SOIL STRUCTURE AND ORGANIC CARBON STABILITY OF RAINFED ALFISOLS UNDER LONG-TERM APPLICATION OF MANURE AND FERTILIZERS

BY

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B.Sc. (Ag.)

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DECLARATION

I, **Mr. HEMANTH. C.C,** hereby declare that the thesis entitled **"SOIL STRUCTURE AND ORGANIC CARBON STABILITY OF RAINFED ALFISOLS UNDER LONG-TERM APPLICATION OF MANURE AND FERTILIZERS"** submitted to the **Acharya N. G. Ranga Agricultural University** for the degree of **Master of Science in Agriculture** is the result of original research work done by me. I also declare that no material contained in the thesis has been published earlier in any manner.

Place : Tirupati

Date :

(HEMANTH. C.C)
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CERTIFICATE

Mr. HEMANTH. C.C has satisfactorily prosecuted the course of research and that thesis entitled **"SOIL STRUCTURE AND ORGANIC CARBON STABILITY OF RAINFED ALFISOLS UNDER LONG-TERM APPLICATION OF MANURE AND FERTILIZERS"** submitted is the result of original research work and is of sufficiently high standard to warrant its presentation to the examination. I also certify that neither the thesis nor its part thereof has been previously submitted by him for a degree of any University.

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This is to certify that the thesis entitled **"SOIL STRUCTURE AND ORGANIC CARBON STABILITY OF RAINFED ALFISOLS UNDER LONG-TERM APPLICATION OF MANURE AND FERTILIZERS"** submitted in partial fulfillment of the requirements for the degree of **'Master of Science in Agriculture'** of the **Acharya N. G. Ranga Agricultural University**, Lam, Guntur is a record of the bonafide original research work carried out by **Mr. HEMANTH. C.C** under our guidance and supervision.

No part of the thesis has been submitted by the student for any other degree or diploma. The published part and all assistance received during the course of the investigations have been duly acknowledged by the author of the thesis.

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Hemanth C.C..... ✍

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LIST OF ABBREVIATIONS AND SYMBOLS

%	:	Per cent
^0C	:	Degree Celsius
@	:	At the rate of
Al	:	Aluminium
AS	:	Aggregate stability
C	:	Carbon
Ca	:	Calcium
$CaCo_3$	:	Calcium carbonate
CD (p=0.05%)	:	Critical Difference at 5 per cent probability level
cm hr^{-1}	:	Centimetre per hour
cm	:	Centimetre
DAS	:	Days after sowing
dS m^{-1}	:	Deci Siemen per metre
EC	:	Electrical conductivity
et al.	:	and other people
etc.	:	And so on
Fe	:	Iron
Fig.	:	Figure
FYM	:	Farm yard manure
g kg^{-1}	:	Gram per kilogram
GMD	:	Geometric mean diameter
HCL	:	Hydrochloric acid
ha^{-1}	:	Per hectare
ha^{-1} yr^{-1}	:	Per hectare per year
h day^{-1}	:	Hour per day
i.e.	:	That is
K	:	Potassium
K_2O	:	Potassium oxide
kg ha^{-1}	:	Kilogram per hectare
Mg m^{-3}	:	Megagram per cubic metre

Mg ha^{-1}	:	Megagram per hectare
m^2	:	Square meter
mg kg^{-1}	:	Milligram per kilogram
m ha	:	Million hectare
m t	:	Million tones
mm day^{-1}	:	Millimetre per day
ml L^{-1}	:	Millilitre per litre
MWD	:	Mean weight diameter
MSL	:	Mean Sea Level
MWHC	:	Maximium water holding capacity
µm	:	Micrometer
N	:	Nitrogen
No.	:	Number
N	:	Normality
NS	:	Non significant
P_2O_5	:	Phosphorus pentoxide
r	:	Correlation co-efficient
pH	:	Potential of Hydrogen ion concentration
RARS	:	Regional Agricultural Research Station
RBD	:	Randomized Block Design
RDF	:	Recommended dose of fertilizer
RDN	:	Recommended Dose of Nitrogen
SEm	:	Standard Error of mean
SOC	:	Soil organic carbon
SQI	:	Sustainability quality index
t ha^{-1}	:	Tonnes per hectare
USDA	:	United States Department of Agriculture
viz.,	:	Namely
WSA	:	Water stable aggregates
$ZnSO_4$	:	Zinc sulphate

ABSTRACT

Name of the Author	:	**HEMANTH C.C**
Title of the Thesis	:	**SOIL STRUCTURE AND ORGANIC CARBON STABILITY OF RAINFED ALFISOLS UNDER LONG-TERM APPLICATION OF MANURE AND FERTILIZERS**
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University	:	**ACHARYA N. G. RANGA AGRICULTURAL UNIVERSITY**
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The present study entitled "**SOIL STRUCTURE AND ORGANIC CARBON STABILITY OF RAINFED ALFISOLS UNDER LONG-TERM APPLICATION OF MANURE AND FERTILIZERS"** was carried out as part of the long-term experiment during *kharif*, 2021 on red sandy loam (*Haplustalf*) soils at Regional Agricultural Research Station, Acharya N.G Ranga Agricultural University, Tirupati, Andhra Pradesh. The experiment was laid out in randomized block design with eleven treatments and four replications. The treatments includes T_1: control (no manure and fertilizers), T_2: Farm yard manure @ 5 t ha^{-1} (once in 3 years), T_3: 20 kg nitrogen (N) ha^{-1}, T_4: 10 kg phosphorus (P) ha^{-1}, T_5: 25 kg potassium (K) ha^{-1}, T_6: 250 kg gypsum ha^{-1}, T_7: 20 kg N + 10 kg P ha^{-1}, T_8: 20 kg N + 10 kg P + 25 kg K ha^{-1}, T_9: 20 kg N + 10 kg P + 25 kg K + 250 kg gypsum ha^{-1}, T_{10}: 20 kg N + 10 kg P + 25 kg K + 100 kg lime ha^{-1}, T_{11}: 20 kg N + 10 kg P + 25 kg K + 250 kg gypsum + 25 kg ha^{-1} zinc sulphate (once in 3 years).

Soil samples were collected from each treatment at two depths *viz.*, 0-15 and 15-30 cm after harvest of crop during *kharif*, 2021. The data was recorded on soil physical, physio-chemical properties along with yield and yield attributing characters.

The physical properties *viz.*, bulk density, porosity, maximum water holding capacity and structural indices *viz.*, mean weight diameter, geometric mean diameