19.77	22.37	38.79	1.54	2.54
$C_1F_0A_0$	0.65	27.19	14.57	38.42	1.61	2.62
$C_1F_0A_1$	0.67	37.63	18.15	44.90	1.60	2.60
$C_1F_0A_2$	0.67	26.02	17.43	31.69	1.77	2.60
$C_1F_1A_0$	0.60	22.98	21.83	41.49	1.73	2.56
$C_1F_1A_1$	0.61	21.88	13.51	18.73	2.02	2.49
$C_1F_1A_2$	0.58	24.06	25.50	42.90	1.79	2.60
$C_1F_2A_0$	0.58	21.79	14.42	32.87	1.76	2.63
$C_1F_2A_1$	0.58	25.85	15.30	37.82	1.57	2.52
$C_1F_2A_2$	0.55	27.68	16.25	33.94	1.73	2.57
CD	NS	NS	NS	13.73	NS	NS
SE	0.02	2.92	3.69	4.88	0.11	0.04

Table: 49 Main effect of treatments and two factor interactions on mean weight diameter of surface soil

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	0.52	0.58	0.62	0.58	0.57	0.57	0.57
C_1	0.52	0.55	0.63	0.60	0.56	0.57	0.58
	A_0	A_1	A_2	Mean	CD SE		CD SE
F_0	0.54	0.50	0.53	0.52	C NS 0.01		CF NS 0.02
F_1	0.59	0.58	0.58	0.58	F 0.04 0.01		CA NS 0.02
F_2	0.64	0.62	0.61	0.62	A NS 0.01		FA NS 0.02
Mean	0.59	0.57	0.57				

Table: 50A Main effect of treatments and two factor interactions on micro porosity (percent) of surface soil

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	17.94	16.88	20.36	19.73	17.75	17.69	18.39
C_1	23.16	28.09	26.10	25.28	28.04	24.04	25.79
	A_0	A_1	A_2	Mean	CD SE		CD SE
F_0	22.09	16.68	22.88	20.55	C 3.60 1.25		CF NS 2.17
F_1	22.28	25.95	19.23	22.48	F NS 1.63		CA NS 2.17
F_2	23.25	26.06	20.45	23.23	A NS 1.63		FA NS 2.60
Mean	22.51	242.90	20.86				

Table: 50B Main effect of treatments and two factor interactions on micro porosity (percent) of sub surface soil

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	20.07	19.55	20.79	18.63	20.86	20.92	21.60
C_1	16.72	20.28	15.32	16.94	15.65	19.63	26.12
	A_0	A_1	A_2	Mean	CD SE		CD SE
F_0	14.01	20.08	21.03	26.26	C 2.75 0.96		CF NS 1.66
F_1	16.72	20.28	15.32	21.94	F 3.36 1.17		CA NS 1.66
F_2	17.77	17.09	19.31	23.39	A NS 1.17		FA NS 1.99
Mean	23.70	25.66	22.21				

4.2.2.3 Macroporosity

The macroporosity of the surface soils ranged from 15.39 to 34.80 percent (Table 48A). The main effect of compaction and the interaction effect of FA significantly influenced the macroporosity of the soil (Table 51). The macroporosity significantly decreased in compacted plots.The macroporosity of the subsurface soils ranged from 13.51 to 25.50 percent (Table 48B). The main effect of compaction significantly decreased the macroprosity. None of the treatments or their interactions significantly influenced the macroporosity of the subsurface soils.

4.2.2.4 Total Porosity

The total porosity of the surface soils ranged from 37.12 to 51.33 percent (Table 48A). The interaction effect of FA significantly influenced the total porosity of the surface soil (Table 52A). The other treatments and their interactions did not significantly influence the total porosity of the soil. The subsurface soils recorded a total porosity ranging from 18.73 to 44.90 percent (Table 48B). None of the treatments or their interactions significantly influenced the total porosity of the sub surface soil.

4.2.2.5 Bulk Density

The bulk density of the surface soils ranged from 1.43 to 2.02 Mg m^{-3} (Table 48A). The three factor interactions significantly influenced the bulk density of surface soils. The treatment $C_1F_1A_1$ recorded the highest bulk density of 2.02 Mg m^{-3} and the treatment $C_1F_0A_1$ recorded the lowest bulk density of 1.43 Mg m^{-3}. The other factor or their interactions did not significantly affect the bulk density of surface soil. The bulk density of the subsurface soils ranged from 1.54 to 2.02 Mg m^{-3} (Table 48B). None of the treatments or their interactions significantly influenced the bulk density of subsurface soils.

Table: 51 Main effect of treatments and two factor interactions on macro porosity (percent) of surface soil

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	27.96	27.04	23.99	22.55	27.98	28.45	26.33
C_1	22.90	21.64	20.17	19.87	22.30	22.55	21.57
	A_0	A_1	A_2	Mean	CD SE		CD SE
F_0	19.86	34.20	22.22	25.43	C 3.99 1.39		CF NS 2.41
F_1	21.17	22.84	29.01	24.34	F NS 1.81		CA NS 2.41
F_2	22.60	18.37	25.26	22.08	A NS 1.81		FA 8.47 2.95
Mean	21.21	25.11	25.50				

Table: 52 Main effect of treatments and two factor interactions on total porosity (percent) of surface soil

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	45.90	42.00	41.57	43.23	42.67	43.57	43.16
C_1	46.66	41.37	44.10	44.44	42.51	45.18	44.04
	A_0	A_1	A_2	Mean	CD SE		CD SE
F_0	45.76	50.12	42.96	46.28	C NS 1.30		CF NS 2.18
F_1	39.50	38.37	47.18	41.68	F NS 1.63		CA NS 2.18
F_2	46.25	39.28	42.98	42.83	A NS 1.63		FA 7.67 2.67
Mean	43.84	42.59	44.37				

Table: 53A Main effect of treatments and two factor interactions on particle density (M g m^{-3}) of surface soil

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	2.63	2.56	2.54	2.51	2.58	2.63	2.57
C_1	2.54	2.59	2.60	2.63	2.55	2.57	2.58
	A_0	A_1	A_2	Mean	CD SE		CD SE
F_0	2.59	2.56	2.65	2.60	C NS 0.02		CF NS 0.03
F_1	2.58	2.55	2.60	2.57	F NS 0.02		CA 0.08 0.03
F_2	2.55	2.59	2.57	2.57	A NS 0.02		FA NS 0.03
Mean	2.57	2.56	2.60				

Table: 53B Main effect of treatments and two factor interactions on particle density (Mg m^{-3}) of sub surface soil

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	2.61	2.51	2.54	2.56	2.56	2.53	2.55
C_1	2.61	2.55	2.57	2.60	2.54	2.59	2.58
	A_0	A_1	A_2	Mean	CD SE		CD SE
F_0	2.63	2.60	2.60	2.61	C NS 0.01		CF NS 0.02
F_1	2.53	2.52	2.53	2.53	F 0.04 0.01		CA NS 0.02
F_2	2.59	2.52	2.56	2.56	A NS 0.01		FA NS 0.02
Mean	2.58	2.55	2.56				

Table: 54 Main effect of treatments and two factor interactions on soil strength (kg m^{-2})

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	1.00	1.33	1.75	1.22	1.22	1.64	1.36
C_1	3.06	3.17	3.00	3.03	3.00	3.19	3.07
	A_0	A_1	A_2	Mean	CD SE		CD SE
F_0	2.00	2.00	2.08	2.03	C 0.15 0.05		CF 0.26 0.09
F_1	2.21	2.17	2.38	2.25	F 0.18 0.06		CA NS 0.09
F_2	2.17	2.17	2.79	2.38	A 0.18 0.06		FA NS 0.11
Mean	2.13	2.11	2.42				

Table: 55A Effect of treatments on chemical characteristics of surface soil

Treatment	Soil pH	Organic carbon (Percent)
$C_0F_0A_0$	5.1	0.45
$C_0F_0A_1$	5.2	0.48
$C_0F_0A_2$	5.0	0.45
$C_0F_1A_0$	5.1	0.48
$C_0F_1A_1$	5.1	0.52
$C_0F_1A_2$	5.1	0.51
$C_0F_2A_0$	5.2	0.54
$C_0F_2A_1$	5.0	0.56
$C_0F_2A_2$	5.2	0.54
$C_1F_0A_0$	5.1	0.58
$C_1F_0A_1$	5.0	0.57
$C_1F_0A_2$	5.2	0.60
$C_1F_1A_0$	5.0	0.64
$C_1F_1A_1$	5.1	0.65
$C_1F_1A_2$	5.2	0.67
$C_1F_2A_0$	5.0	0.65
$C_1F_2A_1$	5.2	0.67
$C_1F_2A_2$	5.1	0.64
CD	NS	NS
SE	0.05	0.02

Table: 55B Effect of treatments on chemical characteristics of sub surface soil

Treatment	Soil pH	Organic carbon (Percent)
$C_0F_0A_0$	5.13	0.52
$C_0F_0A_1$	5.10	0.47
$C_0F_0A_2$	5.00	0.45
$C_0F_1A_0$	5.03	0.48
$C_0F_1A_1$	5.13	0.47
$C_0F_1A_2$	5.00	0.50
$C_0F_2A_0$	5.03	0.46
$C_0F_2A_1$	5.10	0.48
$C_0F_2A_2$	4.90	0.49
$C_1F_0A_0$	5.00	0.50
$C_1F_0A_1$	4.90	0.49
$C_1F_0A_2$	5.07	0.50
$C_1F_1A_0$	5.07	0.51
$C_1F_1A_1$	5.07	0.48
$C_1F_1A_2$	5.03	0.47
$C_1F_2A_0$	5.00	0.48
$C_1F_2A_1$	4.97	0.47
$C_1F_2A_2$	5.00	0.44
CD	NS	NS
SE	0.06	0.02

Table: 56 Main effect of treatments and two factor interactions on pH of sub surface soil

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	5.08	5.06	5.01	5.07	5.11	4.97	5.05
C_1	4.99	5.06	4.99	5.02	4.98	5.03	5.01

	A_0	A_1	A_2	Mean
F_0	5.07	5.00	5.03	5.03
F_1	5.05	5.10	5.02	5.06
F_2	5.02	5.03	4.95	5.00
Mean	5.04	5.04	5.00	

	CD	SE		CD	SE
C	NS	0.02	**CF**	NS	0.03
F	NS	0.03	**CA**	0.09	0.03
A	NS	0.03	**FA**	NS	0.04

4.2.2.6 Particle Density

The particle density of the surface soils ranged from 2.46 to 2.70 Mg m^{-3} (Table 48A). The interaction effect of CA significantly influenced the particle density of surface soil (Table 53A). None of other treatments or their interaction significantly influenced the particle density of surface soil. The particle density of the sub surface soils ranged from 2.47 to 2.63 Mg m^{-3} (Table 48B). The main effect of F significantly influenced the particle density of sub surface soil (Table 53B).

4.2.2.7 Soil Strength

The strength of surface soils ranged from 1.00 to 3.42 kgm^{-2} (Table 48A). The main effects of C, F, A and the interaction effect of CF significantly influenced the soil strength (Table 54). The treatment $C_1F_1A_2$ recorded the highest soil strength of 3.42 kg m^{-2} and the treatments $C_oF_oA_o$, $C_oF_oA_1$ and $C_oF_oA_2$ recorded the lowest soil strength of 1.00 kg m^{-2}.

4.2.3 Effect of treatments on chemical characteristics of soil

4.2.3.1 Soil Reaction

The pH of the surface soil ranged from 5.0 to 5.2 (Table 55A). None of the treatments or their interactions significantly influenced the pH of surface soil. The subsurface soils recorded a soil pH ranging from 4.90 to 5.13 (Table 55B). The interaction effect of CA significantly influenced the pH of subsurface soils (Table 56).

Table: 55A Effect of treatments on chemical characteristics of surface soil

Treatment	**Soil pH**	**Organic carbon (Percent)**
$C_0F_0A_0$	5.1	0.45
$C_0F_0A_1$	5.2	0.48
$C_0F_0A_2$	5.0	0.45
$C_0F_1A_0$	5.1	0.48
$C_0F_1A_1$	5.1	0.52
$C_0F_1A_2$	5.1	0.51
$C_0F_2A_0$	5.2	0.54
$C_0F_2A_1$	5.0	0.56
$C_0F_2A_2$	5.2	0.54
$C_1F_0A_0$	5.1	0.58
$C_1F_0A_1$	5.0	0.57
$C_1F_0A_2$	5.2	0.60
$C_1F_1A_0$	5.0	0.64
$C_1F_1A_1$	5.1	0.65
$C_1F_1A_2$	5.2	0.67
$C_1F_2A_0$	5.0	0.65
$C_1F_2A_1$	5.2	0.67
$C_1F_2A_2$	5.1	0.64
CD	NS	NS
SE	0.05	0.02

Table: 55B Effect of treatments on chemical characteristics of sub surface soil

Treatment	Soil pH	Organic carbon (Percent)
$C_0F_0A_0$	5.13	0.52
$C_0F_0A_1$	5.10	0.47
$C_0F_0A_2$	5.00	0.45
$C_0F_1A_0$	5.03	0.48
$C_0F_1A_1$	5.13	0.47
$C_0F_1A_2$	5.00	0.50
$C_0F_2A_0$	5.03	0.46
$C_0F_2A_1$	5.10	0.48
$C_0F_2A_2$	4.90	0.49
$C_1F_0A_0$	5.00	0.50
$C_1F_0A_1$	4.90	0.49
$C_1F_0A_2$	5.07	0.50
$C_1F_1A_0$	5.07	0.51
$C_1F_1A_1$	5.07	0.48
$C_1F_1A_2$	5.03	0.47
$C_1F_2A_0$	5.00	0.48
$C_1F_2A_1$	4.97	0.47
$C_1F_2A_2$	5.00	0.44
CD	NS	NS
SE	0.06	0.02

Table: 56 Main effect of treatments and two factor interactions on pH of sub surface soil

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	5.08	5.06	5.01	5.07	5.11	4.97	5.05
C_1	4.99	5.06	4.99	5.02	4.98	5.03	5.01
	A_0	A_1	A_2	Mean			
F_0	5.07	5.00	5.03	5.03			
F_1	5.05	5.10	5.02	5.06			
F_2	5.02	5.03	4.95	5.00			
Mean	5.04	5.04	5.00				

	CD	SE		CD	SE
C	NS	0.02	CF	NS	0.03
F	NS	0.03	CA	0.09	0.03
A	NS	0.03	FA	NS	0.04

4.2.3.2 Organic Carbon

The surface soil recorded an organic carbon content ranging from 0.45 to 0.67 percent (Table 55A). The main effects of C and F significantly increased the organic carbon content of surface soils (Table 57). The subsurface soils recorded an organic carbon content ranging from 0.45 to 0.52 percent (Table 55B). None of the treatments or their interactions significantly influenced the organic carbon content of subsurface soils.

4.2.3.3.Available N

The available N content of the surface soil ranged from 183.00 to 220.18 kg ha^{-1} (Table 58A). The main effects of C, F and A and the interaction effect of CF significantly increased the available N content of surface soils (Table 59A).The subsurface soil recorded an available N content ranging from 173.22 to 187.71 kg ha^{-1} (Table 58B). The main effect of C, F and A and the interaction effect of CF significantly increased the available N content of subsurface soils (Table 59B).

4.2.3.4 Available P

The available phosphorus content of the surface soil ranged from 32.45 to 41.34 kg ha^{-1} (Table 58A). The main effect of C, F and the interaction effect of CF significantly increased the available P content of surface soils (Table 60A). The subsurface soils recorded an available phosphorus ranging from 33.80 to 43.16 kg ha^{-1} (Table 58B). The main effect of C, F and the interaction effect of CA significantly increased the available P content of subsurface soils (Table 60B).

4.2.3.5 Available K

Available potassium content of the surface soils ranged from 47.79 to 73.17 kg ha^{-1} (Table 58A). The main effect of C and A and interaction effect of CF and CA significantly

Table: 57 Main effect of treatments and two factor interactions on organic carbon content (percent) of surface soil

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	0.46	0.51	0.55	0.49	0.52	0.50	0.51
C_1	0.58	0.65	0.65	0.62	0.63	0.63	0.63

	A_0	A_1	A_2	Mean
F_0	0.52	0.53	0.53	0.52
F_1	0.56	0.58	0.59	0.58
F_2	0.60	0.62	0.59	0.60
Mean	0.56	0.58	0.57	

	CD	SE		CD	SE
C	0.02	0.01	CF	NS	0.01
F	0.03	0.01	CA	NS	0.01
A	NS	0.01	FA	NS	0.02

Table: 58A Effect of treatments on available N, P, K, exchangeable Ca and Mg content of surface soil

Treatment	Available N (kg ha $^{-1}$)	Available P (kg ha $^{-1}$)	Available K (kg ha $^{-1}$)	Exchangeable Ca (c mol kg $^{-1}$)	Exchangeable Mg (c mol kg $^{-1}$)
$C_0F_0A_0$	183.00	32.45	47.79	1.70	1.40
$C_0F_0A_1$	188.89	34.23	53.01	1.71	1.42
$C_0F_0A_2$	188.88	35.38	55.25	1.70	1.43
$C_0F_1A_0$	189.79	35.97	55.25	1.72	1.44
$C_0F_1A_1$	192.60	37.30	47.79	1.74	1.45
$C_0F_1A_2$	198.16	38.75	64.21	1.75	1.46
$C_0F_2A_0$	201.89	38.03	59.72	1.74	1.47
$C_0 F_2A_1$	202.90	36.19	58.24	1.70	1.50
$C_0F_2A_2$	204.00	36.73	64.21	1.71	1.44
$C_1F_0A_0$	212.42	39.35	70.19	1.73	1.47
$C_1F_0A_1$	212.20	39.66	71.68	1.73	1.46
$C_1F_0A_2$	216.40	40.08	73.17	1.74	1.47
$C_1F_1A_0$	220.16	40.05	66.45	1.78	1.43
$C_1F_1A_1$	219.77	40.81	70.19	1.77	1.45
$C_1F_1A_2$	220.18	39.39	69.44	1.74	1.47
$C_1F_2A_0$	211.40	41.34	66.45	1.68	1.44
$C_1F_2A_1$	211.93	40.05	71.68	1.75	1.45
$C_1F_2A_2$	218.65	38.68	69.48	1.80	1.48
CD	NS	NS	NS	0.07	NS
SE	2.69	0.95	2.89	0.02	0.02

Table: 58B Effect of treatments on available N, P, K, exchangeable Ca and Mg content of subsurface soil

Treatment	**Available N (kg ha $^{-1}$)**	**Available P (kg ha $^{-1}$)**	**Available K (kg ha $^{-1}$)**	**Exchangeable Ca (c mol kg $^{-1}$)**	**Exchangeable Mg (c mol kg $^{-1}$)**
$C_0F_0A_0$	173.61	33.80	56.75	1.68	1.32
$C_0F_0A_1$	176.20	35.43	61.97	1.68	1.32
$C_0F_0A_2$	174.67	36.81	56.00	1.65	1.32
$C_0F_1A_0$	173.22	36.83	56.75	1.64	1.36
$C_0F_1A_1$	173.42	38.88	61.97	1.63	1.36
$C_0F_1A_2$	178.69	37.68	56.75	1.64	1.36
$C_0F_2A_0$	178.38	39.77	58.99	1.65	1.33
$C_0F_2A_1$	174.68	39.25	69.44	1.68	1.35
$C_0F_2A_2$	180.51	41.03	70.93	1.70	1.32
$C_1F_0A_0$	180.24	42.77	61.23	1.65	1.35
$C_1F_0A_1$	181.86	43.16	65.71	1.69	1.35
$C_1F_0A_2$	184.52	42.09	69.44	1.69	1.35
$C_1F_1A_0$	186.00	41.49	69.44	1.67	1.35
$C_1F_1A_1$	187.71	42.01	79.83	1.68	1.36
$C_1F_1A_2$	187.64	40.13	74.67	1.68	1.35
$C_1F_2A_0$	185.18	42.42	73.92	1.68	1.36
$C_1F_2A_1$	186.04	41.75	67.95	1.69	1.34
$C_1F_2A_2$	187.51	41.11	72.43	1.70	1.35
CD	NS	NS	8.65	NS	NS
SE	1.29	0.75	3.01	0.01	0.01

Table: 59A Main effect of treatments and two factor interactions on available nitrogen content (kg ha^{-1}) of surface soil

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	186.93	193.54	202.93	191.56	194.82	197.02	194.46
C_1	213.62	220.04	213.99	214.66	214.63	218.36	215.88

	A_0	A_1	A_2	Mean
F_0	197.71	200.55	202.56	200.27
F_1	204.97	206.21	209.17	206.79
F_2	206.65	207.42	211.33	208.46
Mean	203.11	204.73	207.69	

	CD	SE		CD	SE
C	2.53	0.88	CF	4.39	1.53
F	3.10	1.08	CA	NS	1.53
A	3.10	1.08	FA	NS	1.83

Table: 59B Main effect of treatments and two factor interactions on available nitrogen content (kg ha^{-1}) of sub surface soil

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	174.83	175.13	177.86	175.07	174.79	177.96	175.94
C_1	182.21	187.12	186.25	183.81	185.20	186.56	185.19

	A_0	A_1	A_2	Mean
F_0	176.93	179.03	179.60	178.52
F_1	179.61	180.59	183.16	181.12
F_2	181.78	180.36	184.01	182.05
Mean	179.44	180.00	182.26	

	CD	SE		CD	SE
C	1.22	0.42	CF	2.11	0.73
F	1.49	0.52	CA	NS	0.73
A	1.49	0.52	FA	NS	0.88

Table: 60A Main effect of treatments and two factor interactions on available phosphorus content (kg ha^{-1}) of surface soil

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	34.02	37.34	36.98	35.48	35.91	36.95	36.11
C_1	39.70	40.08	40.02	40.24	40.18	39.38	39.93
	A_0	A_1	A_2	Mean			
F_0	35.90	36.95	37.73	36.86			
F_1	38.01	39.06	39.07	38.71			
F_2	39.68	38.12	37.70	38.50			
Mean	37.86	38.04	38.17				

	CD	SE		CD	SE
C	0.89	0.31	CF	1.54	0.54
F	1.09	0.38	CA	NS	0.54
A	NS	0.38	FA	NS	0.64

Table: 60B Main effect of treatments and two factor interactions on available phosphorus content (kg ha^{-1}) of sub surface soil

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	35.35	37.80	40.02	36.80	37.85	38.51	37.72
C_1	42.67	41.21	41.76	42.23	42.31	41.11	41.88
	A_0	A_1	A_2	Mean			
F_0	38.29	39.30	39.45	39.01			
F_1	39.16	40.45	38.90	39.50			
F_2	41.10	40.50	41.07	40.89			
Mean	39.51	40.08	39.81				

	CD	SE		CD	SE
C	0.71	0.25	CF	NS	0.43
F	0.86	0.30	CA	1.22	0.43
A	NS	0.30	FA	NS	0.51

increased the available K content of the surface soils (Table 61A). The subsurface soils recorded an available potassium content ranging from 56.00 (CoFoA$_2$) to 79.83 ($C_1F_1A_1$) kg ha^{-1} (Table 58B). The treatments differed significantly among themselves in available K content. The main effects of C, F, A and the interaction effect of CF significantly increased the available K content of subsurface soils (Table 61B).

4.2.3.6 Exchangeable Ca

The exchangeable Ca content of the surface soils ranged from 1.68 to 1.80 c mol kg^{-1} (Table 58A). The main effect of C significantly increased the exchangeable Ca content of surface soils (Table 62A). The effect of three factor interactions were also significant The exchangeable Ca content of the sub surface soils ranged from 1.63 to 1.70 c mol kg^{-1} (Table 58B) .The main effect of C and interaction effect of CF significantly increased the exchangeable Ca content of sub surface soils (Table 62B).

4.2.2.7 Exchangeable Mg.

The exchangeable Mg content of the surface soils ranged from 1.40 to 1.50 c mol kg^{-1} (Table 58A). None of the factors or their interactions except CF significantly affected the exchangeable Mg content of surface soils (Table 63A). The sub surface soils recorded an exchangeable Mg content ranging from 1.32 to 1.36 c mol kg^{-1} (Table 58B). The main effect of F significantly affected the exchangeable Mg content of sub surface soils. (Table 62B)

4.2.4. Effect of treatments on biometric observations.

4.2.4.1 Leaf Area Index

The leaf area index at maximum tillering stage ranged from 1.03 to 1.57 (Table 64). The treatment $C_1F_oA_1$ recorded the highest leaf area index of 1.57 and the treatment $C_0F_0A_0$

Table: 61A Main effect of treatments and two factor interactions on available potassium content (kg ha^{-1}) of surface soil

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	52.02	55.75	60.73	54.25	53.01	61.23	56.16
C_1	71.68	68.69	69.18	67.70	71.18	70.68	69.85
	A_0	A_1	A_2	Mean	CD SE		CD SE
F_0	58.99	62.35	64.21	61.85	C 2.71 0.95		CF 4.70 1.64
F_1	60.85	58.99	66.83	62.22	F NS 1.16		CA 4.70 1.64
F_2	63.09	64.96	66.82	64.96	A 3.33 1.16		FA NS 1.97
Mean	60.98	61.10	65.95				

Table: 61B Main effect of treatments and two factor interactions on available potassium content (kg ha^{-1}) of sub surface soil

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	58.24	58.49	66.45	57.49	64.46	61.23	61.06
C_1	65.46	74.65	71.43	68.24	71.16	72.18	70.50
	A_0	A_1	A_2	Mean	CD SE		CD SE
F_0	58.99	63.84	62.72	61.85	C 2.88 1.00		CF 5.00 1.74
F_1	63.09	70.90	65.71	66.57	F 3.53 1.23		CA NS 1.74
F_2	66.45	68.69	71.68	68.94	A 3.53 1.23		FA NS 2.09
Mean	62.24	67.81	66.71				

Table: 62A Main effect of treatments and two factor interactions on exchangeable calcium content (c mol kg^{-1})of surface soil

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	1.70	1.74	1.72	1.72	1.72	1.72	1.72
C_1	1.73	1.76	1.74	1.73	1.75	1.76	1.75
	A_0	A_1	A_2	Mean	CD	SE	CD SE
F_0	1.71	1.72	1.72	1.72	C 0.02	0.01	CF NS 0.01
F_1	1.73	1.75	1.76	1.75	F NS	0.01	CA NS 0.01
F_2	1.71	1.73	1.76	1.73	A NS	0.01	FA NS 0.02
Mean	1.72	1.73	1.74				

Table: 62B Main effect of treatments and two factor interactions on exchangeable calcium content (c mol kg^{-1})of sub surface soil

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	1.68	1.64	1.66	1.66	1.66	1.66	1.66
C_1	1.69	1.67	1.69	1.69	1.67	1.69	1.68
	A_0	A_1	A_2	Mean	CD	SE	CD SE
F_0	1.69	1.67	1.68	1.68	C 0.01	0.04	CF 0.02 0.01
F_1	1.67	1.66	1.66	1.66	F NS	0.006	CA NS 0.01
F_2	1.66	1.67	1.69	1.67	A NS	0.006	FA NS 0.01
Mean	1.73	1.74	1.74				

Table: 63A Main effect of treatments and two factor interactions on exchangeable magnesium content (c mol kg^{-1}) of surface soil

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	1.42	1.45	1.47	1.44	1.46	1.44	1.45
C_1	1.47	1.45	1.46	1.45	1.45	1.47	1.46

	A_0	A_1	A_2	Mean
F_0	1.43	1.44	1.45	1.44
F_1	1.44	1.45	1.46	1.45
F_2	1.46	1.47	1.46	1.46
Mean	1.44	1.45	1.46	

	CD	SE		CD	SE
C	NS	0.005	CF	0.03	0.01
F	NS	0.007	CA	NS	0.01
A	NS	0.007	FA	NS	0.01

Table: 63B Main effect of treatments and two factor interactions on exchangeable magnesium content of (c mol kg^{-1}) of subsurface soil

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	1.42	1.45	1.47	1.44	1.46	1.44	1.34
C_1	1.47	1.45	1.46	1.45	1.45	1.47	1.35

	A_0	A_1	A_2	Mean
F_0	1.43	1.44	1.45	1.33
F_1	1.44	1.45	1.46	1.36
F_2	1.46	1.47	1.46	1.34
Mean	1.34	1.34	1.34	

	CD	SE		CD	SE
C	NS	0.004	CF	NS	0.008
F	0.02	0.01	CA	NS	0.008
A	NS	0.01	FA	NS	0.01

recorded the lowest leaf area index of 1.03. The main effects of C, F, A and the interaction effect of CF and CA significantly affected the leaf area index at maximum tillering stage (Table 65). The leaf area index at panicle initiation stage ranged from 4.13 to 4.74 (Table 64). The treatments $C_1F_1A_2$, $C_1F_2A_0$ and $C_1F_2A_2$ recorded the highest leaf area index of 4.74 and the treatment $C_0F_0A_2$ recorded the lowest leaf area index of 4.13.The main effects of C, F and the interaction effect of CF significantly increased the leaf area index (Table 66). The leaf area index at flowering stage ranged from 4.75 to 4.95 (Table 64). The leaf area index significantly increased in compacted plots. The interaction effect of CF also significantly increased the leaf area index at the flowering stage (Table 67).

4.2.4.2 Time Taken for Maximum Tillering.

The time taken for maximum tillering ranged from 22.00 to 24.00 days (Table 68). The treatments $C_0F_2A_1$ and $C_0F_1A_0$ recorded the highest number of days taken for maximum tillering and the treatments $C_1F_2A_1$ and $C_1F_2A_2$ recorded the lowest number of days taken for maximum tillering. The main effect of C, A and the interaction effect of CA and FA significantly affected the time taken for maximum tillering (Table 69). The three factor interactions also significantly affected the time taken for maximum tillering.

4.2.4.3. Time taken for fifty percent flowering

The time taken for fifty percent flowering ranged from 61 to 63 days (Table 68). The main effects of C, F and the interaction effects of CA significantly affected the time taken for fifty percent flowering (Table 70).

4.2.4.4 Root Length

The root length ranged from 11.33 to 21.00 cm (Table 71). The treatment $C_1F_2A_1$ recorded the highest root length of 21.00 cm and the treatment $C_0F_2A_0$ recorded the lowest

Table:64 Effect of treatments on leaf area index at maximum tillering , panicle initiation and flowering stage.

Treatment	Maximum Tillering	Panicle Initiation	Flowering
$C_0F_0A_0$	1.03	4.21	4.78
$C_0F_0A_1$	1.05	4.16	4.81
$C_0F_0A_2$	1.11	4.13	4.78
$C_0F_1A_0$	1.07	4.19	4.80
$C_0F_1A_1$	1.14	4.30	4.81
$C_0F_1A_2$	1.14	4.33	4.77
$C_0F_2A_0$	1.22	4.43	4.75
$C_0F_2A_1$	1.22	4.50	4.79
$C_0F_2A_2$	1.36	4.55	4.84
$C_1F_0A_0$	1.49	4.62	4.86
$C_1F_0A_1$	1.57	4.73	4.90
$C_1F_0A_2$	1.44	4.73	4.90
$C_1F_0A_0$	1.47	4.70	4.95
$C_1F_1A_1$	1.44	4.73	4.91
$C_1F_1A_2$	1.51	4.74	4.93
$C_1F_2A_0$	1.55	4.74	4.90
$C_1F_2A_1$	1.54	4.73	4.94
$C_1F_2A_2$	1.56	4.74	4.94
CD	0.08	0.11	NS
SE	0.03	0.04	0.03

Table: 65 Main effect of treatments and two factor interactions on leaf area index at maximum tillering stage

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	1.06	1.12	1.27	1.11	1.14	1.20	1.15
C_1	1.50	1.52	1.50	1.50	1.52	1.50	1.51

	A_0	A_1	A_2	Mean
F_0	1.26	1.31	1.27	1.28
F_1	1.27	1.29	1.32	1.29
F_2	1.39	1.38	1.46	1.41
Mean	1.31	1.33	1.35	

	CD	SE		CD	SE
C	0.03	0.01	CF	0.04	0.02
F	0.03	0.01	CA	0.04	0.02
A	0.03	0.01	FA	NS	0.02

Table: 66 Main effect of treatments and two factor interactions on leaf area index at panicle initiation stage

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	4.17	4.28	4.50	4.28	4.32	4.34	4.31
C_1	4.69	4.72	4.73	4.69	4.73	4.74	4.72

	A_0	A_1	A_2	Mean
F_0	4.42	4.44	4.43	4.43
F_1	4.45	4.52	4.52	4504
F_2	4.58	4.62	4.65	4.52
Mean	4.48	4.52	4.54	

	CD	SE		CD	SE
C	0.04	0.01	CF	0.06	0.02
F	0.04	0.02	CA	NS	0.02
A	NS	0.02	FA	NS	0.03

Table: 67 Main effect of treatments and two factor interactions on leaf area index at flowering stage

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	4.79	4.79	4.78	4.77	4.81	4.78	4.79
C_1	4.87	4.92	4.94	4.89	4.92	4.91	4.91

	A_0	A_1	A_2	Mean
F_0	4.81	4.84	4.84	4.83
F_1	4.85	4.88	4.84	4.86
F_2	4.84	4.87	4.86	4.86
Mean	4.83	4.86	4.85	

	CD	SE		CD	SE
C	0.02	0.01	CF	0.04	0.01
F	NS	0.01	CA	NS	0.01
A	NS	0.01	FA	NS	0.02

root length of 11.33 cm. The main effect of C, A and the interaction effect of CF significantly affected the root length (Table 72). The C_1 and A_1 plots recorded significantly higher root length.

4.2.4.5 Root Volume

The root volume ranged from 13.00 to 32.67 cc (Table 71). The main effect of C and F significantly affected the root volume (Table 73). The C_1 and F_2 plots recorded higher root volume.

4.2.4.6 Root Density

The treatments recorded a root density ranging from 1.24 to 1.83 Mg $m^{-3}x10^{-6}$ (Table 71). The main effects of C, F, A and the interaction effect of CA significantly increased the root density (Table 74).

4.2.4.7 Grain yield

The grain yield ranged from 0.91 to 2.72 t ha^{-1} (Table 75). The main effect of C, F and the interaction effect of CF significantly affected the grain yield (Table 76). The compacted plots recorded significantly higher grain yield than non-compacted plots. The F_2 plot recorded significantly higher grain yield than F_0 and F_1 plots.

4.2.4.8 Straw yield

The straw yield ranged from 1.11 to 2.84 t ha^{-1} (Table 75). The treatment $C_1F_2A_1$ recorded the highest straw yield of 2.84 t ha^{-1} and the treatment $C_0F_1A_2$ recorded the lowest straw yield of 1.11 t ha^{-1}. The main effect of C, F and the interaction effects of CF and CA significantly affected the straw yield (Table 77). The compacted plots showed significantly higher straw yield than non compacted plots. The F_2 plots showed

Table: 68 Effect of treatments on time taken for maximum tillering and fifty percent flowering

Treatment	Maximum Tillering (days)	Fifty percent Flowering (days)
$C_0F_0A_0$	23.67	62.67
$C_0F_0A_1$	23.33	62.67
$C_0F_0A_2$	23.00	62.67
$C_0F_1A_0$	24.00	61.67
$C_0F_1A_1$	23.00	62.00
$C_0F_1A_2$	22.33	63.00
$C_0F_2A_0$	23.00	62.33
$C_0F_2A_1$	24.00	62.67
$C_0F_2A_2$	22.67	62.33
$C_1F_0A_0$	22.33	62.67
$C_1F_0A_1$	22.67	62.00
$C_1F_0A_2$	23.00	61.67
$C_1F_1A_0$	23.00	61.33
$C_1F_1A_1$	22.33	61.67
$C_1F_1A_2$	22.33	61.00
$C_1F_2A_0$	23.00	61.67
$C_1F_2A_1$	22.00	61.00
$C_1F_2A_2$	22.00	61.33
CD	0.76	NS
SE	0.27	0.28

Table: 69 Main effect of treatments and two factor interactions on time taken for maximum tillering (days)

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	23.33	23.11	23.22	23.56	23.44	22.67	23.22
C_1	22.67	22.56	22.33	22.78	22.33	22.44	22.52
	A_0	A_1	A_2	Mean			
F_0	23.00	23.00	23.00	23.00			
F_1	23.50	22.67	22.33	22.83			
F_2	23.00	23.00	22.33	22.78			
Mean	23.17	22.89	22.56				

	CD	SE		CD	SE
C	0.25	0.09	CF	NS	0.15
F	NS	0.11	CA	0.44	0.15
A	0.31	0.11	FA	0.54	0.19

Table: 70 Main effect of treatments and two factor interactions on time taken for 50 percent flowering (days)

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	62.67	62.22	62.44	62.22	62.44	62.67	62.44
C_1	62.11	61.33	61.33	61.89	61.56	61.33	61.59
	A_0	A_1	A_2	Mean			
F_0	62.67	62.33	62.17	61.39			
F_1	61.50	61.83	62.00	61.78			
F_2	62.00	61.83	61.83	61.89			
Mean	62.39	61.78	61.89				

	CD	SE		CD	SE
C	0.27	0.09	CF	NS	0.16
F	0.33	0.11	CA	0.46	0.16
A	NS	0.11	FA	NS	0.19

Table: 71 Effect of treatments on root length, root volume, and root density

Treatment	Root length (cm)	Root volume (cc)	Root density (mg m^{-3} x10^{-6})
$C_0F_0A_0$	14.00	13.67	1.24
$C_0F_0A_1$	17.00	13.00	1.25
$C_0F_0A_2$	12.33	15.00	1.31
$C_0F_1A_0$	15.33	19.33	1.36
$C_0F_1A_1$	15.67	23.33	1.29
$C_0F_1A_2$	11.67	17.00	1.42
$C_0F_2A_0$	11.33	26.00	1.42
$C_0 F_2A_1$	11.67	18.67	1.46
$C_0F_2A_2$	14.67	23.00	1.51
$C_1F_0A_0$	15.67	24.00	1.63
$C_1F_0A_1$	16.00	31.33	1.64
$C_1F_0A_2$	16.67	27.67	1.69
$C_1F_1A_0$	18.67	26.00	1.72
$C_1F_1A_1$	18.00	22.00	1.80
$C_1F_1A_2$	15.00	26.67	1.78
$C_1F_2A_0$	19.67	27.33	1.81
$C_1F_2A_1$	21.00	32.67	1.83
$C_1F_2A_2$	16.33	29.33	1.79
CD	3.97	NS	NS
SE	1.38	1.70	0.03

Table: 72 Main effect of treatments and two factor interactions on root length (cm)

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	14.44	14.22	12.56	13.56	14.78	12.89	13.74
C_1	16.11	17.22	19.00	18.00	18.33	16.00	17.44
	A_0	A_1	A_2	Mean	CD SE		CD SE
F_0	14.83	16.50	14.50	15.28	C 1.32 0.46		CF 2.29 0.80
F_1	17.00	16.83	13.33	15.72	F NS 0.56		CA NS 0.80
F_2	15.50	16.33	15.50	15.78	A 1.62 0.56		FA NS 0.96
Mean	15.78	16.56	14.44				

Table: 73 Main effect of treatments and two factor interactions on root volume (cc)

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	13.89	19.89	22.86	19.67	18.33	18.33	18.78
C_1	27.67	24.89	29.78	25.78	28.67	27.89	27.44
	A_0	A_1	A_2	Mean	CD SE		CD SE
F_0	18.83	22.17	21.33	20.78	C 3.02 1.05		CF NS 1.82
F_1	22.67	22.67	21.83	22.39	F 3.70 1.29		CA NS 1.82
F_2	26.67	25.67	26.67	26.17	A NS 1.29		FA NS 2.19
Mean	22.72	23.50	23.11				

Table: 74 Main effect of treatments and two factor interactions root density (Mg $m^{-3}x10^{-6}$)

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	1.27	1.36	1.46	1.34	1.33	1.41	1.36
C_1	1.65	1.77	1.81	1.72	1.75	1.75	1.74
	A_0	A_1	A_2	Mean	CD SE		CD SE
F_0	1.44	1.44	1.50	1.46	C 0.02 0.01		CF NS 0.02
F_1	1.54	1.55	1.60	1.56	F 0.03 0.01		CA 0.04 0.02
F_2	1.62	1.64	1.65	1.63	A 0.03 0.01		FA NS 0.02
Mean	1.53	1.54	1.58				

Table: 75 Effect of treatments on grain yield, straw yield and dry matter production

Treatment	Grain Yield (t ha^{-1})	Straw Yield (t ha^{-1})	Dry Matter Production (t ha^{-1})
$C_0F_0A_0$	1.17	1.43	2.59
$C_0F_0A_1$	1.07	1.33	2.40
$C_0F_0A_2$	1.16	1.38	2.61
$C_0F_1A_0$	1.18	1.64	2.82
$C_0F_1A_1$	1.23	1.30	2.52
$C_0F_1A_2$	0.91	1.11	2.02
$C_0F_2A_0$	1.15	1.36	2.61
$C_0 F_2A_1$	1.12	1.32	2.45
$C_0F_2A_2$	1.39	1.55	2.94
$C_1F_0A_0$	2.08	1.86	3.94
$C_1F_0A_1$	1.96	2.00	3.96
$C_1F_0A_2$	1.91	1.97	3.88
$C_1F_1A_0$	1.92	1.63	3.55
$C_1F_1A_1$	2.09	2.04	4.15
$C_1F_1A_2$	1.98	2.13	4.11
$C_1F_2A_0$	2.15	2.22	4.38
$C_1F_2A_1$	2.72	2.84	5.54
$C_1F_2A_2$	2.37	2.44	4.81
CD	NS	0.27	0.48
SE	0.12	0.09	0.09

Table: 76 Main effect of treatments and two factor interactions on grain yield (t ha^{-1})

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	1.13	1.10	1.22	1.17	1.14	1.15	1.15
C_1	1.99	2.00	2.41	2.05	2.26	2.09	2.13

	A_0	A_1	A_2	Mean
F_0	1.63	1.52	1.53	1.56
F_1	1.55	1.66	1.45	1.55
F_2	1.65	1.92	1.88	1.82
Mean	1.61	1.70	1.62	

	CD	SE		CD	SE
C	0.11	0.04	CF	0.19	0.07
F	0.14	0.05	CA	NS	0.07
A	NS	0.05	FA	NS	0.08

Table: 77 Main effect of treatments and two factor interactions on straw yield (t ha^{-1})

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	1.38	1.35	1.41	1.48	1.32	1.34	1.38
C_1	1.94	1.93	2.50	1.90	2.29	2.18	2.13

	A_0	A_1	A_2	Mean
F_0	1.64	1.67	1.67	1.66
F_1	1.64	1.67	1.62	1.64
F_2	1.79	2.08	1.99	1.96
Mean	1.69	1.80	1.76	

	CD	SE		CD	SE
C	0.09	0.03	CF	0.15	0.05
F	0.11	0.04	CA	0.15	0.05
A	NS	0.04	FA	NS	0.06

Table: 78 Main effect of treatments and two factor interactions on dry matter production (t ha^{-1})

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	2.53	2.45	2.67	2.67	2.46	2.52	2.55
C_1	3.93	3.93	4.91	3.96	4.55	4.27	4.26

	A_0	A_1	A_2	Mean
F_0	3.26	3.18	3.24	3.23
F_1	3.19	3.33	3.07	3.19
F_2	3.49	4.00	3.87	3.79
Mean	3.31	3.50	3.39	

	CD	SE		CD	SE
C	0.16	0.06	CF	0.28	0.10
F	0.19	0.07	CA	0.28	0.10
A	NS	0.07	FA	NS	0.12

significantly higher straw yield, followed by F_1 and F_0 plots .The effect of three factor interactions were also significant.

4.2.3.7 Dry matter production.

The dry matter production of the crops ranged from 2.02 to 5.54 t ha^{-1} (Table 75). As in the case of grain yield and straw yield the treatment C_1F_2 A_1 recorded the highest dry matter production of 5.54 t ha^{-1} and the treatment $C_0F_1A_2$ recorded the lowest dry matter production of 2.02 t ha^{-1}. The main effect of C, F and the interaction effect of CF and CA significantly increased the dry matter production (Table 78). The C_1, F_0 and F_2 plots recorded significantly higher dry matter production compared to C_0 and F_1 plots.

4.2.5 Effect of treatments on quality characteristics

4.2.5.1 Carbohydrate content

The carbohydrate content of the grain ranged from 69.20 to 71.78 percent (Table 79). None of the treatment or their interactions significantly influenced the carbohydrate content.

4.2.5.2. Crude protein content

The crude protein content of the grain ranged from 4.67 to 8.88 percent (Table 79). The main effects of C, F, A and the interaction effects of CF significantly increased the crude protein content (Table 80).

4.2.6 Effect of treatments on total nutrient content of plant

4.2.6.1 Total nitrogen content in the plant

The total nitrogen content in the plant ranged from 1.29 to 2.37 percent (Table 81). The main effects of C, F and A significantly increased the nitrogen content (Table 82).

Table: 79 Effect of treatments on quality characteristics

Treatment	Carbohydrate Content (percent)	Crude protein Content (percent)
$C_0F_0A_0$	70.22	4.67
$C_0F_0A_1$	69.20	7.77
$C_0F_0A_2$	70.32	5.13
$C_0F_1A_0$	70.95	5.38
$C_0F_1A_1$	70.47	5.61
$C_0F_1A_2$	69.77	6.65
$C_0F_2A_0$	70.96	6.42
$C_0 F_2A_1$	69.36	7.13
$C_0F_2A_2$	70.98	7.61
$C_1F_0A_0$	69.97	7.81
$C_1F_0A_1$	70.31	8.17
$C_1F_0A_2$	70.72	8.75
$C_1F_1A_0$	70.10	7.96
$C_1F_1A_1$	70.59	8.29
$C_1F_1A_2$	70.97	8.75
$C_1F_2A_0$	71.38	8.15
$C_1F_2A_1$	71.78	8.75
$C_1F_2A_2$	70.25	8.88
CD	NS	NS
SE	0.51	0.25

Table: 80. Main effect of treatments and two factor interactions on crude protein content (percent)

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	4.86	5.88	7.05	5.49	5.84	6.46	5.93
C_1	8.25	8.34	8.59	7.98	8.40.	8.79	8.39

	A_0	A_1	A_2	Mean
F_0	6.24	6.47	6.94	6.55
F_1	6.67	6.95	7.70	7.11
F_2	7.29	7.94	8.24	7.82
Mean	6.73	7.12	7.63	

	CD	SE		CD	SE
C	0.23	0.08	**CF**	0.40	0.14
F	0.29	0.10	**CA**	NS	0.14
A	0.29	0.10	**FA**	NS	0.17

Table: 81 Effect of treatments on total N, P, K, Ca and Mg content in the plant.

Treatment	N (percent)	P (percent)	K (percent)	Ca (percent)	Mg (percent)
$C_0F_0A_0$	1.29	0.20	1.67	0.46	0.23
$C_0F_0A_1$	1.34	0.20	1.77	0.47	0.23
$C_0F_0A_2$	1.42	0.22	1.69	0.48	0.23
$C_0F_1A_0$	1.51	0.23	1.69	0.48	0.23
$C_0F_1A_1$	1.53	0.25	1.59	0.48	0.23
$C_0F_1A_2$	1.64	0.26	1.60	0.48	0.23
$C_0F_2A_0$	1.63	0.28	1.66	0.48	0.24
$C_0 F_2A_1$	1.74	0.30	1.75	0.48	0.24
$C_0F_2A_2$	1.89	0.31	1.78	0.48	0.24
$C_1F_0A_0$	1.96	0.33	1.96	0.48	0.24
$C_1F_0A_1$	1.94	0.33	2.01.	047	0.24
$C_1F_0A_2$	2.11	0.33	2.09	0.48	0.24
$C_1F_1A_0$	2.00	0.23	2.07	0.48	0.24
$C_1F_1A_1$	2.03	0.34	2.09	0.48	0.24
$C_1F_1A_2$	2.09	0.23	2.17	0.48	0.26
$C_1F_2A_0$	2.11	0.34	2.19	0.48	0.24
$C_1F_2A_1$	2.20	0.34	2.23	0.48	0.24
$C_1F_2A_2$	2.37	0.35	2.32	0.48	0.24
CD	NS	NS	NS	NS	NS
SE	0.08	0.01	0.04	0.003	0.004

4.2.6.2 Total phosphorus content in the plant

The total phosphorus content in the plant ranged from 0.20 to 0.35 percent (Table 81). The main effects of C, F and the interaction effect of CF significantly increased the phosphorus content (Table 83).

4.2.6.3 Total potassium content in the plant

The total potassium content in the plant ranged from 1.60 to 2.32 percent (Table 81). The main effect of C, F, A and the interaction effect of CF significantly increased the potassium content (Table 84).

4.2.6.4 Total calcium content in the plant

The total calcium content of the plant ranged from 0.23 to 0.26 percent (Table 81). Neither the treatments nor their interactions significantly affected the calcium content, except the main effect of C (Table 85).

4.2.6.5 Total magnesium in the plant

The total magnesium content of the plant ranged from 0.46 to 0.48 percent (Table 81). The C_1, F_1 and F_2 plots recorded significantly higher magnesium content than the C_0 and F_0 plots (Table 86).

Table: 82 Main effect of treatments and two factor interactions on total nitrogen content (percent) in the plant

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	1.35	1.56	1.75	1.48	1.54	1.65	1.56
C_1	2.00	2.04	2.23	2.02	2.06	2.19	2.09
	A_0	A_1	A_2	Mean	CD	SE	CD SE
F_0	1.62	1.64	1.77	1.68	C 0.07	0.02	CF NS 0.04
F_1	1.76	1.78	1.87	1.80	F 0.09	0.03	CA NS 0.04
F_2	1.87	1.97	2.13	1.99	A 0.09	0.03	FA NS 0.05
Mean	1.75	1.80	1.92				

Table: 83 Main effect of treatments and two factor interactions on total phosphorus content (percent) in the plant

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	0.21	0.25	0.30	0.24	0.25	0.26	0.25
C_1	0.33	0.33	0.35	0.33	0.34	0.34	0.34
	A_0	A_1	A_2	Mean	CD	SE	CD SE
F_0	0.26	0.27	0.27	0.27	C 0.01	0.003	CF 0.02 0.01
F_1	0.28	0.30	0.30	0.29	F 0.01	0.004	CA NS 0.01
F_2	0.31	0.32	0.33	0.32	A NS	0.004	FA NS 0.007
Mean	0.29	0.29	0.30				

Table: 84 Main effect of treatments and two factor interactions on total potassium content (percent) in the plant

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	1.71	1.62	1.73	1.67	1.70	1.69	1.69
C_1	2.02	2.11	2.25	2.08	2.11	2.19	2.13
	A_0	A_1	A_2	Mean	CD	SE	CD SE
F_0	1.81	1.89	1.89	1.86	C 0.04	0.01	CF 0.07 0.02
F_1	1.88	1.84	1.89	1.87	F 0.05	0.02	CA NS 0.02
F_2	1.93	1.99	2.05	1.99	A 0.07	0.02	FA NS 0.03
Mean	1.87	1.90	1.94				

Table: 85 Main effect of treatments and two factor interactions on total calcium content (percent) in the plant

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	0.47	0.48	0.48	0.47	0.48	0.48	0.47
C_1	0.48	0.48	0.48	0.48	0.48	0.48	0.48
	A_0	A_1	A_2	Mean			
F_0	0.47	0.47	0.48	0.47			
F_1	0.48	0.48	0.48	0.48			
F_2	0.48	0.48	0.48	0.48			
Mean	0.47	0.48	0.48				

	CD	SE		CD	SE
C	0.01	0.001	CF	NS	0.002
F	0.01	0.001	CA	NS	0.002
A	NS	0.001	FA	NS	0.002

Table: 86 Main effect of treatments and two factor interactions on total magnesium content (percent) in the plant

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	0.23	0.23	0.24	0.23	0.24	0.23	0.23
C_1	0.24	0.24	0.24	0.24	0.24	0.24	0.24
	A_0	A_1	A_2	Mean			
F_0	0.24	0.24	0.24	0.24			
F_1	0.24	0.24	0.25	0.24			
F_2	0.24	0.24	0.24	0.24			
Mean	0.24	0.24	0.24				

	CD	SE		CD	SE
C	0.01	0.001	CF	NS	0.002
F	NS	0.002	CA	NS	0.002
A	NS	0.002	FA	NS	0.003

4.3 SUMMER CROPS - Sesamum, Green gram and Cowpea

4.3.1. Effect of treatments on moisture characteristics of soil

4.3.1.1 Moisture content

The moisture content of surface soil of S_0 plots ranged from 13.14 to 23.81 per cent (Table 87). The treatment $C_1F_0A_2$ recorded the highest moisture content and the treatment $C_0F_1A_2$ recorded the lowest moisture content. The moisture content of S_1 plots ranged from 14.29 ($C_0F_0A_0$) to 24.08 percent ($C_1F_2A_2$) (Table 87). In the S_2 plots the moisture content ranged from 13.76 to 22.24 percent (Table 87). The treatment $C_1F_2A_1$ recorded the highest moisture content and the treatment $C_0F_0A_0$ recorded the lowest moisture content. The S_1 plot recorded the highest moisture content of surface soil followed by S_2 and the lowest by S_0 plot (Table 88A). The main effect of compaction significantly influenced the moisture content. The C_1 plot recorded significantly higher moisture content than C_0 plot.

The main effect of farmyard manure and amendments significantly influenced the moisture content. The F_2 plot recorded significantly higher moisture content than the F_1 and F_0 plot. The A_1 plot recorded significantly higher moisture content followed A_2 plot and the lowest by A_0 plot. The interaction effects of SC, SF, SA CF, CA and FA significantly influenced the moisture content. The S_1 plot recorded higher moisture content with and without compaction followed by S_2 plot and lowest by S_0 plot.

In the sub surface soils of S_0 plots moisture content ranged from 11.51 to 18.02 (Table 87). The treatment $C_1F_1A_1$ recorded the highest moisture content and the treatment $C_0F_2A_2$ recorded the lowest moisture content. In the S_1 plots the moisture content ranged from 11.94 to 21.57 per cent (Table 87). The treatment $C_1F_2A_2$ recorded the highest moisture content and the treatment $C_0F_0A_1$ recorded the lowest moisture content. The

Table 87. Effect of treatments on moisture content of soil (percent)

	Surface soil			Subsurface soil		
Treatment	**Sesamum**	**Green gram**	**Cowpea**	**Sesamum**	**Green gram**	**Cowpea**
$C_0F_0A_0$	15.09	14.29	13.76	11.89	12.73	14.94
$C_0F_0A_1$	15.30	16.71	14.61	12.80	11.94	15.75
$C_0F_0A_2$	14.08	15.26	14.05	12.57	13.74	15.00
$C_0F_1A_0$	13.19	15.14	14.74	13.15	14.03	16.20
$C_0F_1A_1$	14.51	15.77	15.05	12.59	14.77	15.24
$C_0F_1A_2$	13.14	16.27	13.90	12.90	15.58	16.05
$C_0F_2A_0$	14.88	16.48	14.86	12.65	16.03	17.13
$C_0F_2A_1$	15.97	16.12	16.28	13.83	15.59	16.01
$C_0F_2A_2$	13.60	15.90	16.71	11.51	14.05	15.00
$C_1F_0A_0$	18.13	18.08	19.35	15.93	16.99	19.27
$C_1F_0A_1$	19.30	19.22	20.88	17.89	18.07	19.63
$C_1F_0A_2$	23.81	20.27	21.54	16.55	19.57	19.15
$C_1F_1A_0$	19.70	19.45	24.20	16.34	18.94	20.02
$C_1F_1A_1$	19.12	20.29	22.09	18.02	19.71	20.36
$C_1F_1A_2$	17.01	22.07	21.01	16.70	19.97	20.73
$C_1F_2A_0$	18.00	23.15	22.24	17.66	20.40	20.35
$C_1F_2A_1$	18.95	23.61	21.26	17.54	21.03	21.40
$C_1F_2A_2$	15.87	24.08	21.98	16.65	21.57	21.98
CD	2.51	2.51	2.51	1.22	1.22	1.22
SE	1.55	1.55	1.55	0.90	0.90	0.90

Table 88A. Main effects of treatments and two factor interactions on field moisture content (percent) of surface soil of sesamum, green gram and cowpea

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	14.79	14.63	15.64	14.72	15.59	14.77	15.02
C_1	19.89	20.29	20.91	19.82	20.45	20.82	20.36

	A_0	A_1	A_2	Mean
F_0	16.45	17.51	18.06	17.34
F_1	17.29	17.69	17.41	17.47
F_2	18.07	18.86	17.91	18.27
Mean	17.27	18.02	17.79	

	C_0	C_1	F_0	F_1	F_2	A_0	A_1	A_2	Mean	
S_0	14.42	18.88	17.62	16.11	16.21	16.49	17.19	16.28	16.65	
S_1	15.77	21.14	17.31	18.17	19.89	17.77	18.62	18.98	18.45	
S_2	14.88	21.08	17.09	18.12	18.73	17.55	18.26	18.15	17.98	
	S	C	F	A	SF	SA	FA	CF	CA	CS
CD	NS	0.84	1.03	1.03	1.78	1.78	1.78	1.45	1.45	1.45
SE	0.64	0.30	0.37	0.37	0.63	0.63	0.63	0.52	0.52	0.52

Table 88B. Main effects of treatments and two factor interactions on field moisture content (percent) of sub surface soil of sesamum, green gram and cowpea

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	13.48	14.50	14.65	14.31	14.31	14.28	14.21
C_1	18.12	18.98	19.84	18.43	19.30	19.21	18.98

	A_0	A_1	A_2	Mean
F_0	15.29	16.01	16.09	15.80
F_1	16.44	16.78	16.99	16.74
F_2	17.37	17.57	16.79	17.24
Mean	16.37	16.79	16.62	

	C_0	C_1	F_0	F_1	F_2	A_0	A_1	A_2	Mean	
S_0	12.65	17.03	14.61	14.95	14.98	14.61	15.45	14.48	14.84	
S_1	14.27	19.58	15.51	17.17	18.11	16.52	16.85	17.41	16.93	
S_2	15.70	20.32	17.29	18.10	18.65	17.99	18.06	17.99	18.01	
	S	C	F	A	SF	SA	FA	CF	CA	CS
CD	1.22	0.49	0.60	0.60	1.03	1.03	1.03	0.84	0.84	0.84
SE	0.31	0.17	0.21	0.21	0.36	0.36	0.36	0.30	0.30	0.30

effects of treatments were significant. Among the three crops, the cowpea plots recorded significantly higher moisture content of sub surface soils followed by the green gram plots and the least by the sesamum plots (Table 88B). The compacted plots recorded significantly higher moisture content than the uncompacted plots. The F_2 plot recorded significantly higher moisture content than the F_1 and F_0 plot. The A_1 plot recorded higher moisture content than the A_2 and the A_0 plot. The effect of two factor interactions such as SC, SF, SA, CF, CA and FA were also significant.

4.3.1.2 Hydraulic conductivity

The sesamum plots recorded a hydraulic conductivity of surface soils ranging from 8.74 to 23.29 cm hr^{-1} (Table 89). The treatment $C_1F_1A_1$ recorded the lowest hydraulic conductivity and the treatment $C_0F_1A_0$ recorded the highest hydraulic conductivity. In the green gram plots, the treatment C_1 F_1 A_0 recorded the lowest hydraulic conductivity of 9.78 cm hr^{-1} and the treatment C_0 F_2 A_2 recorded the highest hydraulic conductivity of 25.42 cm hr^{-1} (Table 89). In the case of cowpea, like sesamum and green gram plots, the lowest hydraulic conductivity of 9.37 cm hr^{-1} was recorded by the treatment $C_1F_1A_0$. The highest hydraulic conductivity of 22.43 cm hr^{-1} was recorded by the treatment $C_0F_2A_2$ (Table 89). The sesamum plots recorded the lowest hydraulic conductivity of surface soils and the green gram plots recorded the highest hydraulic conductivity (Table 90A). The C_1 plot recorded almost half the value for hydraulic conductivity than C_0 plot. The F_0 and F_2 plots recorded significantly higher hydraulic conductivity than F_1 plot. The A_1 and A_2 plots recorded lower hydraulic conductivity than the A_0 plot. The effect of two factor interactions was also

Table 89. Effect of treatments on hydraulic conductivity of soil (cm hr $^{-1}$)

	Surface soil			Subsurface soil		
Treatment	**Sesamum**	**Greengram**	**Cowpea**	**Sesamum**	**Greengram**	**Cowpea**
$C_0F_0A_0$	21.31	20.98	20.40	19.08	15.56	20.15
$C_0F_0A_1$	21.71	21.28	20.62	17.99	16.97	18.28
$C_0F_0A_2$	23.05	21.24	20.86	17.13	17.24	17.83
$C_0F_1A_0$	23.29	21.75	21.37	16.18	17.93	17.82
$C_0F_1A_1$	20.79	21.07	21.37	16.57	16.74	16.83
$C_0F_1A_2$	19.68	20.26	19.59	16.44	16.60	15.29
$C_0F_2A_0$	20.97	24.16	20.74	15.81	16.78	15.47
$C_0F_2A_1$	21.05	23.08	21.98	16.04	15.83	15.48
$C_0F_2A_2$	15.63	25.42	22.43	8.01	15.86	9.70
$C_1F_0A_0$	11.95	10.03	11.19	8.05	9.04	10.06
$C_1F_0A_1$	10.49	10.11	10.51	7.84	8.96	8.14
$C_1F_0A_2$	11.35	10.03	11.70	8.28	9.00	7.74
$C_1F_1A_0$	9.28	9.78	9.37	8.27	9.33	8.27
$C_1F_1A_1$	8.74	10.09	10.30	7.54	9.45	8.38
$C_1F_1A_2$	10.03	9.86	11.36	8.07	9.96	8.31
$C_1F_2A_0$	10.30	10.66	10.07	8.12	9.95	8.75
$C_1F_2A_1$	10.52	10.92	9.44	8.33	9.97	8.64
$C_1F_2A_2$	10.22	10.95	9.50	8.22	9.71	8.76
CD	0.80	0.80	0.80	0.73	0.73	0.73
SE	0.70	0.70	0.70	0.48	0.48	0.48

Table 90A. Main effects of treatments and two factor interactions on hydraulic conductivity (cm hr^{-1}) of surface soil of sesamum, green gram and cowpea

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	21.33	20.96	21.72	21.60	21.43	20.96	21.34
C_1	10.81	9.86	10.27	10.29	10.12	10.55	10.32

	A_0	A_1	A_2	Mean
F_0	15.98	15.79	16.47	16.08
F_1	15.72	15.39	15.13	15.41
F_2	15.95	16.17	15.69	16.00
Mean	15.95	15.78	15.76	

	C_0	C_1	F_0	F_1	F_2	A_0	A_1	A_2	Mean	
S_0	20.83	10.32	16.64	15.30	14.78	6.18	15.55	14.00	15.58	
S_1	22.13	10.27	15.61	15.47	17.53	16.22	16.09	16.29	16.20	
S_2	21.04	10.38	15.97	15.47	1569	15.43	15.70	15.99	15.71	
	S	C	F	A	SF	SA	FA	CF	CA	CS
CD	0.80	0.38	0.47	0.47	0.81	0.81	0.81	0.66	0.66	0.66
SE	0.20	0.14	0.17	0.17	0.29	0.29	0.29	0.23	0.23	0.23

Table 90B. Main effects of treatments and two factor interactions on hydraulic conductivity (cm hr^{-1}) of sub surface soil of sesamum, green gram and cowpea

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	17.80	16.71	14.33	17.19	16.75	14.90	16.28
C_1	8.57	8.62	8.94	8.97	8.58	8.67	8.71

	A_0	A_1	A_2	Mean
F_0	13.66	13.03	12.87	13.18
F_1	12.97	12.58	12.44	12.67
F_2	12.48	12.38	10.04	11.64
Mean	13.03	12.66	11.79	

	C_0	C_1	F_0	F_1	F_2	A_0	A_1	A_2	Mean	
S_0	15.91	8.08	13.06	12.17	10.75	12.58	12.38	11.02	12.00	
S_1	16.61	9.49	12.79	13.33	13.01	13.09	12.98	13.06	13.05	
S_2	16.32	8.56	13.70	12.48	11.13	13.42	12.62	11.27	12.44	
	S	C	F	A	SF	SA	FA	CF	CA	CS
CD	0.73	0.26	0.32	0.32	0.55	0.55	0.55	0.45	0.45	0.45
SE	0.19	0.09	0.11	0.11	0.20	0.20	0.20	0.16	0.16	0.16

lower hydraulic conductivity than the A_0 plot. The effect of two factor interactions was also significant.

In the sub surface soils sesamum plots recorded a hydraulic conductivity ranging from 7.54 to 19.08 cm hr^{-1} (Table 89). The treatment $C_1F_1A_1$ recorded the lowest hydraulic conductivity and the treatment $C_0F_0A_0$ recorded the highest hydraulic conductivity. In the green gram plots the treatment $C_1F_0A_1$ recorded the lowest hydraulic conductivity (8.96 cm hr^{-1}) and the treatment $C_0F_1A_0$ recorded the highest hydraulic conductivity of 17.93 cm hr^{-1} (Table 89). In the cowpea plots the treatment C_1F_0 A_2 recorded the lowest hydraulic conductivity of 7.74 cm hr^{-1} and the treatment $C_0F_0A_0$ recorded the highest hydraulic conductivity of 20.15 cm hr^{-1} (Table 89). The main effects of treatments and two factor interactions were significant (Table 90). The sesamum plots recorded the lowest hydraulic conductivity followed by cowpea plots and the maximum by the green gram plots. The C_1 plot recorded almost half the hydraulic conductivity compared to C_0 plot. The F_2 plot recorded the lowest hydraulic conductivity followed by F_1 and F_0 plots in the increasing order. Among the amendments, the A_2 plot recorded the lowest hydraulic conductivity followed by A_1 plot and the maximum by the A_0 plot.

4.3.1.3 Available water

In the sesamum plots, the available water content of surface soil ranged from 1.96 ($C_0F_1A_2$) to 5.41 percent ($C_1F_1A_2$) (Table 91). The available water content of the green gram plots ranged from 1.57 ($C_0F_2A_0$) to 6.17 percent (C_1 F_0 A_2) (Table 91). In the cowpea plots, the available water content ranged from 1.87 ($C_0F_1A_2$) to 5.89 percent ($C_1F_2A_0$) (Table 91). The green gram plots recorded higher available water content followed by sesamum plots and the least by cowpea plots (Table 92A). The C_1 plot recorded

Table 91. Effect of treatments on available water content of soil (percent)

	Surface soil			Subsurface soil		
Treatment	**Sesamum**	**Greengram**	**Cowpea**	**Sesamum**	**Greengram**	**Cowpea**
$C_0F_0A_0$	2.06	2.15	2.33	1.98	2.43	1.54
$C_0F_0A_1$	2.55	2.59	2.14	2.95	2.14	2.69
$C_0F_0A_2$	2.66	2.18	2.30	3.56	3.04	2.02
$C_0F_1A_0$	3.00	1.97	2.37	2.96	2.74	2.51
$C_0F_1A_1$	2.32	2.71	2.30	3.89	4.05	3.14
$C_0F_1A_2$	1.96	2.27	1.87	2.99	3.40	2.95
$C_0F_2A_0$	2.30	1.57	2.24	1.56	2.96	2.21
$C_0F_2A_1$	2.63	1.59	2.49	3.32	2.46	2.61
$C_0F_2A_2$	3.22	2.57	2.82	2.56	2.24	2.54
$C_1F_0A_0$	4.66	4.83	4.33	4.89	6.51	4.41
$C_1F_0A_1$	4.52	5.23	4.67	3.78	6.51	5.16
$C_1F_0A_2$	3.81	6.17	3.48	4.56	6.62	4.95
$C_1F_1A_0$	5.00	5.54	5.02	5.85	6.19	6.15
$C_1F_1A_1$	4.82	5.71	4.79	4.15	6.81	4.85
$C_1F_1A_2$	5.41	5.33	5.38	5.12	6.53	6.13
$C_1F_2A_0$	6.28	5.53	5.89	6.61	7.35	6.64
$C_1F_2A_1$	4.07	5.00	4.33	4.82	6.88	5.51
$C_1F_2A_2$	4.97	5.03	4.99	5.58	5.17	5.20
CD	0.67	0.67	0.67	0.39	0.39	0.39
SE	0.46	0.46	0.46	0.49	0.49	0.49

Table 92A. Main effects of treatments and two factor interactions on available water content (percent) of surface soil of sesamum, green gram and cowpea

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	2.32	2.30	2.38	2.22	2.36	2.42	2.34
C_1	4.63	5.22	5.12	5.23	4.79	4.95	4.99

	A_0	A_1	A_2	Mean
F_0	3.39	3.62	3.43	3.48
F_1	3.82	3.78	3.70	3.76
F_2	3.97	3.53	3.93	3.68
Mean	3.73	3.58	3.69	

	C_0	C_1	F_0	F_1	F_2	A_0	A_1	A_2	Mean	
S_0	2.52	4.84	3.37	3.75	3.91	3.88	3.48	3.48	3.68	
S_1	2.17	5.37	3.85	3.91	3.54	3.59	3.80	3.91	3.77	
S_2	2.31	4.76	3.21	3.62	3.79	3.69	3.45	3.47	3.54	
	S	C	F	A	SF	SA	FA	CF	CA	CS
CD	0.67	0.25	0.30	0.30	0.53	0.53	0.53	0.43	0.43	0.43
SE	0.17	0.09	0.11	0.11	0.19	0.19	0.19	0.15	0.15	0.15

Table 92B. Main effects of treatments and two factor interactions on available water content (percent) of sub surface soil of sesamum, green gram and cowpea

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	2.22	2.93	2.44	2.30	2.77	2.52	2.53
C_1	5.37	6.01	6.06	6.09	5.65	5.69	5.81

	A_0	A_1	A_2	Mean
F_0	3.51	3.92	3.96	3.79
F_1	4.40	4.41	4.59	4.47
F_2	4.68	4.31	3.76	4.25
Mean	4.20	4.21	4.11	

	C_0	C_1	F_0	F_1	F_2	A_0	A_1	A_2	Mean	
S_0	2.29	5.48	3.38	4.15	4.11	3.98	3.83	3.85	3.89	
S_1	2.83	6.51	4.54	4.96	4.51	4.69	4.81	4.50	4.67	
S_2	2.47	5.44	3.46	4.29	4.11	3.91	3.99	3.97	3.96	
	S	C	F	A	SF	SA	FA	CF	CA	CS
CD	0.39	0.26	0.32	0.32	0.56	0.56	0.56	0.46	0.46	0.46
SE	0.10	0.09	0.12	0.12	0.20	0.20	0.20	0.16	0.16	0.16

significantly higher (almost double) values for available water content compared to C_0 plot. The F_1 and F_2 plots recorded significantly higher available water content compared to F_0 plot. Among the amendments the A_2 plot showed higher available water content than A_1 plot.

In the sub surface soils sesamum plots recorded an available water content ranging from 1.56 ($C_0F_2A_0$) to 6.61percent ($C_1F_2A_0$) (Table 91). The available water content of the green gram plots ranged from 2.14 ($C_0F_0A_1$) to 7.35percent ($C_1F_2A_0$) (Table 91). The cowpea plots recorded an available water content ranging from 1.54 ($C_0F_0A_0$) to 6.64 percent ($C_1F_2A_0$) (Table 91). The main effects of the treatments also showed significant difference. The green gram plots recorded significantly higher available water content followed by the cowpea plots and the least by the sesamum plots (Table 92B). The C_1 plot recorded significantly higher available water content compared to C_0 plot. The F_1 plot recorded higher available water content followed by F_2 plot and the least by F_0 plot. Among the amendments, the A_1 plot recorded higher available water content than A_2 plot.

4.3.1.4 Maximum water holding capacity.

The maximum water holding capacity of surface soils of the sesamum plots ranged from 13.17 ($C_1F_1A_0$, $C_0F_1A_2$) to 23.82 percent ($C_1F_0A_2$) (Table 93). In the green gram plots the maximum water holding capacity ranged from 13.94 ($C_0F_2A_2$) to 20.97 percent ($C_1F_1A_0$) (Table 93). The cowpea plots recorded a maximum water holding capacity ranging from 15.21 ($C_0F_1A_0$) to 24.09 percent ($C_1F_1A_1$) (Table 93). Among the crops, the maximum water holding capacity of plots did not show any significant difference. The C_1 plot recorded significantly higher maximum water holding capacity than C_0 plot (Table 94A). The F_1 and F_2 plots were on par. The A_1 plot showed higher maximum water holding

Table 93. Effect of treatments on water holding capacity of soil (percent)

	Surface soil			Subsurface soil		
Treatment	Sesamum	Greengram	Cowpea	Sesamum	Greengram	Cowpea
$C_0F_0A_0$	15.09	14.57	15.50	12.77	13.12	14.37
$C_0F_0A_1$	15.35	17.16	16.23	12.81	12.63	15.55
$C_0F_0A_2$	14.13	15.71	15.49	12.11	15.13	16.34
$C_0F_1A_0$	13.17	14.05	15.21	12.73	14.92	17.58
$C_0F_1A_1$	14.52	14.94	16.27	12.59	15.96	16.12
$C_0F_1A_2$	13.17	14.19	17.67	12.90	15.15	17.07
$C_0F_2A_0$	14.64	17.63	16.91	12.64	16.61	17.86
$C_0F_2A_1$	15.97	15.99	14.99	14.28	14.85	17.09
$C_0F_2A_2$	13.61	13.94	16.61	11.66	14.21	17.38
$C_1F_0A_0$	18.12	17.39	20.67	15.94	16.69	21.09
$C_1F_0A_1$	19.29	19.55	21.46	17.90	17.80	22.55
$C_1F_0A_2$	23.82	20.62	23.42	16.56	19.50	23.40
$C_1F_1A_0$	19.72	20.97	22.79	16.36	19.75	23.42
$C_1F_1A_1$	19.12	19.37	24.09	17.23	20.08	23.99
$C_1F_1A_2$	16.22	18.52	23.50	17.94	20.55	22.96
$C_1F_2A_0$	18.01	18.48	22.25	16.93	19.56	23.46
$C_1F_2A_1$	18.95	18.17	22.30	17.21	20.99	22.45
$C_1F_2A_2$	16.08	19.26	23.69	16.67	21.55	22.81
CD	3.02	3.02	3.02	1.17	1.17	1.17
SE	1.46	1.46	1.46	0.95	0.95	0.95

Table 94A. Main effects of treatments and two factor interactions on water holding capacity (percent) of surface soil of sesamum, green gram and cowpea

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	15.47	14.79	15.59	15.19	15.71	14.98	15.29
C_1	20.48	20.48	19.69	19.08	20.26	20.57	20.22

	A_0	A_1	A_2	Mean
F_0	16.89	18.17	18.87	17.98
F_1	17.65	18.05	17.21	17.64
F_2	17.99	17.73	17.19	17.64
Mean	17.51	17.98	17.76	

	C_0	C_1	F_0	F_1	F_2	A_0	A_1	A_2	Mean	
S_0	14.41	18.82	17.63	15.99	16.21	16.46	17.20	16.17	16.61	
S_1	15.36	19.15	17.50	17.00	17.25	17.18	17.53	17.04	17.25	
S_2	16.09	22.69	18.80	19.92	19.46	18.89	19.22	20.06	19.39	
	S	C	F	A	SF	SA	FA	CF	CA	CS
CD	NS	0.79	NS	NS	1.68	1.68	1.68	1.37	1.37	1.37
SE	0.77	0.28	0.35	0.35	0.60	0.60	0.60	0.49	0.49	0.49

Table 94B. Main effects of treatments and two factor interactions on water holding capacity (percent) of sub surface soil of sesamum, green gram and cowpea

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	13.87	15.00	15.18	14.74	14.65	14.66	14.68
C_1	19.05	20.25	20.18	19.25	20.02	20.22	19.83

	A_0	A_1	A_2	Mean
F_0	15.67	16.54	17.18	16.46
F_1	17.46	17.66	17.76	17.63
F_2	17.84	17.81	17.38	17.68
Mean	16.99	17.34	17.44	

	C_0	C_1	F_0	F_1	F_2	A_0	A_1	A_2	Mean	
S_0	12.72	16.97	14.68	14.96	14.89	14.56	15.34	14.64	14.85	
S_1	14.73	19.61	15.81	17.74	17.96	16.78	17.05	17.68	17.17	
S_2	16.59	22.90	18.89	20.19	20.18	19.63	19.63	19.99	19.75	
	S	C	F	A	SF	SA	FA	CF	CA	CS
CD	1.16	0.51	0.63	0.63	1.09	1.09	1.09	0.89	0.89	0.89
SE	0.30	0.18	0.22	0.22	0.39	0.39	0.39	0.32	0.32	0.32

capacity than A_2 plot.

In the sub surface soils of sesamum plots, the treatment $C_1F_1A_2$ recorded the highest maximum water holding capacity of 17.94 percent and the treatment $C_0F_2A_2$ recorded the lowest maximum water holding capacity of 11.66 percent (Table 93). The green gram plots recorded a highest maximum water holding capacity of 21.55 percent ($C_1F_2A_2$) and the lowest being 12.63 percent ($C_0F_0A_1$) (Table 93). The cowpea plot recorded the highest maximum water holding capacity of 23.99 percent ($C_1F_1A_1$) and the lowest being of 14.37 percent ($C_0F_0A_0$) (Table 93). The cowpea plots recorded significantly higher maximum water holding capacity followed by green gram plots and the least by sesamum plots. The C_1 plot recorded significantly higher maximum water holding capacity than C_0 plot. The F_2 and F_1 plots recorded significantly higher maximum water holding capacity than F_0 plots. The A_1 and A_2 plots recorded higher maximum water holding capacity than untreated plots. (Table 94B).

4.3.2 Effect of treatments on structural characteristics of soil

4.3.2.1 Mean weight diameter

In the surface soils of sesamum plots the mean weight diameter ranged from 0.47 to 0.63 (Table 95). The treatment $C_1F_0A_0$ recorded the highest mean weight diameter of 0.63 and the treatment $C_0F_0A_0$ and $C_0F_0A_1$ recorded the lowest mean weight diameter of 0.47. The green gram plots recorded a maximum mean weight diameter of 0.64 ($C_1F_0A_1$) and a minimum mean weight diameter of 0.52 ($C_0F_1A_2$) (Table 95). The highest mean weight diameter of cowpea plot was 0.56 ($C_0F_0A_1$) and the lowest mean weight diameter was 0.47 ($C_1F_2A_0$) (Table 95). The green gram plots recorded the highest mean weight diameter

Table 95. Effect of treatments on mean weight diameter of soil

	Surface soil			Subsurface soil		
Treatment	**Sesamum**	**Greengram**	**Cowpea**	**Sesamum**	**Greengram**	**Cowpea**
$C_0F_0A_0$	0.47	0.53	0.49	0.47	0.54	0.52
$C_0F_0A_1$	0.47	0.53	0.56	0.47	0.53	0.54
$C_0F_0A_2$	0.52	0.53	0.55	0.52	0.54	0.56
$C_0F_1A_0$	0.54	0.53	0.54	0.54	0.54	0.54
$C_0F_1A_1$	0.52	0.53	0.53	0.52	0.55	0.55
$C_0F_1A_2$	0.54	0.52	0.52	0.54	0.54	0.57
$C_0F_2A_0$	0.54	0.56	0.51	0.54	0.56	0.52
$C_0F_2A_1$	0.59	0.54	0.50	0.59	0.57	0.54
$C_0F_2A_2$	0.62	0.53	0.50	0.62	0.59	0.53
$C_1F_0A_0$	0.63	0.60	0.49	0.63	0.56	0.53
$C_1F_0A_1$	0.61	0.64	0.50	0.61	0.59	0.52
$C_1F_0A_2$	0.62	0.59	0.51	0.62	0.55	0.55
$C_1F_1A_0$	0.57	0.58	0.52	0.57	0.62	0.53
$C_1F_1A_1$	0.55	0.60	0.49	0.55	0.61	0.51
$C_1F_1A_2$	0.57	0.55	0.49	0.57	0.63	0.51
$C_1F_2A_0$	0.59	0.54	0.47	0.59	0.59	0.52
$C_1F_2A_1$	0.58	0.59	0.48	0.58	0.62	0.51
$C_1F_2A_2$	0.57	0.62	0.50	0.57	0.50	0.53
CD	0.090	0.090	0.090	0.085	0.085	0.085
SE	0.032	0.032	0.032	0.030	0.030	0.030

followed by sesamum plots and the least by cowpea plots. The C_1 plots recorded significantly higher mean weight diameter compared to C_0 plots. The F_2 and F_1 plots recorded significantly higher mean weight diameter than F_0 plots. The A_1 and A_2 plots recorded higher mean weight diameter than A_0 plots (Table 96A).

The subsurface soils of sesamum plots recorded a maximum mean weight diameter of 0.63 ($C_1F_0A_0$) and a minimum mean weight diameter of 0.47 ($C_0F_0A_0$ and $C_0F_0A_1$) (Table 95). The green gram plots showed the maximum mean weight diameter of 0.63 ($C_1F_1A_2$) and a minimum mean weight diameter of 0.50 ($C_1F_2A_2$) (Table 95). The highest mean weight diameter of cowpea plots was 0.57 ($C_0F_1A_2$) and the lowest was 0.51 ($C_1F_1A_1$, $C_1F_1A_2$ and $C_1F_2A_1$) (Table 95). The green gram plots recorded significantly higher mean weight diameter followed by the sesamum plots and the least by the cowpea plots. The C_1 plots recorded significantly highest mean weight diameter than C_0 plots. The F_2 plots recorded significantly higher mean weight diameter than F_0 plots and the F_1 plots which were on par. The A_2 plots recorded higher mean weight diameter than the A_1 plots and A_0 plots, which were on par (Table 96B).

4.3.2.2 Microporosity.

The microporosity of the surface soil of sesamum plots ranged from 18.01 ($C_0F_2A_1$) to 33.38 percent ($C_0F_1A_1$) (Table 97). The green gram plots recorded a highest microporosity of 28.29 ($C_1F_2A_1$) and a lowest microporosity of 15.90 percent ($C_0F_1A_2$) (Table 97). The cowpea plots showed a microporosity ranging from 15.95 ($C_0F_2A_2$) to 25.97 percent ($C_1F_1A_2$) (Table 97). The sesamum plots recorded the highest microporosity followed by green gram and cowpea plots. The C_1 plots recorded significantly higher

Table 96A. Main effects of treatments and two factor interactions on mean weight diameter of surface soil of sesamum, green gram and cowpea

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	0.54	0.52	0.52	0.52	0.53	0.54	0.53
C_1	0.55	0.53	0.53	0.53	0.55	0.54	0.54

	A_0	A_1	A_2	Mean
F_0	0.53	0.57	0.55	0.55
F_1	0.54	0.53	0.52	0.53
F_2	0.52	0.53	0.54	0.53
Mean	0.53	0.54	0.54	

	C_0	C_1	F_0	F_1	F_2	A_0	A_1	A_2	Mean	
S_0	0.52	0.54	0.56	0.52	0.53	0.53	0.54	0.54	0.54	
S_1	0.53	0.59	0.56	0.55	0.56	0.55	0.56	0.55	0.56	
S_2	0.52	0.49	0.51	0.51	0.49	0.50	0.51	0.51	0.51	
	S	C	F	A	SF	SA	FA	CF	CA	CS
CD	0.032	0.017	0.021	0.021	0.037	0.037	0.037	0.030	0.030	0.030
SE	0.008	0.006	0.008	0.008	0.01	0.01	0.01	0.01	0.01	0.01

Table 96B. Main effects of treatments and two factor interactions on mean weight diameter of sub surface soil of sesamum, green gram and cowpea

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	0.52	0.54	0.56	0.53	0.54	0.56	0.54
C_1	0.58	0.56	0.55	0.57	0.57	0.56	0.57

	A_0	A_1	A_2	Mean
F_0	0.54	0.55	0.56	0.55
F_1	0.56	0.55	0.56	0.55
F_2	0.55	0.57	0.56	0.56
Mean	0.55	0.55	0.56	

	C_0	C_1	F_0	F_1	F_2	A_0	A_1	A_2	Mean	
S_0	0.53	0.59	0.55	0.55	0.58	0.55	0.55	0.57	0.56	
S_1	0.55	0.58	0.55	0.58	0.57	0.57	0.56	0.56	0.57	
S_2	0.54	0.52	0.54	0.53	0.52	0.56	0.53	0.54	0.53	
	S	C	F	A	SF	SA	FA	CF	CA	CS
CD	0.036	0.016	NS	NS	0.035	0.035	0.035	0.028	0.028	0.028
SE	0.009	0.006	0.007	0.007	0.01	0.01	0.01	0.01	0.01	0.01

Table 97. Effect of treatments on micro porosity of soil (percent)

	Surface soil			Subsurface soil		
Treatment	Sesamum	Greengram	Cowpea	Sesamum	Greengram	Cowpea
$C_0F_0A_0$	24.68	20.19	21.45	17.97	15.67	17.27
$C_0F_0A_1$	21.92	19.40	20.34	21.10	15.57	17.99
$C_0F_0A_2$	20.23	18.57	19.19	27.08	16.42	16.93
$C_0F_1A_0$	25.15	17.47	18.71	19.22	16.40	15.80
$C_0F_1A_1$	33.38	17.14	18.99	17.93	17.38	16.51
$C_0F_1A_2$	19.63	15.90	19.04	25.25	17.73	17.33
$C_0F_2A_0$	19.33	16.48	18.21	17.48	16.37	17.23
$C_0F_2A_1$	18.01	16.91	17.91	19.57	16.58	16.42
$C_0F_2A_2$	19.01	16.36	15.95	17.05	15.95	18.19
$C_1F_0A_0$	22.14	23.42	19.88	23.97	25.06	21.40
$C_1F_0A_1$	24.09	24.09	21.75	28.62	26.36	22.24
$C_1F_0A_2$	24.25	26.05	24.16	22.25	29.61	23.42
$C_1F_1A_0$	22.59	25.33	21.99	19.78	31.01	25.14
$C_1F_1A_1$	25.30	24.82	25.08	27.72	28.23	25.19
$C_1F_1A_2$	28.93	25.04	25.97	31.17	29.63	24.58
$C_1F_2A_0$	26.96	27.64	25.78	25.79	28.00	24.24
$C_1F_2A_1$	28.64	28.29	25.27	28.28	33.35	23.20
$C_1F_2A_2$	21.09	27.64	25.86	23.93	30.89	24.18
CD	3.67	3.67	3.67	2.86	2.86	2.86
SE	2.51	2.51	2.51	2.40	2.40	2.40

microporosity than C_0 plots. The F_1 plots recorded the highest microporosity followed by the F_0 plots and F_2 plots. The A_1 plots recorded highest microporosity than A_2 plots and A_0 plots (Table 98A).

The microporosity of sub surface soils of the sesamum plots ranged from 17.05 ($C_0F_2A_2$) to 31.17 percent ($C_1F_1A_2$) (Table 97). The green gram plots recorded a maximum microporosity of 33.35 percent ($C_1F_2A_1$) a minimum microporosity of 15.57 percent ($C_0F_0A_1$) (Table 97). The cowpea plots showed a range in microporosity from 15.80 percent ($C_0F_1A_0$) to 25.19 percent ($C_1F_1A_1$) (Table 97). As in the case of surface soil samples, the sesamum plots recorded highest microporosity followed by green gram plots and the least by cowpea plots. The C_1 plot recorded significantly highest microporosity than C_0 plot. The F_1 plot recorded highest microporosity followed by the F_2 plot and the least by F_0 plot. The A_2 plot recorded the highest microporosity, which was on par with the A_1 plot, and the least by A_0 plot (Table 98B).

4.3.2.3 Macroporosity.

The macroporosity of the surface soil of sesamum plots ranged from 13.43 ($C_0F_0A_0$) to 21.68 percent ($C_0F_2A_1$) (Table 99). The green gram plots showed a macroporosity ranging from 13.44 ($C_1F_2A_2$) to 21.14 percent ($C_0F_2A_0$) (Table 99). The cowpea plots recorded a highest macroporosity of 24.47 percent ($C_1F_0A_1$) and a lowest macroporosity of 13.83 percent ($C_1F_1A_2$) (Table 99). The cowpea plots recorded the highest macroporosity followed by green gram plots and the least by sesamum plots. The C_0 plots recorded significantly highest macroporosity than C_1 plots. The F_1 and F_2 plots were on par and

Table 98A. Main effects of treatments and two factor interactions on micro porosity (percent) of surface soil of sesamum, green gram and cowpea

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	20.66	20.60	17.56	20.18	20.45	18.21	19.61
C_1	23.31	25.01	26.36	23.98	25.26	25.45	24.89

	A_0	A_1	A_2	Mean
F_0	21.96	21.93	22.07	21.98
F_1	21.87	24.11	22.43	22.81
F_2	22.41	22.50	20.99	21.97
Mean	22.08	22.85	21.83	

	C_0	C_1	F_0	F_1	F_2	A_0	A_1	A_2	Mean	
S_0	22.37	24.88	22.88	25.83	22.17	23.47	25.22	22.19	23.63	
S_1	17.60	25.82	21.96	20.96	22.23	21.76	21.78	21.61	21.72	
S_2	18.86	23.97	21.13	21.63	21.49	21.00	21.56	21.69	21.42	
	S	C	F	A	SF	SA	FA	CF	CA	CS
CD	NS	1.23	NS	NS	2.60	2.60	2.60	2.12	2.12	2.10
SE	0.98	0.48	0.59	0.59	1.03	1.03	1.03	0.84	0.84	0.84

Table 98B. Main effects of treatments and two factor interactions on micro porosity (percent) of sub surface soil of sesamum, green gram and cowpea

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	20.66	20.60	17.57	20.18	20.44	18.21	17.94
C_1	23.31	25.01	26.36	23.98	25.26	25.45	26.19

	A_0	A_1	A_2	Mean
F_0	20.22	21.98	22.61	21.61
F_1	21.19	22.16	24.28	22.55
F_2	21.52	22.90	21.70	22.04
Mean	20.98	22.34	22.87	

	C_0	C_1	F_0	F_1	F_2	A_0	A_1	A_2	Mean	
S_0	20.29	25.72	23.50	23.50	22.02	20.69	23.87	24.45	23.01	
S_1	16.45	29.13	21.45	23.40	23.52	22.09	22.91	23.37	22.79	
S_2	17.08	23.72	19.88	20.74	20.57	20.16	20.26	20.77	20.40	
	S	C	F	A	SF	SA	FA	CF	CA	CS
CD	NS	1.12	NS	NS	2.37	2.37	2.37	1.94	1.94	1.94
SE	0.60	0.46	0.57	0.57	0.98	0.98	0.98	0.80	0.80	0.80

Table 99. Effect of treatments on macro porosity of soil (percent)

	Surface soil			Subsurface soil		
Treatment	Sesamum	Greengram	Cowpea	Sesamum	Greengram	Cowpea
$C_0F_0A_0$	13.43	17.58	18.42	11.19	16.82	23.14
$C_0F_0A_1$	20.18	20.15	21.76	13.70	15.39	22.05
$C_0F_0A_2$	18.09	18.38	22.46	11.33	14.69	23.51
$C_0F_1A_0$	14.30	16.17	22.12	22.14	17.95	25.19
$C_0F_1A_1$	14.21	18.32	20.57	13.85	17.02	23.22
$C_0F_1A_2$	16.78	19.78	21.00	13.45	18.20	23.07
$C_0F_2A_0$	15.65	21.14	22.80	17.03	16.28	22.72
$C_0F_2A_1$	21.68	16.64	23.14	19.48	17.81	23.13
$C_0F_2A_2$	15.37	16.80	24.40	11.59	15.84	20.87
$C_1F_0A_0$	15.54	17.42	20.15	7.97	14.89	19.38
$C_1F_0A_1$	17.33	17.90	24.47	7.69	13.98	19.55
$C_1F_0A_2$	16.75	16.46	19.23	10.48	15.64	18.17
$C_1F_1A_0$	20.33	13.95	19.81	10.80	13.43	16.79
$C_1F_1A_1$	13.80	15.22	15.15	9.41	15.12	16.95
$C_1F_1A_2$	13.94	15.43	13.83	11.04	14.03	16.77
$C_1F_2A_0$	12.57	14.66	14.90	9.20	17.16	16.01
$C_1F_2A_1$	19.71	14.15	15.74	7.32	11.68	16.88
$C_1F_2A_2$	12.11	13.44	15.97	9.48	17.65	16.23
CD	3.83	3.83	3.83	2.36	2.36	2.36
SE	2.51	2.51	2.51	2.40	2.40	2.40

showed significantly lower macroporosity than F_0 plot. The A_1 plot recorded higher macroporosity than A_2 and A_0 plots (Table 100).

The macroporosity of the sub surface soil of the sesamum plots ranged from 7.32 ($C_1F_2A_1$) to 22.14 percent ($C_0F_1A_0$) (Table 99).The green gram plots recorded a highest macroporosity of 18.20 percent ($C_0F_1A_2$) and a lowest macroporosity of 11.68 percent ($C_1F_2A_1$) (Table 99). The cowpea plots recorded a macroporosity ranging from 16.01 ($C_1F_2A_0$) to 25.19 percent ($C_0F_1A_0$) (Table 99). The cowpea plots recorded significantly highest macroporosity followed by green gram plots and the least by sesamum plots. The C_0 plots showed significantly higher macroporosity than C_1 plots. The F_1 plots recorded highest macroporosity than F_2 plots and F_0 plots. The A_1 and A_2 plots were on par and recorded lower macroporosity than A_0 plots (Table 100B).

4.3.2.4 Total porosity

The sesamum plots recorded a total porosity of surface soils ranging from 31.49 ($C_1F_2A_2$) to 44.79 percent ($C_1F_2A_1$) (Table 101). The green gram plots showed a total porosity ranging from 33.16 percent ($C_0F_2A_2$) to 42.52 percent ($C_1F_0A_2$) (Table 101). The total porosity of the cowpea plots ranged from 39.56 percent ($C_0F_1A_1$) to 46.55 percent ($C_1F_0A_1$) (Table 101). The cowpea plots recorded the significantly highest total porosity than sesamum and green gram plots which were on par. The C_1 plots recorded significantly highest total porosity than C_0 plots. The F_1 and F_2 plots recorded lower total porosity than F_0 plots. The A_1 plots showed highest total porosity than A_0 plots and A_2 plots (Table 102A).

Table 100A. Main effects of treatments and two factor interactions on macro porosity (percent) of surface soil of sesamum, green gram and cowpea

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	18.94	18.14	19.74	17.96	19.63	19.23	18.94
C_1	18.36	15.72	14.80	16.59	17.05	15.24	16.30

	A_0	A_1	A_2	Mean
F_0	17.09	20.30	18.56	18.65
F_1	17.78	16.21	16.80	16.93
F_2	16.95	18.51	16.35	17.27
Mean	17.27	18.34	17.24	

	C_0	C_1	F_0	F_1	F_2	A_0	A_1	A_2	Mean	
S_0	16.63	15.78	16.89	15.56	16.18	15.31	17.82	15.51	16.21	
S_1	18.33	15.40	17.98	16.48	16.14	16.82	17.06	16.72	16.87	
S_2	21.85	17.69	21.08	18.75	19.49	19.69	20.14	19.48	19.77	
	S	C	F	A	SF	SA	FA	CF	CA	CS
CD	NS	1.36	1.66	1.66	2.89	2.89	2.89	2.36	2.36	2.36
SE	0.98	0.48	0.59	0.59	1.03	1.03	1.03	0.84	0.84	0.84

Table 100B. Main effects of treatments and two factor interactions on macro porosity (percent) of sub surface soil of sesamum, green gram and cowpea

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	16.87	19.34	18.31	19.16	18.41	16.95	18.17
C_1	14.19	13.82	13.51	13.96	13.17	14.39	13.84

	A_0	A_1	A_2	Mean
F_0	15.57	15.40	15.64	15.53
F_1	17.72	15.93	16.09	16.58
F_2	16.40	16.05	15.28	15.91
Mean	16.56	15.79	15.67	

	C_0	C_1	F_0	F_1	F_2	A_0	A_1	A_2	Mean	
S_0	14.86	9.27	10.39	13.45	12.35	13.06	11.91	11.23	12.07	
S_1	16.67	14.84	15.24	15.96	16.07	16.09	15.17	16.01	15.75	
S_2	22.99	17.42	20.97	20.32	19.31	20.54	20.30	19.77	20.20	
	S	C	F	A	SF	SA	FA	CF	CA	CS
CD	2.36	1.30	NS	NS	2.76	2.76	NS	2.25	2.25	2.25
SE	0.60	0.46	0.57	0.57	0.98	0.98	0.98	0.80	0.80	0.80

Table 101. Effect of treatments on total porosity of soil (percent)

	Surface soil			Subsurface soil		
Treatment	Sesamum	Greengram	Cowpea	Sesamum	Greengram	Cowpea
$C_0F_0A_0$	38.16	37.76	39.87	29.20	32.49	40.36
$C_0F_0A_1$	42.10	39.56.	42.20	34.80	30.96	40.05
$C_0F_0A_2$	38.33	36.96	41.65	35.07	31.11	40.45
$C_0F_1A_0$	33.64	33.63	40.83	41.36	34.36	40.92
$C_0F_1A_1$	36.25	35.37	39.56	31.77	34.39	39.73
$C_0F_1A_2$	36.41	35.69	40.15	38.71	35.93	40.40
$C_0F_2A_0$	34.98	37.62	41.02	34.52	32.65	39.94
$C_0F_2A_1$	39.69	34.12	41.07	39.05	34.59	39.55
$C_0F_2A_2$	34.37	33.16	40.35	28.64	35.15	39.05
$C_1F_0A_0$	37.69	40.85	40.03	31.90	39.96	40.77
$C_1F_0A_1$	41.42	41.96	46.55	36.31	40.34	44.44
$C_1F_0A_2$	37.72	42.52	42.71	32.73	45.17	41.96
$C_1F_1A_0$	41.81	39.28	42.07	33.85	44.50	40.96
$C_1F_1A_1$	42.51	41.78	40.53	37.14	43.58	41.98
$C_1F_1A_2$	39.51	40.51	39.75	42.21	42.59	41.47
$C_1F_2A_0$	42.72	41.20	40.63	31.66	45.16	40.28
$C_1F_2A_1$	44.79	42.07	40.59	32.27	44.70	40.08
$C_1F_2A_2$	31.49	41.09	41.74	33.41	42.67	40.50
CD	2.73	2.73	2.73	2.77	2.77	2.77
SE	2.43	2.43	2.43	3.07	3.07	3.07

The total porosity of the sub surface soils of sesamum plots ranged from 28.64 ($C_0F_2A_2$) to 42.21 percent ($C_1F_1A_2$) (Table 101). The green gram plots recorded a total porosity ranging from 30.96 ($C_0F_0A_1$) to 45.17 percent ($C_1F_0A_2$) (Table 101). The highest total porosity of the cowpea plots was 41.98 percent ($C_1F_1A_1$) and the lowest total porosity was 39.05 percent ($C_0F_2A_2$) (Table 101).The cowpea plots recorded significantly highest total porosity followed by the green gram plots and the least by the sesamum plots. The C_1 plots recorded significantly higher total porosity than C_0 plots. The F_1 plot showed significantly higher total porosity than F_2 plot. The A_2 plots recorded higher total porosity than A_1 plots and A_0 plots (Table 102B).

4.3.2.5 Bulk density.

The bulk density of the surface soils of sesamum plots ranged from 1.54 Mg m^{-3} ($C_1F_0A_2$) to 1.81 Mg m^{-3} ($C_1F_2A_2$) (Table 103). The green gram plots recorded a highest bulk density of 1.82 Mg m^{-3} ($C_1F_0A_1$ and $C_1F_2A_2$) and a lowest bulk density of 1.58 Mg m^{-3} ($C_0F_0A_0$ and $C_0F_2A_0$) (Table 103). The bulk density of cowpea plots ranged from 1.47 Mg m^{-3} ($C_0F_2A_0$) to 1.92 Mg m^{-3} ($C_1F_1A_0$ and $C_1F_1A_1$) (Table 103). The cowpea plots showed significantly higher bulk density followed by green gram plots and the least by sesamum plots. The C_1 plots showed significantly higher bulk density than C_0 plots. The F_1, F_2 and the F_0 plots were on par. The A_2 plots showed significantly higher bulk density followed by A_1 plots and the least by the A_0 plots (Table 104A)

The bulk density of the sub surface soils of sesamum plots ranged from 1.51 Mg m^{-3} ($C_0F_1A_0$) to 1.95 Mg m^{-3} ($C_0F_1A_1$) (Table 103). The green gram plots recorded a bulk density ranging from 1.52 Mg m^{-3} ($C_0F_0A_1$) to 1.95 Mg m^{-3} ($C_1F_2A_2$) (Table 103). The

Table 102A. Main effects of treatments and two factor interactions on total porosity (percent) of surface soil of sesamum, green gram and cowpea

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	39.61	36.84	37.38	37.49	38.88	37.45	37.94
C_1	41.27	40.87	40.70	40.69	42.47	39.68	40.95

	A_0	A_1	A_2	Mean
F_0	39.05	42.30	39.98	40.44
F_1	38.54	39.33	38.68	38.85
F_2	39.69	40.39	37.03	39.04
Mean	39.09	40.67	38.56	

	C_0	C_1	F_0	F_1	F_2	A_0	A_1	A_2	Mean	
S_0	37.09	39.96	39.22	38.36	38.00	38.15	41.12	36.32	38.53	
S_1	35.98	41.25	39.94	37.71	38.21	38.39	39.14	38.32	38.62	
S_2	40.74	41.62	42.17	40.48	40.90	40.74	41.75	41.05	41.18	
	S	C	F	A	SF	SA	FA	CF	CA	CS
CD	2.73	1.31	NS	1.61	2.79	2.79	2.79	2.23	2.23	2.23
SE	0.69	0.47	0.57	0.57	0.99	0.99	0.99	0.81	0.81	0.81

Table 102B. Main effects of treatments and two factor interactions on total porosity (percent) of sub surface soil of sesamum, green gram and cowpea

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	34.94	37.51	35.91	36.20.	36.10	36.05	36.12
C_1	38.92	40.92	38.97	38.79	39.73	40.30	39.61

	A_0	A_1	A_2	Mean
F_0	35.79	37.27	37.74	36.93
F_1	39.33	38.10	40.22	39.21
F_2	37.37	38.37	36.57	37.43
Mean	37.49	37.91	38.18	

	C_0	C_1	F_0	F_1	F_2	A_0	A_1	A_2	Mean	
S_0	34.79	34.61	33.34	37.50	33.26	33.76	35.22	35.22	34.70	
S_1	33.52	43.19	36.67	39.23	39.15	38.19	38.09	38.77	38.35	
S_2	40.05	41.02	40.79	40.91	39.90	40.54	40.42	40.64	40.53	
	S	C	F	A	SF	SA	FA	CF	CA	CS
CD	2.77	1.66	2.03	NS	3.52	3.52	3.52	2.88	2.88	2.88
SE	0.71	0.59	0.72	0.72	1.72	1.72	1.72	1.02	1.02	1.02

Table 103. Effect of treatments on bulk density of soil (Mg m^{-3})

	Surface soil			Subsurface soil		
Treatment	Sesamum	Greengram	Cowpea	Sesamum	Greengram	Cowpea
$C_0F_0A_0$	1.60	1.58	1.62	1.85	1.66	1.67
$C_0F_0A_1$	1.67	1.62	1.53	1.70	1.52	1.68
$C_0F_0A_2$	1.62	1.61	1.63	1.68	1.67	1.58
$C_0F_1A_0$	1.70	1.61	1.53	1.51	1.69	1.52
$C_0F_1A_1$	1.61	1.60	1.63	1.95	1.53	1.60
$C_0F_1A_2$	1.64	1.60.	1.61	1.76	1.65	1.69
$C_0F_2A_0$	1.65	1.58	1.47	1.71	1.85	1.66
$C_0 F_2A_1$	1.56	1.64	1.61	1.61	1.63	1.56
$C_0F_2A_2$	1.74	1.61	1.68	1.93	1.70	1.68
$C_1F_0A_0$	1.65	1.78	1.82	1.75	1.68	1.87
$C_1F_0A_1$	1.59	1.82	1.91	1.66	1.68	1.84
$C_1F_0A_2$	1.54	1.68	1.89	1.75	1.73	1.86
$C_1F_1A_0$	1.56	1.66	1.92	1.74	1.91	1.79
$C_1F_1A_1$	1.64	1.76	1.92	1.70	1.87	1.97
$C_1F_1A_2$	1.65	1.70	1.79	1.51	1.59	1.84
$C_1F_2A_0$	1.47	1.67	1.85	1.79	1.85	1.93
$C_1F_2A_1$	1.60	1.64	1.79	1.77	1.93	1.74
$C_1F_2A_2$	1.81	1.82	1.88	1.77	1.95	1.75
CD	0.065	0.065	0.065	0.72	0.72	0.72
SE	0.072	0.072	0.072	0.77	0.77	0.77

cowpea plots showed a bulk density ranging from 1.52 Mg m^{-3} ($C_0F_1A_0$) to 1.93 Mg m^{-3} ($C_1F_2A_0$). (Table 103). The green gram plots recorded significantly higher bulk density than sesamum and cowpea plots, which were on par.(Table 104B). The C_1 plots showed significantly higher bulk density than C_0 plots. The F_1 plots showed significantly higher bulk density than F_2 plots and F_0 plots. The A_2 plots showed significantly higher bulk density than A_1 and A_0 plots.

4.3.2.6 Particle density.

The particle density of sesamum plots ranged from 2.33 Mg m^{-3} ($C_0F_1A_2$) to 2.67 Mg m^{-3} ($C_0F_0A_0$) (Table 105). The green gram plots recorded a particle density ranging from 2.53 m^{-3} ($C_0F_2A_1$, $C_1F_1A_1$ and $C_1F_0A_0$) to 2.67 Mg m^{-3} ($C_0F_0A_0$) (Table 105). The cowpea plots recorded a highest particle density of 2.60 Mg m^{-3} ($C_0F_2A_1$ and $C_0F_2A_2$) and a lowest particle density of 2.42 Mg m^{-3} ($C_1F_2A_2$) (Table 105). The green gram plots recorded significantly higher particle density followed by sesamum plots and the least by cowpea plots (Table 106A). The C_1 plots recorded significantly lower particle density than C_0 plots. The F_1 plots showed significantly highest particle density than F_2 plots and F_0 plots which were on par. The A_2 plots showed significantly higher particle density compared to A_1 plots and A_0 plots.

The particle density of subsurface soils of the sesamum plots ranged from 2.45 Mg m^{-3} ($C_0F_1A_2$) to 2.62 Mg m^{-3} ($C_0F_0A_0$) (Table 105). The green gram plots recorded a highest particle density of 2.67 Mg m^{-3} ($C_0F_0A_1$) and a least particle density of 2.41 Mg m^{-3} ($C_1F_2A_0$) (Table 119). The cowpea plots showed a particle density ranging from 2.42 Mg m^{-3} ($C_1F_0A_0$) to 2.60 Mg m^{-3} ($C_1F_0A_2$) (Table 105). The green gram plots recorded

Table 104A. Main effects of treatments and two factor interactions on bulk density ($Mg\ m^{-3}$) of surface soil of sesamum, green gram and cowpea

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	1.59	1.61	1.64	1.61	1.61	1.61	1.62
C_1	1.71	1.74	1.75	1.74	1.73	1.73	1.74

	A_0	A_1	A_2	Mean
F_0	1.68	1.69	1.66	1.67
F_1	1.66	1.69	1.66	1.67
F_2	1.62	1.64	1.76	1.67
Mean	1.65	1.67	1.69	

	C_0	C_1	F_0	F_1	F_2	A_0	A_1	A_2	Mean	
S_0	1.64	1.61	1.61	1.63	1.64	1.61	1.61	1.67	1.63	
S_1	1.61	1.73	1.61	1.65	1.66	1.65	1.68	1.67	1.67	
S_2	1.59	1.86	1.73	1.73	1.71	1.70	1.73	1.74	1.73	
	S	C	F	A	SF	SA	FA	CF	CA	CS
CD	0.065	0.039	NS	0.048	0.083	0.083	0.083	0.068	0.068	0.068
SE	0.02	0.01	0.02	0.02	0.03	0.03	0.03	0.02	0.02	0.02

Table 104B. Main effects of treatments and two factor interactions on bulk density (($Mg\ m^{-3}$) of sub surface soil of sesamum, green gram and cowpea

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	1.68	1.64	1.70	1.67	1.66	1.70	1.67
C_1	1.81	1.79	2.42	1.76	2.44	1.83	2.01

	A_0	A_1	A_2	Mean
F_0	1.75	1.68	1.71	1.71
F_1	1.69	1.77	2.67	2.05
F_2	1.79	1.71	1.79	1.77
Mean	1.75	1.72	2.06	

	C_0	C_1	F_0	F_1	F_2	A_0	A_1	A_2	Mean	
S_0	1.74	1.71	1.73	1.69	1.76	1.72	1.73	1.73	1.73	
S_1	1.65	2.47	1.66	2.71	1.82	1.77	1.69	2.71	2.06	
S_2	1.63	1.84	1.75	1.74	1.72	1.74	1.73	1.73	1.74	
	S	C	F	A	SF	SA	FA	CF	CA	CS
CD	0.18	0.42	0.51	0.51	0.89	0.89	0.89	0.73	0.73	0.73
SE	0.18	0.15	0.18	0.18	0.32	0.32	0.32	0.23	0.23	0.23

Table 105. Effect of treatments on particle density of soil (Mg m^{-3})

	Surface soil			Subsurface soil		
Treatment	Sesamum	Greengram	Cowpea	Sesamum	Greengram	Cowpea
$C_0F_0A_0$	2.67	2.67	2.45	2.62	2.63	2.51
$C_0F_0A_1$	2.60	2.61	2.55	2.57	2.67	2.48
$C_0F_0A_2$	2.45	2.62	2.59	2.54	2.59	2.43
$C_0F_1A_0$	2.50	2.55	2.55	2.48	2.62	2.49
$C_0F_1A_1$	2.43	2.61	2.57	2.48	2.62	2.49
$C_0F_1A_2$	2.33	2.60	2.56	2.45	2.60	2.51
$C_0F_2A_0$	2.45	2.63	2.55	2.54	2.60	2.51
$C_0F_2A_1$	2.55	2.53	2.60	2.57	2.65	2.51
$C_0F_2A_2$	2.45	2.59	2.60	2.49	2.61	2.43
$C_1F_0A_0$	2.56	2.53	2.47	2.53	2.58	2.42
$C_1F_0A_1$	2.60	2.63	2.48	2.57	2.55	2.52
$C_1F_0A_2$	2.45	2.59	2.52	2.51	2.66	2.60
$C_1F_1A_0$	2.56	2.59	2.48	2.55	2.60	2.56
$C_1F_1A_1$	2.45	2.53	2.52	2.50	2.60	2.53
$C_1F_1A_2$	2.56	2.61	2.36	2.54	2.45	2.60
$C_1F_2A_0$	2.46	2.61	2.44	2.49	2.41	2.53
$C_1F_2A_1$	2.46	2.53	2.44	2.50	2.43	2.46
$C_1F_2A_2$	2.50	2.63	2.42	2.51	2.44	2.48
CD	0.068	0.068	0.068	0.030	0.030	0.030
SE	0.04	0.04	0.04	0.04	0.04	0.04

significantly higher particle density followed by the sesamum plots and the least by cowpea plots (Table 106B). The C_1 plots recorded significantly lower particle density than C_0 plots. The F_0 plots recorded significantly higher particle density followed by the F_1 plots and F_2 plots.The A_2 plots showed significantly lower particle density than A_1 plots and A_0 plots which were on par.

4.3.2.7 Soil Strength.

The surface soils of sesamum plots showed a soil strength ranging from 1.08 kg m^{-2} ($C_0F_0A_1$) to 3.50 kg m^{-2} ($C_1F_1A_1$) (Table 107). The soil strength of green gram plots ranged from 1.08 kg m^{-2} ($C_0F_0A_0$ and $C_0F_0A_1$) to 3.33 kg m^{-2} ($C_1F_1A_0$ and $C_1F_2A_1$) (Table 107). The cowpea plots showed the highest soil strength of 3.33 kg m^{-2} ($C_1F_2A_2$) and a lowest soil strength of 1.08 kg m^{-2} ($C_0F_0A_0$, $C_0F_1A_1$ and $C_0F_2A_0$) (Table 107). The sesamum plots showed higher soil strength followed by the green gram plots and the least by the cowpea plots (Table 108). The C_1 plots recorded significantly higher (more than 2.5 times) soil strength than C_0 plots. The F_1 plot showed significantly higher soil strength followed by F_2 plots and least by F_0 plots. The A_2 plots recorded significantly higher soil strength followed by A_1 plots and the least by A_0 plots.

4.3.3. Effect of treatments on chemical characteristics of soil

4.3.3.1 Soil reaction

The surface soils of sesamum plots recorded a soil pH ranging from 5.00 ($C_1F_2A_2$) to 5.30 ($C_1F_1A_2$) (Table 109). The soil pH of green gram plots ranged from 4.90 ($C_0F_1A_2$) to 5.27 ($C_0F_1A_0$) (Table 109). The cowpea plots showed a soil pH ranging from 4.97 ($C_0F_1A_2$) to 5.27 ($C_1F_0A_2$) (Table 109). The sesamum plots recorded significantly higher soil pH followed by green gram plots and the least by cowpea plots (Table 110A). The C_1 plots

Table 106A. Main effects of treatments and two factor interactions on particle density (Mg m^{-3}) of surface soil of sesamum, green gram and cowpea

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	2.55	2.58	2.57	2.55	2.57	2.58	2.57
C_1	2.52	2.52	2.51	2.52	2.51	2.51	2.52

	A_0	A_1	A_2	Mean
F_0	2.51	2.53	2.56	2.54
F_1	2.54	2.56	2.55	2.55
F_2	2.56	2.53	2.55	2.54
Mean	2.54	2.54	2.55	

	C_0	C_1	F_0	F_1	F_2	A_0	A_1	A_2	Mean	
S_0	2.54	2.51	2.49	2.56	2.53	2.53	2.53	2.50	2.53	
S_1	2.60	2.58	2.60	2.58	2.58	2.56	2.58	2.56	2.59	
S_2	2.55	2.45	2.50	2.50	2.50	2.50	2.50	2.51	2.51	
	S	C	F	A	SF	SA	FA	CF	CA	CS
CD	0.078	0.02	0.03	0.03	0.05	0.05	0.05	0.04	0.04	0.04
SE	0.08	0.07	0.08	0.08	0.01	0.01	0.01	0.01	0.01	0.01

Table 106B. Main effects of treatments and two factor interactions on particle density ((Mg m^{-3}) of sub surface soil of sesamum, green gram and cowpea

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	2.56	2.52	2.54	2.55	2.55	2.51	2.54
C_1	2.55	2.55	2.47	2.51	2.52	2.53	2.52

	A_0	A_1	A_2	Mean
F_0	2.55	2.56	2.56	2.56
F_1	2.55	2.54	2.53	2.54
F_2	2.51	2.52	2.50	2.51
Mean	2.54	2.54	2.53	

	C_0	C_1	F_0	F_1	F_2	A_0	A_1	A_2	Mean	
S_0	2.57	2.52	2.56	2.50	2.51	2.53	2.53	2.50	2.53	
S_1	2.62	2.52	2.61	2.57	2.52	2.57	2.59	2.56	2.54	
S_2	2.49	2.52	2.49	2.53	2.49	2.50	2.50	2.51	2.51	
	S	C	F	A	SF	SA	FA	CF	CA	CS
CD	0.04	0.02	0.02	0.02	0.04	0.04	0.04	0.03	0.03	0.03
SE	0.08	0.07	0.08	0.08	0.01	0.01	0.01	0.01	0.01	0.01

Table 107. Effect of treatments on soil strength (kg m^{-2})

	Surface soil		
Treatment	Sesamum	Greengram	Cowpea
$C_0F_0A_0$	1.16	1.08	1.08
$C_0F_0A_1$	1.08	1.08	1.17
$C_0F_0A_2$	1.33	1.17	1.25
$C_0F_1A_0$	1.17	1.33	1.33
$C_0F_1A_1$	1.67	1.25	1.08
$C_0F_1A_2$	1.25	1.25	1.50
$C_0F_2A_0$	1.42	1.50	1.08
$C_0 F_2A_1$	1.58	1.75	1.42
$C_0F_2A_2$	2.50	1.33	1.33
$C_1F_0A_0$	2.58	2.92	2.83
$C_1F_0A_1$	2.58	2.67	2.75
$C_1F_0A_2$	2.75	2.83	3.00
$C_1F_1A_0$	3.42	3.33	3.25
$C_1F_1A_1$	3.50	3.25	3.17
$C_1F_1A_2$	3.08	3.08	3.08
$C_1F_2A_0$	3.17	3.00	3.17
$C_1F_2A_1$	2.67	3.33	3.25
$C_1F_2A_2$	3.25	3.17	3.33
CD	0.21	0.21	0.21
SE	0.15	0.15	0.15

Table 108. Main effects of treatments and two factor interactions on strength (kg m^{-2}) of surface soil of sesamum, green gram and cowpea

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	1.16	1.31	1.55	1.24	1.34	1.44	1.34
C_1	2.77	3.24	3.15	3.07	3.01	3.06	3.05

	A_0	A_1	A_2	Mean
F_0	1.94	1.89	2.06	1.96
F_1	2.30	2.32	2.20	2.28
F_2	2.22	2.33	2.49	2.35
Mean	2.16	2.18	2.25	

	C_0	C_1	F_0	F_1	F_2	A_0	A_1	A_2	Mean	
S_0	1.46	1.30	1.92	2.35	2.43	2.15	2.18	2.36	2.23	
S_1	1.30	3.06	1.96	2.25	2.35	2.19	2.22	2.13	2.19	
S_2	1.25	3.09	2.01	2.34	2.26	2.12	2.14	2.25	2.17	
	S	C	F	A	SF	SA	FA	CF	CA	CS
CD	NS	0.08	0.01	0.01	0.17	0.17	0.17	0.14	0.14	0.14
SE	0.05	0.03	0.04	0.04	0.06	0.06	0.06	0.05	0.05	0.05

Table 109. Effect of treatments on soil pH

	Surface soil			Subsurface soil		
Treatment	Sesamum	Greengram	Cowpea	Sesamum	Greengram	Cowpea
$C_0F_0A_0$	5.13	5.03	5.07	5.00	5.07	5.07
$C_0F_0A_1$	5.17	5.23	5.07	5.03	5.07	5.07
$C_0F_0A_2$	5.03	5.23	5.23	5.00	5.07	5.07
$C_0F_1A_0$	5.07	5.27	5.20	5.00	4.97	4.93
$C_0F_1A_1$	5.23	5.13	5.03	5.07	4.97	4.97
$C_0F_1A_2$	5.10	4.90	4.97	4.97	5.00	5.10
$C_0F_2A_0$	5.03	5.03	5.07	5.00	4.90	4.90
$C_0F_2A_1$	5.17	5.03	5.07	5.03	4.97	4.93
$C_0F_2A_2$	5.13	5.07	5.13	5.07	5.03	5.03
$C_1F_0A_0$	5.20	5.10	5.13	5.07	4.90	4.97
$C_1F_0A_1$	5.07	5.23	5.20	5.10	4.90	4.90
$C_1F_0A_2$	5.20	5.23	5.27	5.00	5.00	4.97
$C_1F_1A_0$	5.07	5.23	5.17	5.00	5.00	4.97
$C_1F_1A_1$	5.10	5.03	5.07	5.10	4.90	4.93
$C_1F_1A_2$	5.30	5.03	5.07	5.03	4.93	4.97
$C_1F_2A_0$	5.10	5.03	5.03	5.07	4.97	4.97
$C_1F_2A_1$	5.17	5.13	5.10	5.03	4.93	4.93
$C_1F_2A_2$	5.00	5.17	5.13	5.03	5.03	5.03
CD	0.043	0.043	0.043	0.020	0.020	0.020
SE	0.07	0.07	0.07	0.05	0.05	0.05

Table 110A. Main effects of treatments and two factor interactions on pH of surface soil of sesamum, green gram and cowpea

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	5.13	5.10	5.08	5.10	5.12	5.08	5.10
C_1	5.18	5.11	5.09	5.11	5.12	5.11	5.13

	A_0	A_1	A_2	Mean
F_0	5.11	5.16	5.20	5.16
F_1	5.17	5.10	5.06	5.11
F_2	5.05	5.11	5.11	5.09
Mean	5.11	5.12	5.12	

	C_0	C_1	F_0	F_1	F_2	A_0	A_1	A_2	Mean	
S_0	5.11	5.13	5.13	5.14	5.10	5.10	5.15	5.12	5.13	
S_1	5.10	5.13	5.07	5.10	5.07	5.11	5.13	5.10	5.12	
S_2	5.09	5.13	5.16	5.08	5.08	5.11	5.09	5.13	5.11	
	S	C	F	A	SF	SA	FA	CF	CA	CS
CD	0.020	0.028	0.034	NS	0.059	0.059	0.059	0.063	0.063	0.063
SE	0.01	0.01	0.02	0.02	0.03	0.03	0.03	0.02	0.02	0.02

Table 110B. Main effects of treatments and two factor interactions on pH of sub surface soil of sesamum, green gram and cowpea

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	5.04	4.99	4.98	4.98	5.01	5.03	5.01
C_1	4.98	4.98	5.00	4.99	4.97	5.00	4.99

	A_0	A_1	A_2	Mean
F_0	5.01	5.01	5.02	5.01
F_1	4.98	4.99	5.00	4.99
F_2	4.97	4.97	5.04	4.99
Mean	4.99	4.99	5.02	

	C_0	C_1	F_0	F_1	F_2	A_0	A_1	A_2	Mean	
S_0	5.01	5.04	5.03	5.03	5.04	5.02	5.06	5.01	5.03	
S_1	5.00	4.95	5.00	4.96	4.97	4.96	4.95	5.01	4.98	
S_2	5.01	4.96	5.01	4.98	4.97	4.96	4.96	5.02	4.98	
	S	C	F	A	SF	SA	FA	CF	CA	CS
CD	0.020	NS	NS	NS	0.059	0.059	0.059	NS	NS	NS
SE	0.005	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02

showed significantly higher soil pH than C_0 plots. The F_1 and F_2 plots showed significantly lower soil pH than F_0 plots. The A_1 and A_2 plots were on par and showed higher soil pH than A_0 plots.

The sub surface soils of sesamum plots recorded a soil pH ranging from 4.97 ($C_0F_1A_2$) to 5.10 ($C_1F_1A_1$ and $C_1F_0A_1$) (Table 109). The green gram plots recorded a maximum soil pH of 5.07 for all C_0F_0 treatments and a mimimum soil pH of 4.90 in three of the compacted plots and in one uncompacted plot (Table 109). The cowpea plots recorded a maximum soil pH of 5.10 ($C_0F_1A_2$) and a minimum soil pH of 4.90 ($C_0F_2A_0$ and $C_1F_0A_1$) (Table 109). The sesamum plots recorded significantly higher soil pH than green gram and cowpea plots which were on par (Table 110B). The C_0 plots recorded significantly higher soil pH than C_1 plots. The F_2 and F_1 plots recorded lower soil pH than F_0 plots. The A_2 plots recorded higher soil pH than A_1 and A_0 plots.

4.3.3.2 Organic Carbon.

In surface soils of sesamum plots the treatment $C_1F_2A_2$ recorded the highest organic carbon content of 0.67 percent and the treatment $C_0F_0A_0$ recorded the lowest organic carbon content of 0.41 percent (Table 111). The green gram plots recorded a maximum organic carbon content of 0.57 percent ($C_1F_2A_0$, $C_1F_1A_2$, $C_1F_1A_0$ and $C_1F_0A_2$) and a minimum organic carbon content of 0.43 percent ($C_0F_0A_0$) (Table 111). The cowpea plots recorded an organic carbon content ranging from 0.43 percent ($C_0F_0A_0$) to 0.59 percent ($C_1F_0A_2$) (Table 111).The sesamum plots showed higher organic carbon content than green gram and cowpea plots, which were on par. (Table 112A).The C_1 plots recorded significantly higher organic carbon content than C_0 plots. The F_2 plots recorded significantly higher organic carbon content

Table 111. Effect of treatments on organic carbon content of soil (percent)

	Surface soil			Subsurface soil		
Treatment	Sesamum	Greengram	Cowpea	Sesamum	Greengram	Cowpea
$C_0F_0A_0$	0.41	0.43	0.43	0.42	0.42	0.42
$C_0F_0A_1$	0.43	0.44	0.44	0.42	0.43	0.43
$C_0F_0A_2$	0.44	0.44	0.43	0.47	0.44	0.43
$C_0F_1A_0$	0.49	0.48	0.48	0.47	0.44	0.43
$C_0F_1A_1$	0.46	0.48	0.47	0.46	0.44	0.44
$C_0F_1A_2$	0.51	0.50	0.43	0.48	0.46	0.46
$C_0F_2A_0$	0.52	0.49	0.49	0.48	0.49	0.49
$C_0 F_2A_1$	0.54	0.50	0.50	0.46	0.47	0.47
$C_0F_2A_2$	0.54	0.53	0.53	0.52	0.44	0.44
$C_1F_0A_0$	0.55	0.53	0.54	0.55	0.48	0.48
$C_1F_0A_1$	0.58	0.55	0.53	0.57	0.48	0.48
$C_1F_0A_2$	0.58	0.57	0.59	0.57	0.49	0.50
$C_1F_1A_0$	0.61	0.57	0.57	0.59	0.49	0.49
$C_1F_1A_1$	0.61	0.55	0.55	0.58	0.50	0.51
$C_1F_1A_2$	0.65	0.57	0.55	0.56	0.50	0.50
$C_1F_2A_0$	0.65	0.57	0.57	0.57	0.53	0.52
$C_1F_2A_1$	0.65	0.56	0.56	0.58	0.52	0.52
$C_1F_2A_2$	0.67	0.55	0.55	0.59	0.53	0.53
CD	0.044	0.044	0.044	0.014	0.014	0.014
SE	0.02	0.02	0.02	0.01	0.01	0.01

Table 112A. Main effects of treatments and two factor interactions on organic carbon content of soil (percent) of surface soil of sesamum, green gram and cowpea

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	0.43	0.48	0.51	0.47	0.47	0.48	0.47
C_1	0.56	0.58	0.59	0.57	0.57	0.58	0.58

	A_0	A_1	A_2	Mean
F_0	0.48	0.50	0.50	0.50
F_1	0.53	0.52	0.53	0.53
F_2	0.55	0.56	0.56	0.55
Mean	0.52	0.53	0.53	

	C_0	C_1	F_0	F_1	F_2	A_0	A_1	A_2	Mean	
S_0	0.48	0.61	0.50	0.55	0.59	0.54	0.54	0.56	0.55	
S_1	0.47	0.55	0.49	0.52	0.53	0.51	0.52	0.52	0.52	
S_2	0.46	0.55	0.49	0.50	0.53	0.51	0.50	0.51	0.52	
	S	C	F	A	SF	SA	FA	CF	CA	CS
CD	NS	0.01	0.01	NS	0.02	0.02	0.02	0.006	0.006	0.006
SE	0.01	0.003	0.004	0.004	0.007	0.007	0.007	0.006	0.006	0.006

Table 112 B. Main effects of treatments and two factor interactions on organic carbon content of soil (percent) of sub surface soil of sesamum, green gram and cowpea

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	0.43	0.45	0.47	0.45	0.45	0.46	0.45
C_1	0.51	0.52	0.54	0.52	0.53	0.53	0.53

	A_0	A_1	A_2	Mean
F_0	0.46	0.47	0.48	0.47
F_1	0.48	0.49	0.49	0.50
F_2	0.51	0.50	0.51	0.51
Mean	0.49	0.49	0.50	

	C_0	C_1	F_0	F_1	F_2	A_0	A_1	A_2	Mean	
S_0	0.46	0.57	0.49	0.52	0.53	0.51	0.51	0.53	0.52	
S_1	0.44	0.50	0.45	0.47	0.49	0.47	0.47	0.47	0.47	
S_2	0.45	0.50	0.46	0.47	0.49	0.47	0.47	0.47	0.47	
	S	C	F	A	SF	SA	FA	CF	CA	CS
CD	0.01	0.007	0.009	0.009	0.015	0.015	0.015	0.012	0.012	0.012
SE	0.003	0.003	0.003	0.003	0.005	0.005	0.005	0.004	0.004	0.004

followed by F_1 plots and the least by F_0 plots. The A_1 and A_2 plots recorded higher organic carbon content than A_0 plots.

The sub surface soils of sesamum plots recorded a maximum organic carbon content of 0.59 percent ($C_1F_2A_2$ and $C_1F_1A_0$) and a minimum organic carbon content of 0.42 percent ($C_0F_0A_0$) (Table 111).The organic carbon content of the green gram plots ranged from 0.42 percent ($C_0F_0A_0$) to 0.53 percent ($C_1F_2A_2$ and $C_1F_2A_0$). The cowpea plots recorded an organic carbon content ranging from 0.42 percent ($C_0F_0A_0$) to 0.53 percent ($C_1F_2A_2$) (Table 111). The sesamum plots recorded significantly higher organic carbon content than green gram and cowpea plots which were on par (Table 112B). The C_1 plots recorded significantly higher organic carbon content than C_0 plots. The F_2 plots recorded significantly higher organic carbon than F_1 plots and the least by F_0 plots. The A_2 plots recorded significantly higher organic carbon content than A_1 and A_0 plots which were on par.

4.3.3.3.Available N

The available N content of surface soils of the sesamum plots ranged from 182.38 kg ha^{-1} ($C_0F_0A_0$) to 233.05 kg ha^{-1} ($C_1F_1A_1$) (Table 113).The green gram plots recorded an available N content ranging from 181.35 kg ha^{-1} ($C_0F_0A_0$) to 218.34 kg ha^{-1} ($C_1F_1A_2$) (Table 113).The cowpea plots recorded an available N content ranging from 184.59 kg ha^{-1} ($C_0F_0A_2$) to 234.10 kg ha^{-1} ($C_1F_1A_1$) (Table 113).The sesamum plots recorded significantly higher available N content followed by the cowpea plots and the least by green gram plots (Table 114A). The C_1 plots showed significantly higher available N content than C_0 plots. The F_1 and F_2 plots showed significantly higher available N content than F_0 plots. The A_1 plots showed higher available N content than A_2 and A_0 plots.

Table 113. Effect of treatments on available N content of soil (kg ha^{-1})

	Surface soil			Subsurface soil		
Treatment	**Sesamum**	**Greengram**	**Cowpea**	**Sesamum**	**Greengram**	**Cowpea**
$C_0F_0A_0$	182.38	181.35	184.81	171.58	174.35	174.18
$C_0F_0A_1$	185.47	183.39	189.31	174.93	175.44	174.91
$C_0F_0A_2$	188.04	183.08	184.59	175.07	175.06	176.55
$C_0F_1A_0$	189.09	184.19	188.45	17512	178.78	177.55
$C_0F_1A_1$	192.79	183.64	193.75	173.41	178.06	172.40
$C_0F_1A_2$	194.74	181.48	192.64	174.88	176.92	176.33
$C_0F_2A_0$	197.71	182.63	196.18	179.95	174.11	176.18
$C_0F_2A_1$	201.77	181.50	198.77	177.25	173.81	174.97
$C_0F_2A_2$	206.44	181.78	200.50	177.86	173.60	175.01
$C_1F_0A_0$	213.89	213.68	212.20	180.75	188.97	176.08
$C_1F_0A_1$	221.82	215.43	213.68	183.26	190.93	179.90
$C_1F_0A_2$	219.98	217.45	214.52	185.59	190.41	180.20
$C_1F_1A_0$	224.64	214.30	217.68	186.68	192.04	185.41
$C_1F_1A_1$	233.05	217.86	234.10	187.93	186.58	189.09
$C_1F_1A_2$	226.05	218.34	221.98	185.02	187.19	189.63
$C_1F_2A_0$	223.01	214.04	217.19	185.87	185.35	186.51
$C_1F_2A_1$	225.51	217.12	223.33	186.11	188.34	189.05
$C_1F_2A_2$	219.58	217.52	217.57	185.16	191.34	185.89
CD	2.43	2.43	2.43	2.48	2.48	2.48
SE	2.11	2.11	2.11	2.26	2.26	2.26

Table 114A. Main effects of treatments and two factor interactions on available N content (kg ha $^{-1}$) of surface soil of sesamum, green gram and cowpea

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	184.04	188.97	194.13	187.42	189.37	190.36	189.05
C_1	215.84	223.00	219.49	216.80	222.43	219.22	219.49

	A_0	A_1	A_2	Mean
F_0	198.05	200.52	201.28	199.95
F_1	203.06	209.19	205.87	206.04
F_2	205.23	207.99	207.23	206.82
Mean	202.11	205.90	204.99	

	C_0	C_1	F_0	F_1	F_2	A_0	A_1	A_2	Mean	
S_0	193.1	223.12	201.92	210.06	212.43	205.22	210.06	209.13	208.43	
S_1	182.56	216.19	199.06	199.97	199.09	198.36	199.82	199.82	199.38	
S_2	191.43	219.13	198.85	208.10	208.91	202.75	207.81	205.30	205.29	
	S	C	F	A	SF	SA	FA	CF	CA	CS
CD	2.43	1.14	1.40	1.40	2.43	2.43	2.43	1.98	1.98	1.98
SE	0.62	0.41	0.50	0.50	0.86	0.86	0.86	0.70	0.70	0.70

Table 114B. Main effects of treatments and two factor interactions on available N content (kg ha $^{-1}$) of sub surface soil of sesamum, green gram and cowpea

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	174.61	175.94	175.86	175.75	175.02	175.70	175.49
C_1	184.46	187.40	187.12	185.30	186.85	186.83	186.33

	A_0	A_1	A_2	Mean
F_0	177.65	179.89	181.15	179.57
F_1	182.59	181.24	181.16	181.67
F_2	181.33	181.67	181.47	181.49
Mean	180.53	180.94	181.26	

	C_0	C_1	F_0	F_1	F_2	A_0	A_1	A_2	Mean	
S_0	175.55	185.15	178.5	180.50	182.03	179.99	180.48	180.59	180.36	
S_1	175.56	189.07	182.5	183.26	181.17	182.26	182.27	182.41	182.32	
S_2	175.34	184.75	177.63	181.23	181.26	179.31	180.05	180.77	180.05	
	S	C	F	A	SF	SA	FA	CF	CA	CS
CD	NS	0.87	1.06	NS	1.84	1.84	1.84	1.50	1.50	1.50
SE	0.63	0.31	0.38	0.38	0.65	0.65	0.65	0.53	0.53	0.53

In the sub surface soils of sesamum plots the treatments $C_0F_0A_0$ showed the lowest available N content of 171.58 kg ha^{-1} and the treatment $C_1F_1A_1$ showed the highest available N content of 187.93 kg ha^{-1} (Table 113).The available N content of green gram plots ranged from 173.60 kg ha^{-1} ($C_0F_2A_2$) to 192.04 KG ha^{-1} ($C_1F_1A_0$) (Table 113). The cowpea plots recorded an available N content ranging from 172.40 kg ha^{-1} ($C_0F_1A_1$) to 189.63 kg ha^{-1} ($C_1F_1A_2$) (Table 113). The green gram plots showed higher available N content than sesamum and cowpea plots which were on par (Table 114B). The C_1 plots showed significantly higher available N content than C_0 plots. The F_1 and F_2 plots showed significantly higher available N content than F_0 plots. The A_2 plots showed higher available N content than A_1 and A_0 plots.

4.3.3.4. Available P

In the surface soils of sesamum plots the treatment $C_1F_1A_2$ recorded the highest available P content of 45.98 kg ha^{-1} and the treatment $C_0F_0A_0$ recorded the lowest available P content of 31.53 kg ha^{-1}(Table 115). The green gram plots recorded an available P content ranging from 31.94 kg ha^{-1} ($C_0F_1A_2$) to 45.73 kg ha^{-1} ($C_1F_2A_2$) (Table 115). The cowpea plots recorded an available P content ranging from 26.94 kg ha^{-1} ($C_0F_0A_0$) to 44.29 kg ha^{-1} ($C_1F_1A_0$) (Table 115). The sesamum plots recorded significantly highest available P content than green gram and cowpea plots, which were on par (Table 116A).The C_1 plots recorded significantly higher available P content than C_0 plots. The F_2 plots recorded the significantly higher available P content followed by F_1 plots and the least by F_0 plots. The A_2 plots recorded significantly higher available P content than A_1 and A_0 plots.

The available P content of sub surface soil of sesamum plots ranged from 34.33 kg

Table 115. Effect of treatments on available P content of soil (kg ha $^{-1}$)

	Surface soil			Subsurface soil		
Treatment	Sesamum	Greengram	Cowpea	Sesamum	Greengram	Cowpea
$C_0F_0A_0$	31.53	33.88	26.94	34.33	34.07	35.04
$C_0F_0A_1$	32.84	32.07	31.38	35.05	34.90	34.85
$C_0F_0A_2$	33.08	33.13	32.29	35.60	34.16	33.44
$C_0F_1A_0$	33.58	33.00	33.08	37.93	36.33	33.81
$C_0F_1A_1$	32.21	32.47	31.15	38.57	38.31	35.21
$C_0F_1A_2$	36.16	31.94	32.95	39.43	39.27	33.87
$C_0F_2A_0$	36.97	32.24	32.88	36.88	37.62	37.47
$C_0F_2A_1$	36.67	34.95	33.63	36.76	36.80	35.86
$C_0F_2A_2$	35.24	34.87	34.19	38.79	39.37	38.01
$C_1F_0A_0$	37.96	39.51	37.82	40.74	41.57	40.70
$C_1F_0A_1$	40.15	40.16	42.22	46.34	44.65	46.07
$C_1F_0A_2$	42.08	40.90	42.26	48.29	43.99	43.66
$C_1F_1A_0$	44.52	42.65	44.29	48.08	45.01	43.36
$C_1F_1A_1$	45.12	42.05	42.86	47.05	46.66	46.84
$C_1F_1A_2$	45.98	43.20	43.41	47.44	47.63	47.35
$C_1F_2A_0$	45.52	42.93	41.35	47.78	47.35	49.28
$C_1F_2A_1$	43.60	43.02	43.04	48.50	45.28	45.73
$C_1F_2A_2$	45.33	45.73	42.94	47.75	47.10	46.12
CD	1.34	1.34	1.34	0.62	0.62	0.62
SE	1.22	1.22	1.22	0.99	0.99	0.99

Table 116A. Main effects of treatments and two factor interactions on available P content (kg ha $^{-1}$) of surface soil of sesamum, green gram and cowpea

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	31.90	32.94	34.73	32.78	33.04	33.76	33.19
C_1	40.34	43.78	43.71	41.84	42.47	43.53	42.62

	A_0	A_1	A_2	Mean
F_0	34.61	36.47	37.29	36.12
F_1	38.52	37.64	38.94	38.37
F_2	38.82	39.15	39.72	39.22
Mean	37.31	37.75	38.64	

	C_0	C_1	F_0	F_1	F_2	A_0	A_1	A_2	Mean	
S_0	34.25	43.36	36.27	39.59	40.55	38.35	38.43	39.65	38.81	
S_1	33.28	42.24	36.61	37.55	39.12	37.53	37.45	38.29	37.62	
S_2	32.05	42.24	35.48	37.96	38.06	36.06	37.37	38.00	37.15	
	S	C	F	A	SF	SA	FA	CF	CA	CS
CD	1.34	0.66	0.81	0.81	1.41	1.41	1.41	1.15	1.15	1.15
SE	0.34	0.24	0.29	0.29	0.50	0.50	0.50	0.41	0.41	0.41

Table 116B. Main effects of treatments and two factor interactions on available P content (kg ha $^{-1}$) of sub surface soil of sesamum, green gram and cowpea

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	34.60	36.96	37.47	35.94	36.22	36.88	36.34
C_1	43.93	46.60	47.21	44.87	46.34	46.52	45.91

	A_0	A_1	A_2	Mean
F_0	37.74	40.31	39.76	39.27
F_1	40.75	42.11	42.50	41.78
F_2	42.73	41.44	42.86	42.34
Mean	40.41	41.28	41.70	

	C_0	C_1	F_0	F_1	F_2	A_0	A_1	A_2	Mean	
S_0	37.06	46.88	40.05	43.08	42.74	40.96	42.04	42.88	41.96	
S_1	36.72	45.47	38.89	42.20	42.20	40.32	41.04	41.92	41.09	
S_2	35.28	45.39	38.86	40.07	42.07	39.94	40.76	40.30	40.34	
	S	C	F	A	SF	SA	FA	CF	CA	CS
CD	0.62	0.54	0.66	0.66	1.14	1.14	1.14	0.93	0.93	0.93
SE	0.16	0.19	0.23	0.23	0.40	0.40	0.40	0.33	0.33	0.33

ha^{-1} ($C_0F_0A_0$) to 48.50 kg ha^{-1} ($C_1F_2A_1$) (Table 115). The green gram plots recorded an available P content ranging from 34.07 kg ha^{-1} ($C_0F_0A_0$) to 47.63 kg ha^{-1} ($C_1F_1A_2$) (Table 115).The cowpea plots recorded an available P content ranging from 33.44 kg ha^{-1} ($C_0F_0A_2$) to 49.28 kg ha^{-1} ($C_1F_2A_0$) (Table 115).The sesamum and green gram plots recorded significantly higher available P content followed the cowpea plots (Table 116B). The C_1 plots showed significantly higher available P content than C_0 plots. The F_2 plots recorded significantly higher available P content followed by F_1 plot and the least by F_0 plot. The A_2 and A_1 plots were on par and showed significantly higher P content than A_0 plots.

4.3.3.5. Available K

In the surface soils of sesamum plots the treatment $C_1F_2A_2$ recorded the highest available K content of 74.15 kg ha^{-1} and the treatment $C_0F_0A_2$ and $C_0F_0A_1$ recorded the lowest available K content of 48.37 kg ha^{-1} (Table 117). The green gram plots recorded an available K content ranging from 69.85 kg ha^{-1} ($C_1F_1A_1$) to 48.23 kg ha^{-1} ($C_0F_1A_0$) (Table 117). The cowpea plots recorded available K content ranging from 45.78 kg ha^{-1} ($C_0F_1A_0$) to 71.96 kg ha$^{-1(}$ ($C_1F_2A_1$) (Table 117). The sesamum plots recorded significantly highest available K content than green gram and cowpea plots, which were on par (Table 118A). The C_1 plots recorded significantly higher available K content than C_0 plots. The F_2 plots recorded significantly higher available K content followed by F_1 plots and the least by F_0 plots. The A_2 plots recorded significantly higher available K content than A_1 and A_0 plots

The available K content of sub surface soil of sesamum plots ranged from 58.45 kg ha^{-1} ($C_0F_0A_0$) to 69.22 kg ha^{-1} ($C_1F_2A_2$) (Table 117). The green gram plots recorded the highest available K content of 69.79 kg ha^{-1} ($C_1F_2A_2$) to 58.72 kg ha^{-1} (C_0F_2 A_2)

Table 117. Effect of treatments on available K content of soil (kg ha $^{-1}$)

	Surface soil			Subsurface soil		
Treatment	**Sesamum**	**Greengram**	**Cowpea**	**Sesamum**	**Greengram**	**Cowpea**
$C_0F_0A_0$	48.57	49.13	48.33	58.45	58.85	58.95
$C_0F_0A_1$	48.37	50.34	47.71	60.32	59.77	57.63
$C_0F_0A_2$	48.37	48.88	46.29	59.96	59.44	58.32
$C_0F_1A_0$	51.03	48.23	45.78	59.66	60.45	58.43
$C_0F_1A_1$	54.05	49.40	47.77	62.84	58.75	59.71
$C_0F_1A_2$	51.49	52.18	49.57	62.75	60.57	60.36
$C_0F_2A_0$	62.64	54.66	51.76	61.50	60.39	60.36
$C_0 F_2A_1$	61.18	53.87	50.98	62.80	60.49	60.50
$C_0F_2A_2$	65.05	53.08	52.28	61.30	58.72	58.19
$C_1F_0A_0$	67.44	68.06	62.26	65.18	63.69	63.62
$C_1F_0A_1$	69.37	67.26	64.02	64.06	64.82	63.33
$C_1F_0A_2$	71.43	67.51	66.23	69.12	62.65	62.94
$C_1F_1A_0$	70.95	69.70	65.69	66.67	64.74	64.06
$C_1F_1A_1$	69.25	69.85	67.29	67.16	65.84	63.62
$C_1F_1A_2$	69.82	68.73	71.71	69.07	65.60	64.99
$C_1F_2A_0$	72.09	68.12	69.40	68.19	66.54	65.04
$C_1F_2A_1$	71.89	68.12	71.96	67.47	68.95	68.61
$C_1F_2A_2$	74.15	69.23	68.68	69.22	69.79	70.30
CD	3.77	3.77	3.77	2.03	2.03	2.03
SE	1.72	1.72	1.72	1.36	1.36	1.36

Table 118A. Main effects of treatments and two factor interactions on available K content (kg ha $^{-1}$) of surface soil of sesamum, green gram and cowpea

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	48.44	49.84	56.17	51.12	51.51	51.98	51.52
C_1	67.06	69.22	70.40	68.19	68.78	69.71	68.89

	A_0	A_1	A_2	Mean
F_0	57.30	57.85	58.12	57.75
F_1	58.56	59.60	60.58	59.58
F_2	63.11	63.00	63.74	63.29
Mean	59.66	60.15	60.81	

	C_0	C_1	F_0	F_1	F_2	A_0	A_1	A_2	Mean	
S_0	54.52	70.70	58.92	61.04	67.83	62.11	62.35	63.38	62.62	
S_1	51.08	68.51	58.53	59.68	61.18	59.65	59.80	59.93	58.21	
S_2	48.93	67.47	55.80	57.96	60.84	57.20	58.28	59.12	58.21	
	S	C	F	A	SF	SA	FA	CF	CA	CS
CD	3.77	0.93	1.14	1.14	1.98	1.98	1.98	1.62	1.62	1.62
SE	0.96	0.33	0.41	0.41	0.70	0.70	0.70	0.57	0.57	0.57

Table 118B. Main effects of treatments and two factor interactions on available K content (kg ha $^{-1}$) of sub surface soil of sesamum, green gram and cowpea

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	48.44	49.94	56.15	51.12	51.52	51.91	59.98
C_1	67.06	69.22	70.40	68.19	68.78	68.71	66.12

	A_0	A_1	A_2	Mean
F_0	61.46	61.65	62.07	61.73
F_1	62.33	62.99	63.89	63.07
F_2	63.67	64.81	64.59	64.35
Mean	62.49	63.15	63.52	

	C_0	C_1	F_0	F_1	F_2	A_0	A_1	A_2	Mean	
S_0	54.53	70.70	58.92	61.09	67.82	62.11	62.35	63.38	64.21	
S_1	51.08	68.51	58.52	59.68	61.18	59.65	59.80	59.94	62.78	
S_2	48.93	67.47	55.80	57.96	60.84	57.20	58.28	59.12	62.06	
	S	C	F	A	SF	SA	FA	CF	CA	CS
CD	2.03	0.73	0.90	0.90	1.56	1.56	1.56	1.27	1.27	1.27
SE	0.52	0.26	0.32	0.32	0.55	0.55	0.55	0.45	0.45	0.45

(Table 117). The cowpea plots recorded an available K content ranging from 57.63 $kgha^{-1}$ ($C_0 F_0 A_1$) to 70.30 kg ha^{-1} ($C_1F_2A_2$) (Table 117). The sesamum plots recorded significantly higher available K content followed by the green gram plots and the least by the cowpea plots. (Table 118B). The C_1 plots showed significantly higher available K content than C_0 plot. The F_2 plots recorded significantly higher available K content followed by F_1 plot and the least by F_0 plot. The A_2 and A_1 plots were on par and showed significantly higher K content than A_0 plot.

4.3.3.6. Exchangeable Ca

The surface soils of sesamum plots recorded a higher exchangeable Ca content of 1.64 c mol kg $^{-1}$ and a lowest of 1.57 c mol kg $^{-1}$ (Table 119). The exchangeable Ca content of the green gram plot ranged from 1.58 c mol kg $^{-1}$ to 1.62 c mol kg $^{-1}$ (Table 1119) . The cowpea plots recorded a exchangeable Ca content ranging from 1.57 c mol kg $^{-1}$ to 1.63 c mol kg $^{-1}$ (Table 119). The green gram and cowpea plots were on par and recorded significantly higher exchangeable Ca content than sesamum plots (Table 120A). The C_1 plots recorded significantly lower exchangeable Ca content than C_0 plots. The F_0 plots recorded significantly higher exchangeable Ca content than F_1 and F_2 plots. The A_1 and A_0 plots recorded significantly higher exchangeable Ca content than A_2 plots.

The sub surface soils of sesamum plots recorded an exchangeable Ca content ranging from 1.60 c mol kg $^{-1}$ ($C_0F_0A_0$) to 1.73 c mol kg $^{-1}$ ($C_0F_2A_1$ and $C_0F_1A_2$) (Table 119). The green gram plots recorded a highest exchangeable Ca content of 1.66 c mol kg $^{-1}$ and a lowest exchangeable Ca content of 1.59 c mol kg $^{-1}$ (Table 119). The exchangeable

Table 119. Effect of treatments on exchangeable Ca content of soil (c mol kg $^{-1}$)

	Surface soil			Subsurface soil		
Treatment	Sesamum	Greengram	Cowpea	Sesamum	Greengram	Cowpea
$C_0F_0A_0$	1.06	1.59	1.58	1.60	1.59	1.59
$C_0F_0A_1$	1.61	1.60	1.61	1.62	1.59	1.61
$C_0F_0A_2$	1.59	1.60	1.61	1.66	1.60	1.61
$C_0F_1A_0$	1.58	1.61	1.61	1.68	1.60	1.60
$C_0F_1A_1$	1.60	1.58	1.58	1.70	1.61	1.60
$C_0F_1A_2$	1.62	1.58	1.57	1.73	1.61	1.61
$C_0F_2A_0$	1.59	1.59	1.60	1.67	1.59	1.59
$C_0F_2A_1$	1.64	1.60	1.58	1.73	1.59	1.59
$C_0F_2A_2$	1.60	1.59	1.59	1.65	1.59	1.59
$C_1F_0A_0$	1.60	1.61	1.58	1.62	1.61	1.61
$C_1F_0A_1$	1.57	1.61	1.61	1.58	1.61	1.64
$C_1F_0A_2$	1.57	1.62	1.61	1.59	1.61	1.64
$C_1F_1A_0$	1.58	1.62	1.63	1.60	1.64	1.64
$C_1F_1A_1$	1.57	1.60	1.63	1.68	1.66	1.65
$C_1F_1A_2$	1.58	1.59	1.58	1.69	1.66	1.65
$C_1F_2A_0$	1.58	1.59	1.60	1.70	1.65	1.64
$C_1F_2A_1$	1.59	1.58	1.57	1.70	1.65	1.65
$C_1F_2A_2$	1.59	1.57	1.58	1.69	1.65	1.66
CD	0.009	0.009	0.009	0.079	0.079	0.079
SE	0.01	0.01	0.01	0.02	0.02	0.02

Table 120A. Main effects of treatments and two factor interactions on exchangeable Ca content of (c mol kg^{-1}) of surface soil of sesamum, green gram and cowpea

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	1.60	1.59	1.60	1.59	1.59	1.60	1.60
C_1	1.59	1.59	1.58	1.60	1.59	1.59	1.59

	A_0	A_1	A_2	Mean
F_0	1.59	1.60	1.60	1.60
F_1	1.61	1.59	1.59	1.59
F_2	1.59	1.59	1.58	1.59
Mean	1.60	1.60	1.59	

	C_0	C_1	F_0	F_1	F_2	A_0	A_1	A_2	Mean	
S_0	1.60	1.58	1.59	1.59	1.60	1.59	1.59	1.59	1.59	
S_1	1.59	1.60	1.60	1.60	1.59	1.60	1.59	1.59	1.60	
S_2	1.59	1.59	1.60	1.60	1.58	1.60	1.59	1.59	1.60	
	S	C	F	A	SF	SA	FA	CF	CA	CS
CD	0.009	0.006	0.008	0.008	0.01	0.01	0.01	0.01	0.01	0.01
SE	0.002	0.002	0.003	0.003	0.005	0.005	0.005	0.004	0.004	0.004

Table 120B. Main effects of treatments and two factor interactions on exchangeable Ca of (c mol kg^{-1}) of sub surface soil of sesamum, green gram and cowpea

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	1.60	1.62	1.65	1.61	1.63	1.65	1.62
C_1	1.64	1.61	1.67	1.63	1.64	1.65	1.64

	A_0	A_1	A_2	Mean
F_0	1.60	1.61	1.62	1.61
F_1	1.63	1.65	1.66	1.65
F_2	1.64	1.65	1.64	1.64
Mean	1.62	1.64	1.64	

	C_0	C_1	F_0	F_1	F_2	A_0	A_1	A_2	Mean	
S_0	1.67	1.64	1.61	1.60	1.61	1.65	1.61	1.61	1.66	
S_1	1.65	1.60	1.68	1.63	1.63	1.67	1.62	1.63	1.62	
S_2	1.60	1.64	1.69	1.62	1.62	1.67	1.62	1.63	1.62	
	S	C	F	A	SF	SA	FA	CF	CA	CS
CD	NS	0.01	0.02	0.02	0.03	0.03	0.03	0.02	0.02	0.02
SE	0.002	0.005	0.006	0.006	0.01	0.01	0.01	0.008	0.008	0.008

Ca content of cowpea plots ranged from 1.59 c mol kg $^{-1}$ to 1.66 c mol kg $^{-1}$ (Table 119). The cowpea plots showed significantly higher exchangeable Ca content followed by green gram plots and the least by sesamum plots (Table 120B). The C_1 plots recorded significantly higher exchangeable Ca content than C_0 plots. The F_1 and F_2 plots recorded significantly higher exchangeable Ca content than F_0 plots. The A_1 and A_2 plots recorded significantly higher exchangeable Ca content than A_0 plots.

4.3.3.7. Exchangeable Mg

The exchangeable Mg content of the surface soils of the sesamum plots ranged from 1.40 c mol kg $^{-1}$ ($C_0F_0A_2$) to 1.53 c mol kg $^{-1}$($C_1F_0A_0$) (Table 121). The green gram plots recorded an exchangeable Mg content ranging from 1.39 c mol kg $^{-1}$ ($C_0F_0A_0$) to 1.51 c mol kg $^{-1}$ ($C_1F_0A_1$) (Table 121). The cowpea plots recorded exchangeable Mg content ranging from 1.37 c mol kg $^{-1}$ ($C_0F_0A_1$) to 1.53 c mol kg $^{-1}$ ($C_0F_1A_2$) (Table 121). The cowpea plots recorded higher exchangeable Mg content than sesamum and green gram plots (Table 122A). The C_1 plots recorded a significantly higher exchangeable Mg content than C_0 plots. The F_2 plots showed significantly higher exchangeable Mg content than F_1 and F_0 plots . The A_2 plots recorded significantly higher exchangeable Mg content than A_1 plots and A_0 plots.

The exchangeable Mg content of sub surface soils of sesamum plots ranged from 1.33 c mol kg $^{-1}$ ($C_0F_1A_2$ and $C_1F_1A_0$) to 1.40 c mol kg $^{-1}$ ($C_1F_2A_0$) (Table 121). The green gram plots recorded an exchangeable Mg content ranging from 1.37 c mol kg $^{-1}$ ($C_1F_1A_0$) to 1.42 c mol kg $^{-1}$ ($C_1F_2A_0$) (Table 121). The cowpea plots recorded an exchangeable Mg content ranging from 1.37 c mol kg $^{-1}$ ($C_1F_2A_0$) to 1.43 c mol kg $^{-1}$ ($C_1F_0A_0$ and $C_1F_1A_2$)

Table 121. Effect of treatments on exchangeable Mg content of soil (c mol kg^{-1})

	Surface soil			Subsurface soil		
Treatment	**Sesamum**	**Greengram**	**Cowpea**	**Sesamum**	**Greengram**	**Cowpea**
$C_0F_0A_0$	1.41	1.39	1.39	1.34	1.39	1.40
$C_0F_0A_1$	1.42	1.40	1.37	1.34	1.38	1.38
$C_0F_0A_2$	1.40	1.41	1.41	1.36	1.39	1.40
$C_0F_1A_0$	1.45	1.41	1.37	1.36	1.39	1.39
$C_0F_1A_1$	1.45	1.45	1.43	1.36	1.39	1.39
$C_0F_1A_2$	1.41	1.48	1.53	1.33	1.39	1.39
$C_0F_2A_0$	1.42	1.49	1.52	1.35	1.41	1.40
$C_0F_2A_1$	1.48	1.50	1.49	1.34	1.41	1.40
$C_0F_2A_2$	1.51	1.50	1.52	1.35	1.40	1.40
$C_1F_0A_0$	1.53	1.48	1.49	1.34	1.38	1.43
$C_1F_0A_1$	1.49	1.51	1.51	1.35	1.38	1.41
$C_1F_0A_2$	1.44	1.47	1.48	1.37	1.39	1.42
$C_1F_1A_0$	1.44	1.45	1.47	1.33	1.37	1.39
$C_1F_1A_1$	1.45	1.43	1.47	1.34	1.38	1.41
$C_1F_1A_2$	1.50	1.45	1.48	1.35	1.41	1.43
$C_1F_2A_0$	1.42	1.46	1.51	1.40	1.42	1.37
$C_1F_2A_1$	1.43	1.49	1.52	1.34	1.40	1.40
$C_1F_2A_2$	1.43	1.48	1.52	1.34	1.38	1.38
CD	0.047	0.047	0.047	0.021	0.021	0.021
SE	0.022	0.022	0.022	0.013	0.013	0.013

Table 122A. Main effects of treatments and two factor interactions on exchangeable Mg content (c mol kg^{-1}) of surface soil of sesamum, green gram and cowpea

	C_0	C_1	F_0	F_1	F_2	A_0	A_1	A_2	Mean	
S_0	1.44	1.46	1.45	1.45	1.45	1.45	1.45	1.45	1.45	
S_1	1.45	1.47	1.44	1.44	1.49	1.45	1.46	1.46	1.46	
S_2	1.45	1.49	1.44	1.46	1.51	1.46	1.46	1.48	1.47	
	S	C	F	A	SF	SA	FA	CF	CA	CS
CD	NS	0.01	0.02	0.02	0.03	0.03	0.03	0.02	0.02	0.02
SE	0.01	0.004	0.005	0.005	0.009	0.009	0.009	0.007	0.007	0.007

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	1.40	1.44	1.49	1.43	1.44	1.44	1.44
C_1	1.49	1.46	1.47	1.47	1.48	1.47	1.47

	A_0	A_1	A_2	Mean
F_0	1.45	1.45	1.45	1.45
F_1	1.43	1.44	1.47	1.45
F_2	1.47	1.48	1.47	1.48
Mean	1.45	1.46	1.47	

Table 122B. Main effects of treatments and two factor interactions on exchangeable Mg content (c mol kg^{-1}) of sub surface soil of sesamum, green gram and cowpea

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	1.38	1.38	1.38	1.38	1.38	1.38	1.38
C_1	1.38	1..38	1.37	1.37	1.38	1.38	1.38

	A_0	A_1	A_2	Mean
F_0	1.38	1.37	1.39	1.38
F_1	1.37	1.38	1.38	1.38
F_2	1.38	1.38	1.38	1.38
Mean	1.38	1.38	1.38	

	C_0	C_1	F_0	F_1	F_2	A_0	A_1	A_2	Mean	
S_0	1.34	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	
S_1	1.39	1.38	1.38	1.38	1.39	1.38	1.39	1.39	1.39	
S_2	1.39	1.40	1.40	1.40	1.39	1.40	1.40	1.40	1.40	
	S	C	F	A	SF	SA	FA	CF	CA	CS
CD	0.02	NS	NS	NS	0.01	0.01	0.01	NS	NS	NS
SE	0.005	0.002	0.003	0.003	0.005	0.005	0.005	0.004	0.004	0.004

(Table 121). The main effects of treatments except C, F and A were not significant. The cowpea plots recorded significantly higher exchangeable Mg content followed by green gram plots and the least by sesamum plots. (Table 122B)

4.4. Sesamum

4.4.1 Effect of treatments on biometric observations

4.4.1.1 Leaf area index

The leaf area index at 30 days after sowing ranged from 1.18 to 1.27 (Table 123). The main effects of C, F and A significantly influenced the leaf area index (Table 124). The leaf area index was significantly higher in F_2 plots compared to F_0 and F_1 plots. The F_1 plots recorded significantly higher leaf area index than F_0 plot. The A_0 and A_1 plots were on par and recorded significantly lower leaf area index than A_2 plots .

The leaf area index at 60 days after sowing ranged from 1.85 to 2.00 (Table 123). The main effect of C, F and A significantly influenced the leaf area index (Table 125). The C_1 plots recorded significantly higher leaf area index than C_0 plots. The F_2 plot recorded significantly higher leaf area under than F_0 and F_1 plots and the F_1 plot recorded significantly higher leaf area index than F_0 plot. The A_2 and A_1 plots were on par and recorded significantly higher leaf area index than A_0 plots.

The leaf area index at harvest ranged from 1.73 to 1.87 (Table 123). There was significant difference among treatments in leaf area index at harvest. The treatments $C_1F_2A_2$,$C_1F_2A_0$ and $C_1F_2A_1$ recorded the highest leaf area index of 1.87 and the treatments $C_0F_0A_0$, $C_0F_0A_1$ and $C_0F_0A_2$ recorded the least leaf area index of 1.73. The main effect of C and F significantly influenced the leaf area index at harvest (Table 126). The leaf area

Table 123. Effect of treatments on leaf area index at 30 days after sowing, 60 days after sowing and harvest of sesamum.

Treatment	30 days after sowing	60 days after sowing	Harvest
$C_0F_0A_0$	1.18	1.85	1.73
$C_0F_0A_1$	1.19	1.87	1.73
$C_0F_0A_2$	1.19	1.86	1.73
$C_0F_1A_0$	1.20	1.86	1.75
$C_0F_1A_1$	1.20	1.89	1.75
$C_0F_1A_2$	1.20	1.90	1.76
$C_0F_2A_0$	1.20	190	1.77
$C_0F_2A_1$	1.21	1.89	1.79
$C_0F_2A_2$	1.21	1.92	1.82
$C_1F_0A_0$	1.22	1.95	1.81
$C_1F_0A_1$	1.22	1.96	1.81
$C_1F_1A_2$	1.25	1.97	1.82
$C_1F_0A_0$	1.25	1.97	1.83
$C_1F_1A_1$	1.23	2.00	1.84
$C_1F_1A_2$	1.26	1.99	1.87
$C_1F_2A_0$	1.27	1.99	1.87
$C_1F_2A_1$	1.27	2.00	1.87
$C_1F_2A_2$	1.27	1.99	1.85
CD	NS	NS	0.003
SE	0.005	0.01	0.01

Table 124. Main effect of treatments and two factor interactions on leaf area index at 30 days after sowing of sesamum

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	1.19	1.20	1.21	1.19	1.20	1.20	1.20
C_1	1.23	1.25	1.27	1.25	1.24	1.26	1.25
	A_0	A_1	A_2	Mean	CD SE		CD SE
F_0	1.20	1.21	1.22	1.21	C 0.01 0.001	CF	0.01 0.003
F_1	1.23	1.21	1.23	1.22	F 0.01 0.002	CA	0.01 0.003
F_2	1.24	1.24	1.24	1.24	A 0.01 0.002	FA	0.01 0.004
Mean	1.22	1.22	1.23	.			

Table 125 Main effect of treatments and two factor interactions on leaf area index at 60 days after sowing of sesamum

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	1.86	1.88	1.91	1.87	1.89	1.89	1.88
C_1	1.96	1.99	2.00	1.97	1.99	1.98	1.98
	A_0	A_1	A_2	Mean	CD SE		CD SE
F_0	1.90	1.92	1.92	1.91	C 0.01 0.004	CF	0.01 0.007
F_1	1.92	1.94	1.94	1.94	F 0.01 0.01	CA	0.01 0.007
F_2	1.95	1.95	1.96	1.95	A 0.01 0.01	FA	0.01 0.009
Mean	1.92	1.94	1.94				

Table 126. Main effect of treatments and two factor interactions on leaf area index at harvest of sesamum

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	1.73	1.75	179	1.75	1.76	1.77	1.76
C_1	1.81	1.85	1.86	1.84	1.84	1.85	1.84
	A_0	A_1	A_2	Mean	CD SE		CD SE
F_0	1.77	1.77	1.78	1.79	C 0.01 0.004	CF	NS 0.007
F_1	1.79	1.82	1.82	1.80	F 0.01 0.005	CA	NS 0.007
F_2	1.82	1.83	1.84	1.83	A NS 0.005	FA	NS 0.008
Mean	1.79	1.80	1.81				

index was significantly higher in C_1 plots compared to C_0 plots. The F_2 plots recorded significantly higher leaf area index than F_0 and F_1 plots and the F_1 plot recorded significantly higher leaf area index than F_0 plots.

4.4.1.2 Time taken for 50 percent flowering

The time taken for 50 percent flowering ranged from 35.67 to 38.33 days (Table 127). The main effect of C significantly influenced the time taken for 50 percent flowering (Table 128). The C_0 plots recorded significantly more time taken for 50 percent flowering compared to C_1 plots.

4.4.1.3 Root length

The root length ranged from 16.28 to 21.05 cm (Table 129). The main effect of C and interaction effect of CF significantly influenced the root length (Table 130). The root length was significantly higher in C_0 plots compared to C_1 plots.

4.4.1.4. Root Volume

The root volume ranged from 7.92 to 10.13 cc (Table 129). There was significant difference among treatments in root volume. The treatment $C_1F_1A_1$ recorded the highest root volume of 10.13 cc and the treatment $C_0F_0A_0$ recorded the lowest root volume of 7.92 cc. The main effects of C and F significantly influenced the root volume (Table 131). The root volume was significantly higher in C_1 plots compared to C_0 plots. The F_1 and F_2 plots were on par but recorded significantly higher root volume than F_0 plot.

4.4.1.5 Root density

The root density ranged from 1.15 to 1.74 Mg m^{-3} x 10^{-6} (Table 129). The main effects of C, F and A significantly influenced the root density (Table 132). The C_1 plots recorded significantly higher root density then C_0 plots. The F_0 plots recorded significantly

Table 127. Effect of treatments on time taken for fifty percent flowering of sesamum

Treatment	50 % Flowering (days)
$C_0F_0A_0$	38.33
$C_0F_0A_1$	38.00
$C_0F_0A_2$	37.67
$C_0F_1A_0$	37.67
$C_0F_1A_1$	38.00
$C_0F_1A_2$	38.00
$C_0F_2A_0$	37.00
$C_0 F_2A_1$	38.33
$C_0F_2A_2$	37.67
$C_1F_0A_0$	37.33
$C_1F_0A_1$	37.33
$C_1F_0A_2$	36.33
$C_1F_1A_0$	36.00
$C_1F_1A_1$	36.67
$C_1F_1A_2$	36.00
$C_1F_2A_0$	36.33
$C_1F_2A_1$	36.07
$C_1F_2A_2$	35.67
CD	NS
SE	0.48

Table 128. Main effect of treatments and two factor interactions on time taken for 50 percent flowering (days) of sesamum

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	38.00	37.89	37.67	37.67	38.11	37.78	37.85
C_1	37.00	36.22	36.00	36.56	36.67	36.00	36.41
	A0	**A1**	**A2**	**Mean**	**CD SE**		**CD SE**
F_0	37.83	37.67	37.00	37.50	C 0.45 0.16		CF NS 0.27
F_1	36.83	37.33	37.00	37.06	F NS 0.20		CA NS 0.27
F_2	36.67	37.17	36.67	36.83	A NS 0.20		FA NS 0.32
Mean	37.11	37.39	36.89				

Table 129. Effect of treatments on root length, root volume, and root density of sesamum.

Treatment	Root length (cm)	Root volume (cc)	Root density (Mg m^{-3}x10^{-6})
$C_0F_0A_0$	19.47	7.92	1.15
$C_0F_0A_1$	19.10	8.55	1.15
$C_0F_0A_2$	19.78	8.63	1.18
$C_0F_1A_0$	19.89	9.23	1.21
$C_0F_1A_1$	21.01	8.58	1.19
$C_0F_1A_2$	21.05	8.72	1.22
$C_0F_2A_0$	20.84	8.83	1.21
$C_0 F_2A_1$	20.88	9.25	1.25
$C_0F_2A_2$	20.23	9.33	1.21
$C_1F_0A_0$	18.58.	9.02	1.32
$C_1F_0A_1$	17.89	9.25	1.34
$C_1F_0A_2$	17.89	9.33	1.41
$C_1F_1A_0$	18.30	9.13	1.46
$C_1F_1A_1$	17.45	10.13	1.49
$C_1F_1A_2$	16.28	9.71	1.44
$C_1F_2A_0$	17.92	9.87	1.62
$C_1F_2A_1$	17.54	9.63	1.64
$C_1F_2A_2$	17.13	9.63	1.74
CD	NS	0.62	NS
SE	0.64	0.22	0.03

Table 130. Main effect of treatments and two factor interactions on root length (cm) of sesamum

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	19.45	20.65	20.65	20.07	20.33	20.36	20.25
C_1	18.11	17.34	17.53	18.27	17.62	17.10	17.66
	A_0	A_1	A_2	Mean	CD SE	CD SE	
F_0	19.03	18.48	18.84	18.78	C 0.60 0.21	CF 1.04 0.36	
F_1	19.09	19.23	18.67	19.00	F NS 0.27	CA NS 0.36	
F_2	19.38	19.21	19.68	19.09	A NS 0.27	FA NS 0.43	
Mean	19.17	18.97	18.73				

Table 131. Main effect of treatments and two factor interactions on root volume (cc) of sesamum

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	8.37	8.85	9.14	8.66	8.80	8.89	8.78
C_1	9.20	9.66	9.70	9.34	9.67	9.57	9.53
	A_0	A_1	A_2	Mean	CD SE	CD SE	
F_0	8.47	8.90	8.98	8.78	C 0.21 0.007	CF NS 0.13	
F_1	9.18	9.36	9.22	9.25	F 0.25 0.009	CA NS 0.13	
F_2	9.35	9.44	9.50	9.43	A NS 0.009	FA NS 0.15	
Mean	9.00	9.23	9.23				

Table 132. Main effect of treatments and two factor interactions on root density ($Mg\ m^{-3} x10^{-6}$) of sesamum

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	1.16	1.20	1.25	1.19	1.20	1.22	1.20
C_1	1.36	1.47	1.67	1.47	1.49	1.53	1.50
	A_0	A_1	A_2	Mean	CD SE	CD SE	
F_0	1.24	1.25	1.29	1.26	C 0.01 0.01	CF 0.05 0.02	
F_1	1.34	1.34	1.33	1.34	F 0.04 0.01	CA NS 0.02	
F_2	1.42	1.45	1.51	1.46	A 0.04 0.01	FA NS 0.02	
Mean	1.33	1.34	1.38				

lowest root density. The F_2 plots recorded significantly highest root density. The A_0 and A_1 plots were on par and the A_2 plots recorded significantly higher root density than A_0 and A_1 plots.

4.4.1.6 Seed yield

The seed yield of sesamum ranged from 320.23 to 529.79 kg ha^{-1} (Table 133). There was significant difference among treatments in seed yield. The treatment $C_0F_0A_0$ recorded the lowest seed yield of 320.23 kg ha^{-1} and the treatment $C_1F_2A_1$ recorded the highest seed yield of 529.79 kg ha^{-1}. The main effects of C, F and A significantly influenced the seed yield (Table 134). The C_1 plot recorded significantly higher seed yield than C_0 plot. The F_2 plot recorded significantly higher seed yield than F_0 plot and the F_1 plots recorded significantly higher grain yield than F_0 plot. The A_2 plot recorded significantly higher seed yield than A_0 plot.

4.4.1.7. Stover yield

The stover yield ranged from 1230.78 to 1684.37 kg ha^{-1} (Table 133). The main effect of C, F and A significantly affected the stover yield (Table 135). The stover yieldwas significantly higher in C_1 plots compared to C_0 plots. The F_2 plots recorded significantly higher stover yield than F_0 plots. The F_0 and F_1 plots were on par and the F_1 and F_2 plots were on par. The A_2 plots recorded significantly higher stover yield than A_0 and A_1 plots and the A_1 plots recorded significantly higher stover yield than A_0 plots

4.4.1.8 Dry matter production

The dry matter production ranged from 1551.02 to 2199.47 kg ha^{-1} (Table 133). The main effect of compaction significantly influenced the dry matter production (Table 136). The C_1 plots recorded significantly higher dry matter production than C_0 plots.

Table 133. Effect of treatments on seed yield, stover yield, and dry matter production of sesamum

Treatment	Seed Yield (kg ha^{-1})	Stover Yield (kg ha^{-1})	Dry Matter Production (kg ha^{-1})
$C_0F_0A_0$	320.23	1230.78	1551.02
$C_0F_0A_1$	346.88	1246.14	1594.85
$C_0F_0A_2$	334.09	1298.30	1632.39
$C_0F_1A_0$	372.75	1283.00	1654.15
$C_0F_1A_1$	350.35	1239.73	1590.08
$C_0F_1A_2$	378.35	1296.60	1674.95
$C_0F_2A_0$	369.28	1238.72	1608.00
$C_0F_2A_1$	364.46	1251.17	1615.65
$C_0F_2A_2$	386.50	1286.80	1673.30
$C_1F_0A_0$	440.47	1595.97	2036.34
$C_1F_0A_1$	432.90	1647.08	2340.16
$C_1F_0A_2$	490.63	1647.20	2134.16
$C_1F_1A_0$	474.72	1613.55	2088.26
$C_1F_1A_1$	491.68	1646.89	2138.57
$C_1F_1A_2$	466.03	1659.41	2125.05
$C_1F_2A_0$	486.96	1658.32	2165.32
$C_1F_2A_1$	529.79	1684.37	2194.32
$C_1F_2A_2$	520.68	1678.12	2199.47
CD	32.60	NS	NS
SE	11.35	12.13	68.73

Table 134. Main effect of treatments and two factor interactions on seed yield (kg ha^{-1}) of sesamum

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	333.73	367.15	373.41	354.09	353.90	366.31	358.10
C_1	454.67	477.48	512.48	467.39	484.79	492.45	481.54
	A_0	A_1	A_2	Mean	CD	SE	CD SE
F_0	380.35	389.89	412.36	394.20	C 10.87	3.78	CF NS 6.56
F_1	423.74	421.02	422.19	422.31	F 13.31	4.64	CA NS 6.56
F_2	428.12	447.13	453.59	442.95	A 13.31	4.64	FA NS 7.87
Mean	410.74	419.34	429.38				

Table 135. Main effect of treatments and two factor interactions on stover yield (kg ha^{-1}) of sesamum

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	1258.41	1273.11	1258.90	1250.84	1245.68	1293.90	1263.47
C_1	1630.08	1639.95	1673.61	1622.62	1659.45	1661.58	1647.88
	A_0	A_1	A_2	Mean	CD	SE	CD SE
F_0	1413.38	1446.61	1472.75	1444.25	C 11.40	3.97	CF 19.74 6.88
F_1	1448.28	1443.31	1478.01	1456.53	F 13.96	4.86	CA 19.74 6.88
F_2	1448.52	1467.77	1482.46	1466.25	A 13.96	4.86	FA NS 8.25
Mean	1436.73	1452.56	1477.73				

Table136. Main effect of treatments and two factor interactions on dry matter production (kg ha^{-1}) of sesamum

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	1592.75	1639.73	1632.32	1604.39	1600.19	1660.21	1621.60
C_1	2170.22	2117.30	2186.37	2096.65	2224.35	2152.89	2157.96
	A_0	A_1	A_2	Mean	CD	SE	CD SE
F_0	1793.68	1967.51	1883.27	1881.49	C 64.55	22.49	CF NS 38.95
F_1	1871.21	1864.33	1900.00	1878.51	F NS	29.21	CA NS 38.95
F_2	1886.66	1904.99	1936.99	1909.34	A NS	29.21	FA NS 46.74
Mean	1850.52	1912.27	1906.55				

4.4.2. Effect of treatments on total nutrient content

4.4.2.1 Total N content in the plant

The total N content ranged from 0.97 to 1.34 per cent (Table 137). There was significant difference among treatments in the N content. The treatment $C_0F_0A_0$ recorded the lowest N content of 0.97 per cent and the treatment $C_1F_0A_0$ recorded the highest N content of 1.34 percent. The main effects of C and F significantly influenced the N content (Table 138). The C_1 plot recorded significantly higher N content than C_0 plot. The F_2 plots recorded significantly higher N content than F_0 and F_1 plots

4.4.2.2 Total P content in the plant

The total P content ranged from 0.18 to 0.29 percent (Table 137). The main effect of C and F significantly influenced the P content (Table 139). The C_1 plots recorded significantly higher P content than C_0 plots. The F_2 plot recorded significantly higher P content than F_0 plot. The F_0 and F_1 plots were on par and the F_1 and F_2 plots were on par.

4.4.2.3 Total K content in the plant

The total K content ranged from 0.36 to 0.58 percent (Table 137). There was significant difference among treatments in the K content. The treatment $C_1F_0A_2$ recorded the highest K content of 0.58 per cent and the treatment $C_0F_0A_0$ recorded the lowest K content of 0.36 per cent. The main effects of C and A significantly influenced the K content (Table 140). The K content was significantly higher in C_1 plots compared to C_0 plots. The A_1 and A_2 plots were on par and recorded significantly higher K content than A_0 plot.

Table 137. **Effect of treatments on total N, P, K, Ca and Mg content of sesamum**

Treatment	N (percent)	P (percent)	K (percent)	Ca (percent)	Mg (percent)
$C_0F_0A_0$	0.97	0.18	0.36	0.22	0.15
$C_0F_0A_1$	1.12	0.21	0.41	0.28	0.17
$C_0F_0A_2$	1.14	0.22	0.44	0.32	0.18
$C_0F_1A_0$	1.23	0.23	0.46	0.36	0.18
$C_0F_1A_1$	1.22	0.24	0.47	0.35	0.18
$C_0F_1A_2$	1.17	0.25	0.50	0.37	0.17
$C_0F_2A_0$	1.27	0.26	0.52	0.39	0.18
$C_0F_2A_1$	1.24	0.27	0.54	0.39	0.19
$C_0F_2A_2$	1.24	0.26	0.52	0.35	0.16
$C_1F_0A_0$	1.34	0.26	0.52	0.35	0.18
$C_1F_0A_1$	1.28	0.28	0.55	0.36	0.19
$C_1F_0A_2$	1.26	0.29	0.58	0.36	0.19
$C_1F_1A_0$	1.27	0.28	0.55	0.36	0.19
$C_1F_1A_1$	1.24	0.25	0.52	0.37	0.21
$C_1F_1A_2$	1.31	0.25	0.51	0.38	0.20
$C_1F_2A_0$	1.29	0.26	0.51	0.43	0.20
$C_1F_2A_1$	1.26	0.26	0.52	0.40	0.21
$C_1F_2A_2$	1.33	0.26	0.52	0.40	0.21
CD	0.10	NS	0.06	NS	NS
SE	0.04	0.03	0.02	0.02	0.02

Table 138. Main effect of treatments and two factor interactions on total N content (percent) of sesamum

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	1.08	1.20	1.25	1.16	1.19	1.18	1.18
C_1	1.29	1.27	1.29	1.30	1.26	1.30	1.29
	A_0	A_1	A_2	Mean	CD SE	CD SE	
F_0	1.16	1.20	1.20	1.19	C 0.03 0.01	CF 0.06 0.02	
F_1	1.25	1.23	1.24	1.24	F 0.04 0.01	CA NS 0.02	
F_2	1.28	1.25	1.28	1.27	A NS 0.01	FA NS 0.03	
Mean	1.23	1.23	1.24				

Table 139. Main effect of treatments and two factor interactions on total P content (percent) of sesamum

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	0.20	0.24	0.26	0.22	0.24	0.25	0.24
C_1	0.28	0.26	0.26	0.27	0.26	0.27	0.27
	A_0	A_1	A_2	Mean	CD SE	CD SE	
F_0	0.22	0.25	0.26	0.24	C 0.03 0.01	CF 0.05 0.02	
F_1	0.26	0.25	0.25	0.25	F 0.03 0.01	CA NS 0.02	
F_2	0.26	0.27	0.26	0.26	A NS 0.01	FA NS 0.02	
Mean	0.25	0.26	0.26				

Table 140. Main effect of treatments and two factor interactions on total K content (percent) of sesamum

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	1.52	1.54	1.57	1.51	1.56	1.56	1.54
C_1	1.59	1.59	1.60	1.59	1.59	1.60	1.60
	A_0	A_1	A_2	Mean	CD SE	CD SE	
F_0	1.50	1.58	1.59	1.56	C 0.02 0.01	CF NS 0.01	
F_1	1.56	1.57	1.57	1.57	F NS 0.01	CA NS 0.01	
F_2	1.59	1.58	1.58	1.58	A 0.02 0.01	FA 0.04 0.01	
Mean	1.55	1.58	1.58				

4.4.2.4 Total Ca content in the plant

The total Ca content ranged from 0.22 to 0.43 percent (Table 137). The main effects of C and F significantly influenced the Ca content (Table 141). The C_1 plots recorded significantly higher Ca content than C_0 plots. The F_2 plots recorded significantly higher Ca content than F_0 and F_1 plots and the F_1 plots recorded significantly higher Ca content than F_0 plots.

4.4.2.5 Total Mg content in the plant

The total Mg content ranged from 0.15 to 0.21 per cent (Table 137). The main effects of C and F significantly influenced the Mg content (Table 142). The C_1 plots recorded significantly higher Mg content than C_0 plots. The F_1 and F_2 plots were on par and recorded significantly higher Mg content than F_0 plots.

4.4.3 Effect of treatments on quality characteristics

4.4.3.1. Oil Content

The oil content of sesamum ranged from 47.54 to 51.77 percent (Table 143). The main effects of C and F significantly influenced the oil content (Table 144). The C_1 plots recorded significantly higher oil content than C_0 plots. The F_2 plots recorded significantly higher oil content than F_0 plots and F_1 plots .

4.4.3.2 Crude protein content

The crude protein content ranged from 6.02 to 8.36 percent (Table 143). There was significant difference among treatment in the crude protein content. The treatment $C_1F_0A_0$ recorded the highest crude protein content of 8.36 per cent and the treatment $C_0F_0A_0$ recorded the lowest protein content of 6.02 percent. The main effects of C and F significantly influenced the crude protein content (Table 145). The C_1 plots recorded

Table 141. Main effect of treatments and two factor interactions on total Ca content (percent) of sesamum

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	0.27	0.36	0.37	0.32	0.34	0.35	0.34
C_1	0.36	0.37	0.41	0.38	0.38	0.38	0.38
	A_0	A_1	A_2	Mean			
F_0	0.29	0.32	0.34	0.32			
F_1	0.36	0.36	0.38	0.37			
F_2	0.41	0.39	0.37	0.39			
Mean	0.35	0.36	0.36				

	CD	SE		CD	SE
C	0.02	0.01	CF	0.03	0.01
F	0.02	0.01	CA	NS	0.01
A	NS	0.01	FA	NS	0.01

Table 142. Main effect of treatments and two factor interactions on total Mg content (percent) of sesamum

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	0.17	0.18	0.18	0.17	0.18	0.17	0.18
C_1	0.19	0.20	0.21	0.19	0.20	0.20	0.20
	A_0	A_1	A_2	Mean			
F_0	0.17	0.18	0.36	0.19			
F_1	0.19	0.20	0.38	0.19			
F_2	0.19	0.20	0.36	0.19			
Mean	0.18	0.19	0.19				

	CD	SE		CD	SE
C	0.01	0.01	CF	NS	0.01
F	0.02	0.01	CA	NS	0.01
A	NS	0.01	FA	NS	0.01

significantly higher crude protein content than C_0 plots. The F_2 plots recorded significantly higher crude protein content than F_0 plots.

4.5 Green gram

4.5.1 Effect of treatments on biometric observations

4.5.1.1 Leaf area index

The leaf area index at 30 days after sowing ranged from 0.59 to 0.70 (Table 146). The main effects of treatments except A were significant (Table 147). The C_1 plots showed significantly higher leaf area index than C_2 plots. The F_1 and F_2 plots recorded significantly higher leaf area index than F_0 plots.

The leaf area index at 60 days after sowing ranged from 2.57 to 2.68 (Table 146). The main effects of treatment except the effects of A were significant (Table 147). The C_1 plots showed significantly higher leaf area index at 60 days after sowing than C_0 plots. The F_2 and F_1 plots recorded significantly higher leaf area index at 60 days after showing than F_0 plots.

The leaf area index at harvest ranged from 2.35 ($C_0F_2A_0$) to 2.58 ($C_1F_0A_1$) (Table 146). The treatment effects and main effects except that of A were significant (Table 149). The C_1 plots recorded significantly higher leaf area index at harvest than C_0 plots. The F_1 and F_2 plots showed significantly lower leaf area index at harvest than F_0 plots.

4.5.1.2 Time taken for 50 percent flowering

The time taken for 50 percent flowering ranged from 37.00 days to 39.67 days Table 150). The effect of treatments except C were not significant (Table 151). The C_1 plots showed significantly less number of days for 50 percent flowering compared to C_0 plots.

Table 143. Effect of treatments on oil and crude protein content of sesamum seeds.

Treatment	Oil content (percent)	Protein content (percent)
$C_0F_0A_0$	47.54	6.02
$C_0F_0A_1$	48.68	7.00
$C_0F_0A_2$	48.29	7.15
$C_0F_1A_0$	48.51	7.67
$C_0F_1A_1$	49.19	7.61
$C_0F_1A_2$	49.39	7.31
$C_0F_2A_0$	49.22	7.92
$C_0F_2A_1$	50.80	7.75
$C_0F_2A_2$	50.44	7.54
$C_1F_0A_0$	50.02	8.36
$C_1F_0A_1$	49.84	8.24
$C_1F_0A_2$	50.26	7.87
$C_1F_1A_0$	50.28	7.96
$C_1F_1A_1$	50.29	7.71
$C_1F_1A_2$	51.00	8.15
$C_1F_2A_0$	50.73	8.05
$C_1F_2A_1$	50.87	7.92
$C_1F_2A_2$	51.77	8.30
CD	NS	0.65
SE	0.53	0.23

Table 144. Main effect of treatments and two factor interactions on oil content (percent) of sesamum

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	48.17	49.03	50.15	48.42	49.56	49.37	49.12
C_1	50.04	50.52	50.92	50.34	50.34	50.81	50.50
	A_0	A_1	A_2	Mean	CD SE		CD SE
F_0	48.78	49.26	49.28	49.11	C 0.49 0.17		CF NS 0.30
F_1	49.39	49.74	50.20	49.78	F 0.60 0.21		CA NS 0.30
F_2	49.97	50.84	50.80	50.54	A NS 0.21		FA NS 0.36
Mean	49.38	49.95	50.09				

Table 145. Main effect of treatments and two factor interactions on crude protein content (percent) of sesamum

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	6.72	7.53	7.74	7.20	7.45	7.33	7.33
C_1	8.16	7.94	8.11	8.12	7.96	8.13	8.07
	A_0	A_1	A_2	Mean	CD SE		CD SE
F_0	7.19	7.62	7.51	7.44	C 0.22 0.08		CF 0.38 0.13
F_1	7.82	7.66	7.73	7.73	F 0.27 0.09		CA NS 0.13
F_2	7.98	7.83	7.95	7.92	A NS 0.09		FA NS 0.36
Mean	7.66	7.70	7.73				

Table 146. Effect of treatments on leaf area index at 30 days after sowing, 60 days after sowing and at harvest of green gram.

Treatment	30 days after sowing	60 days after sowing	Harvest
$C_0F_0A_0$	0.59	2.57	2.57
$C_0F_0A_1$	0.59	2.58	2.42
$C_0F_0A_2$	0.59	2.58	2.56
$C_0F_1A_0$	0.60	2.59	2.52
$C_0F_1A_1$	0.59	2.59	2.43
$C_0F_1A_2$	0.60	2.58	2.39
$C_0F_2A_0$	0.62	2.59	2.35
$C_0F_2A_1$	0.59	2.59	2.47
$C_0F_2A_2$	0.60	2.59	2.40
$C_1F_0A_0$	0.61	2.62	2.52
$C_1F_0A_1$	0.64	2.63	2.58
$C_1F_0A_2$	0.66	2.63	2.56
$C_1F_1A_0$	0.67	2.66	2.56
$C_1F_1A_1$	0.68	2.68	2.56
$C_1F_1A_2$	0.70	2.68	2.54
$C_1F_2A_0$	0.68	2.68	2.56
$C_1F_2A_1$	0.68	2.66	2.55
$C_1F_2A_2$	0.64	2.66	2.55
CD	NS	NS	0.06
SE	0.01	0.01	0.02

Table 147 .Main effect of treatments and two factor interactions on leaf area index at 30 days after sowing of green gram

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	0.59	0.60	0.60	0.60	0.59	0.60	0.60
C_1	0.65	0.68	0.69	0.67	0.67	0.67	0.67
	A_0	A_1	A_2	Mean	CD	SE	CD SE
F_0	0.61	0.62	0.62	0.62	C 0.01	0.004	CF NS 0.006
F_1	0.64	0.63	0.64	0.64	F 0.01	0.004	CA NS 0.006
F_2	0.66	0.64	0.64	0.64	A NS	0.004	FA NS 0.007
Mean	0.64	0.63	0.63				

Table 148. Main effect of treatments and two factor interactions on leaf area index at 60 days after sowing of green gram

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	2.58	2.59	2.58	2.58	2.58	2.59	2.58
C_1	2.62	2.67	2.67	2.65	2.66	2.65	2.65
	A_0	A_1	A_2	Mean	CD	SE	CD SE
F_0	2.60	2.60	2.60	2.60	C 0.01	0.003	CF 0.02 0.005
F_1	2.62	2.64	2.62	2.63	F 0.01	0.004	CA NS 0.005
F_2	2.63	2.62	2.63	2.63	A NS	0.004	FA NS 0.007
Mean	2.62	2.62	2.62				

Table 149. Main effect of treatments and two factor interactions on leaf area index at harvest of green gram

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	2.50	2.45	2.40	2.46	2.44	2.45	2.45
C_1	2.55	2.55	2.55	2.55	2.56	2.55	2.65
	A_0	A_1	A_2	Mean	CD	SE	CD SE
F_0	2.51	2.50	2.56	2.60	C 0.02	0.01	CF 0.04 0.01
F_1	2.54	2.50	2.46	2.63	F 0.03	0.01	CA NS 0.01
F_2	2.46	2.51	2.47	2.63	A NS	0.01	FA 0.04 0.02
Mean	2.62	2.62	2.62				

4.5.1.3 Root length

The root length ranged from 18.65 cm to 27.52cm (Table 152). The main effect of treatments except that of amendments were significant (Table 153). The C_1 plots showed significant higher root length than C_0 plots. The F_1 and F_2 plots recorded significantly higher root length than F_0 plots.

4.5.1.4. Root volume

The root volume ranged from 6.40 cc to 9.95 cc (Table 152). The effects of treatments except C were not significant (Table 154). The C_1 plots recorded significantly higher root volume than C_0 plots

4.5.1.5. Root density

The root density ranged from 1.19 Mg m^{-3} x 10^{-6} to 1.78 Mg m^{-3} x 10^{-6} (Table 152). The main effects of treatments were significant (Table 155). The C_1 plots recorded significantly higher root density than C_0 plots. The F_2 plots recorded significantly higher root density, followed by the F_1 plots and the least by the F_0 plots. The A_2 plots showed significantly higher root density followed by theA_1 plots and the least by A_0 plots

4.5.1.6 Seed yield

The seed yield ranged from 1196.83 kg ha^{-1} to 1250.92 kg ha^{-1} (Table 156). The effect of treatments except C were not significant (Table 157). The C_1 plots showed significantly higher seed yield than C_0 plots.

4.5.1.7 Haulm yield

The haulm yield ranged from 2222.43 kg ha^{-1} to 2395.95 kg ha^{-1} (Table 156). The main effect of C and F were significant (Table 158). The C_1 plots showed significantly

Table 150. Effect of treatments on time taken for fifty percent flowering of green gram

Treatment	50 % Flowering (days)
$C_0F_0A_0$	38.67
$C_0F_0A_1$	39.67
$C_0F_0A_2$	39.33
$C_0F_1A_0$	39.00
$C_0F_1A_1$	38.67
$C_0F_1A_2$	38.67
$C_0F_2A_0$	38.33
$C_0F_2A_1$	38.67
$C_0F_2A_2$	38.33
$C_1F_0A_0$	38.00
$C_1F_0A_1$	37.33
$C_1F_0A_2$	37.33
$C_1F_1A_0$	37.67
$C_1F_1A_1$	37.67
$C_1F_1A_2$	37.67
$C_1F_2A_0$	37.33
$C_1F_2A_1$	37.67
$C_1F_2A_2$	37.00
CD	NS
SE	0.05

Table 151. Main effect of treatments and two factor interactions on time taken for 50 percent flowering (days) of green gram

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	39.22	38.78	38.44	38.67	39.00	38.78	38.81
C_1	37.56	37.69	37.32	37.67	37.56	37.33	37.52
	A_0	A_1	A_2	Mean	**CD SE**		**CD SE**
F_0	38.33	38.50	38.33	38.39	**C** 0.38 0.02	**CF**	NS 0.03
F_1	38.33	38.17	38.17	38.22	**F** NS 0.02	**A**	NS 0.03
F_2	37.83	38.17	37.67	37.89	**A** NS 0.02	**FA**	NS 0.03
Mean	38.17	38.28	38.06				

Table 152. Effect of treatments on root length, root volume and root density of green gram

Treatment	Root length (cm)	Root volume (cc)	Root density (Mg m^{-3}x10^{-6})
$C_0F_0A_0$	18.99	6.40	1.19
$C_0F_0A_1$	19.64	6.56	1.21
$C_0F_0A_2$	19.18	6.64	1.22
$C_0F_1A_0$	19.40	6.82	1.23
$C_0F_1A_1$	20.69	7.19	1.33
$C_0F_1A_2$	20.96	6.83	1.33
$C_0F_2A_0$	21.26	7.30	1.26
$C_0F_2A_1$	19.66	7.10	1.24
$C_0F_2A_2$	18.65	7.96	1.34
$C_1F_0A_0$	20.99	9.25	1.34
$C_1F_0A_1$	22.52	8.73	1.45
$C_1F_0A_2$	24.27	9.73	1.58
$C_1F_1A_0$	24.21	9.95	1.63
$C_1F_1A_1$	24.75	9.72	1.67
$C_1F_1A_2$	25.62	9.17	1.73
$C_1F_2A_0$	26.56	8.44	1.66
$C_1F_2A_1$	27.26	8.63	1.74
$C_1F_2A_2$	27.52	8.86	1.78
CD	NS	NS	NS
SE	0.67	0.37	0.05

Table 153. Main effect of treatments and two factor interactions on root length (cm) of green gram

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	19.27	20.35	19.81	19.88	20.00	19.59	19.82
C_1	22.59	24.86	27.11	23.92	24.84	25.80	24.86
	A_0	A_1	A_2	Mean	CD SE		CD SE
F_0	19.99	21.08	21.72	20.93	C 0.63 0.22		CF 1.09 0.38
F_1	21.80	22.72	23.29	22.61	F 0.77 0.27		CA 1.09 0.38
F_2	23.91	23.46	23.08	23.48	A NS 0.27		FA NS 0.46
Mean	21.90	22.42	22.70				

Table 154. Main effect of treatments and two factor interactions on root volume (cc) of green gram

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	6.54	6.95	7.45	6.84	6.95	7.15	6.98
C_1	9.24	9.58	8.64	9.21	9.03	9.22	9.15
	A_0	A_1	A_2	Mean	CD SE		CD SE
F_0	7.83	7.65	8.19	7.89.	C 0.35 0.12		C F 0.61 0.21
F_1	8.39	8.46	7.95	8.26	F NS 0.16		CA NS 0.21
F_2	7.87	7.87	8.41	8.05	A NS 0.16		FA NS 0.25
Mean	8.03	7.99	8.18				

Table 155. Main effect of treatments and two factor interactions on root density ($Mg\ m^{-3} x10^{-6}$) of green gram

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	1.21	1.29	1.28	1.23	1.26	1.30	1.26
C_1	1.46	1.67	1.72	1.54	1.62	1.70	1.62
	A_0	A_1	A_2	Mean	CD SE		CD SE
F_0	1.27	1.33	1.40	1.33	C 0.04 0.02		CF 0.08 0.03
F_1	1.43	1.50	1.53	1.48	F 0.05 0.02		CA NS 0.03
F_2	1.46	1.49	1.56	1.50	A 0.05 0.02		FA NS 0.03
Mean	1.38	1.44	1.50				

higher haulm yield than C_0 plots. The F_1 and F_2 plots showed significantly higher haulm yield than F_0 plots.

4.5.1.8 Dry matter production

The dry matter production ranged from 3424.49 kg ha^{-1} to 3550.09 kg ha^{-1} (Table 156). The interaction effects of treatments were not significant.

4.5.2. Effect of treatments on total nutrient content

4.5.2.1 Total N content in the plant

The total N content ranged from 2.00percent ($C_0F_0A_0$) to 2.52 percent ($C_1F_0A_0$) (Table 159). The main effects and the two factor interactions were significant (Table 160). The C_1 plot recorded significantly higher N content than C_0 plots. The F_2 plots recorded significantly higher N content followed by the F_1 plots and the least by F_0 plots. The A_2 plot shower higher N content followed by the A_1 plots and the least by A_0 plots.

4.5.2.2 Total P content in the plant

The P content ranged from 0.25 percent ($C_0F_0A_0$) to 0.41 percent ($C_1F_0A_0$) (Table 159). But the main effect of treatment and two factor interactions were significant (Table 161). The C_1 plots showed significantly higher P content than C_0 plots. The F_2 plots showed significantly higher P content than F_0 and F_1 plots which were on par. The A_2 plots showed significantly higher P content than A_0 and A_1 plots which were on par.

4.5.2.3 Total K content in the plant

The total K content ranged from 1.02 percent ($C_0F_2A_0$) to 1.36 percent ($C_1F_2A_2$) (Table 159). The interaction effects and the main effects of treatments were (Table 162). The C_1 plots showed significantly higher K content than C_0 plots. The F_2 plots showed

Table 156. Effect of treatments on seed yield, haulm yield, and dry matter production of green gram

Treatment	Seed Yield (kg ha^{-1})	Haulm Yield (kg ha^{-1})	Dry Matter Production (kg ha^{-1}).
$C_0F_0A_0$	1196.83	2222.43	3685.93
$C_0F_0A_1$	1198.91	2225.38	3424.49
$C_0F_0A_2$	1200.52	2249.39	3449..79
$C_0F_1A_0$	1201.65	2255.20	3455.85
$C_0F_1A_1$	1203.56	2278.70	3482.26
$C_0F_1A_2$	1204.06	2317.25	3488.11
$C_0F_2A_0$	1199.06	2284.54	3485.38
$C_0F_2A_1$	1203.18	2313.35	3488.50
$C_0F_2A_2$	1203.58	2319.84	3488.01
$C_1F_0A_0$	1213.73	2324.65	3526.40
$C_1F_0A_1$	1213.47	2326.77	3533.56
$C_1F_0A_2$	1217.56	2395.95	3542.09
$C_1F_1A_0$	1219.38	2329.95	3546.14
$C_1F_1A_1$	1220.48	2329.25	3550.09
$C_1F_1A_2$	1219.63	2329.73	3545.53
$C_1F_2A_0$	1250.92	2324.41	3546.77
$C_1F_2A_1$	1218.09	2325.61	3543.67
$C_1F_2A_2$	1218.20	2329.45	3547.75
CD	NS	NS	NS
SE	7.98	22.56	64.22

Table157. Main effect of treatments and two factor interactions on seed yield (kg ha^{-1}) of green gram

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	1198.75	1203.09	1201.94	1199.18	1201.88	1202.72	1201.26
C_1	1214.92	1219.83	1229.07	1228.01	1217.35	1218.46	1221.27
	A_0	A_1	A_2	Mean	CD	SE	CD SE
F_0	1205.28	1206.19	1209.04	1206.84	C 7.50	2.61	CF NS 4.52
F_1	1210.52	1212.02	1211.85	1211.46	F NS	3.39	CA NS 4.52
F_2	1224.99	1210.64	1210.89	1215.51	A NS	3.39	FA NS 5.42
Mean	1313.60	1209.62	1210.59				

Table 158. Main effect of treatments and two factor interactions on haulm yield (kg ha^{-1}) of green gram

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	2232.40	2283.72	2295.95	2254.06	2274.32	2283.69	2270.69
C_1	2319.30	2350.66	2326.49	2321.51	2347.15	2327.79	2332.15
	A_0	A_1	A_2	Mean	CD	SE	CD SE
F_0	2267.89	2272.64	2287.02	2275.85	C 21.20	7.39	CF NS 12.79
F_1	2290.99	233733.	2323.25	2317.19	F 25.97	9.05	CA NS 12.79
F_2	2304.48	2322.48	2306.95	2311.22	A NS	9.05	FA NS 15.35
Mean	2287.78	2310.73	2305.74				

Table 159. **Effect of treatments on total N, P, K, Ca and Mg content of green gram**

Treatment	N (percent)	P (percent)	K (percent)	Ca (percent)	Mg (percent)
$C_0F_0A_0$	2.00	0.25	1.02	0.28	0.16
$C_0F_0A_1$	2.08	0.28	1.25	0.34	0.19
$C_0F_0A_2$	2.15	0.33	1.31	0.36	0.20
$C_0F_1A_0$	2.17	0.31	1.30	0.34	0.22
$C_0F_1A_1$	2.23	0.32	1.28	0.39	0.23
$C_0F_1A_2$	2.22	0.36	1.28	0.35	0.21
$C_0F_2A_0$	2.19	0.36	1.28	0.36	0.20
$C_0F_2A_1$	2.26	0.38	1.30	0.39	0.21
$C_0F_2A_2$	2.39	0.40	1.30	0.38	0.22
$C_1F_0A_0$	2.52	0.41	1.30	0.39	0.24
$C_1F_0A_1$	2.31	0.37	1.30	0.39	0.23
$C_1F_0A_2$	2.32	0.38	1.31	0.41	0.23
$C_1F_1A_0$	2.37	0.35	1.31	0.44	0.22
$C_1F_1A_1$	2.39	0.38	1.32	0.40	0.23
$C_1F_1A_2$	2.40	0.35	1.32	0.45	0.22
$C_1F_2A_0$	2.48	0.35	1.34	0.46	0.23
$C_1F_2A_1$	2.40	0.36	1.34	0.39	0.23
$C_1F_2A_2$	2.43	0.38	1.36	0.43	0.24
CD	0.09	NS	0.06	NS	NS
SE	0.03	0.01	0.02	0.01	0.04

Table 160. Main effect of treatments and two factor interactions on total N content (percent) of green gram

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	2.08	2.21	2.28	2.12	2.19	2.25	2.19
C_1	2.39	2.38	2.40	2.42	2.37	2.38	2.39
	A_0	A_1	A_2	Mean	CD	SE	CD SE
F_0	2.26	2.20	2.24	2.27	C 0.03	0.01	CF 0.05 0.02
F_1	2.27	2.31	2.31	2.29	F 0.04	0.01	CA 0.05 0.02
F_2	2.29	2.33	2.41	2.34	A 0.04	0.01	FA 0.06 0.02
Mean	2.27	2.28	2.32				

Table 161. Main effect of treatments and two factor interactions on total P content (percent) of green gram

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	0.29	0.33	0.38	0.31	0.33	0.36	0.33
C_1	0.39	0.36	0.37	0.38	0.37	0.37	0.37
	A_0	A_1	A_2	Mean	CD	SE	CD SE
F_0	0.33	0.32	0.36	0.34	C 0.01	0.005	CF 0.02 0.01
F_1	0.33	0.35	0.35	0.35	F 0.02	0.01	CA 0.02 0.01
F_2	0.37	0.37	0.39	0.38	A 0.02	0.01	FA 0.02 0.01
Mean	0.34	0.35	0.37				

Table 162. Main effect of treatments and two factor interactions on total K content (percent) of green gram

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	1.19	1.29	1.30	1.20	1.28	1.30	1.26
C_1	1.31	1.32	1.35	1.32	1.32	1.34	1.33
	A_0	A_1	A_2	Mean	CD	SE	CD SE
F_0	1.16	1.27	1.32	1.25	C 0.02	0.01	CF 0.04 0.01
F_1	1.30	1.30	1.30	1.30	F 0.03	0.01	CA 0.04 0.01
F_2	1.31	1.32	1.33	1.32	A 0.03	0.01	FA 0.04 0.01
Mean	1.26	1.30	1.32				

significantly higher K content followed by F_1 plots and the least by F_0 plots. The A_2 plots showed significantly higher K content than A_0 plots and A_1 and A_2 plots were on par.

4.5.2.4 Total Ca content in the plant

The Ca content ranged from 0.22 percent to 0.43 percent (Table 159). The main effects of treatments except C and the interaction effects of treatments except CA were not significant (Table 163). The C_1 plots recorded significantly higher Ca content than C_0 plots. The F_1 and F_2 plots showed higher Ca content than F_0 plots.

4.5.2.5 Total Mg content in the plant

The total Mg content ranged from 0.16 percent to 0.24 percent (Table 159). The main effects of treatment except the effect of A and the effect of two factor interactions except FA and CF were significant (Table 164). The C_1 plots showed significantly higher Mg content than C_0 plots. The F_1 and F_2 plots recorded significantly higher Mg content than F_0 plots.

4.5.3. Effect of treatments on quality characteristics

4.5.3.1. Crude protein content

The crude protein content ranged from 12.43 percent ($C_0F_0A_0$) to 15.76 percent ($C_1F_0A_0$) (Table 165). The main effect and interaction effects of treatments except A were significant. The C_1 plots recorded significantly higher crude protein content than C_0 plots. The F_1 and F_2 plots recorded significantly higher crude protein content than F_0 plots (Table 166).

Table 163. Main effect of treatments and two factor interactions on total Ca content (percent) of green gram

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	0.32	0.36	0.37	0.36	0.37	0.36	0.35
C_1	0.40	0.43	0.43	0.43	0.49	0.43	0.42
	A_0	A_1	A_2	Mean	CD SE		CD SE
F_0	0.33	0.36	0.38	0.36	C 0.01 0.005		CF NS 0.01
F_1	0.39	0.39	0.40	0.39	F 0.01 0.01		CA 0.02 0.01
F_2	0.41	0.39	0.40	0.40	A NS 0.01		FA NS 0.01
Mean	0.41	0.39	0.40				

Table 164. Main effect of treatments and two factor interactions on total Mg content (percent) of green gram

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	0.18	0.22	0.26	0.19	0.21	0.21	0.21
C_1	0.23	0.23	0.23	0.23	0.23	0.23	0.23
	A_0	A_1	A_2	Mean	CD SE		CD SE
F_0	0.20	0.21	0.21	0.21	C 0.02 0.01		CF NS 0.01
F_1	0.23	0.23	0.22	0.23	F 0.02 0.01		CA 0.02 0.01
F_2	0.22	0.22	0.23	0.23	A NS 0.01		FA NS 0.03
Mean	0.22	0.22	0.22	.			

Table 165. Effect of treatments on crude protein content of green gram

Treatment	Crude protein content (percent)
$C_0F_0A_0$	12.43
$C_0F_0A_1$	13.00
$C_0F_0A_2$	13.23
$C_0F_1A_0$	13.59
$C_0F_1A_1$	13.92
$C_0F_1A_2$	13.85
$C_0F_2A_0$	13.71
$C_0 F_2A_1$	14.13
$C_0F_2A_2$	14.96
$C_1F_0A_0$	15.76
$C_1F_0A_1$	14.46
$C_1F_0A_2$	14.52
$C_1F_1A_0$	14.79
$C_1F_1A_1$	14.90
$C_1F_1A_2$	14.98
$C_1F_2A_0$	14.88
$C_1F_2A_1$	15.08
$C_1F_2A_2$	15.19
CD	0.56
SE	0.20

Table166. Main effect of treatments and two factor interactions on crude protein content (percent) of green gram

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	12.89	3.79	14.26	13.24	13.68	14.01	13.65
C_1	14.91	14.89	15.05	15.14	14.81	14.90	14.95
	A_0	A_1	A_2	Mean	CD SE		CD SE
F_0	14.09	13.73	13.88	13.90	C 0.19 0.07		CF 0.32 0.11
F_1	14.19	14.41	14.42	14.34	F 0.23 0.08		CA 0.32 0.11
F_2	14.29	14.61	15.07	14.66	A NS 0.08		FA 0.40 0.14
Mean	14.19	14.25	14.41				

4.6. Cowpea

4.6.1. Effect of treatments on biometric observations

4.6.1.1 Leaf area index

The leaf area index at 30 days after sowing ranged from 0.89 to 1.00 (Table 167). The main effect of treatments except the effect of amendments and the two factor interactions except CF were significant (Table 168). The C_1 plots recorded significantly higher leaf area index at 30 days after sowing than C_0 plots. The F_1 and F_2 plots showed significantly higher leaf area index at 30 days after sowing than F_0 plots.

The leaf area index at 60 days after sowing ranged from 2.84 ($C_0F_1A_0$) to 3.01 ($C_1F_2A_0$) (Table 167). The main effect of treatments except the effect of amendment and the two factor interactions except CA were significant (Table 169). The C_1 plots recorded significantly higher leaf area index at 60 days after sowing than C_0 plots. The F_1 plots showed significantly higher leaf area index at 60 days after sowing than F_0 plots.

The leaf area index at harvest ranged from 2.70 to 2.88 (Table 167) .The main effect of treatments were significant (Table 170). The C_1 plots recorded significantly higher leaf area index at harvest than C_0 plots. The F_1 and F_2 plots showed significantly higher leaf area index at harvest than F_0 plots. The A_1 and A_2 plots showed significantly higher leaf area index at harvest than A_0 plots.

4.6.1.2 Time taken for 50 percent flowering

The time taken for 50 percent flowering ranged from 43 days ($C_1F_1A_1$) to 45.33 days ($C_0F_0A_0$) (Table171). However the main effect of C and the two factor interaction FA were

Table167. Effect of treatments on leaf area index at 30 days after sowing, 60 days after sowing and harvest of cowpea

Treatment	30 days after sowing	60 days after sowing	Harvest
$C_0F_0A_0$	0.90	2.88	2.70
$C_0F_0A_1$	0.91	2.90	2.71
$C_0F_0A_2$	0.89	2.85	2.71
$C_0F_1A_0$	0.91	2.84	2.75
$C_0F_1A_1$	0.92	2.90	2.75
$C_0F_1A_2$	0.93	2.89	2.76
$C_0F_2A_0$	0.93	2.85	2.77
$C_0 F_2A_1$	0.94	2.87	2.78
$C_0F_2A_2$	0.90	2.89	2.76
$C_1F_0A_0$	0.95	2.97	2.81
$C_1F_0A_1$	0.96	2.96	2.82
$C_1F_0A_2$	0.96	2.95	2.83
$C_1F_1A_0$	0.97	2.94	2.81
$C_1F_1A_1$	0.98	2.98	2.85
$C_1F_1A_2$	1.00	2.99	2.88
$C_1F_2A_0$	0.98	3.01	2.86
$C_1F_2A_1$	0.98	2.98	2.86
$C_1F_2A_2$	0.98	2.99	2.88
CD	NS	NS	NS
SE	0.007	0.02	0.01

Table 168.Main effect of treatments and two factor interactions on leaf area index at 30 days after sowing of cowpea

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	0.90	0.92	0.92	0.91	0.92	0.91	0.91
C_1	0.96	0.98	0.98	0.97	0.98	0.98	0.97
	A_0	A_1	A_2	Mean	CD SE		CD SE
F_0	0.93	0..93	0.93	0.93	C 0.01 0.002		CF NS 0.004
F_1	0.94	0.95	0.96	0.95	F 0.01 0.003		CA 0.01 0.004
F_2	0.95	0.96	0.94	0.95	A NS 0.003		FA 0.01 0.005
Mean	0.94	0.95	0.94				

Table 169. Main effect of treatments and two factor interactions on leaf area index at 60 days after sowing of cowpea

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	2.88	2.88	2.91	2.87	2.88	2.89	2.89
C_1	2.94	2.97	2.98	2.96	2.97	2.96	296.
	A_0	A_1	A_2	Mean	CD SE		CD SE
F_0	2.92	2.93	2.90	2.91	C 0.01 0.005		CF 0.02 0.009
F_1	2.92	2.95	2.95	2.94	F 0.02 0.006		CA NS 0.009
F_2	2.63	2.92	2.93	2.93	A NS 0.006		FA 0.03 0.01
Mean	2.92	2.93	2.93				

Table 170. Main effect of treatments and two factor interactions on leaf area index at harvest of cowpea

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	2.71	2.75	2.77	2.74	2.74	2.75	2.74
C_1	2.82	2.84	2.86	2.83	2.84	2.86	2.84
	A_0	A_1	A_2	Mean	CD SE		CD SE
F_0	2.76	2.76	2.77	2.76	C 0.01 0.003		CF NS 0.009
F_1	2.82	2.84	2.86	2.80	F 0.01 0.005		CA NS 0.009
F_2	2.82	2.82	2.82	2.82	A 0.01 0.005		FA NS 0.01
Mean	2.78	2.79	2.80				

significant (Table 172). The C_1 plots recorded significantly lower number of days than C_0 plots.

4.6.1.3 Root length

The root length ranged from 20.66 cm ($C_0F_0A_1$) to 31.11cm ($C_1F_2A_1$) (Table 173). The main effect of treatments except the effect of C and the effect of two factor interaction except FA were not significant (Table 174). The C_1 plots showed significantly higher root length than C_0 plots.

4.6.1.4. Root volume

The root volume ranged from 8.74 cc ($C_0F_2A_1$) to 14.24 cc ($C_1F_2A_2$) (Table 173). The main effect of treatments and the two factor interaction except FA were significant (Table 175). The C_1 plots recorded significantly higher root volume than C_0 plots. The F_1 and F_2 plots recorded significantly higher root volume than F_0 plots. The A_2 plots recorded significantly higher root volume than A_0 plots.

4.6.1.5 Root density

The root density ranged from 1.19 Mg m^{-3} x 10^{-6} ($C_0F_2A_1$) to 1.77 Mgm^{-3} x 10^{-6} ($C_1F_2A_2$) (Table 173). The main effect of treatments except the effect of C and F and the effect of two factor interactions except CF were not significant (Table 176). The C_1 plots recorded significantly higher root density than C_0 plots. The F_2 plots recorded significantly higher root density, followed by the F_1 plots and the least by the F_0 plots.

4.6.1.6 Seed yield

The seed yield ranged from 479.90 kg ha^{-1} ($C_1F_2A_2$) to 594.78 kg ha^{-1} ($C_1F_2A_1$) (Table 177). None of the treatments or their interactions were significant.

Table 171. Effect of treatments on time taken for fifty percent flowering of cowpea

Treatment	50 % Flowering (days)
$C_0F_0A_0$	45.33
$C_0F_0A_1$	45.00
$C_0F_0A_2$	44.33
$C_0F_1A_0$	44.67
$C_0F_1A_1$	44.67
$C_0F_1A_2$	44.67
$C_0F_2A_0$	44.33
$C_0F_2A_1$	45.00
$C_0F_2A_2$	43.33
$C_1F_0A_0$	43.67
$C_1F_0A_1$	43.33
$C_1F_0A_2$	44.33
$C_1F_0A_0$	44.00
$C_1F_1A_1$	43.00
$C_1F_1A_2$	44.33
$C_1F_2A_0$	43.33
$C_1F_2A_1$	44.33
$C_1F_2A_2$	43.33
CD	NS
SE	0.43

Table 172. Main effect of treatments and two factor interactions on time taken for 50 percent flowering (days) of cowpea

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	44.89	44.67	44.22	44.78	44.89	44.11	44.59
C_1	44.11	43.78	43.67	43.67	43.89	44.00	43.85
	A_0	A_1	A_2	Mean	CD SE	CD SE	
F_0	44.50	44.67	44.33	44.50	C 0.40 0.14	CF NS 0.24	
F_1	44.30	43.83	44.50	44.22	F NS 0.18	CA NS 0.24	
F_2	43.83	44.67	43.33	43.94	A NS 0.18	FA 0.85 0.30	
Mean	44.22	44.39	44.06				

Table 173. Effect of treatments on root length, root volume and root density of cowpea

Treatment	Root length (cm)	Root volume(cc)	Root density (Mg $m^{-3}x10^{-6}$)
$C_0F_0A_0$	21.12	9.18	1.21
$C_0F_0A_1$	20.66	8.79	1.22
$C_0F_0A_2$	21.11	9.31	1.23
$C_0F_1A_0$	21.85	9.66	1.26
$C_0F_1A_1$	22.90	9.63	1.29
$C_0F_1A_2$	22.68	9.05	1.22
$C_0F_2A_0$	23.57	9.20	1.23
$C_0F_2A_1$	22.11	8.74	1.19
$C_0F_2A_2$	21.96	9.45	1.23
$C_1F_0A_0$	23.99	10.87	1.39
$C_1F_0A_1$	24.46	11.14	1.43
$C_1F_0A_2$	26.13	12.53	1.37
$C_1F_1A_0$	29.21	12.41	1.54
$C_1F_1A_1$	27.54	13.19	1.53
$C_1F_1A_2$	29.16	13.73	1.65
$C_1F_2A_0$	30.47	12.44	1.68
$C_1F_2A_1$	31.11	12.40	1.66
$C_1F_2A_2$	29.33	14.24	1.77
CD	NS	NS	NS
SE	0.57	0.40	0.04

Table 174. Main effect of treatments and two factor interactions on root length (cm) of cowpea

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	20.96	22.48	22.55	22.18	21.89	21.92	22.00
C_1	24.86	28.64	30.31	27.89	27.71	28.26	27.93
F_0	22.55	22.56	23.62.	22.91	CD SE		CD SE
F_1	25.53	25.22	25.92	25.56	C 0.40 0.19		CF NS 0.33
F_2	27.02	26.61	25.65	26.43	F NS 0.23		CA NS 0.33
Mean	25.03	24.80	25.06		A NS 0.23		FA 0.85 0.40

Table 175. Main effect of treatments and two factor interactions on root volume (cc) of cowpea

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	09.09	09.45	09.13	09.34	09.05	09.27	9.22
C_1	11.51	13.13	13.03	11.92	12.24	13.50	12.56
	A_0	A_1	A_2	Mean	CD SE		CD SE
F_0	10.02	09.97	10.92	10.30	C 0.37 0.13		CF 0.65 0.22
F_1	11.06	11.41	11.39	11.29	F 0.4 0.16		CA 0.65 0.22
F_2	10.82	10.57	11.85	11.08	A 0.46 0.16		FA NS 0.27
Mean	10.63	10.65	11.39				

Table 176. Main effect of treatments and two factor interactions on root density ($Mg\ m^{-3} x10^{-6}$) of cowpea

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	1.22	1.26	1.22	1.23	1.23	1.23	1.23
C_1	1.40	1.57	1.70	1.54	1.54	1.60	1.56
	A_0	A_1	A_2	Mean	CD SE		CD SE
F_0	1.30	1.32	1.30	1.31	C 0.04 0.01		CF 0.07 0.02
F_1	1.40	1.41	1.44	1.42	F 0.05 0.02		CA NS 0.02
F_2	1.46	1.43	1.50	1.46	A NS 0.02		FA NS 0.03
Mean	1.39	1.41	1.41				

Table 177. Effect of treatments on seed yield, haulm yield, and dry matter production of cowpea

Treatment	Seed Yield (kg ha^{-1})	Haulm Yield (kg ha^{-1})	Dry Matter Production (kg ha^{-1})
$C_0F_0A_0$	512.59	1125.21	1637.80
$C_0F_0A_1$	534.19	1176.18	1698.20
$C_0F_0A_2$	545.92	1219.57	1765.22
$C_0F_1A_0$	553.15	1281.02	1834.17
$C_0F_1A_1$	558.50	1220.17	1778.67
$C_0F_1A_2$	549.80	1246.92	1796.72
$C_0F_2A_0$	564.50	1389.15	1953.73
$C_0F_2A_1$	568.96	1363.91	1932.83
$C_0F_2A_2$	561.45	1373.60	1935.19
$C_1F_0A_0$	563.77	1247.32	1811.10
$C_1F_0A_1$	519.70	1294.96	1864.67
$C_1F_0A_2$	573.82	1274.34	1848.06
$C_1F_1A_0$	585.15	1448.91	2034.31
$C_1F_1A_1$	556.83	1324.25	1881.19
$C_1F_1A_2$	569.36	1318.04	1887.58
$C_1F_2A_0$	590.43	1366.67	1949.26
$C_1F_2A_1$	594.78	1327.89	1926.20
$C_1F_2A_2$	479.90	1395.28	1975.18
CD	NS	NS	NS
SE	78.91	30.59	32.03

4.6.1.7 Haulm yield

The haulm yield ranged from 1125.21 kg ha^{-1} ($C_0F_0A_0$) to 1448.91 $kgha^{-1}$ ($C_1F_1A_0$) (Table 177). The main effect of treatments except the effect of A and the effect of two factor interaction except CA were significant. (Table 178). The C_1 plots showed significantly higher haulm yield than C_0 plots. The F_2 plot recorded significantly higher haulm yield than F_1 plots and F_0 plots.

4.6.1.8 Dry matter production

The dry matter production ranged from 1637.80 kg ha^{-1} ($C_0F_0A_0$) to 2034.31 kg ha^{-1} ($C_1F_1A_0$) (Table 177). The main effects of C and F and the interaction effect of CF and FA were significant (Table 179). The C_1 plots recorded significantly higher dry matter production than C_0 plots. The F_2 plots showed significantly higher dry matter production than F_1 and F_0 plots.

4.6.2 Effect of treatments on total nutrient content in plant

4.6.2.1 Total N content in the plant

The total N content ranged from 2.13 percent ($C_0F_0A_0$) to 3.15 percent ($C_1F_2A_2$) (Table 180). The main effects of treatments and the effect of two factor interaction CF were significant. (Table181). The C_1 plots recorded significantly higher N content than C_0 plots. The F_1 and F_2 plots showed significantly higher N content than F_0 plots. The A_1 and A_2 plots recorded significantly higher N content than A_0 plots.

4.6.2.2 Total P content in the plant

The total P content ranged from 0.31 percent ($C_0F_0A_0$) to 0.55 percent ($C_1F_1A_1$) (Table 180). The main effect of treatment except the effect of A were significant

Table 178. Main effect of treatments and two factor interactions on haulm yield (kg ha^{-1}) of cowpea

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	1173.65	1249.37	1375.55	1265.13	1253.42	1280.03	1266.19
C_1	1272.21	1363.71	1363.68	1354.30	1315.70	1329.22	1333.07
	A_0	A_1	A_2	Mean	CD SE		CD SE
F_0	1186.26	1235.57	1246.95	1222.93	C 28.73 10.01		CF 49.77 17.34
F_1	1346.96	1272.21	1282.48	1306.55	F 35.19 12.26		CA NS 17.34
F_2	1377.91	1345.90	1384.44	1369.42	A NS 12.26		FA 60.96 21.23
Mean	1309.71	1284.56	1304.62				

Table 179 Main effect of treatments and two factor interactions on dry matter production (kg ha^{-1}) of cowpea

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	1706.41	1803.14	1940.56	1808.57	1803.23	1832.38	1814.73
C_1	1841.27	1934.36	1950.21	1931.55	1890.69	1930.61	1908.62
	A_0	A_1	A_2	Mean	CD SE		CD SE
F_0	1724.45	1781.43	1806.64	1770.84	C 30.08 10.48		CF 52.10 18.15
F_1	1934.24	1829.93	1842.15	1868.77	F 36.84 12.83		CA NS 18.15
F_2	1951.49	1929.51	1955.19	1945.40	A NS 12.83		FA 63.81 22.23
Mean	1870.06	1846.96	1867.99				

Table 180. Effect of treatments on total N, P, K, Ca and Mg content of cowpea

Treatment	N (percent)	P (percent)	K (percent)	Ca (percent)	Mg(percent)
$C_0F_0A_0$	2.13	0.31	1.02	0.27	0.17
$C_0F_0A_1$	2.78	0.36	1.20	0.34	0.20
$C_0F_0A_2$	2.81	0.38	1.32	0.36	0.23
$C_0F_1A_0$	2.76	0.45	1.27	0.37	0.24
$C_0F_1A_1$	2.92	0.40	1.33	0.39	0.23
$C_0F_1A_2$	2.84	0.42	1.35	0.39	0.22
$C_0F_2A_0$	2.67	0.51	1.25	0.38	0.23
$C_0 F_2A_1$	2.67	0.44	1.30	0.44	0.23
$C_0F_2A_2$	2.76	0.41	1.22	0.40	0.23
$C_1F_0A_0$	2.77	0.40	1.31	0.37	0.22
$C_1F_0A_1$	2.83	0.45	134	0.38	0.23
$C_1F_0A_2$	2.67	0.50	1.39	0.48	0.24
$C_1F_1A_0$	2.67	0.45	1.27	0.38	0.25
$C_1F_1A_1$	2.67	0.55	1.30	0.40	0.25
$C_1F_1A_2$	2.81	0.43	1.34	0.37	0.25
$C_1F_2A_0$	2.82	0.46	1.34	0.39	0.23
$C_1F_2A_1$	3.10	0.45	142	0.43	0.24
$C_1F_2A_2$	3.15	0.52	1.48	0.41	0.23
CD	0.27	NS	NS	NS	0.04
SE	0.10	0.03	0.05	0.02	0.01

(Table182). The C_1 plots showed significantly higher P content than C_0 plots. The F_1 and F_2 plots recorded significantly higher P content than F_0 plots.

4.6.2.3 Total K content in the plant

The total K content ranged from 1.02 percent ($C_0F_0A_0$) to 1.48 percent ($C_1F_2A_2$) (Table180). The main effects of treatments except the effect of F were significant (Table 183). The C_1 plots recorded significantly higher K content than C_0 plots. The A_2 plots recorded significantly higher K content than A_1 plots and A_0 plots.

4.6.2.4 Total Ca content in the plant

The total Ca content ranged from 0.27 percent ($C_0F_0A_0$) to 0.48 percent ($C_1F_0A_2$) (Table 180). The main effects of treatments were significant (Table 184). The C_1 plots recorded significantly higher Ca content than C_0 plots. The F_2 plots showed significantly higher Ca content than F_0 plots. The A_1 and A_2 plots showed significantly higher Ca content than A_0 plots.

4.2.6.5 Total Mg content in the plant

The Mg content ranged from 0.17 percent ($C_0F_0A_0$) to 0.25 percent ($C_1F_1A_2$ and $C_1F_1A_1$) (Table 180). The main effect of treatments and the effect of two factor interactions except CA were significant (Table 185). The C_1 plots recorded significantly higher Mg than C_0 plots. The F_1 and F_2 plots showed significantly higher Mg content than F_0 plots. The A_1 and A_2 plots recorded significantly higher Mg content than A_0 plots.

4.6.3 Effect of treatments on quality characteristics

4.6.3.1 Crude protein content

The crude protein content ranged from 13.31 percent ($C_0F_0A_0$) to 19.71 percent

Table 181. Main effect of treatments and two factor interactions on total N content (percent) of cowpea

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	2.57	2.84	2.70	2.52	2.79	2.81	2.71
C_1	2.76	2.72	3.02	2.75	2.87	2.88	2.83
	A_0	A_1	A_2	Mean	CD SE		CD SE
F_0	2.45	2.80	2.74	2.67	C 0.09 0.03		CF 0.16 0.05
F_1	2.71	2.80	2.89	2.78	F 0.11 0.04		CA NS 0.05
F_2	2.75	2.89	2.96	2.86	A 0.11 0.04		FA NS 0.07
Mean	2.64	2.83	2.84				

Table 182. Main effect of treatments and two factor interactions on total P content (percent) of cowpea

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	0.35	0.43	0.45	0.42	0.40	0.40	0.41
C_1	0.45	0.48	0.47	0.43	0.48	0.48	0.47
	A_0	A_1	A_2	Mean	CD SE		CD SE
F_0	0.35	0.40	0.44	0.40	C 0.03 0.01		CF NS 0.02
F_1	0.45	0.47	0.43	0.45	F 0.04 0.01		CA NS 0.02
F_2	0.48	0.44	0.47	0.46	A NS 0.01		FA NS 0.02
Mean	0.43	0.44	0.44				

Table 183. Main effect of treatments and two factor interactions on total K content (percent) of cowpea

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	1.18	1.32	1.26	1.19	1.28	1.30	1.25
C_1	1.35	1.31	1.41	1.31	1.35	1.40	1.36
	A_0	A_1	A_2	Mean	CD SE		CD SE
F_0	1.17	1.27	1.36	1.26	C 0.02 0.02		CF 0.03 0.03
F_1	1.27	1.32	1.35	1.31	F NS 0.02		CA NS 0.03
F_2	1.31	1.36	1.35	1.34	A 0.02 0.02		FA NS 0.04
Mean	1.25	1.31	1.35				

Table 184. Main effect of treatments and two factor interactions on total Ca content (percent) of cowpea

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	0.32	0.38	0.41	0.34	0.39	0.38	0.37
C_1	0.41	0.38	0.41	0.38	0.40	0.42	0.40
	A_0	A_1	A_2	Mean	CD SE		CD SE
F_0	0.32	0.36	0.42	0.37	C 0.02 0.01		CF 0.04 0.01
F_1	0.38	0.39	0.38	0.38	F 0.03 0.01		CA NS 0.01
F_2	0.39	0.44	0.40	0.41	A 0.03 0.01		FA 0.05 0.02
Mean	0.36	0.40	0.40				

Table 185. Main effect of treatments and two factor interactions on total Mg content (percent) of cowpea

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	0.20	0.23	0.23	0.21	0.22	0.23	0.23
C_1	0.23	0.25	0.23	0.23	0.24	0.23	0.23
	A_0	A_1	A_2	Mean	CD SE		CD SE
F_0	0.20	0.22	0.24	0.22	C 0.01 0.005		CF 0.02 0.01
F_1	0.25	0.24	0.24	0.24	F 0.02 0.01		CA NS 0.01
F_2	0.23	0.23	0.23	0.23	A 0.02 0.01		FA 0.03 0.01
Mean	0.23	0.23	0.24				

($C_1F_2A_2$) (Table 186). The main effects of treatments were significant. The C_1 plots recorded significantly higher crude protein than C_0 plots (Table 187). The F_1 and F_2 plots showed significantly higher crude protein content than F_0 plots. The A_1 and A_2 plots showed higher crude protein content than A_0 plots.

Table 186. Effect of treatments on crude protein content of cowpea

Treatment	Crude protein content
$C_0F_0A_0$	13.31
$C_0F_0A_1$	17.38
$C_0F_0A_2$	17.58
$C_0F_1A_0$	17.27
$C_0F_1A_1$	18.29
$C_0F_1A_2$	17.77
$C_0F_2A_0$	16.71
$C_0F_2A_1$	16.67
$C_0F_2A_2$	16.92
$C_1F_0A_0$	17.31
$C_1F_0A_1$	17.67
$C_1F_0A_2$	16.71
$C_1F_1A_0$	16.67
$C_1F_1A_1$	16.71
$C_1F_1A_2$	17.54
$C_1F_2A_0$	17.60
$C_1F_2A_1$	19.40
$C_1F_2A_2$	19.71
CD	NS
SE	0.59

Table 187. Main effect of treatments and two factor interactions on crude protein content (percent) of cowpea

	F_0	F_1	F_2	A_0	A_1	A_2	Mean
C_0	16.09	17.77	16.77	15.77	17.44	17.42	16.88
C_1	17.23	16.97	18.90	17.19	17.93	17.99	17.70
	A_0	**A_1**	**A_2**	**Mean**	**CD SE**		**CD SE**
F_0	15.31	17.52	17.15	16.66	C 0.56 0.20		CF 0.97 0.34
F_1	16.97	17.49	17.66	17.37	F 0.69 0.24		CA NS 0.34
F_2	17.16	18.03	18.31	17.83	A 0.69 0.24		FA NS 0.41
Mean	16.48	17.68	17.71				

DISCUSSION

DISCUSSION

The nature of excessive permeability of the *Onattukara* soils result in very poor water retention capacity, very high hydraulic conductivity and infiltration rates. So whatever the nutrients and water added to these soils are not utilized by the crops and subjected to loss. Soil compaction helps to minimize these constraints to some extent. Compaction of sandy soils modified the physical and chemical properties of the soil and yield of crops. Application of locally available amendments such as coir pith and *kayal* silt helps to conserve soil moisture and improves the nutrient status. Inclusion of legumes in the cropping system of *Onattukara* tract enriches the available nitrogen status of soil through nitrogen fixation. The data collected on the above observation were statistically analyzed and the results are discussed in this chapter in the light of published information

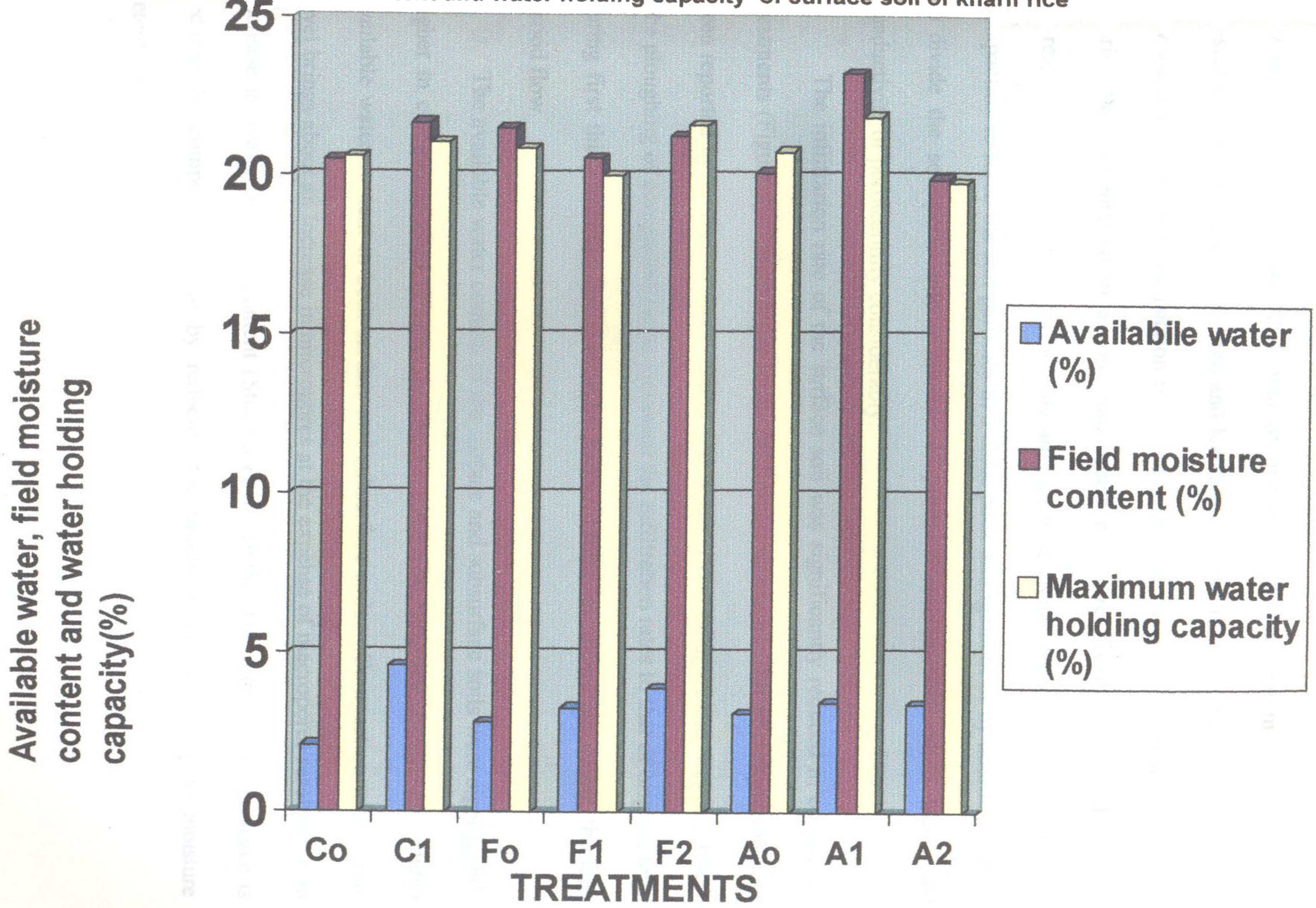
5.1. Kharif - rice

5.1:1 Effect of treatments on moisture characteristics.

Soil compaction modified the moisture characteristics of soils such as field moisture content, hydraulic conductivity, infiltration rate, available water and maximum water holding capacity.

The effect of treatments on moisture content was not significant in the surface and sub surface soils. Since the crop was harvested in standing water there was no significant difference in the field moisture content among treatments. But the A_1 plots showed significantly higher moisture content in the surface soil compared to A_2 plots (Figure 2). This result is in accordance with Rajendran (1991) who reported that the moisture content

Figure 2. Main effects of treatments on available water, field moisture content and water holding capacity of surface soil of kharif rice



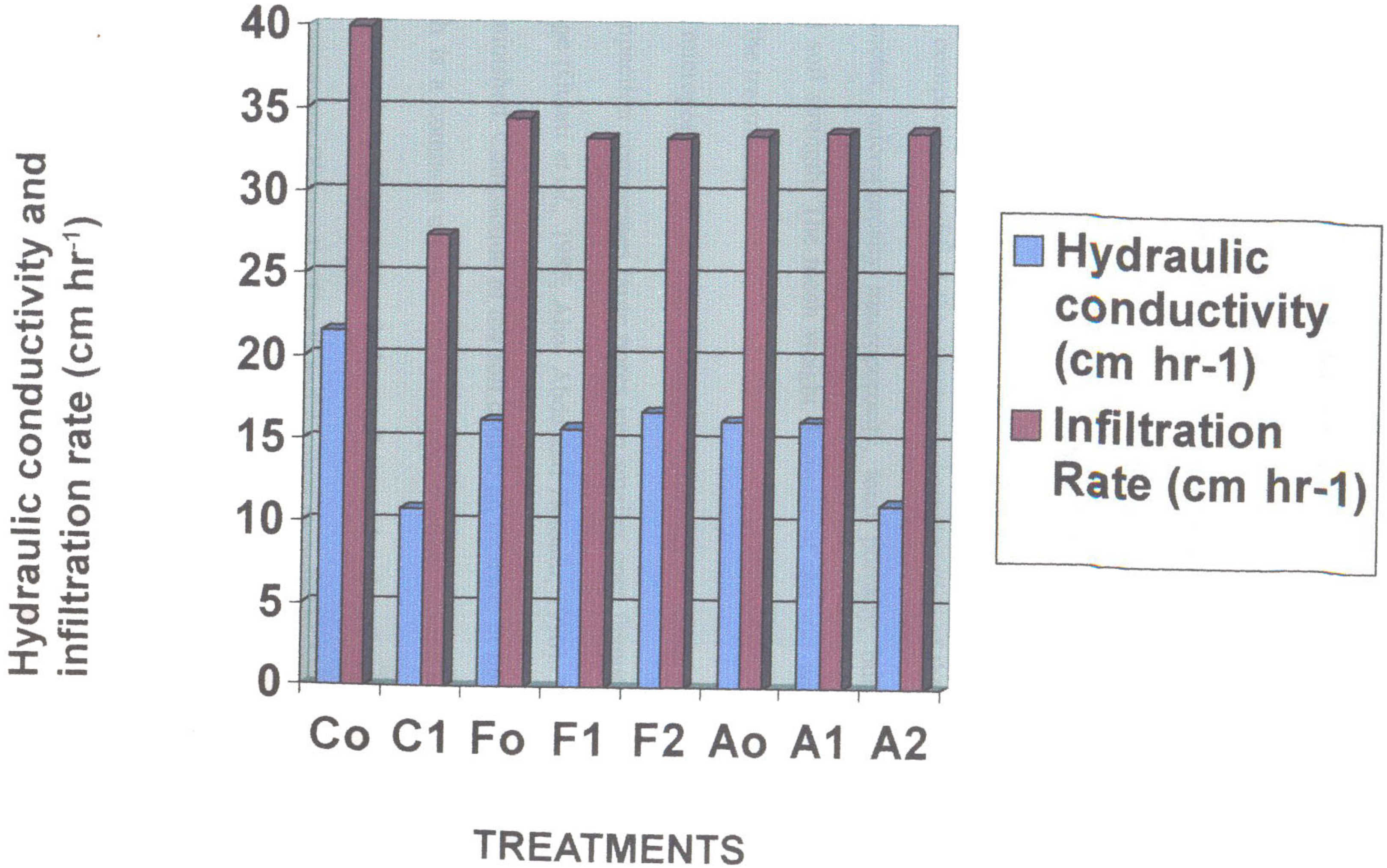
of subsoil up to 60 cm depth was consistently higher in coir waste mulch treatment in the cotton and cotton - green gram cropping system in a loamy sand .

The hydraulic conductivity of the compacted treatment was almost 50 per cent low and significantly lower than that of uncompacted treatment in the surface and subsurface soils (Figure 3). Nimmo and Katherine (1988) reported that in sandy soils at low water content, soil compaction by bringing the fine particles closer together or by altering their orientation in a way that affects pore size distribution could cause a decrease in hydraulic conductivity. Any attempt to decrease the size of pore either by compaction to force the soil particles in a close pack arrangement or by addition of clay, to divide the soil pores into a number of pores of smaller radii could reduce the conductivity or permeability considerably.

The infiltration rate of the surface soil was significantly reduced in compacted treatments (Figure 3). The changes in the infiltration rate as a result of compaction have been reported by several workers. (Patel and Singh, 1981, Douglas and Mckyes, 1982). The ploughing of compacted fields increased the infiltration rates to that of original level during first thirty minutes but essentially had no effect on infiltration during the later period flow.

The available water content of the surface and subsurface soils were significantly higher in compacted plots (Figure 2). The F_2 plots also recorded significantly higher available water content in both surface and subsurface soils. Compaction to a certain level brings about an increase in micropores at the expense of macropores resulting in an increase in available water content (Sharma *et al.* 1995). The intra aggregate space is reduced by compaction there by reducing the radius of pores leading to moisture retention.

Figure 3. Main effects of treatments on hydraulic conductivity and infiltration rate of surface soil of kharif rice



In addition to supplying the nutrients, organic matter like farmyard manure promotes soil aggregation. Under submergence however, it helps to create a reduced zone that may favour rice growth and generally increases water holding capacity of mineral soils. The farmyard manure treated plots retained higher water content at all suction values between 0 and 1000 kPa (Bhagat, 1990). The farmyard manure acts as a bridge between the cations and anions and more water retention takes place.

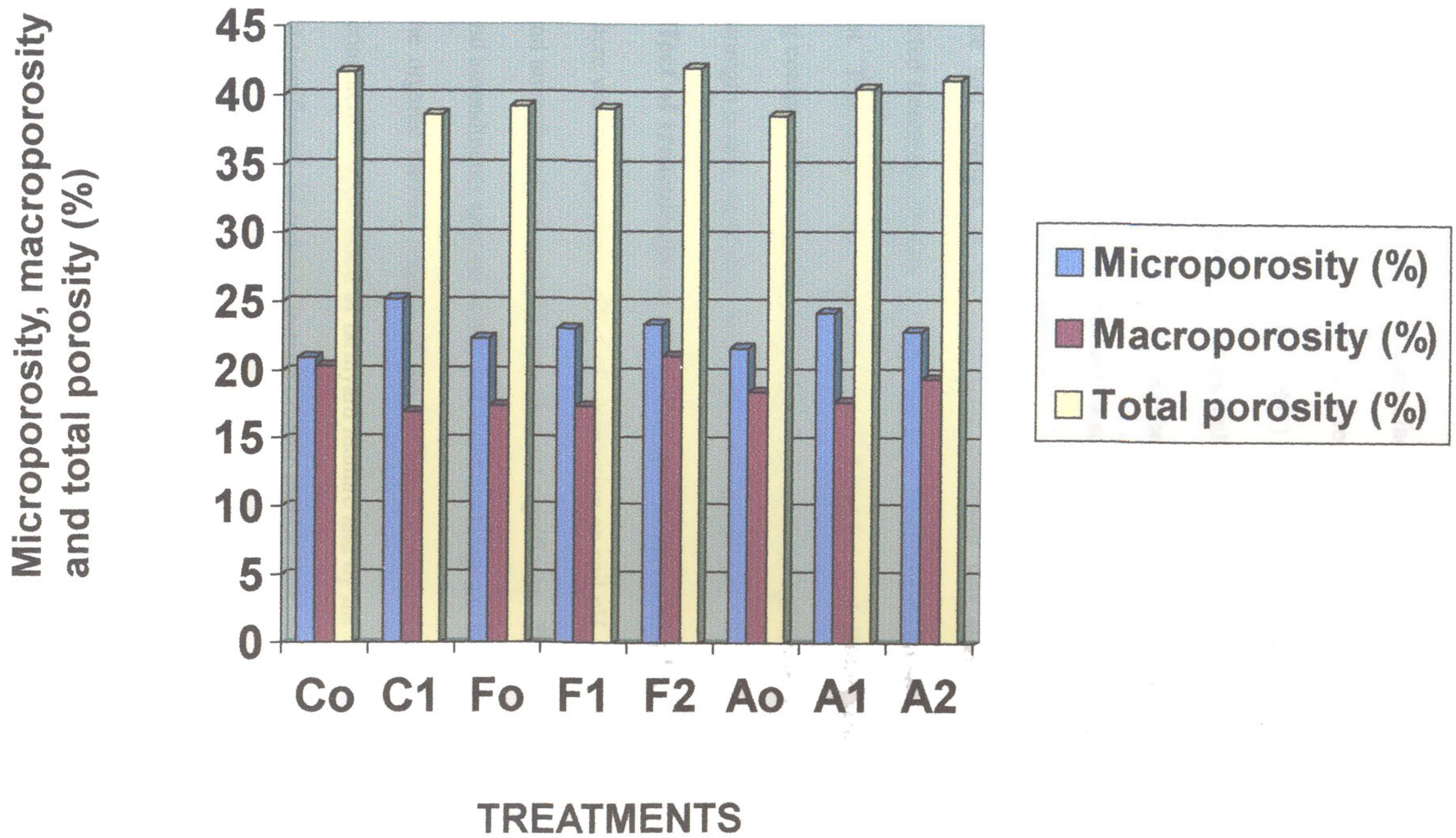
The maximum water holding capacity of the soil was not significantly influenced by the treatments, but availability of water is increased by capillary rise (Figure 2).

5.1.2 Effect of treatments on structural characteristics of soil.

Soil compaction modified the structural characteristics of the soil such as mean weight diameter, microporosity macroporosity, total porosity, bulk density, particle density and soil strength. The mean weight diameter of the soil was not significantly affected by the treatments.

The microporosity of the soils was significantly higher in compacted plots (Figure 4). Soil compaction compresses large pores into smaller ones favouring water retention over drainage (Gulati *et al.,* 1985, Abo- Abda and Hussain, 1990). The intra aggregate space is diminished. Compaction of the soil caused an increase in the volume of storage pores which is a common characteristic of applied stress (Gupta *et al.,* 1989). The macroporosity and total porosity of the surface and subsurface soil decreased in compacted treatments (Figure 4). The F_2 and A_2 plots recorded higher macroporosity and total porosity. The decrease in total porosity of soil as a result of compaction has been reported by (Ogunremi *et al.* 1986) Compaction interlocked the aggregates in such a way that it minimized the volume of macropores and reduced the percolation losses (Acharya and Sood, 1992).

Figure 4. Main effects of treatments on microporosity,macroporosity and total porosity of surface soil of kharif rice



The bulk density of the subsurface soil increased as a result of compaction (Figure 6). In the surface soil there was no effect of compaction. The A_2 plots also recorded higher bulk density in the surface and subsurface soils, though not statistically significant. The increase in bulk density of soil as a result of compaction has been reported by Ogunremi *et al.* (1986) and Gediga, (1991) Yadav and Somani (1990) reported that mixing of clayey soil had little effect on bulk density. By compacting the soil we are increasing the mass per unit volume of soil, thereby increasing the bulk density.

The particle density of the soil was not much affected by compaction and application of amendments (Figure 6).

The soil strength of the compacted treatment was significantly higher than uncompacted treatment (Figure 5). The effect of amendments on soil strength was not significant. This result was in accordance with MCAfee *et al.* (1989) who reported that presowing compaction on a clay soil increased the soil strength from 3.5 M Pa to 4.5 M Pa. Soil strength is also dependent on moisture content of soil.

5.1.3 Effect of treatments on chemical characteristics of soil.

There was no significant effect of compaction on soil pH. The effect of farmyard manure and amendments on soil pH were also not significant. The quantity of farmyard manure and amendments applied in this soil could not bring any changes in soil pH.

The organic carbon content of the surface and subsurface soils increased as a result of compaction, application of farmyard manure and by the application of coir pith, though not significant. In order to initiate organic carbon build up in soil, organic carbon input must exceed 2.5 t ha^{-1} $year^{-1}$ (Sharma *et al.* 1995)

The available nitrogen content of the soil increased in compacted treatment and farmyard manure applied plots (Figure 7). Increase in the available nitrogen content of

Figure 5. Main effects of treatments on mean weight diameter and strength of surface soil of kharif rice

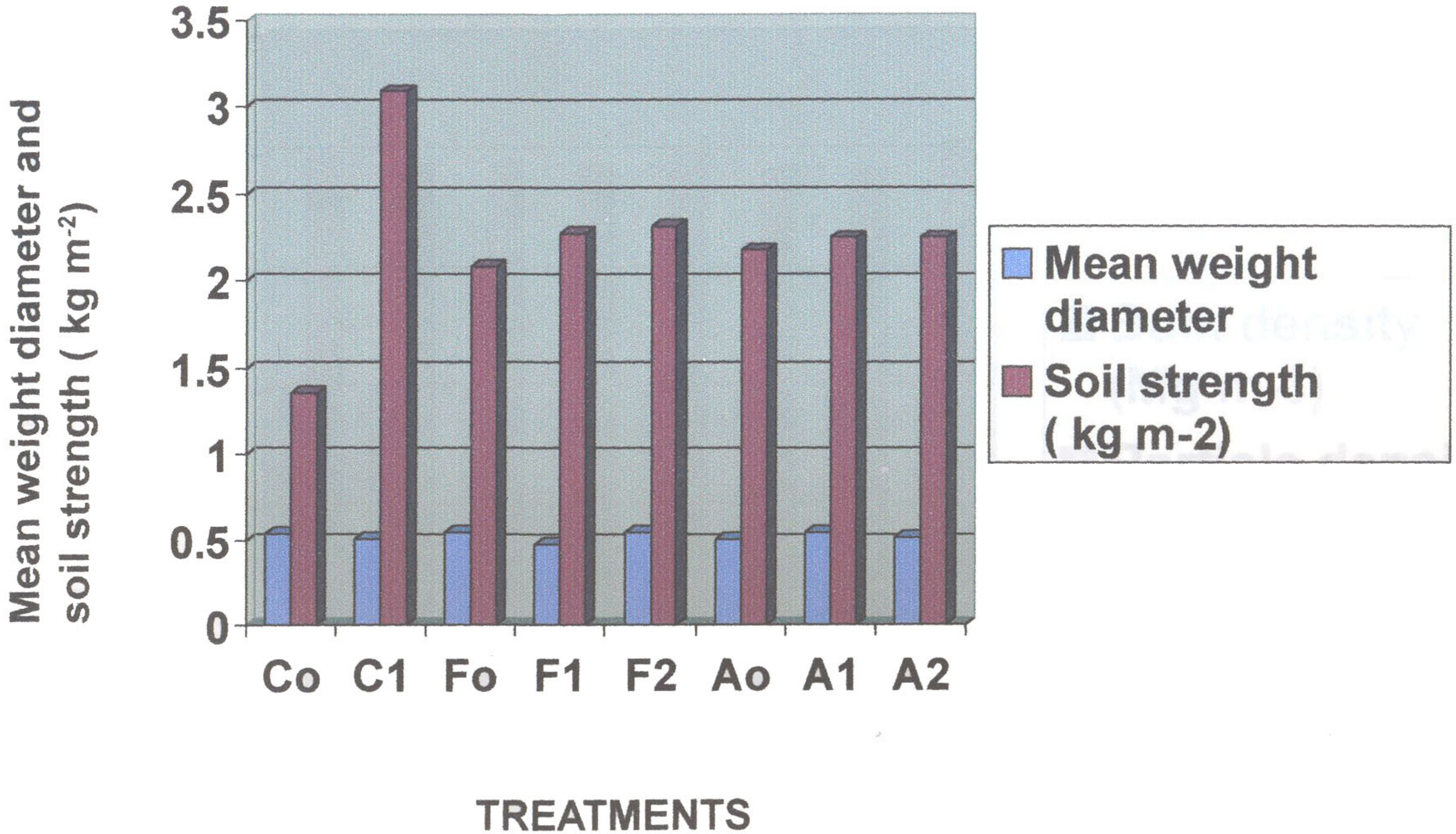
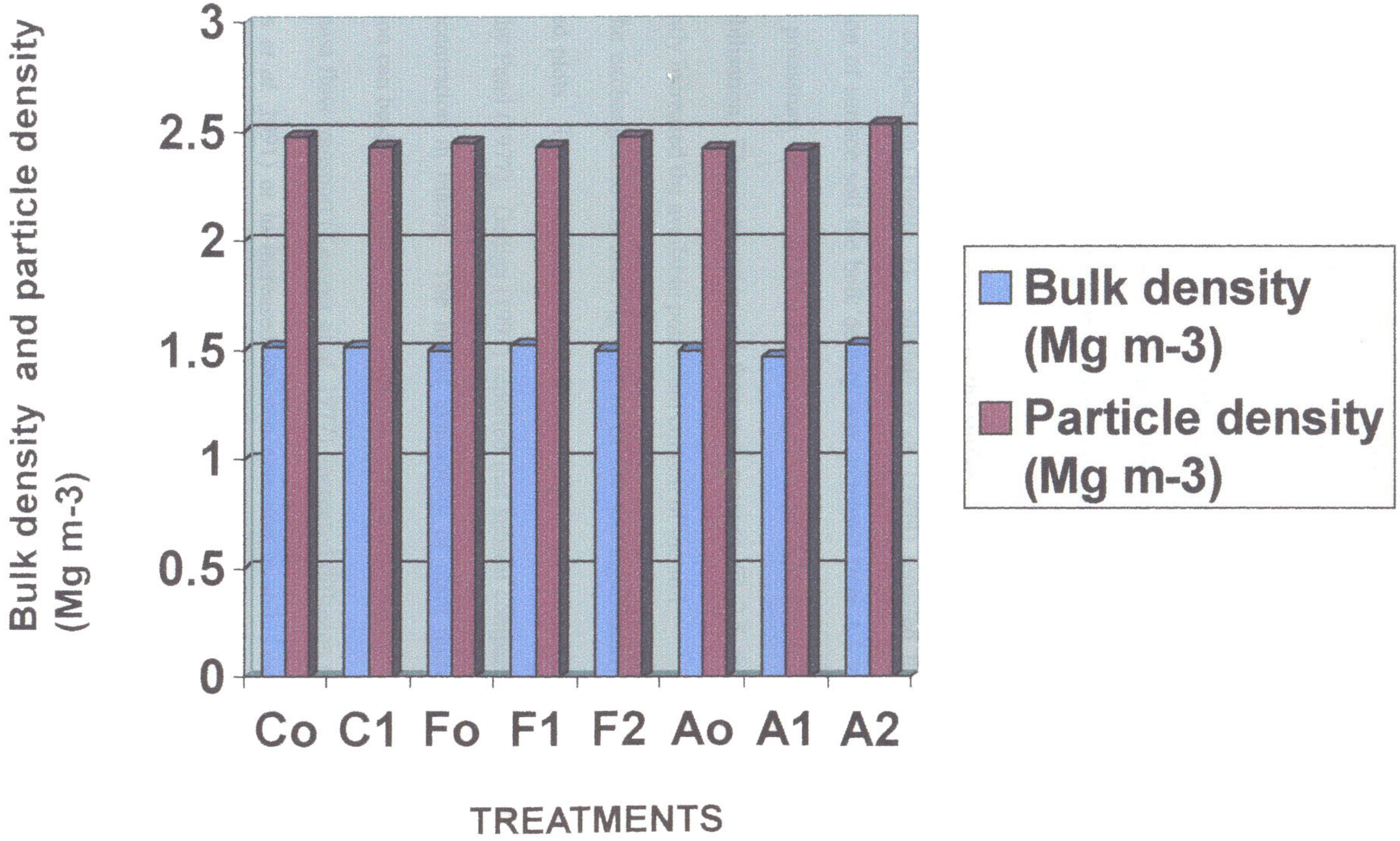


Figure 6. Main effects of treatments on bulk density and particle density of surface soil of kharif rice



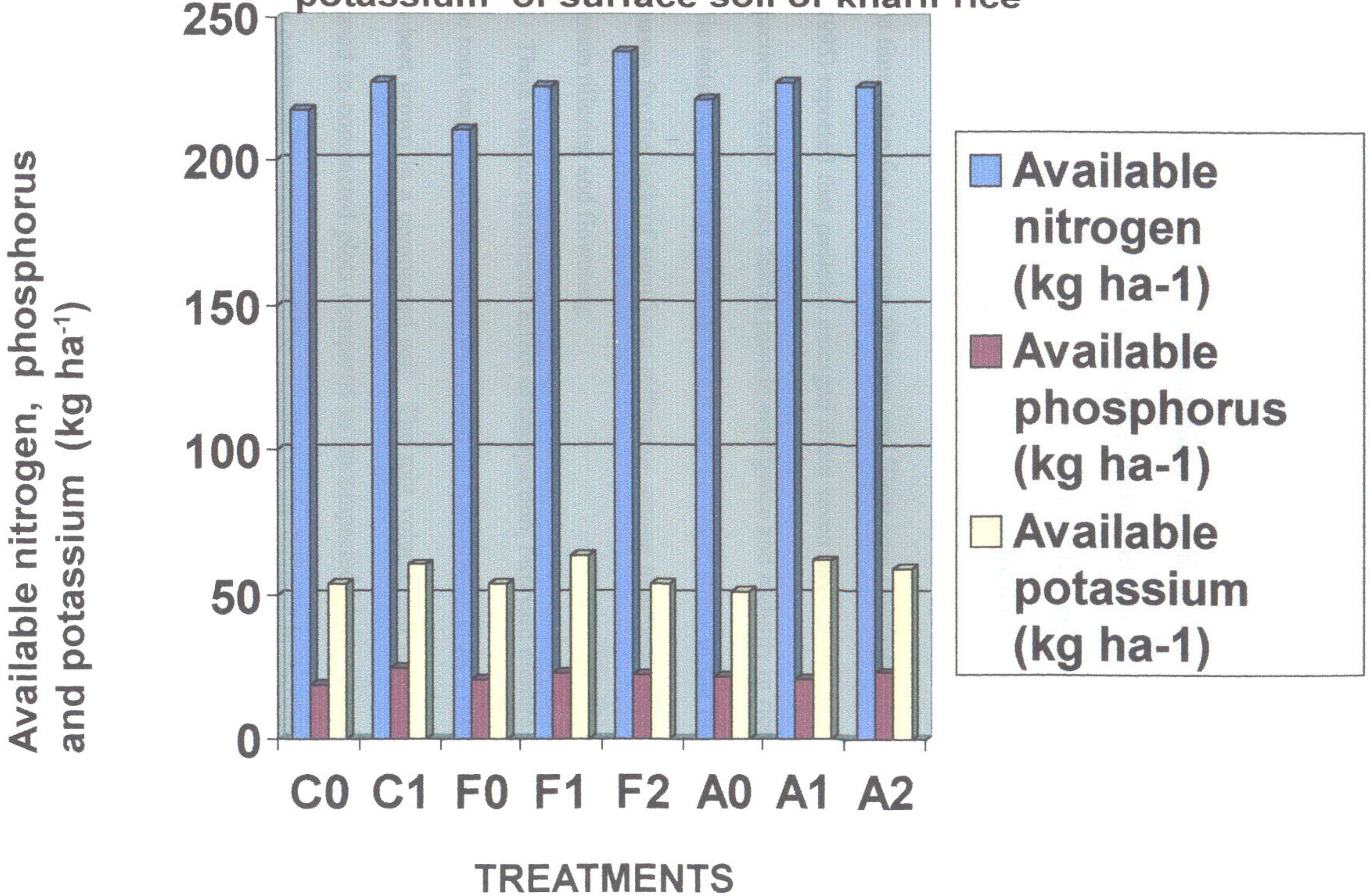
the soils as a result of compaction has been reported by several workers (Mahajan *et al.* 1981, Agrawal and Jhorar, 1989). The application of farmyard manure increases the organic carbon content of the soil, which in turn increases the available nitrogen status of the soil.

The available phosphorus content of the soil significantly increased in compacted treatment compared to uncompacted treatment (Figure 7). This result is in accordance with Dolan *et al.*(1986) who stated that surface compaction resulted in an enhancement of P uptake of corn.

The available potassium content of the surface and subsurface soils increased as a result of compaction (Figure 7). Mathan *et al.* (1994) reported that as a result of compaction of surface soil the bulk density was increased from 1.5 to 1.8 Mg m^{-3}, the available potassium content of the soil also increased perhaps due to moisture retention and solubilisation. The application of farmyard manure @ 2.5 tha^{-1} and coir pith significantly increased the available potassium content of the soil.

The exchangeable Ca and Mg content of the soil significantly increased in the compacted plots. The increased concentration of Mg in the compacted plots has been reported by Patel (1977). Gediga (1991) reported that subsoil compaction increased the Ca^{45} concentration in maize. The higher availability of plant nutrients as result of compaction can be due to greater water retention and lower hydraulic conductivity in the case of mass flow transport (Kemper e*t al.* 1977), increased diffusion coefficient of ions (Bhadoria *et al.* 1991) or to increased ion concentration in soil. Low permeability or hydraulic conductivity as a result of compaction reduces the nutrient losses by leaching resulting in an increase in the available and exchangeable nutrients in the soil.

Figure 7. Main effects of treatments on available nitrogen, phosphorus and potassium of surface soil of kharif rice



5.1.4 Effect of treatments on biometric observations.

The leaf area index at maximum tillering stage and panicle initiation stage were not significantly affected by compaction or farmyard manure or amendment, though the compacted plots recorded higher leaf area index than uncompacted plots. The leaf area index at flowering stage was significantly higher in compacted treatment. The leaf area index was significantly higher in F_1 plots. The effect of coir pith and *kayal* silt on leaf area index were not significant. This corroborates the finding of Ogunremi *et al.* (1986) who reported an increase in leaf area as a result of compaction.

There was no significant effect of compaction, farmyard manure and amendments on the time taken for maximum tillering and 50per cent flowering. However Sharma *et al.* (1995) reported that panicles emerged about seven days earlier as a result of subsoil compaction. Water stress delays panicle emergence and maturity in rice. But during the panicle initiation stage of this crop, there was no water stress in the field. This may be the reason for the lack of significant difference among treatments on the time taken for maximum tillering and flowering.

There was no significant effect of compaction, farmyard manure and amendments on the root length. Similar report was made by Kaselowsky *et al.* (1989) in the case of sugar beet grown in a compacted soil. The root volume and root density significantly increased in compacted plots compared to uncompacted plots. Increased root growth under compacted treatment could be ascribed to the increase in nutrient content per unit volume of soil due to increase in bulk density owing to compaction effect that made more nutrients available per unit volume of soil (Ogunremi *et al.* 1985). Prihar *et al.* (1985) have reported that some times it is necessary to compact the soil with roller to establish better seed – soil contact. This stimulates the rooting for the optimum growth of upland crops.

5.1.5 Effect of treatments on yield and quality.

The grain and the dry matter production were significantly higher in compacted treatments compared to uncompacted treatments. Increase in yield as a result of compaction has been reported earlier by Ghildyal (1978); Ognuremi *et al*, (1986) and Gediga (1991).

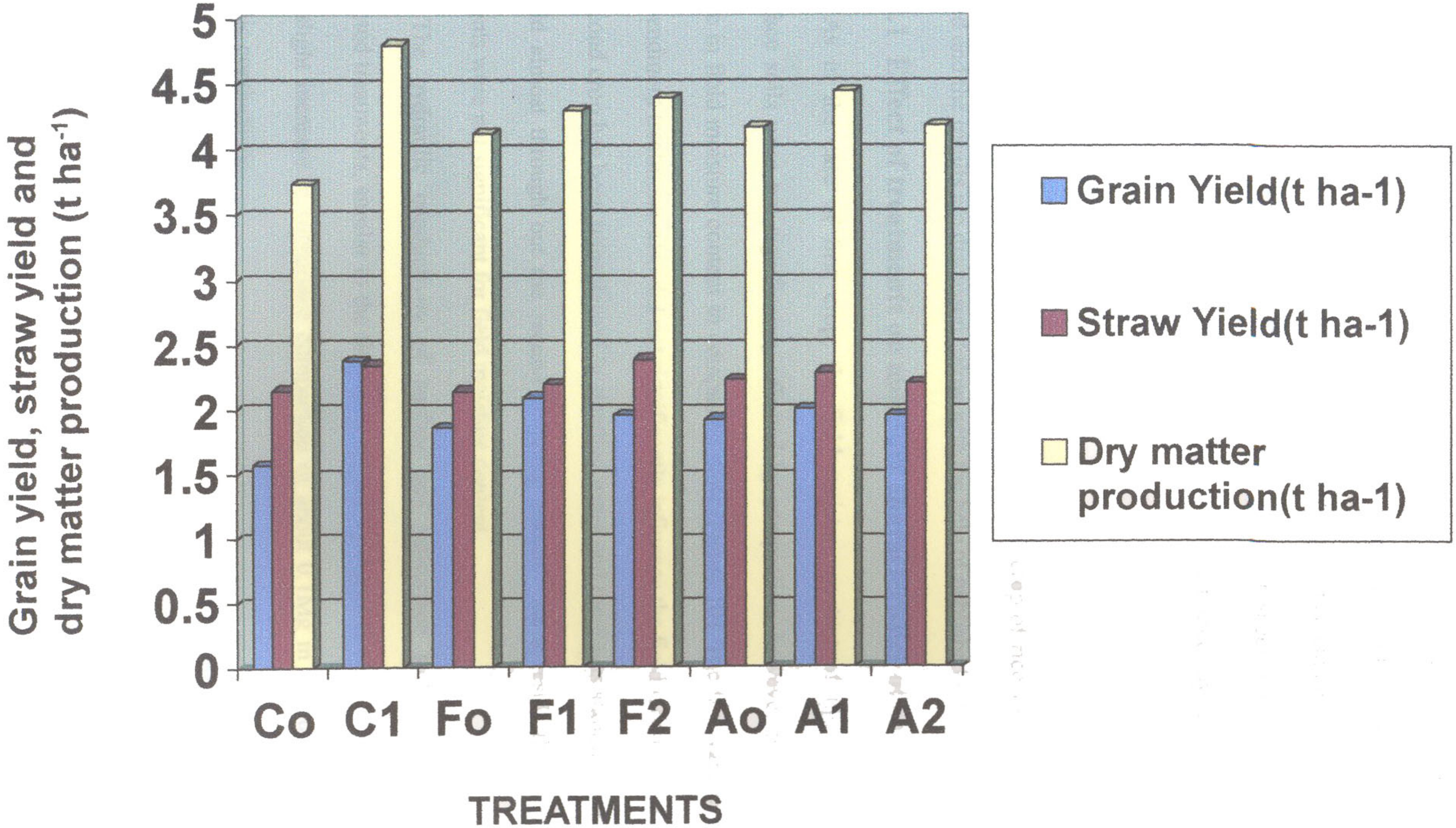
The grain yield was significantly higher in F_1 plots (Figure 8). The effect of coir pith and *kayal* silt on grain yield, straw yield and dry matter production were not significant. The carbohydrate content of the grain was not significantly influenced by compaction and farm yard manure where as the protein content of the grain was significantly higher in compacted plots and *kayal* silt treated plots. This may be due to the increased availability of nitrogen leading to maximum uptake in the compacted treatment (Agrawal, 1991) and in *kayal* silt treated plots.

Gupta *et al.* (1984) compiled the report of the result of compaction for a highly permeable soil. It was found that the nitrogen uptake by pearl millet grain and total dry matter was increased significantly by 40 percent due to compaction in loamy sand at Jobner.

5.1.4 Effect of treatments on total nutrient content

The nitrogen, phosphorus and potassium contents of the plants were significantly higher in compacted treatments. The higher concentration of N, P and K in compacted plots has been reported by Patel (1977). Patel attributed this increase in nutrient uptake to the reducing conditions caused by soil compaction. In addition, compaction of a

Figure 8. Main effects of treatments on grain yield, straw yield and dry matter production of kharif rice



permeable sandy soil decreases water percolation and thus curtails leaching losses. The calcium and magnesium content of the plants were not affected by the treatments.

Gupta *et al.* (1984) reported that compaction of loamy sand by 1500 Kg roller at Hissar increased the nitrogen content of grain and straw by 25 percent and 15 percent and the phosphorus content by 40 percent and more than two fold respectively. The potassium content of grain was not affected but that of straw increased by 15 percent by compaction.

5.2 Rabi- Rice.

The data obtained from the observation of second crop of rice were statistically analysed and the results are discussed below with the help of published information.

5.2.1 Effect of treatments on moisture characteristics of soil

As in the case of first crop, the field moisture content of the surface and subsurface soils were not significantly affected by compaction, however there was an increase in field moisture content in compacted plots (Figure 10). The farmyard manure and amendment treatments also did not significantly influence the field moisture content. The second crop has been transplanted in standing water and there was standing water in the field almost through out the second cropping season. As a result the effect of treatments were not significant for field moisture content.

The hydraulic conductivity of surface and subsurface soils was lower in compacted treatments, similar to the first crop (Figure 9). Agrawal *et al.* (1987) reported that a slight increase in subsurface compaction of about 0.1Mg m^{-3} reduced saturated hydraulic conductivity.

Figure 9. Main effects of treatments on hydraulic conductivity of surface soil of rabi rice

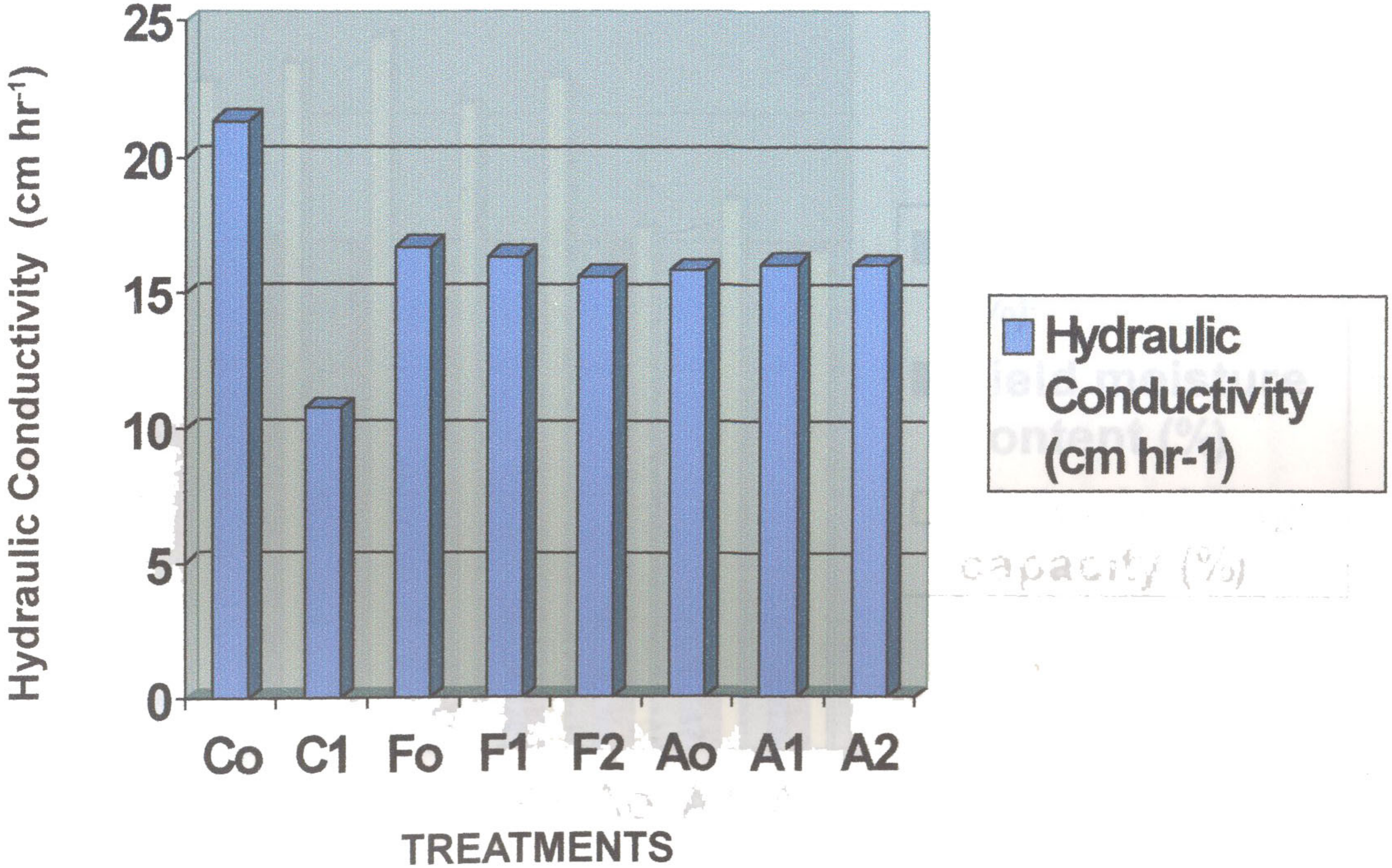
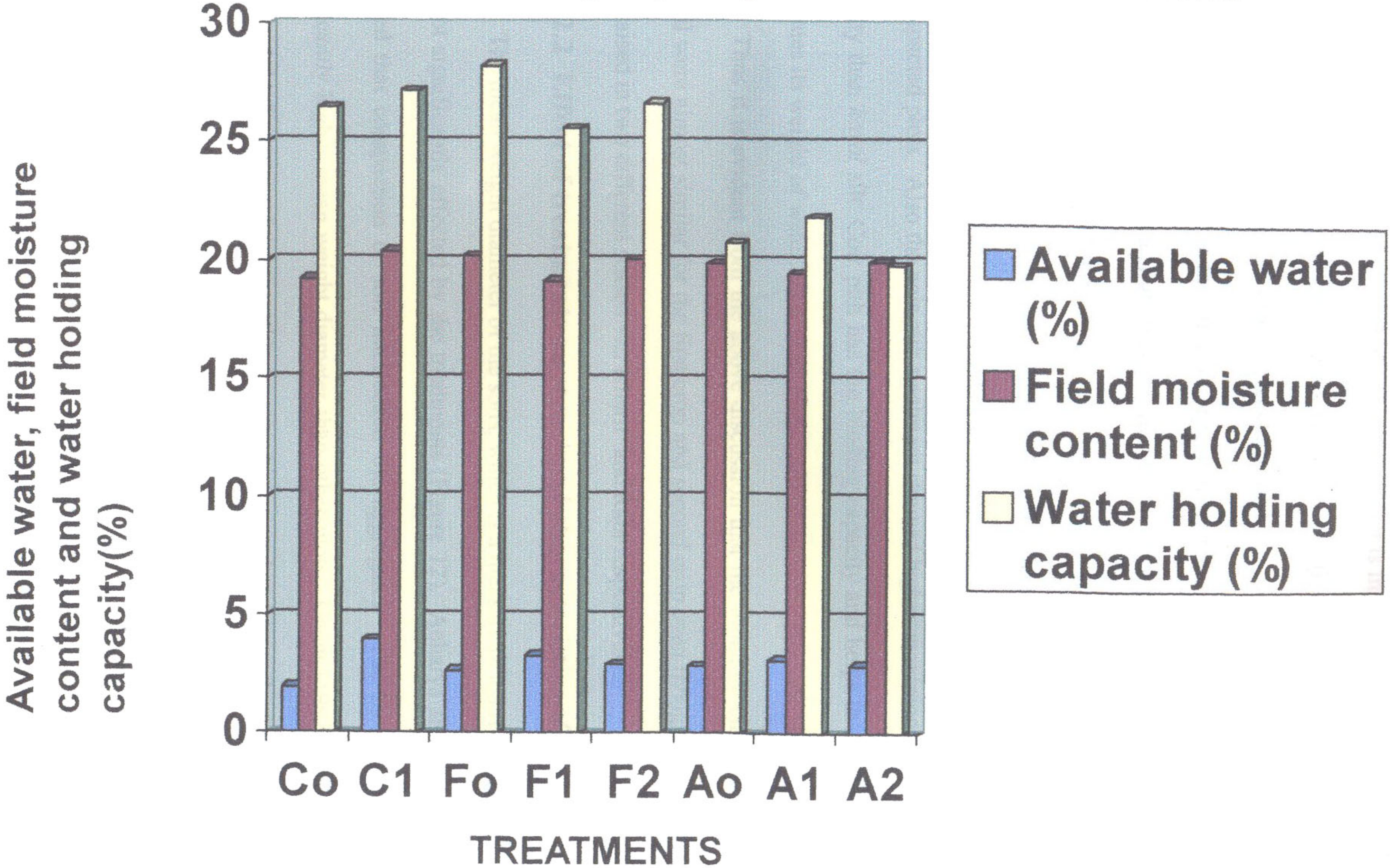


Figure 10. Main effects of treatments on available water, field moisture content and water holding capacity of surface soil of rabi rice



The available water content of surface and subsurface soils was significantly higher in compacted treatment (Figure 10). This result is in accordance with that of first crop. The surface soils of the F_1 plots recorded significantly higher available water content. In the subsurface soils the F_2 plots recorded significantly higher available water content. This may be due to the effect of organic matter and soil water bridging. Agrawal *et al.* (1987) reported that a slight increase in subsurface compaction of about 0.1 Mg m^{-3} increased soil moisture retention.

The maximum water holding capacity was not affected by the treatments (Figure 10). However the compacted plots recorded higher maximum water holding capacity than uncompacted plots. Also the coir pith treatment showed higher maximum water holding capacity than *kayal* silt. Coir pith has the binding capacity and helps in retaining about five times its weight of water.

Thus it is evident from the above discussion that the moisture characteristics of the soil were almost similar for the first crop and second crop even though the two crops were raised in two different season viz. Kharif and Rabi respectively.

5.2.2 Effect of treatments on structural characteristics of soil.

The mean weight diameter of the soils, which is a measure of aggregate stability was not significantly affected by the treatments (Figure 12). Acharya and Sood (1992) reported that compaction of soil interlocked the aggregates. The F_2 plots recorded significantly higher mean weight diameter than other plots. Unger (1997) reported that mean weight diameter of water stable aggregates was related to soil organic matter or organic carbon.

The microporosity of the surface and subsurface soils was significantly higher in compacted plots (Figure 11). The macroporosity of the soil was significantly lower in

Figure 11. Main effects of treatments on microporosity, macroporosity and total porosity of surface soil of rabi rice

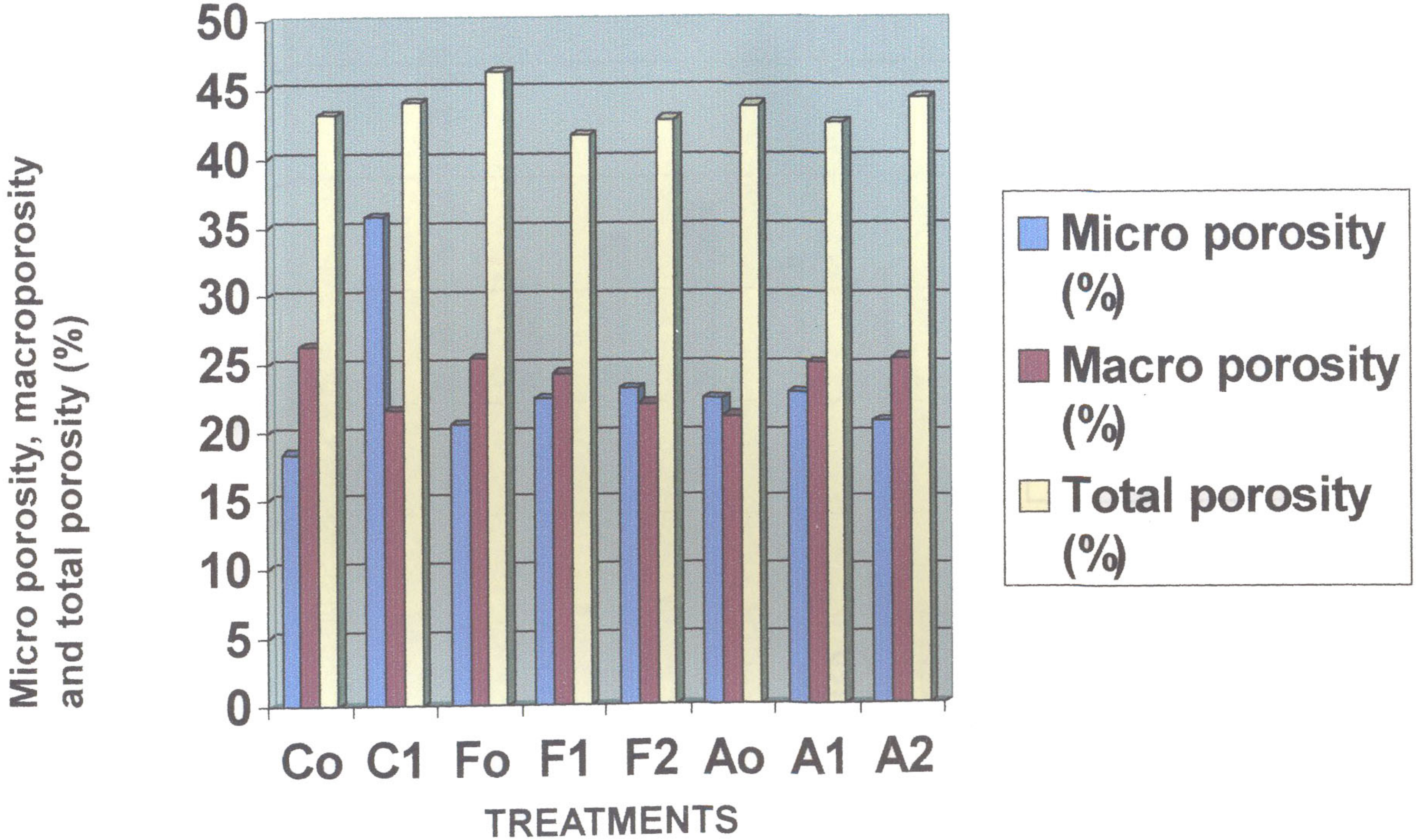
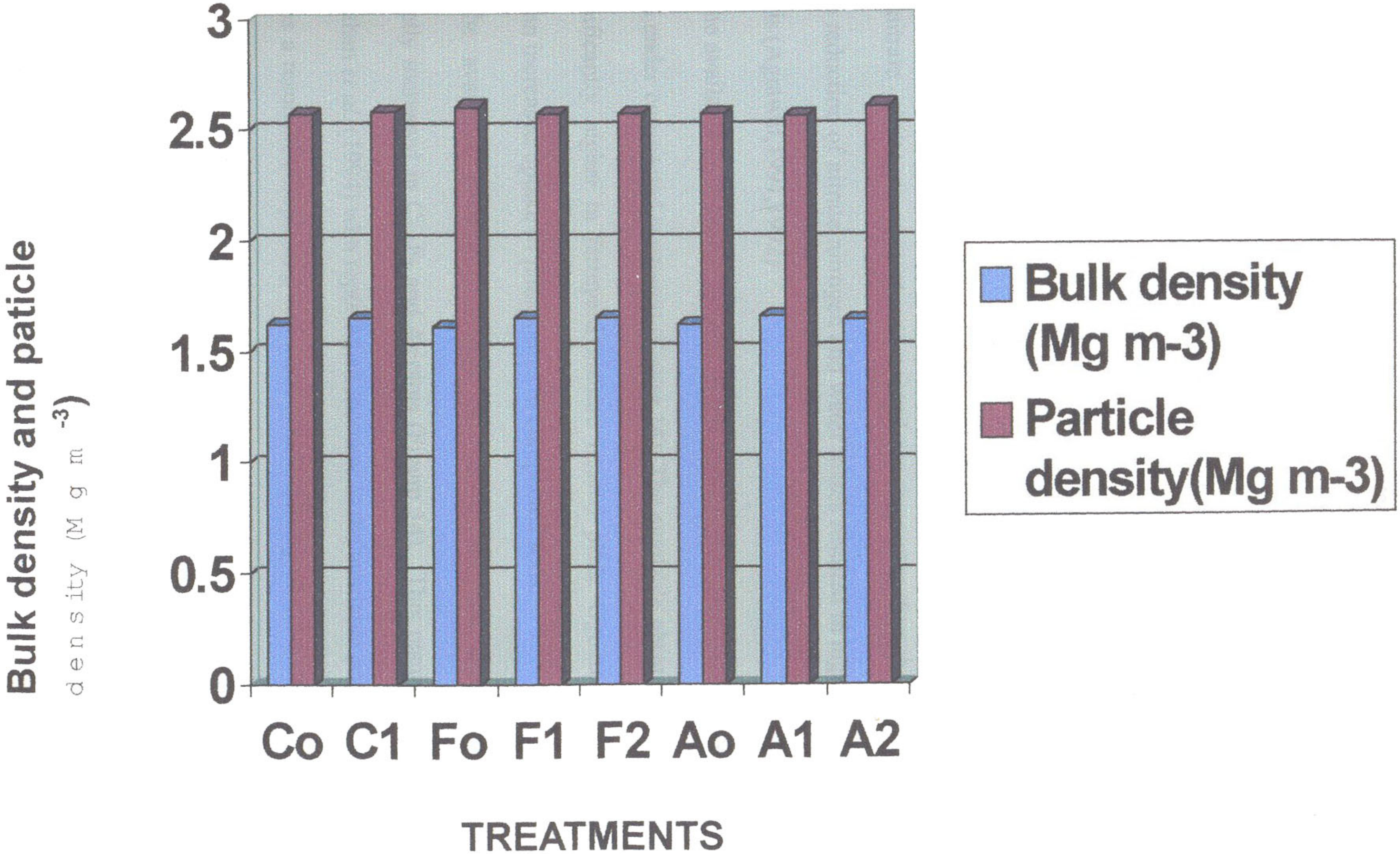


Figure 13. Main effects of treatments on bulk density and particle density in surface soil of kharif rice

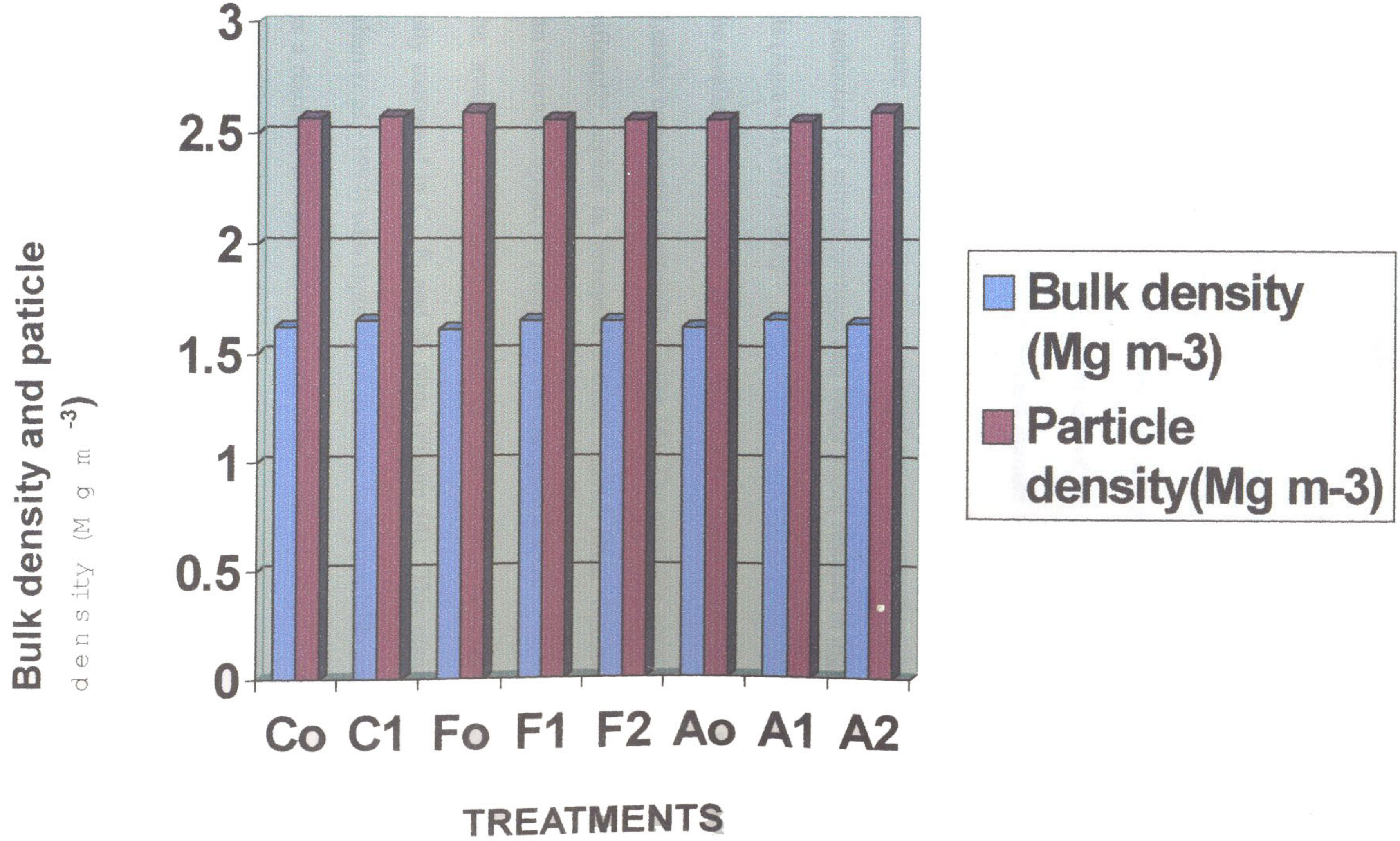


compacted treatments. Compaction inter locked the aggregates in such a way that it minimised the volume of macropores and reduced the percolation losses. (Acharya and Sood, 1992). The micropores are further divided into smaller pores leading to increase in porosity. The treatments did not significantly affect the total porosity of the soil. The F_2 plots and the A_1 and A_2 plots recorded higher total porosity. The results are in accordance with that of M C A fee *et al.* (1989) who reported that presowing compaction on a clay soil reduced the total porosity by 6 per cent v/v owing to the loss of pores greater than 60 μm and water retention was increased.

The treatments did not significantly influence the bulk density of the soil even though the compacted plots recorded higher values in the surface and subsurface soils (Figure 13). Changes in bulk density of the soil as a result of compaction have been reported by Cassel (1982) and Canarche *et al.* (1984).

The particle density of the surface and subsurface soil were not significantly affected by the treatments (Figure 13). The F_0 plots recorded significantly higher particle density than F_1 and F_2 plots. When organic matter is increased, the quantity or the proportion of heavy mineral particles reduced per unit volume resulting in lower particle density of the soil. Since the application of farmyard manure reduces the mass per unit volume of soil solids (particle density), the farmyard manure treated plots recorded lower particle density. The compaction treatments affect the arrangement of soil particles and rearrange them according to the pressure of the load. As a result there may be no change in the soil solids and in turn particle density. Soil strength will be more in a soil, which is well aggregated and the particles are in close contact.

Figure 13. Main effects of treatments on bulk density and particle density of surface soil of kharif rice



5.2.3 Effect of treatments on chemical characteristics of soil

The pH of the soil was not significantly affected by the treatments as in the case of first crop. Unlike in the case of first crop the compaction treatment and farmyard manure treatments significantly increased the organic carbon content of the surface soil. The effect of treatments on the organic carbon of the subsurface soil was not significant.

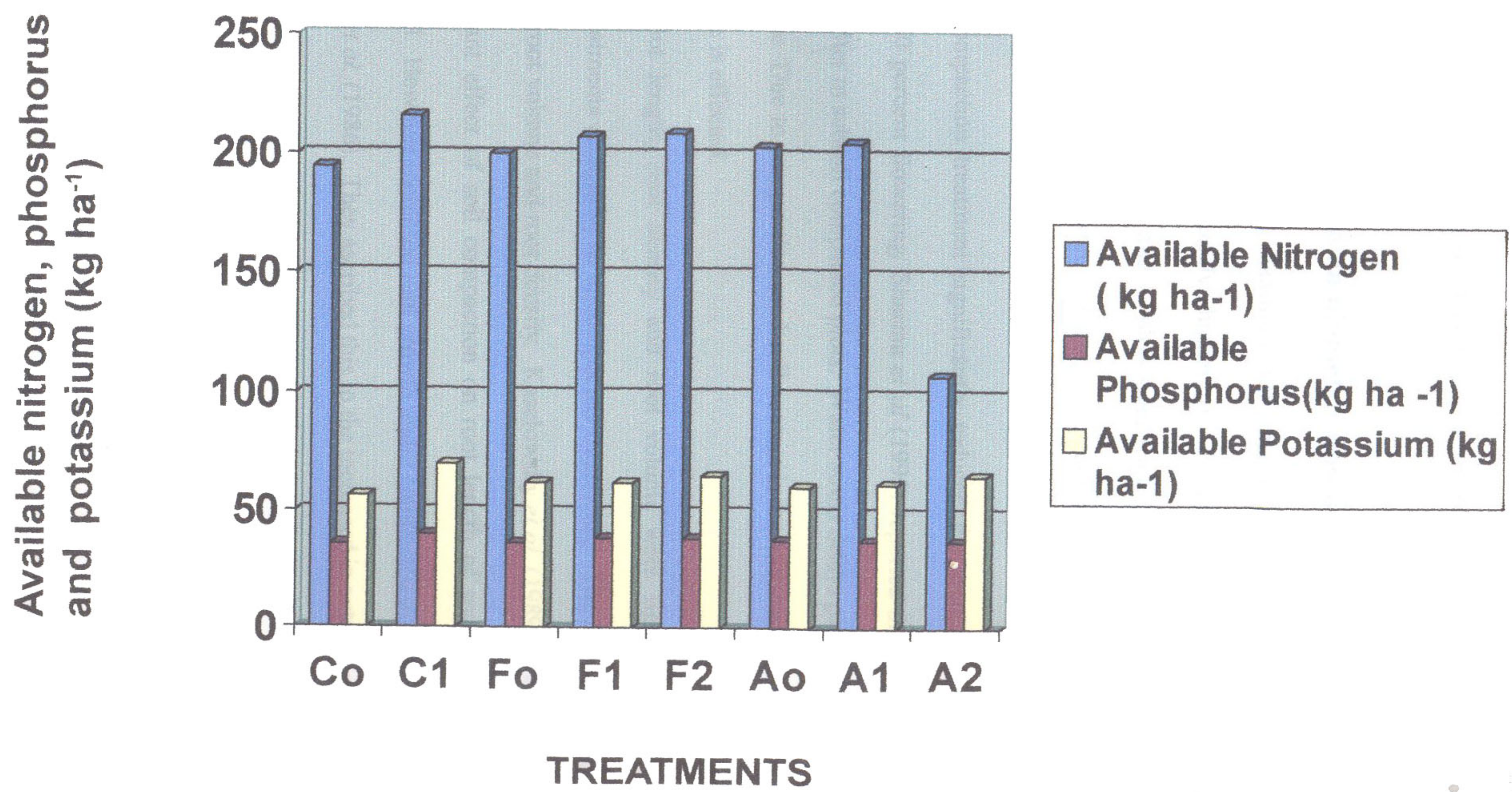
The available nitrogen content of the soil was not significantly influenced by the treatments even though the available N content of the compacted plots was higher than uncompacted plot (Figure 14). The farmyard manure treated plots also recorded higher available nitrogen content. Agrawal (1991) reported that in a surface compacted sandy soil, the nitrate – nitrogen content was several times greater than that in uncompacted soil. The reduction of nitrate nitrogen and water losses resulted in higher productivity of sandy soils (Agrawal,1991,1992)

The available phosphorus content of the surface and subsurface soil significantly increased under compacted treatment (Figure 14). The available phosphorus content was also significantly higher in farmyard manure treated plots. Ogunremi *et al.*, (1986) reported an increased uptake of phosphorus in compacted soils.

The available potassium content of the surface and subsurface soil was significantly increased in C_1, F_2 and A_2 plots (Figure 14). This result is in accordance with Mathan *et al.* (1994) who reported an increase in the available potassium content of the soil as a result of compacting soil from a bulk density of 1.5 to 1.8 Mg m^{-3}. They attributed this to the increased moisture retention and solubilisation as a result of compaction.

The exchangeable calcium content of the soil was significantly higher in compacted treatments of both surface and subsurface soils, where as the exchangeable

Figure 14. Main effects of treatments on available nitrogen, phosphorus and potassium of surface soil of rabi rice



magnesium content of the soil was not significantly influenced by the treatments Gediga (1991) reported that subsoil compaction increased the Ca^{45} concentration in maize.

5.2.4 Effect of compaction on biometric observations.

The leaf area index at maximum tillering stage, panicle initiation stage and flowering stage was significantly higher in compacted treatment compared to uncompacted plots. The F_2, A_1 and A_2 plots significantly increased the leaf area index at maximum tillering and panicle initiation stages. Ogunremi *et al.* (1986) reported that the leaf area was higher in compacted treatments compared to the uncompacted treatment.

The compaction treatment significantly reduced the time taken for maximum tillering and 50 percent flowering. Sharma *et al* (1995) reported that panicles emerged seven days earlier in subsoil compacted plots. Water stress delays panicle emergence and maturity in rice. Due to compaction seed-soil contact is increased and early germination and emergence is effected.

The root length, root density and root volume were significantly higher in compacted treatments compared to uncompacted treatments. The F_2 plots significantly increased the root volume and root density. Kaselowsky *et al.* (1989) reported that there is no significant effect of soil compaction on root length of sugar beet grown in a compacted soil. However increased root growth under compacted treatment was reported by Ogunremi *et al.* (1986). They ascribed this to the increased in nutrient content per unit volume of soil due to increase in bulk density owing to compaction effect that made more nutrients available per unit volume of soil.

5.2.5 Effect of treatments on yield and quality.

As in the case of first crop, the grain yield, straw yield and dry matter production were significantly higher in compacted treatments in the second crop (Figure 15). The farmyard manure treated plots also significantly increased the grain yield, straw yield and dry matter production. Nair *et al.* (1976) reported that the compaction of soil increased the grain yield of upland rice crop in a lateritic sandy loam soil. Increase in the grain yield of rice as a result of compaction has been reported by several workers (Ghildyal, 1978; Ognuremi *et al*, 1986, Acharya and Sood, 1992). Sub soil compaction has the potential for increasing and stabilizing rice yields in coarse textured, rain fed low land soils. Subsoil compaction is far effective than puddling to conserve rainwater and is far more practical than subsurface plastic barriers (Sharma *et al.*, 1995).

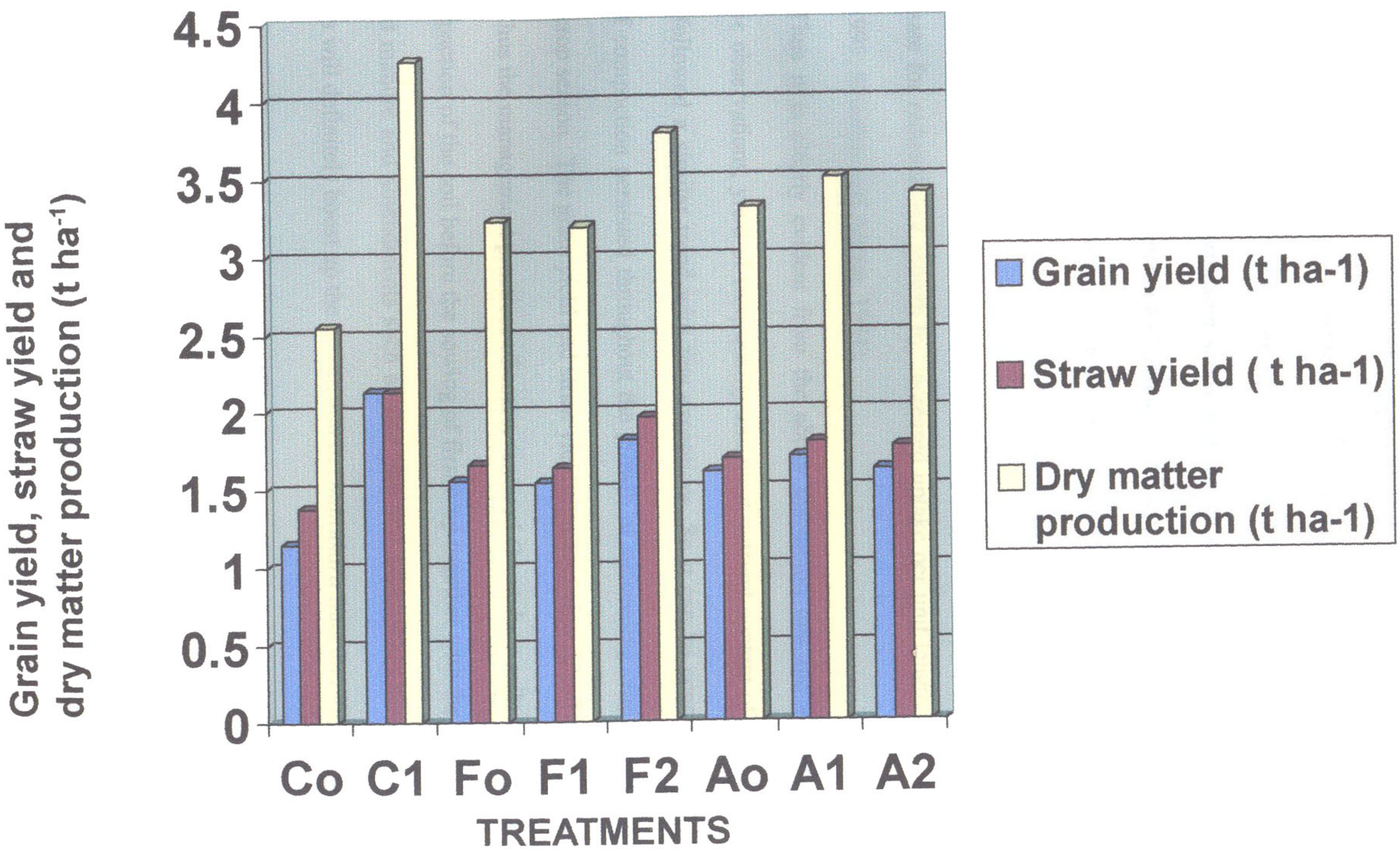
The compaction was given during the first crop. The effect of which was equally good for the second crop also leading to more yield in compacted plots.

The carbohydrate content of the grain was not significantly influenced by the treatments. However the crude protein content of the grain was significantly higher in compacted plots, farmyard manure treated plots and *kayal* silt treated plots. This may be due to the higher nitrogen content of the soil and nitrogen uptake in the compacted treatments.

5.2.6 Effect of treatments on the total nutrient content of plant

The nitrogen, phosphorus and potassium content of the plant were significantly higher in C_1 and F_2 plots. The A_2 plots recorded significantly higher content of nitrogen and potassium. The compacted treatment showed higher N utilization at different growth stages over other treatments due to higher dry matter accumulation and increased

Figure 15. Main effects of treatments on grain yield, straw yield and dry matter production of rabi rice



nitrogen concentration of rice. The compacted treatment showed higher uptake of N by 23per cent (Ogunremi *et al*, 1986). The higher content of N, P, Mg and Mn in the compacted plots treatments was reported by Patel (1977) who attributed this to the increase in nutrient uptake to the reducing conditions caused by soil compaction. In addition, compaction of a permeable sandy soil decreases water percolation and thus curtails leaching loss. Westermann and Sojka (1996) reported that subsoil compaction of fine loamy soil enhanced the phosphorus and potassium uptake by corn when the rainfall was average or above average. Compaction may actually increase the nutrient uptake if it increases the movement of ions to the roots via diffusion. Roots may also partially compensate for reduced root growth by, increased uptake per unit length (Hoffman and Jungk, 1995; Shierlaw and Alston, 1984).

Thus it is clearly evident from the above discussion that the soil properties, biometric observations, yield of rice, quality and plant nutrient content of the two crops of rice followed a similar trend with few exceptions. So it can be concluded that the effect of compaction persisted throughout the growth of succeeding crop of rice in the second crop season. The grain yield and straw yield increased significantly in compacted plots. Thus the management practices of coarse textured *Onattukara* soils should include the compaction of the soil before the sowing of first crop together with the application of farmyard manure and amendments such as coir pith and *kayal* silt. These management practices will definitely boost up the production in *Onattukara* tract and improves the soil health.

5.3 Summer crops - Seasmum, green gram and cowpea

The data on the soil properties of sesamum, green gram and cowpea are pooled and statistically analysed and the results are discussed below.

5.3.1 Effect of treatments on moisture characteristics of the soil

The moisture content of the green gram plots was significantly higher than sesamum and cowpea plots (Figure 17). The compacted plots recorded significantly higher moisture content than uncompacted plots. The F_2 and A_1 plots recorded significantly higher field moisture content. Same results have been reported by a number of workers. Sub soil compaction created by surface rolling one to two days after irrigation or rain fall reduces water and nutrient losses and increases soil moisture storage in highly permeable deep sandy soils there by increasing, their productivity by 30 to 50per cent (Agrawal *et al.*, 1987; Agrawal, 1988 and Gupta *et al.* 1989). Sharma *et al.* (1995) reported that the compacted plots have the greatest soil water after rice crop harvest. High soil moisture content after harvest is essential to increase cropping intensity through production of an upland crop of rice. Thus subsoil compaction may enable farmers to increase cropping intensity in rain fed low land rice areas.

The hydraulic conductivity of the green gram plots was significantly higher compared to sesamum and cowpea plots of both surface and subsurface soils (Figure 16). The compacted plots recorded significantly lower hydraulic conductivity than uncompacted plots. Progressive decrease in saturated hydraulic conductivity with compaction was observed by various workers. Waldron *et al.* (1971) stated that compaction caused local shearing and particle rearrangements resulting in greater reduction in hydraulic conductivity.

The available water content of both surface and subsurface soils were greater in green gram plots (Figure 17). The compacted plots recorded significantly higher available water content than uncompacted plots in both the surface and subsurface soils.

Figure 16. Main effects of treatments on hydraulic con uctivity of surface soil of sesamum, greengram and cowpea

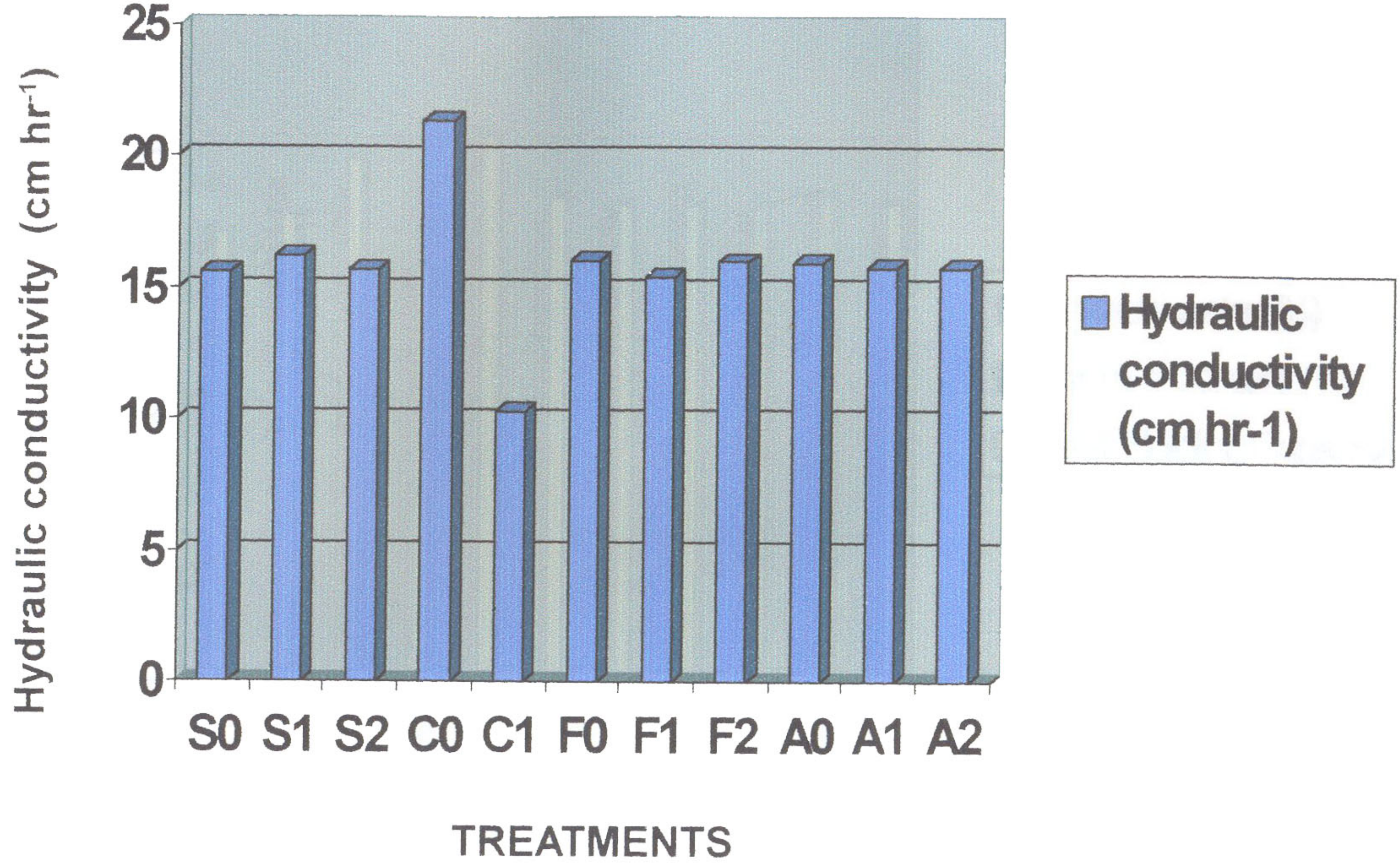
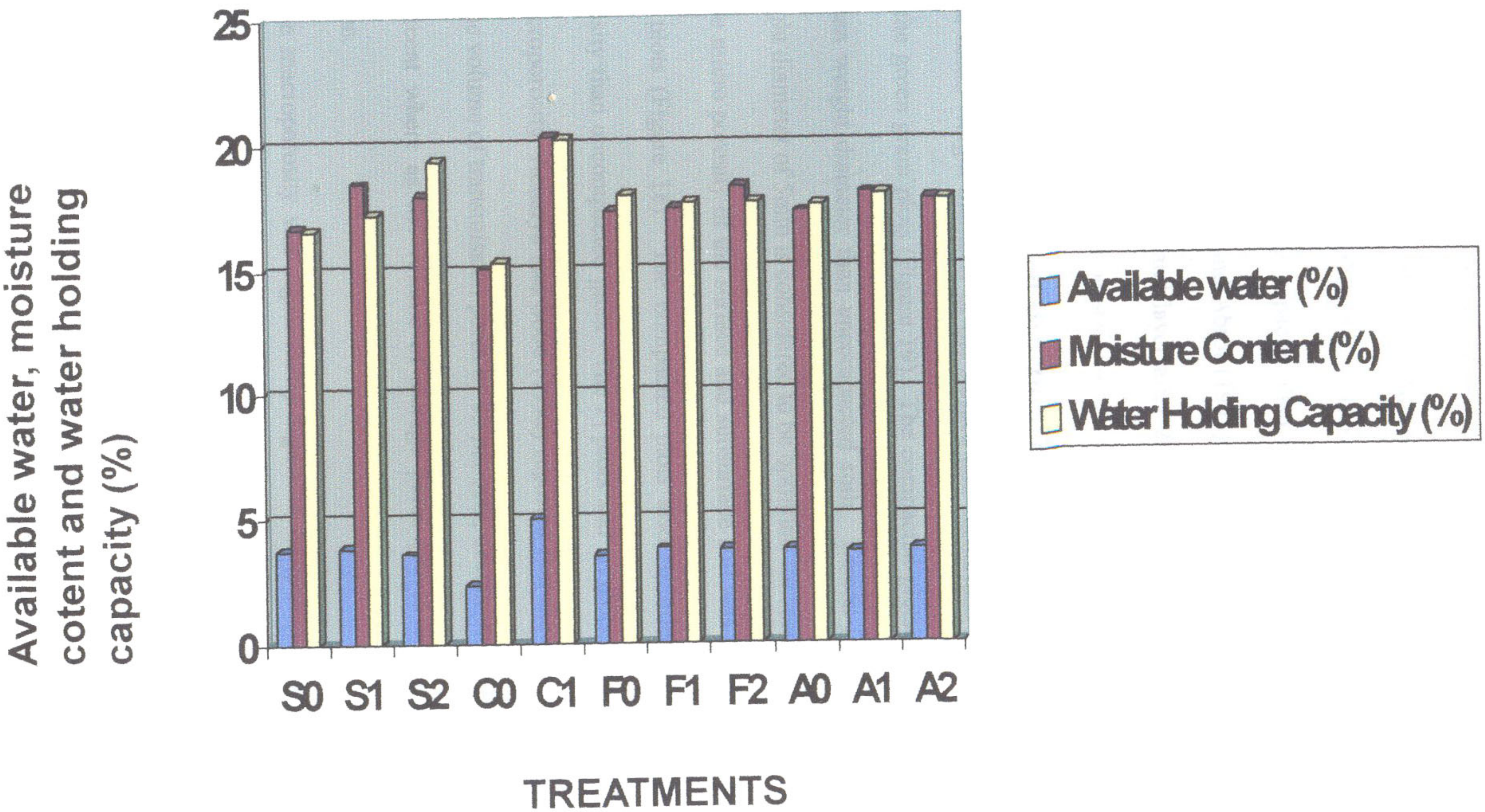


Figure 17. Main effects of treatments on available water, field moisture content and water holding capacity of surface soil of sesamum, greengram and cowpea



Similar result was reported by Reddy (1973). He attributed the increase in available water content to the squeezing effect of compaction on large pores.

The maximum water holding capacity was higher in cowpea plots compared to sesamum and green gram plots (Figure 17). The compacted plots recorded significantly higher maximum water holding capacity than uncompacted plots. This result is in accordance with that of Gupta and Abrol (1993). They reported that amount of water retained in the 0-10cm loamy sand layer after 24 hours of irrigation was 21.5per cent higher in the soil compacted by 8 passes of 490 kg roller than in uncompacted soil.

5.3.2 Effect of treatments on structural characteristics of soil

The mean weight diameter of the surface and subsurface soils was significantly higher in the green gram plots (Figure 19). The compacted plots recorded significantly higher mean weight diameter than uncompacted soils. Larson (1964) reported that a mean weight diameter of 5mm is considered to be optimum for seed beds.

The micro porosity of the surface and subsurface soil was significantly higher in sesamum plots (Figure 18). The compacted plots also recorded significantly higher microporosity than uncompacted plots. The F_1 plots and A_1 plots recorded significantly higher microporosity. Acharya and Sood (1992) reported that the compacted treatments reduced the volume of transmission pores by 83 per cent, decreased the percolation losses by 30 percent where as the volume of storage pores (50 to 0.5μm) increased with compaction.

The macroporosity was significantly higher in cowpea plots (Figure 18). The compacted plots recorded significantly lower macroporosity than uncompacted plots. This result was in accordance with Acharya and Sood (1992). They reported that

Figure 18. Main effects of treatments on microporosity,macroporosity and total porosity of surface soil of sesamum, greengram and cowpea

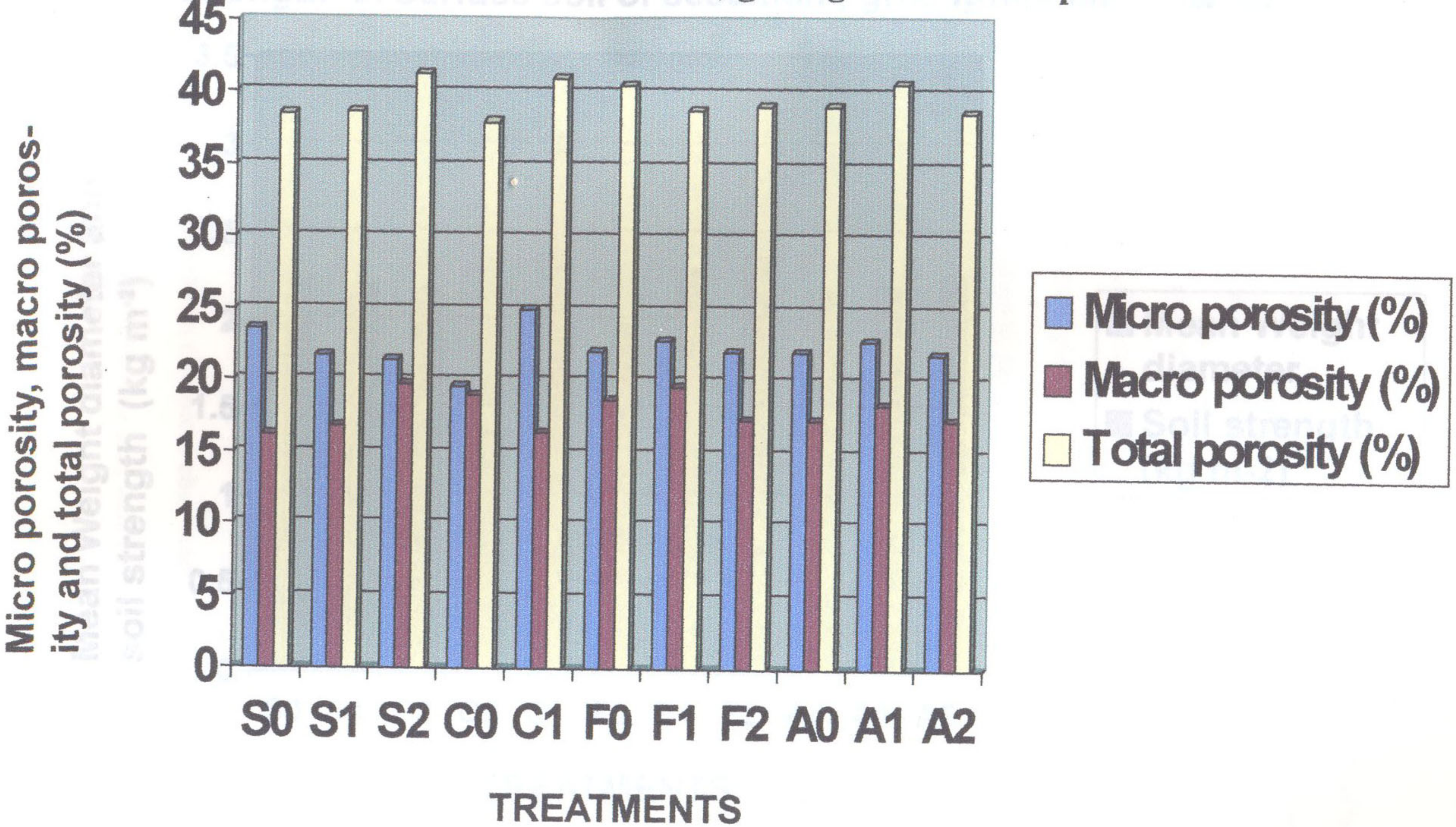
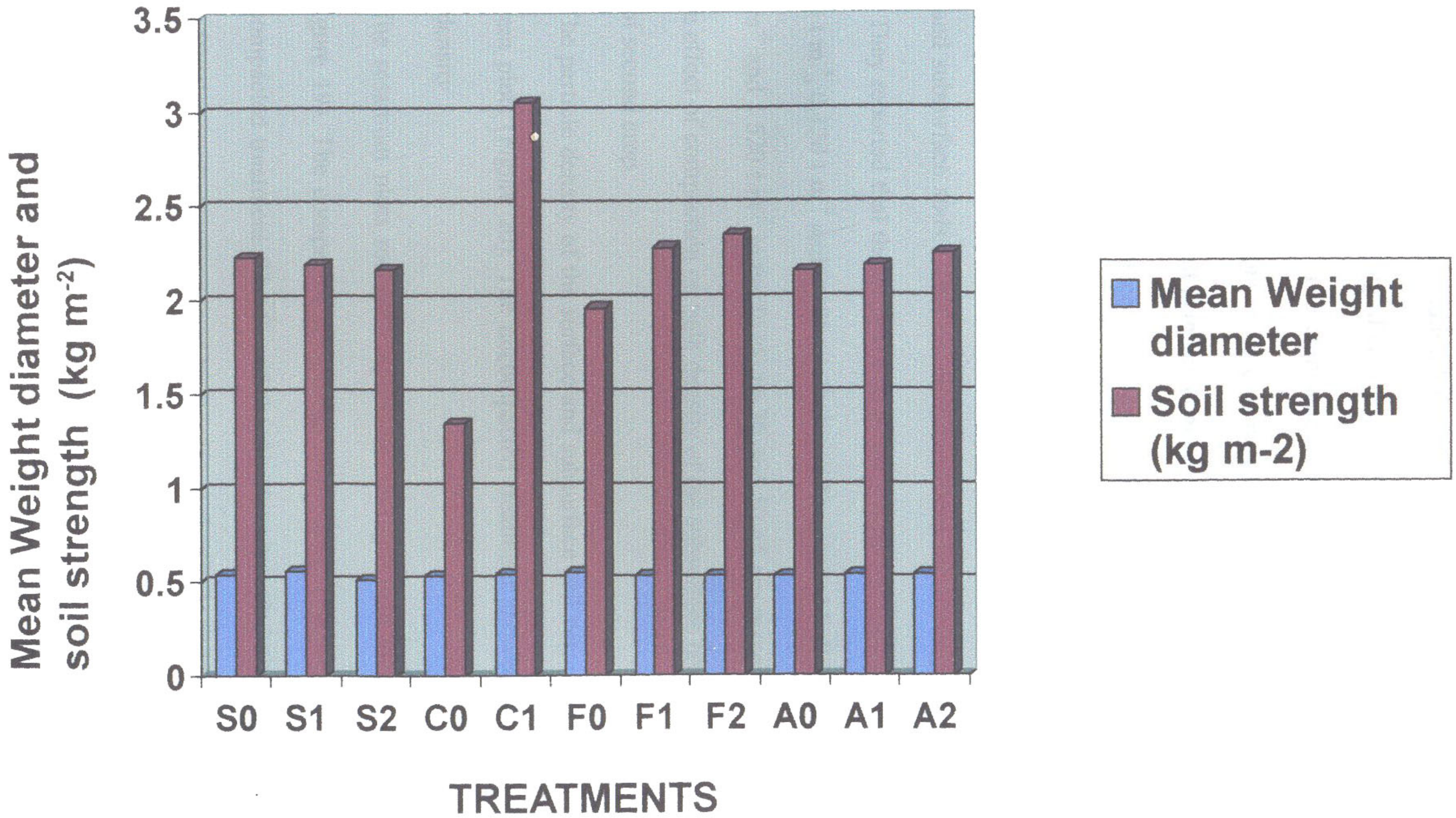


Figure 19. Main effects of treatments on mean weight diameter and strength of surface soil of sesamum, greengram and cowpea



compaction interlocked the aggregates in such a way that it minimized the volume of macropores and reduced the percolation losses.

The total porosity was significantly higher in cowpea plots for both surface and subsurface soils (Figure 18). The compacted plots recorded significantly higher total porosity than uncompacted plots. The coir pith treated plots also showed significantly higher total porosity. This result is in accordance with that of Ogunremi *et al.* (1986)

The bulk density of surface soils was significantly higher in cowpea plots (Figure 20). Where as the green gram plots recorded significantly higher bulk density of subsurface soils. The compacted plots showed significantly higher bulk density of surface and subsurface soils. This result corroborates the findings of Gupta and Abrol (1993). They reported that the compaction of the loamy sand increased the bulk density by 0.140 t m^{-3}, 0.120 t m^{-3} and 0.100 t m^{-3} above the original bulk density of 1.480 t m^{-3} 1.530 t m^{-3} and 1.520 t m^{-3} in the 0-15, 15-30 and 30-45 cm respectively. According to them, the effect of compaction on bulk density of the subsurface layers persisted until the harvest of second crop.

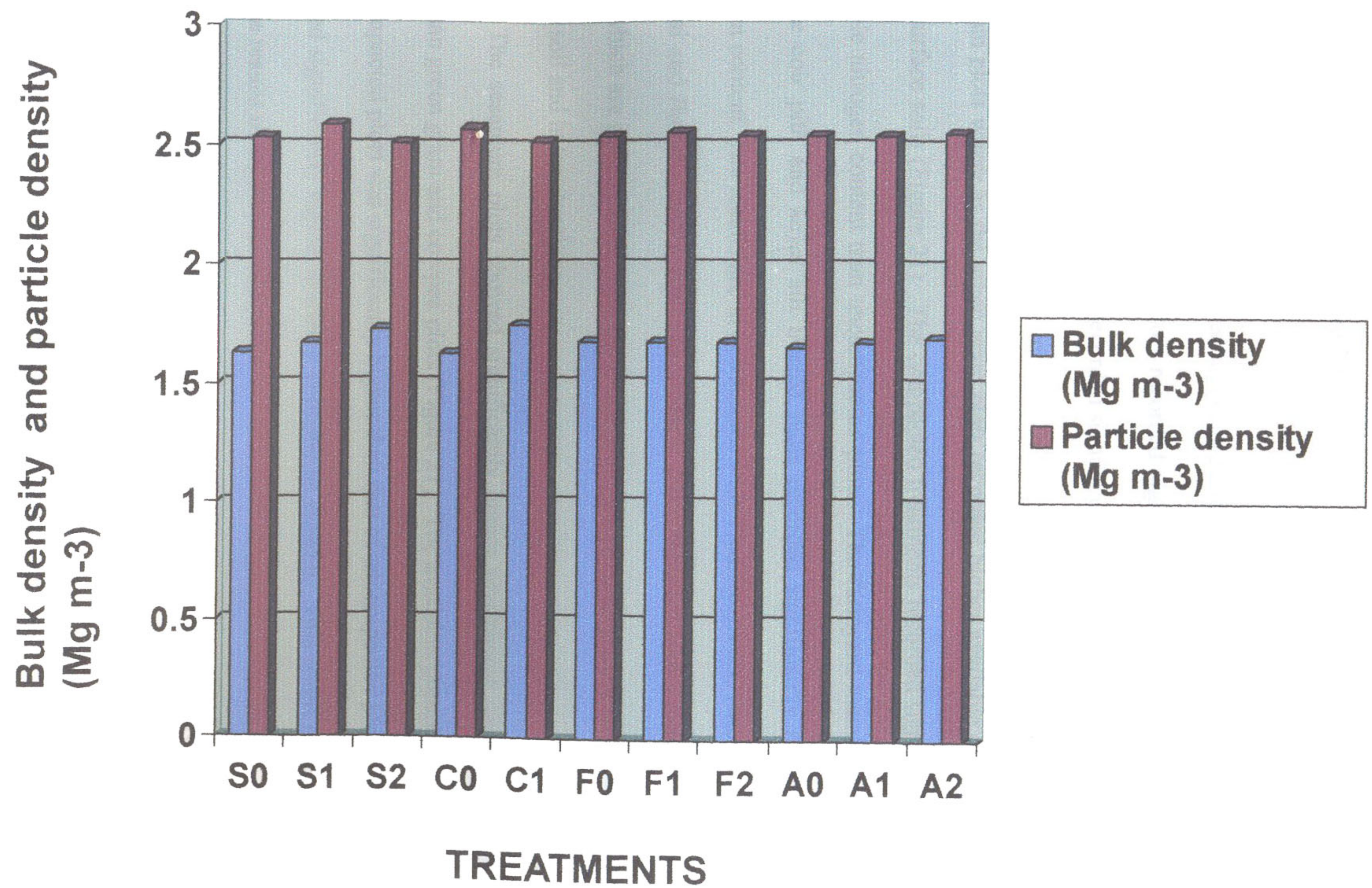
The particle density of the surface and subsurface soil was significantly higher in green gram plots (Figure 20). The uncompacted treatment showed significantly higher particle density

The sesamum plots recorded higher soil strength than green gram and cowpea plots (Figure 19). The compacted treatments showed significantly higher soil strength than uncompacted treatment. The F_1 and the A_2 plots recorded significantly higher soil strength. Similar results were reported by Bauder *et a*l. (1981) and Swan *etal.*(1987)

5.3.3 Effect of treatments on chemical characteristics of soil.

The pH of the surface and subsurface soils were significantly higher in sesamum

Figure 20. Main effects of treatments on bulk density and particle density of surface soil of sesamum, greengram and cowpea



plots. The soil pH was higher in compacted plots. The coir pith and *kayal* silt treated plots also recorded significantly higher pH. The compaction of the soil helped to retain more cations in the soil. This may be the reason for increase in pH in the compacted treatments

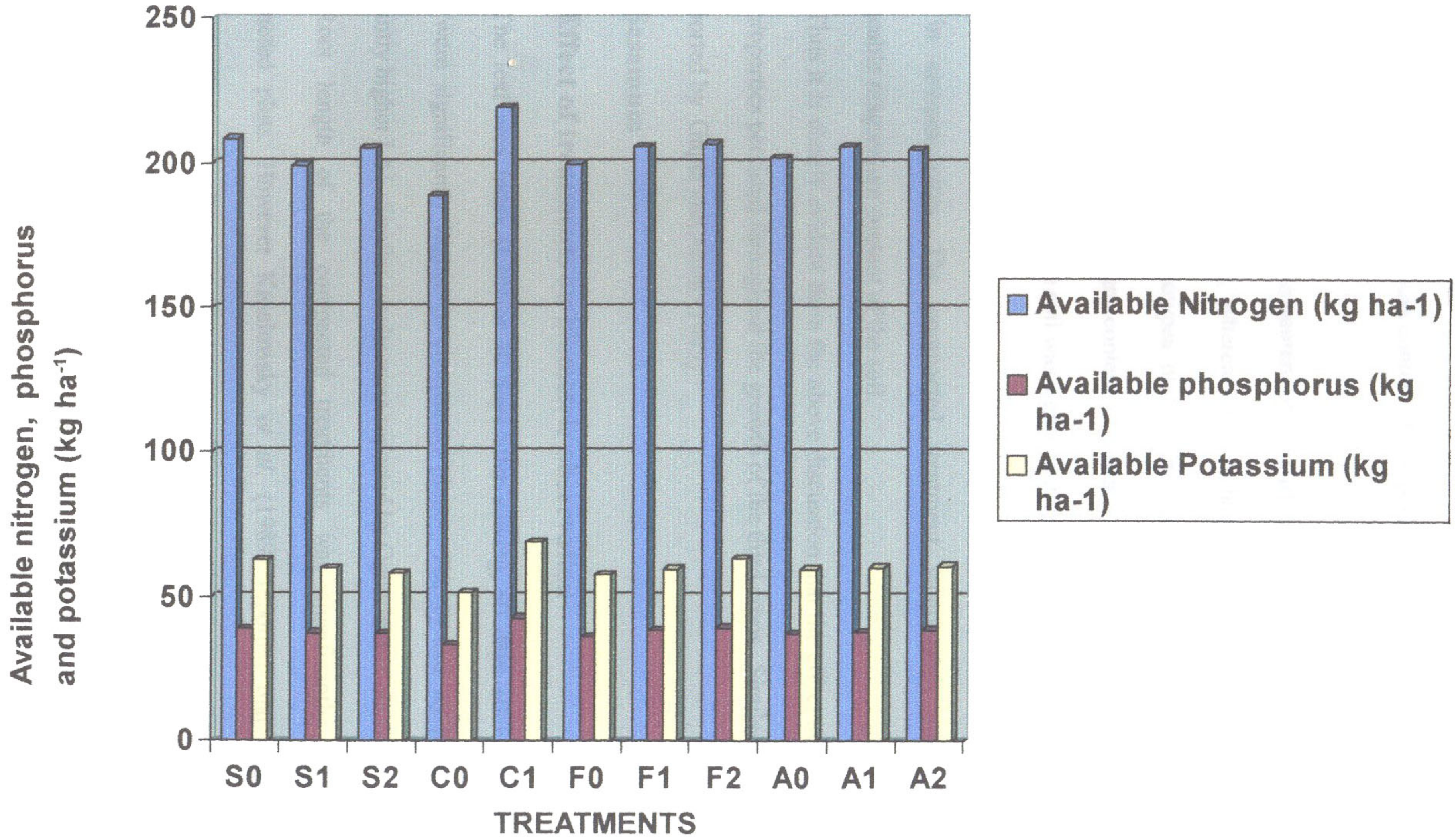
The sesamum plots recorded higher organic carbon content than green gram and cowpea plots. The compacted plots recorded significantly higher organic carbon than uncompacted plots. The F_2 plots recorded significantly higher organic carbon content.

The available nitrogen content of the surface soils was significantly higher in sesamum plots where as the green gram plots recorded higher available nitrogen content in subsurface soils (Figure 21). The compacted treatments recorded significantly higher available nitrogen content than uncompacted plots. The farmyard manure treated plots and the coir pith and *kayal* silt treated plots recorded significantly higher available nitrogen content. The results are in accordance with Tindzhyulis and Brazauskas (1987), Agrawal and Jhorar (1989), Agrawal (1991). They reported that compaction of sandy soils, which are conducive to leaching resulted in considerably greater nitrate retention in the top soil and in less leaching.

The sesamum plots showed significantly higher phosphorus content of surface soils than green gram and cowpea plots (Figure 21). The available phosphorus content of the compacted plots was significantly higher than that of uncompacted plots. The F_2 plots recorded significantly higher available phosphorus content. This result is in accordance with the results of Ogunremi *etal.*(1986)

The available potassium content of the soil was significantly increased in sesamum plots (Figure 21). The compacted plots showed significantly higher available potassium content. The F_2 and A_2 plots showed significantly higher potassium content.

Figure 21. Main effects of treatments on available nitrogen, phosphorus and potassium of surface soil of sesamum, greengram and cowpea



Mathan *et al.* (1994) reported that increase in compaction from 1.5 to1.8 Mg m^{-3} resulted in an increase in available potassium content of soil perhaps due to moisture retention and solubilisation.

The exchangeable calcium content of the surface soil was significantly higher in green gram and cowpea plots, whereas the exchangeable calcium content of the subsurface soil was higher in cowpea plots. The compaction treatment significantly reduced the exchangeable calcium content of surface soil, where as the exchangeable calcium content of the subsurface soil was significantly increased by compaction.

The exchangeable magnesium content of the surface and subsurface soil was higher in cowpea plots. The compacted treatment significantly increased the exchangeable magnesium content of the soil.

Thus it is clearly evident from the above discussion that the effect of compaction on soil properties persisted throughout the growth of the third crops. Similar results have been reported by Gupta and Abrol (1993)

5.4 Sesamum

5.4.1 Effect of treatments on biometric observation

The leaf area index (LAI) at 30 days after sowing, 60 days after sowing and harvest were significantly higher in compacted plots. The F_2 and A_2 plots showed significantly higher LAI. Similar results were reported by Ogunremi *et al.*(1986)

Root length of the compacted treatments was significantly lower than uncompacted plots. However Kaselowsky *et al.* (1989) reported that there is no significant effect of soil compaction on total root length of sugar beet grown in compacted soil.

The root volume and root density of the compacted plots were significantly higher compared to uncompacted plots. The farmyard manure treated plots recorded significantly higher root volume and root density. The *kayal* silt treated plots recorded significantly higher root density. Sharma (1995) reported that in compacted plots root mass density was greater in 0-10cm layer. About 98per cent of the total root length density was in 0-20cm layer in compacted plots. Root: shoot dry weight ratios was greatest in compacted plots. Sub soil compaction led to greater concentration of rice roots in plough layer above the compacted zone.

The time taken for 50per cent flowering was significantly lower in compacted plots. Sesamum took an average of 36 to 37 days for 50per cent flowering in all the treatments. The other treatments did not significantly affect the above observation. This was in conformity with the findings of Sharma (1995).

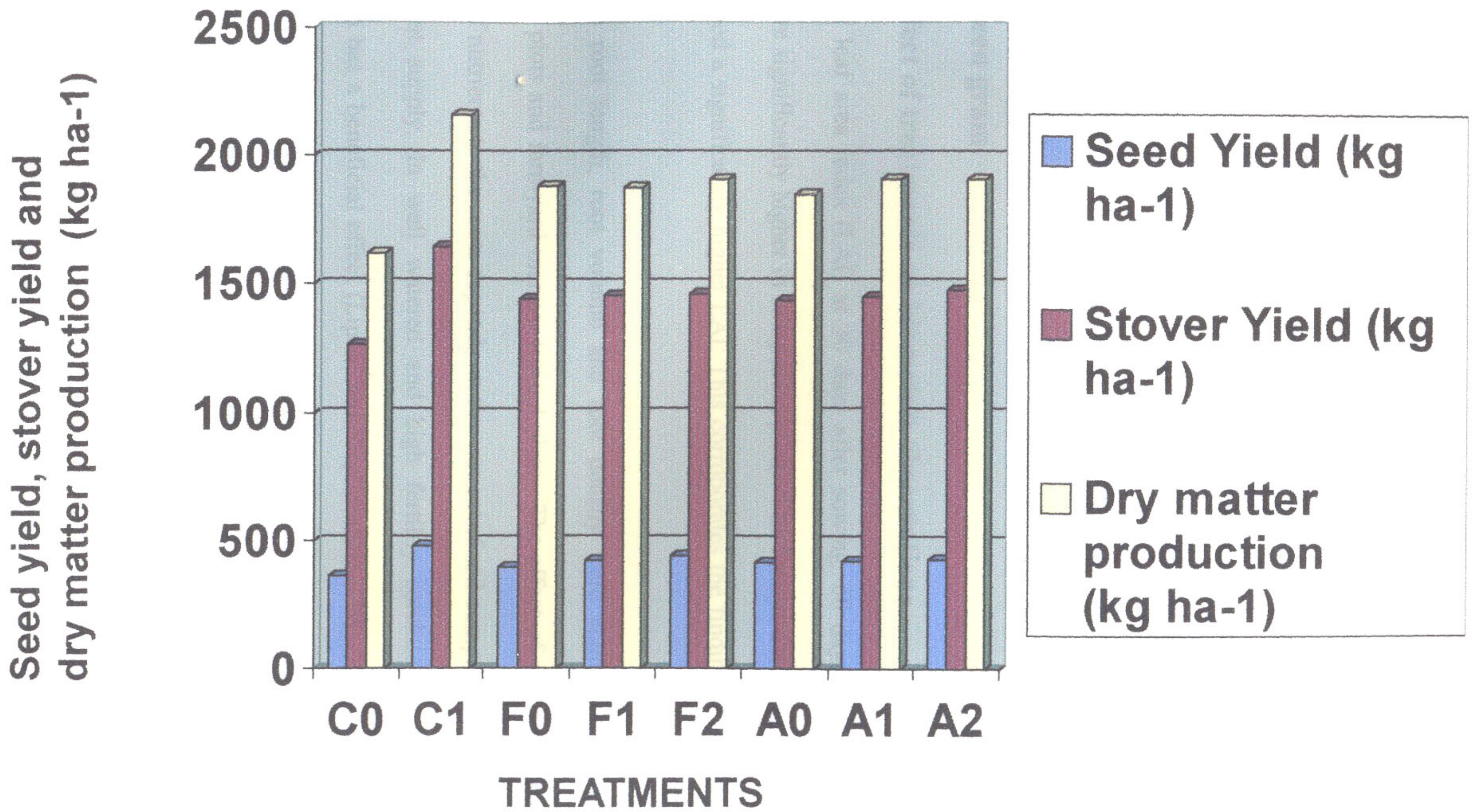
5.4.2 Effect of treatments on the yield and quality.

The seed yield, stover yield and dry matter production were significantly higher in compacted treatment compared to uncompacted treatment (Figure 22). The F_2 and A_2 plots showed significantly higher yield. The increase in yield as a result of compaction has been reported by several workers (Mathan and Natesan (1990), Gupta and Abrol (1993), Sharma *et al.* (1995). The increase in water and nutrient retention in the soil due to compaction resulted in higher yields in compacted plots.

The oil content of sesamum in the compacted plots and the F_2 was significantly higher than other treatments. This may be attributed to the better growth of plants in compacted plots.

The crude protein content of the compacted plots and the F_2 plots were significantly higher. The higher nutrient retention in the compacted plots compared to the

Figure 22. Main effects of treatments on seed yield, stover yield and dry matter production of sesamum



uncompacted plots resulted in higher crude protein content. The crude protein content reflects the level of nitrogen uptake.

5.4.2 The effect of treatments on the total nutrient content in plant.

The nitrogen, phosphorus, potassium, calcium and magnesium content of the plant was significantly higher in compacted plots compared to uncompacted plots. The farm yard manure treated plots recorded significantly higher N, P, Ca and Mg content. This corroborates the findings of Ogunremi *et al.*, (1986), Agrawal and Jhorar (1989), and Agrawal(1991).

5.5 Green gram

5.5.1 Effect of treatments on biometric observations

The leaf area index (LAI) at 30 days after sowing, 60 days after sowing and harvest were significantly higher in compacted plots. The farmyard manure treated plots also recorded a significantly higher LAI. This corroborates the findings of Ogunremi *et al.* (1986).

The root length, root volume and root density were significantly higher in compacted plots and farmyard manure treated plots. The effect of soil compaction on transport of nutrients to the roots depends on the amount of soil compaction and on water and nutrient supply. In well watered and high fertility conditions, moderate soil compaction has a beneficial effect (Lipiec and Stepniewski, 1995). This can be due to the greater water retention and hydraulic conductivity in the case of mass flow transport, (Kemper *et al.*,1977) increased diffusion coefficient of ions (Warncke and Barber, 1972, Bhadoria *et al.*,1991) or to increased ion concentration in soil.

5.5.2 Effect of treatments on yield and quality.

The seed yield and haulm yield were significantly higher in compacted plots (Figure 23). Gupta and Abrol (1993) reported that the compaction of the loamy sand significantly increased the grain yield of rain fed pearl millet and guar by 25.4 percent and 25.0 percent over the control yields of 1.36 t ha^{-1} and 1.00 t ha^{-1} respectively.

The crude protein content of seed in the C_1, F_1 and F_2 plots was significantly higher than C_0 and F_0 plots. Better N utilization in the compacted treatment at all growth stages due to higher dry matter accumulation and increased concentration of nitrogen has been reported by Ogunremi (1986). This may be the reason for higher crude protein content in compacted treatments.

5.5.3 Effect of treatments on total nutrient content in plant.

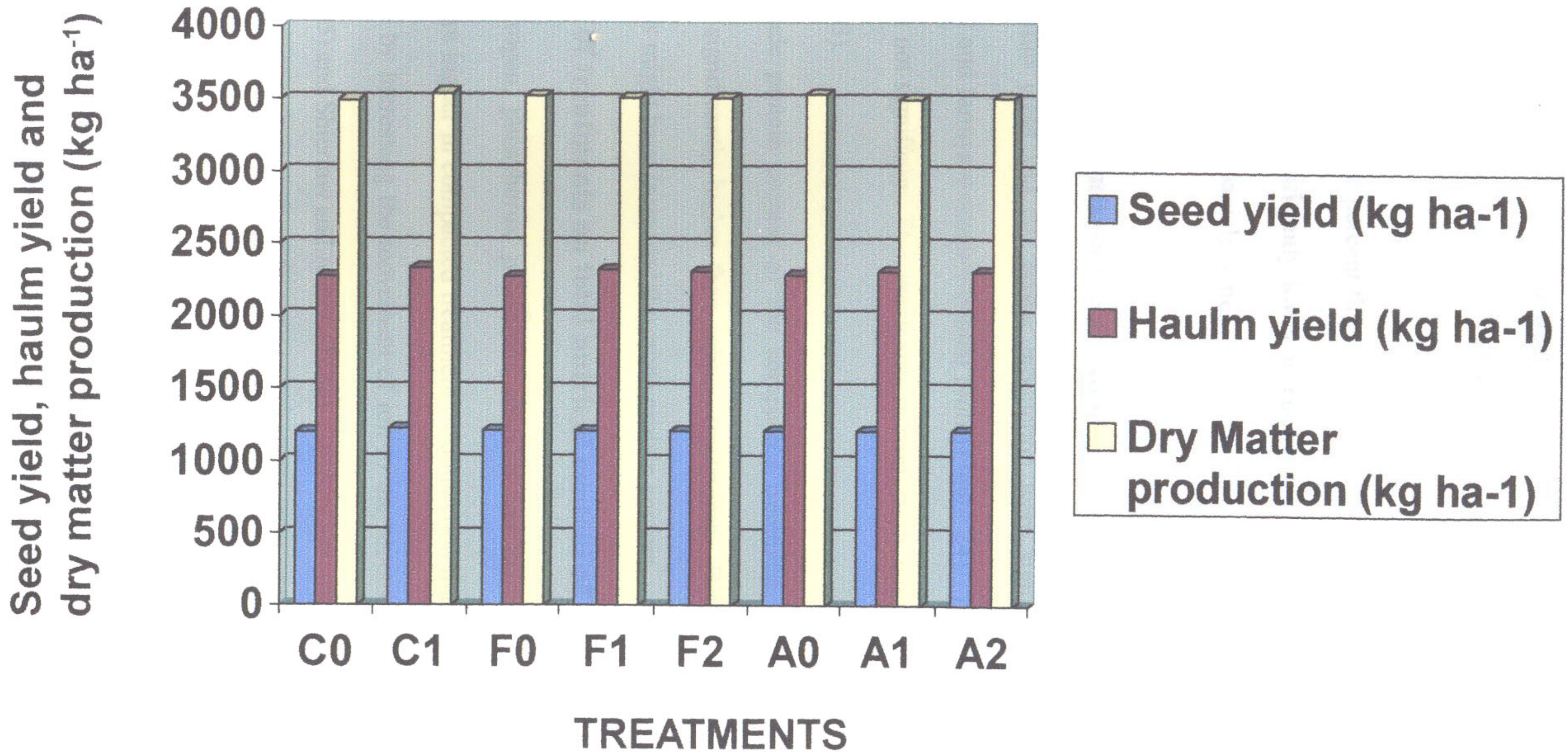
The compacted plots recorded significantly higher nitrogen, phosphorus, potassium, calcium and magnesium content of the plant tissue. The farm yard manure and *kayal* silt treatments showed significantly higher N, P, K, Ca and Mg content of plant tissue. This is in agreement with the findings of Lipiec and Stepniewski,(1995) and Mathan *et al.*, (1994)

5.6 Cowpea.

5.6.1 Effect of treatments on biometric observations

The leaf area index (LAI) at 30 days after sowing, 60 days after sowing and harvest were significantly higher in compacted plots. The farmyard manure treated plots also recorded significantly higher LAI. This was in conformity with the findings of Ogunremi *et al.* (1986).

Figure 23. Main effects of treatments on seed yield, haulm yield and dry matter production of greengram



The root length, root volume and root density were significantly higher in compacted plots. The farmyard manure treatments also recorded significantly higher root length, root volume and root density. This was in conformity with the findings of Ogunremi (1986).

The time taken for 50 percent flowering was 43 to 44 days in all treatments. The above observation was significantly lower in compacted treatments. However Sharma (1995) has reported that panicle emerged seven days earlier in subsoil compacted treatments.

5.6.2 Effect of treatments on yield and quality.

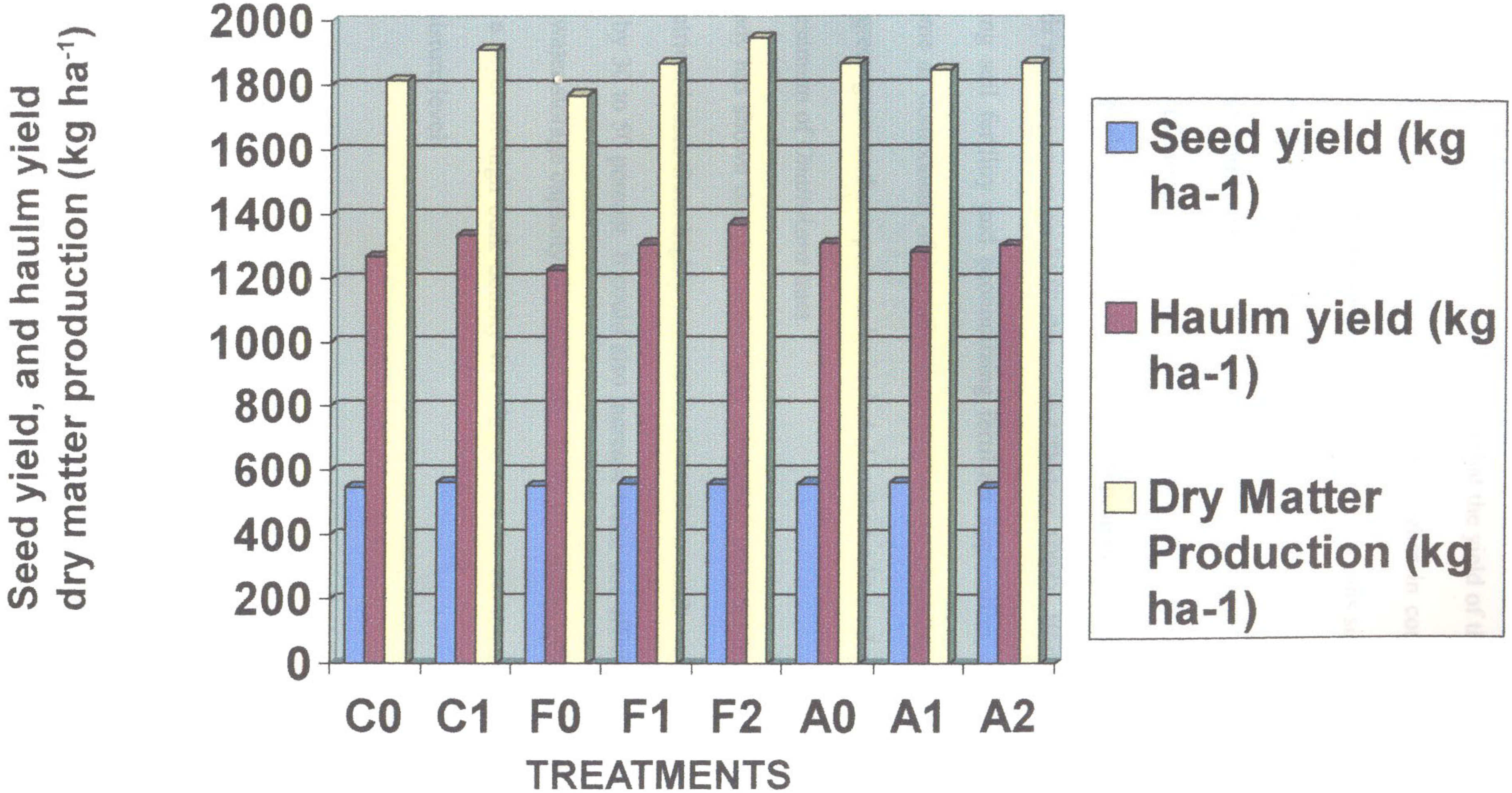
The haulm yield and dry matter production were significantly higher in the compacted plot and farmyard manure treated plots (Figure 24). The treatment effect on grain yield was not significant. This result was in conformity with the findings of Gupta and Abrol (1993).

The crude protein content of the compacted treatment and farmyard manure treatment was significantly higher than control treatments. Better N retention in the compacted plots might have increased the crude protein content.

5.6.3 Effect of treatments on total nutrient content of plant.

The nitrogen, phosphorus, potassium, calcium and magnesium content of the plant tissue were higher in compacted treatment. Compaction may actually increase the nutrient uptake by increasing the movement of ion to the roots via diffusion (Hoffman and Jungk (1995) and Shierlaw and Alston (1984).

Figure 24. Main effects of treatments on seed yield, haulm yield and dry matter production of cowpea



5.7 Effect of treatments on cropping system.

It is clearly evident from the above discussion that the yield of the two crops of rice, sesamum, green gram and cowpea were significantly higher in compacted treatments. The observations on the soil properties and biometric observations suggest that the effect of compaction persisted through out the third crop season. This is in conformity with the findings of Gupta and Abrol (1993).

Diversification of cropping provides an insurance against total crop failure. Thus there is a need for developing efficient rice based, cropping system that can ensure stable optimal yields and maximum profit (Pathania and Thakur, 1994). With the over all view of maintaining soil fertility and economizing fertilizer application, it is beneficial to include legume as component of intensive cropping system (Palaniappan, 1985). With this in view green gram and cowpea can be included in the traditional cropping system of Rice-Rice-Sesamum of *Onattukara* tract.

This study has shown that the surface and subsurface compaction could reduce the water and nutrient losses from highly permeable *Onattukara* sandy soil and increase the productivity by 30 to 50 percent. It could also increase water use efficiency of crops and increase the water storage capacity of surface soil. It has also demonstrated the feasibility of inducing a layer of high bulk density in a large area by compaction of the soil at optimum moisture level.

SUMMARY

SUMMARY

An investigation was carried out at Rice Research Station, Kayamkulam to study the effect of soil compaction with organic manure and amendments on soil physical properties, nutrient availability, rooting pattern, yield and quality of crops like rice, sesamum, green gram and cowpea under rice based cropping system of *Onattukara* tract of Kerala.

The treatments included two levels of compaction, three levels of farm yard manure and three levels of soil amendments in different combinations. The compaction treatments were zero compaction and compaction with four passes of 400 kg roller. The farm yard manure treatments consisted of no farm yard manure, farm yard manure @ 2.5 t ha^{-1} and farm yard manure @ 5 t ha^{-1}. Coir pith @ 5 t ha-^{1} , *kayal* silt @ 5 t ha^{-1} and control were the amendment treatments.

Two crops of rice (variety - Bhagya) were raised in the kharif and rabi seasons. During the summer season, each plot of rice was divided into three equal plots and sesamum, green gram and cowpea were raised in these plots. The compaction treatment was given only once, before the sowing of kharif rice. All other treatments were given before the planting of each crop.

The soil properties, nutrient availability, rooting pattern and yield of all the crops were altered by the treatments. After the harvest of the first crop of rice, the available water content was significantly higher in compacted plots compared to uncompacted plots. The hydraulic conductivity and infiltration rate were significantly lower in compacted plots. The field moisture content was higher in coir pith and *kayal* silt treated plots. The microporosity of the soil was also higher in compacted plots.

As a result of compaction treatment the soil strength increased from 1.08 to 3.33 kg m^{-2}. Among the nutrients available N, P, K and exchangeable Ca and Mg were significantly higher in compacted plots. The leaf area index at flowering stage was significantly higher in compacted plots and farm yard manure treated plots. The root volume and root density were significantly higher in compacted treatment, farm yard manure treatment and coir pith and *kayal* silt treatments. The grain yield, straw yield, dry matter production and crude protein content were significantly higher in compacted plots. The treatment $C_1F_1A_1$ recorded the highest grain yield of 3.15 t ha^{-1}. The *kayal* silt and coir pith treatments significantly increased the crude protein content. The N, P and K content in plants were significantly higher in compacted and farm yard manure treated plots.

The treatments significantly influenced the soil properties, nutrient availability and yield of rabi rice also. The available water content was significantly higher in compacted plots where as hydraulic conductivity showed a significant decrease in compacted plots. The mean weight diameter significantly increased in farm yard manure treated plots. There was an increase in the microporosity of the surface soil and a decrease in macroporosity as a result of compaction. Soil strength significantly increased in compacted plots, farmyard manure treated plots and coir pith and *kayal* silt treated plots. The organic carbon content of the soil was higher in compacted and farm yard manure treated plots. The compacted plots recorded significantly higher available N, P, K and exchangeable Mg content.

The leaf area index significantly increased in compacted plots. The time taken for maximum tillering and 50 percent flowering significantly decreased in compacted plots. Root length, root volume and root density were significantly higher in compacted plots. The highest grain yield of 2.72 t ha^{-1} was recorded in $C_1F_2A_1$ treatment. The grain yield, straw yield, dry matter production and crude protein content were significantly higher in compacted treatment and farm yard manure treatment. The N, P and K content in plants were also higher in the compacted and farm yard manure treated plots. The coir pith and *kayal* silt treated plots recorded higher potassium content.

The effect of compaction persisted after the harvest of summer crops also as evident from the result. The main effects of compaction, farm yard manure, coir pith and *kayal* silt significantly increased the field moisture content, available water content, maximum water holding capacity, bulk density, microporosity and total porosity and decreased the hydraulic conductivity and macroporosity for sesamum, green gram and cowpea. The available N and P content of the soil was higher in compacted plots.

The leaf area index, root volume, root length and root density were significantly higher in compacted treatment, farm yard manure treatment and amendment treatment. The compacted plots recorded relatively less time taken for 50 percent flowering.

Highest seed yield of sesamum was recorded in the $C_1F_2A_1$ treatment. Main effect of compaction and farm yard manure significantly increased the oil content and protein content. The treatment $C_1F_2A_0$ recorded the highest seed yield of green gram. The N, P and K and protein content were significantly increased by compaction treatment. The highest seed yield of cowpea was recorded in the $C_1F_2A_1$ treatment. The N, P and K content in plants and protein content were significantly increased in the compacted treatment.

Thus it can be concluded that compaction of coarse textured soil along with application of 2.5 t ha^{-1} farm yard manure and 5 t ha^{-1} coir pith significantly improved the soil physical properties, nutrient availability and in turn the yield of different crops under rice based cropping system of *Onattukara* tract of Kerala. Among the amendments the coir pith was found to be the best as far as yield is concerned in relation to soil physical properties.

Further investigations with more compaction and with reduced levels of amendments like coir pith and *kayal* silt can be carried out to get more confirmatory results for using the locally available materials, free of cost. Definitely the compaction technology can be adopted to increase the rice yield of *Onattukara* belt especially during the first crop without much financial involvement. This technology can be tried in similar soils which contains more than 70 to 80 percent sand, to increase the production potential.

REFERENCES

REFERENCES

Abo-Abda, A. and Hussain, G. 1990. Impact of machinery compaction and tillage systems on infiltration rates of sandy soils. *Arid Soil Res. Rehabil.* **4:** 157-162

Acharya, C.L. and Sood, M.C. 1992. Effect of tillage methods on soil physical properties and water expenses of rice on an acidic alfisol. *J. Ind. Soc. Soil Sci.* **40:** 409-414

Agrawal, R.P. 1980.. Soil and water management in arid zone. *Trans. Indian Soc. Desert Technol.* **5**: 129-135

Agrawal, R.P. 1988. Soil, water and crop management for sandy ecosystem. *Int. J. Trop. Agric.* **6**: 20-25

Agrawal, R.P. 1991. Water and nutrient management in sandy soils by compaction. *Soil Tillage Res.* **19:** 121-130

*Agrawal, R.P. 1992. Managing soil compaction for cotton production. *Soil compaction and soil management.* Proceedings of International Conference on Soil, June 8-12 1992, Scientific – Creative Association "Ecofiller", Tallinn, Estonia, pp 50-55

*Agrawal, R.P. and Jhorar, B.S. 1989. Reducing nitrogen leaching in sandy soils. *Proceedings of International Symposium On Managing Sandy Soils,* February 1989. Central Arid Zone Research Institute, Jodhpur, pp. 414-417

Agrawal, R.P., Jhorar, B.S., Dhankar, J.S. and Raj, M.1987. Compaction of sandy soils for irrigation management. *Irrig. Sci.* **8:** 227-232

*Al-Janabi, A.S.1989. The effect of soil compaction on soil physical properties and wheat growth. *Mesopotamia Journal of Agriculture.* **21**(1): 85-96

Arunarajagopal, Asokaraja, N. and Velu.G. 1995. Impact of irrigation management practices and soil amendments in ground nut. *Madras Agric. J.* **82**: 341-344

*Arvidsson, J. 1993. Nutrient uptake in compacted soil – result from two field experiments with barley. *Proceedings of International Conference on Protection of the Soil Environment by Avoidance of Compaction and proper Soil Tillage*, August 23-27, 1993. Melitopol Research Institute of Agricultural Mechanics, Melitopol, Ukraine, pp. 21-25

Barraclough, P.B. and Weir, A.H..1988. Effects of compacted sub soil on root and shoot growth, water use and nutrient uptake of winter wheat. *J.Agric.Sci.*110:207-216

Bauder, J.W., Randall, G.W. and Swan, J.B. 1981. Effect of four continuous tillage systems on mechanical impedence of a clay loam soil. *Soil Sci. Soc. Am. J.* **45**: 802-806

Bavel, V.C.H.M. 1949. Mean weight diameter of soil aggregates as a statistical index of aggregation. *Soil Sci. Soc. Am. Proc.* **14**: 20-23

*Bhadoria, P.B.S., Kaselowsky,J., Classen,N. and Jungk,A. 1991. Impedence factor for chloride diffusion in soil as affected by bulk density and water content. *Z. pflanzenernachr. Bodenkd.*, **154**: 69-72

Bhagat, R.M. 1990. Effect of tillage and residue management on hydro-thermal regime, nutrient uptake and yield of wheat in a river deposit . *Soil Tillage Res.*, **17**: 315-326

Bindhu, J.S. 1999. Production potential and economics of sesamum – pulse intercropping in *Onattukara* tract, MSc (Ag) thesis, Kerala Agricultural University, Trichur. p.110

Byrd, C.W. and Cassel, D.K. 1980. The effect of sand content upon cone index and selected physical properties. *Soil Sci.* **129:** 197-204

Cameron, D.R., Knoalenko, C.G. and Ivarson, K.C 1978. Nitrogen and chloride leaching in sandy field plot. *Soil Sci.* **126:** 174-180

Canarache, A., Colibas, I. Horobeanu, I., Patru,V., Simota, H. and Trandafirescu,T. 1984. Effect of induced compaction by wheel traffic on soil physical properties and yield of maize in Romania. *Soil Tillage Res.***4:** 199 - 213

Carter, M.R. 1988. Temporal variability of soil macro porosity in a fine sandy loam under mould board ploughing and direct drilling. *Soil Tillage Res.* **12:** 37-51

Carter, M.R. 1990. Relationship of strength properties to bulk density and macro porosity in cultivated loamy sand to loam soils. *Soil Tillage Res.* **15:** 257 – 268

Carter, M.R. 1991. Evaluation of shallow tillage for spring cereals on a fine sandy loam . 2. Soil Physical, Chemical and Biological Properties. *Soil Tillage Res.* **21:** 37-52

Carter, M.R., Kunelius, H.T., White, R.P. and Campbell, A.J. 1990. Development of direct drilling systems for sandy loam soils in the cool humid climate of Altantic Canada. *Soil Tillage Res.* **16:** 371-387

Cassel, D.K. 1982. Tillage effects on soil bulk density and mechanical impedence. *Predicting Tillage Effects on Soil Physical Properties and processes* (eds.Unger, P.W. and Van Doren,D.M.) American Society of Agronomy., Madison, Wisconsin, p. 145

Chaney, R. and Swift, R.S., 1984. The influence of organic matter on aggregate stability in some British soils. *J. Soil Sci.* **35:** 223-230

Chaudhary, M.R., Gajri, P.R., Prihar, S.S. and Khera, R. 1985. Effect of deep tillage on soil physical properties and maize yields on coarse textured soils. *Soil Tillage Res.* **6:** 31-44

Christensen, B.T. 1986. Straw incorporation and soil organic matter in macro aggregates and particle size separates. *J. Soil Sci.* **37:** 125-135

Cruse, R.M., Cassel, D.K. and Averett, F.G. 1980. Effect of particle surface roughness on densification of coarse textured soil. *Soil Sci. Soc. Am. J.* **44:** 692-697

Dolan, M.S. Dowdy, R.H., Voorhees, W.B., Johnson, J.F. and Bidwellschrader.1992. Corn phosphorus and potassium uptake in response to soil compaction. *Agron J.* **84:** 639-642

Douglas, E. and Mckyes, E. 1982. Tillage practices related to limiting plant growth factors and crop yields. *Can. Agric. Eng.* **25**: 47-55

Durai, R., Chinnaswami, K.N. and Kumaraswamy,K. 1996. Conservation of moisture through amendments under varying irrigation regimes on sugarcane (*Saccharum Officinarum). Indian J. Agron.* **41**(3): 468-471

Gajri, P.R., Arora, V.K. and Chaudhary, M.R. 1994. Maize growth responses to deep tillage, straw mulching and farm yard manure in coarse textured soils of N.W. India. *Soil Use and Management.* **10:** 15-20

Gediga, K.1991. Influence of sub soil compaction on the uptake of ^{45}Ca from the soil profile and on maize yield. *Soil Tillage Res.* **19:** 251-355

Ghildyal, B.P. 1978. Effect of compaction and puddling on soil physical properties and rice growth. *Soils and Rice.* International Rice Research Institute, Los Banos, Phillipines, pp. 317-336

Gomez, K.A. and Gomez, A.A. 1984. *Statistical procedures for Agricultural Research.* Second edition. John Wiley and Sons, Newyork. p.680

Greacen, E.L. and Sands, R. 1980. Compaction of forest soils – a review. *Aust. J. Soil Res.* **18:** 163-189

Gulati, I.J., Ladha, K.C., Lal, F. and Gupta.R.P. 1985. Effect of compacting sandy soil on soil physical properties and yield of guar. *Trans. Indian Soc. Desert Technol.* **10**: 19-23

Gupta, R.P. and Abrol, I.P. 1993. A study of some tillage practices for sustainable crop production in India. *Soil Tillage Res.* **27:** 253-272

*Gupta, J.P., Agrawal, R.P. and Somani, L.L., 1989. Managing soil physical environment. *Reviews of Research on Sandy Soils in India.* International Symposium on Managing Sandy Soils, February 1989, Central Arid Zone Research Institute, Jodhpur, pp. 175-192

Gupta, R.P. and Dakshinamoorthi, C. 1980. *Procedures for physical analysis of agrometerological data.* Indian Agricultural Research Institute, New Delhi, p. 101

Gupta, R.P., Kumar,S. and Singh,T. 1984. *Soil Management to increase crop production.* Indian Council of Agricultural Research, New Delhi, p. 158

Gupta, S.C., Sharma, P.P. and DeFranchi, S.A. 1989. Compaction effects on soil structure. *Adv. Agron.* **42:** 311-338

Hadas, A., Rawitz,E., Elkin,H. and Margolin, M. 1994. Short-term variations of soil physical properties as a function of the amount and C/N ratio of decomposing cotton residuces. I. Soil aggregation and aggregate tensile strength. *Soil Tillage Res.* **32:** 183 – 198

Hallmark, W.B. and Barber, S.A. 1981. Root growth and morphology, nutrient uptake, and nutrient status of Soya beans as affected by soil K and bulk density. *Agron. J.* **73:** 779-782

Hart, P.B.S., Kings, J.A., Ross, C.W. and Julian, J.F. 1988. Bio chemical and Physical properties of Tokomaru silt loam under pasture and after 10 years of cereal cropping. *N.Z.J. Agric. Res.* **31:** 77-86

Haynes, R.J., Swift, R.S. and Stephen, R.C. 1991. Influence of mixed cropping rotations (pasture-arable) on organic matter content, water stable aggregation and clod porosity in a group of soils. *Soil Tillage Res.*, **19:** 77-87

Hifiker, R.E. and Lowery, B., 1988. Effect of conservation tillage systems on corn root growth. *Soil Tillage Res.*, **12:** 269-283

Hoffmann,C. and Jungk.A. 1995. Growth and phosphorus supply of sugar beet as affected by soil compaction and water tension. *Plant soil.* **176:** 15-25

Horne, D.J., Ross, C.W. and Hughes, K.A. 1992. Ten years of a maize /oats rotation under three tillage systems on a silt loam in New Zealand. 1. A comparison of some soil properties. *Soil Tillage Res.* **22:** 131-143

Jackson, M.L., 1973. *Soil Chemical Analysis.* Prentice Hall of India Private Ltd., New Delhi, p. 498.

Jadhav. 1989. Nutrient balance with fertilizer management under wheat based cropping system. *J. Maharashtra Agric. Univ.* **14** (3): 288-291

Kaddah, M.T. 1971. Subsoil chiseling and slip plowing effects on soil properties and wheat grown on a stratified fine sandy soil. *Agron. J.* **68:** 36-39

Kalarani,S. 1995. Competitive and complimentary effects of bhindi + cowpea: intercropping system in summer rice fallows. MSc.(Ag.) Thesis, Kerala Agricultural University, Trichur, p.121

Kartha, A.R.S. and Sethi, A.S.1957. A cold percolation method for rapid gravimetric estimation of oil in small quantities of oil seed. *Indian J. Agric Sci.* **27**(2):211-217

*Kaselowsky, J., Classen, N. and Jungk, A.1989. Effect of soil compaction on the development of shoots and roots of sugar beet and its phosphate nutrition. *Mittelungen der Dentsehn Boden Kundlichen Gesellschaft.* **59**(2): 733-736

KAU. 1996. *Package of Practices Recommendations-Crops.* Kerala Agricultural University, Thrissur. p.267

Kay, B.D., Dexter, A.R., Rasiah, V. and Grant, C.D. 1994. Weather, cropping practices and sampling depth effects on tensile strength and aggregate stability. *Soil Tillage Res.* **32:** 135-148

Kemper, W.D., Stewart, B.A. and Porter, L.K. 1977. *Compaction of Agricultural soils.* ASAE Monograph. American Society of Agricultural Engineers, St. Joseph, MI, p. 217.

Khanna, P.K., Nath, J., Tanija, S.N. and Gopal, V.P. 1975. Effect of organic manuring on some physical properties of sandy loam soils of Hissar. *J.Indian Soc. Soil Sci.* **23:** 380-383

Kulkarni, B.K. and Savant, N.K. 1977. Effect of soil compaction on root exchange capacity of crop plants. *Plant Soil.* **48**: 269-276

Kumar,K., Malik, R.S. and Bhandari, A.R. 1993. Effect of soil compaction on root growth and yield of peas (*Pisum Sativum*). *J. Indian Soc. Soil Sci.* **42** 132-134

Lal, R. 1995. Tillage and mulching effects on maize yield for seventeen consecutive seasons on a tropical alfisol. *J. Sustainable Agric.* **5**(4): 79-93

Larson, W.E. 1964. Soil parameters for evaluating tillage needs and operations. *Soil Sci. Soc. Am. Proc.* **28:** 118-122

Lipiec, J., Hakansson,I. Tarkiewiez,S. and Kossowski,J. 1991. Soil Physical properties and growth of spring barley as related to the degree of compactness of two soils. *Soil Tillage Res.*, **19:** 307-317

Lipiec,J. and Stepniewski, W. 1995. Effect of soil compaction and tillage systems on uptake and losses of nutrients. *Soil Tillage Res.* **35:** 37-52

Mahajan, P.S., Arora, Y. and Chaudhary, M.R. 1981. Manipulation of nitrate nitrogen distribution by different cultural pratices. *J. Indian Soc. Soil Sci.* **29:** 441-445

Mathan.K.K. and Natesan.R. 1990. Effect of soil compaction on soil strength and productivity of swelling clay soils. *J. Ind. Soc. Soil Sci.* **38**: 385-388

Mathan,K.K., Natesan,R. and Rajkannan, B. 1994. Effect of surface and sub soil compaction of a sandy soil on nitrogen and potassium availability and grain yield of maize. *J. Indian Soc. Soil Sci.* **42**: 450-452

Mathew, J., Mathew,R., Varughese.K., Santha Kumari.G. and Pillai, G.R. 1996. Influence of summer cropping and fallowing on fertilizer use efficiency and productivity of rice. *J. Trop. Agric.* **34**: 142-144

McAfee, M., Liindstrom, J. and Johansson, W.1989. Effects of presowing compaction on soil physical properties, soil atmosphere and growth of oats on a dry soil. *J. Soil Sci.* **40**: 707-717

Miller, E.E. and Gardner, W.H. 1962. Water infiltration into stratified soil. *Soil Sci. Soc. Am. Proc.* **19**: 267-271

Misra, R.K., Alston, A.M. and Dexter, A.R. 1988. Root growth and phosphorus uptake in relation to the size and strength of soil aggregates. I. Experimental studies. *Soil Tillage Res.*, **11:** 103-116

Nair, R.R., Pisharody, P.N. and Pillai, G.R. 1976. Response of upland rice to N as influenced by bulk density of soil. *Agric. Res. J. Kerala.* **14** : 168-170

Nicous, R., Charreau, C. and Chopart, J.L. 1993. Tillage and soil physical properties in Semi-arid West Africa. *Soil Tillage Res.* **27:** 125 –147

Nimmo, J.R. and Katherine, C.A. 1988. Hydraulic conductivity of a sandy soil at low water content after compaction by various methods. *Soil Sci. Soc. Am.J.* **52:** 303-310.

Nitant, H.C. and Singh.P. 1995. Effect of deep tillage on dry land production of red gram (*Cajanus cajan L.)* in central India. *Soil Tillage Res.* **34**: 17-26

Oades, J.M. 1984. Soil organic matter and structural stability: mechanisms and implications for management. *Plant Soil.* **76:** 319-337

Ogunremi, L.T., Lal,R. and Babalola, O., 1986. Effects of tillage methods and water regimes on soil properties and yield of low land rice from a sandy loam soil in South-West Nigeria. *Soil Tillage Res.* **6:** 223-322

Pabin, J., Sienkiewie, J. and Wlodek, S. 1991. Effect of loosening and compacting on soil physical properties and sugar beet yield. *Soil Tillage Res.* **19**: 345-350

Palaniappan, S.P. 1985. *Cropping system in the tropics. Principles and managements* Wiley Eastern Ltd., New Delhi. p. 215

Pande, H.K., Mahapatra, I.C., Morachan, V.B., Chatterjee, B.N., Ghildayal, B.P., Singh G.B. and Bapat, S.R. 1985. Research need and directions on rice based cropping systems. *National Symposium on cropping systems*, April 3-5, 1985. (ed. Mahendra Pal) , Indian Society of Agronomy, New Delhi, pp. 76-94

Patnaik, S., Chalam, A.B. and Sahoo, R. 1971 Management of upland soils for optimizing rice yields. *Oryza*, **8:** 275-280

*Patel, M.S. 1977. Effect of soil physical manipulation on water and nitrogen economy in paddy on a loamy sand. Ph.D, thesis, Punjab Agricultural University, Ludhiana. p.214

Patel, M.S. and Singh, N.T., 1981. Change in bulk density and water intake rate of a course textured soil in relation to different levels of compaction. *J. Indian Soc. Soil Sci.* **29:** 110-112

Pathania, P.K. and Thakur, R.C. 1994. Effect of soil moisture conservation (bunding) on single and intercropped paddy rice (*Orza Sativa L.). Soil Tillage Res.* **32**(213-221)

Piper; C.S. 1966. *Soil and plant analysis.* Hans publishers, Bombay, p.384

Prihar, S.S.,Ghildyal, B.P., Painuli, D.K. and Sur, H.S. 1985. Physical properties of mineral soils affecting rice-based cropping systems. *Soil physics and rice*, International Rice Research Institute, Manila, pp. 57-70

Rajendran, P. 1991. Evaluation of coir waste and farm yard manure on soil properties in a cotton based cropping system. MSc(Ag) thesis, Tamilnadu Agricultural University, Coimbatore, p.146

Rasmussen, P.E. and Collins, H.P.1996. Long term impact of tillage, fertilizer and crop residue on soil organic matter in temperate semi arid regions. *Adv. Agron.* **45**:93-134

Reddy. N..M. 1973. Studies on the effects of soil compaction on plant growth and soil properties. Ph.D thesis, University of Agricultural Sciences, Bangalore, p.218

Sadasivam, S. and Manickam, A. 1992. *Bio Chemical methods.* Wiley Eastern Ltd, New Deihi, p. 86

Sharma, P.K and Agrarwal, G.C.1984. Soil structure under different land uses. *Catena.***11**: 197-200

Sharma, P.K., Ingram, K.T. and Harnpichitvitaya, D. 1995. Subsoil compaction to improve water use efficiency and yields of rain fed low land rice in coarse textured soils. *Soil Tillage Res.* **36:** 33-44

Sharma, P.K, Verma, T.S. and Bhagat, R.M. 1995. Soil structural improvements with the addition of *Lantana camara* biomass in rice-wheat cropping. *Soil Use and Management.* **11**: 199-203

Shierlaw, J., and Alston, A.M.1984. Effect of soil compaction on root growth and uptake of phosphorus. *Plant Soil.* **77**: 15-28

Simpson, J.E., Adair, C.R., Kohler G.O., Dawson, E.H., Dabald, H.A., Kester, E.B. and Hlick, J.T. 1965. *Quality evaluation studies on foreign and domestic rices.* Technical Bulletin No:1331, United States Department of Agriculture, Washington, p.92

Singh and Singh, K.P. 1995. Effect of plant residue and fertilizer on grain yield of dry land rice under reduced tillage cultivation. *Soil Tillage Res.* **34:** 115-125

Smika, D.E., Heerman, D.F., Duke, H.R. and Batcheldar, A.R. 1977. Nitrate-N percolation through irrigated sandy soil as affected by water management. *Agron. J.*, **72:** 499-502

Srinivasan, K., Santha.R. and Ramaswamy.M. 1991. Effect of summer pulses on growth and productivity of succeeding kharif maize. *Indian. J. Pulses Res.* **4**(1):51-55

Subbiah, B.V and Asija, G.L. 1956. A rapid procedure for the estimation of available nitrogen in soils. *Current Sci.* **25**(8):259-260

Sur, H.S., Prihar, S.S. and Jalota, S.K. 1981. Effect of rice-wheat and maize rotations on water transmission and wheat root development in a sandy loam of the Punjab, India. *Soil Tillage Res.* **1:** 361-371

Swan, J.P., Moncrief, J.F. and Voorhees, W.B. 1987. *Soil compaction; causes, effects and control.* Minnesota Extension Service Bulletin No. 3115, University of Minnesota, Minnesota, p.78

*Tindzhyulisc, A.P. and Brazauskas, R.P. 1987. Sod podsol soils of silty loam texture in Luthuania *Compaction of Arable Soils.* (ed. Kouda, V.A.) Akad Nauk USSR, Moscow, pp. 60-66

TNAU.1995. *Twenty five years of soil physical research in Tamilnadu.* Tamilnadu Agricultural University, Coimbatore, p. 77

Trojan, M.D. and Linden, D.R. 1998. Macroporosity and hydraulic properties of earth worm affected soils as influenced by tillage and residue management. *Soil Sci. Soc. Am,J.* **62:** 1687-1692.

Unger, P.W. 1997. Aggregate and organic carbon concentration interrelationships of Torrertic paleustol. *Soil Tillage Res.* **42:** 95-113

Vepraskas, M.J. 1984. Cone Index of loamy sands as influenced by pore size distribution and effective stress. *Soil Sci. Am .J.*, **48:** 1220-1225

Waldron, L.T., McMurdie, J.L. and Vomocil, J.A. 1971. Hydraulic conductivity of an isotrophically compressed soil. *Soil Sci. Soc. Amer. Proc.* **34**: 393-396

Warkentin, B.P.1971. Compaction as it affects soil conditions. Effect of compaction on content and transmission of water in soils. *Compaction of agricultural soils.* ASAE Monograph No:1. American Society of Agricultural Engineers, St. Joseph, MI, p. 217.

Warncke, D.D. and Barber, S.A. 1972. Diffusion of zinc in soil .II: The influence of soil bulk density and its interaction with soil moisture. *Soil Sci. Soc. Am. Proc.* **36**: 42-46

Watts, D.G. and Martin, D.L. 1981 Managing water and nitrogen to minimize leaching on sands. *Irrigation the Hope and the Promise.* Irrigation Association, Silver sprint, United States of America, p. 153

Westermann, D.T. and Sojka, R.E.1996. Tillage and nitrogen placement effects on nutrient uptake by potato. *Soil Sci. Soc. Amer. J.* **60**:1448-1453

William, R.S. 1946. Physiology of plant growth with special reference to the concept of NAR. *Ann. Bot.* **10**: 41-72

Wolkowskii, R.P. 1990. Relationship between wheel traffic-induced soil compaction, nutrient availability and crop growth: a review. *J. Prod. Agric.* **3**: 460-469

Wolkowskii, R.P. 1991. Corn growth response to K fertilization on three compacted soils. *Soil Tillage Res.* **21**: 287-298

Yadav, B.L. and Somani, L.L. 1990. Interactive effect of soil compaction and mixing heavy textured soil in a loamy sand soil on physical properties of sandy soil and yield of cluster bean. *Trans. Indian Soc. Desert Technol.* **15:** 43-48

APPENDIX

APPENDIX 1

WEATHER DATA DURING THE CROPS PERIOD (MAY'98 - APRIL'99)

STANDARD WEEK	PERIOD		RAIN FALL (mm)	AVERAGE MAXIMUM TEMPERA-TURE (°C)	AVERAGE MINIMUM TEMPERA-TURE (°C)	AVERAGE RELATIVE HUMIDITY (%)
	From	To				
18	April 30	May 6	30.1	35.2	24.9	75.0
19	May 7	May 13	56.3	35.4	24.7	80.5
20	May 14	May 20	124.8	32.5	25.9	85.0
21	May 21	May 27	5.5	33.9	25.6	82.5
22	May 28	June 3	77.1	34.1	25.6	83.0
23	June 4	June 10	49.8	33.0	24.3	82.0
24	June 11	June 17	140.8	31.5	23.7	87.5
25	June 18	June 24	64.3	31.9	23.9	82.5
26	June 25	July 1	160.7	29.9	23.1	90.5
27	July 2	July 8	54.6	31.5	25.8	80.0
28	July 9	July 15	41.6	31.9	23.8	85.0
29	July 16	July 22	67.0	29.9	23.6	87.0
30	July 23	July 29	66.5	31.5	23.4	86.0
31	July 30	August 5	18.20	31.2	24.0	84.0
[illegible]	August 6	August 12	47.80	30.0	23.9	83.5
[illegible]	August 13	August 19	29.1	30.1	24.3	87.0
[illegible]	August 20	August 26	262.1	30.6	23.6	82.5
35	August 27	September 2	46.1	31.0	23.6	85.5
36	September 3	September 9	185.5	30.3	23.8	86.5
37	September 10	September 16	80.2	31.8	23.3	85.0
38	September 17	September 23	52.3	31.3	24.0	92.0
39	September 24	September 30	83.9	29.4	23.3	80.0
40	October 1	October 7	25.1	30.5	23.2	82.5
41	October 8	October 14	305.3	28.6	23.1	81.0
[illegible]	October 15	October 21	39.2	31.1	22.7	86.0
[illegible]	October 22	October 28	21.6	30.9	23.7	79.0

ANDARD WEEK	PERIOD		RAIN FALL (mm)	AVERAGE MAXIMUM TEMPERA-TURE(°C)	AVERAGE MINIMUM TEMPERA-TURE(°C)	AVERAGE RELATIVE HUMIDITY (%)
	FROM	TO				
44	October 29	November 4	19.8	31.3	23.1	85.0
45	November 5	November 11	129.8	30.0	22.4	79.0
46	November 12	November 18	22.3	31.5	23.5	85.0
47	November 19	November 25	0	32.1	22.9	70.0
48	November 26	December 2	1.7	31.7	23.2	78.5
49	December 3	December 9	22.2	32.0	22.2	81.5
50	December 10	December 16	34.5	31.4	20.6	80.0
51	December 17	December 23	2.9	31.8	21.0	81.5
52	December 24	December 31	0	32.5	20.6	78.0
1	January 1	January 7	0	32.3	19.7	73.0
2	January 8	January 14	3.4	33.0	18.6	72.5
3	January 15	January 21	0	33.8	21.5	73.5
4	January 22	January 28	0	33.4	21.8	72.5
5	January 29	February 4	2.6	32.4	22.2	70.0
6	February 5	February 11	0	32.5	21.9	69.8
7	February 12	February 18	1.8	32.4	21.5	69.5
8	February 19	February 25	0	34.3	22.2	75.5
9	February 26	March 4	21	35.0	26.1	65.0
10	March 5	March 11	31	35.0	23.8	71.5
11	March 12	March 18	21	33.6	25.1	68.0
12	March 19	March 25	2.1	32.5	24.5	71.5
13	March 26	April 1	1.2	33.5	23.5	77.5
14	April 2	April 8	5.8	33.9	23.3	79.0
15	April 9	April 15	74.6	33.4	23.9	79.5
16	April 16	April 22	23.8	33.0	23.4	77.0
17	April 23	April 29	216.7	31.9	24.5	79.0

IMPACT OF SOIL COMPACTION ON THE PRODUCTIVITY OF ONATTUKARA SOILS

By

SREELATHA, A.K.

ABSTRACT OF A THESIS
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ABSTRACT

An investigation was carried out at Rice Research station, Kayamkulam to study the effect of soil compaction with organic manure and amendments on soil physical properties, nutrient availability, rooting pattern, yield and quality of crops like rice, sesamum, greengram and cowpea under rice based cropping system of *Onattukara* tract of Kerala.

The compaction treatment with four passes of a 400 kg roller significantly improved the soil physical properties, nutrient availability and yield of all the crops. The available water content, microporosity, available N, P and K, root volume and root density significantly increased in compacted treatments for all the crops. Application of coirpith and *kayal* silt improved the field moisture content in kharif rice. The hydraulic conductivity and infiltration rates decreased in compacted plots.

The compacted plots recorded less number of days for 50 percent flowering of sesamum, green gram and cowpea. The rabi crop of rice, sesamum and cowpea recorded the highest grain yields of 2.72 t ha^{-1}, 529.79 kg ha^{-1} and 594.78 kg ha^{-1} in the compacted treatment along with coirpith and farm yard manure (@2.5 tha^{-1}) combination, where as the kharif crop of rice recorded the highest grain yield of 3.15 t ha^{-1} in the compacted and coir pith treatments along with 5 t ha^{-1} farm yard manure. The seed yield of green gram was highest in compacted and 5 t ha^{-1} farm yard manure treated plots with no amendments.

Thus it can be concluded that compaction of coarse textured soils along with the application of 2.5 t ha^{-1} farm yard manure and 5 t ha^{-1} coir pith significantly improved the soil physical properties, nutrient availability and inturn the yeild of different crops under rice based cropping system of *Onattukara.*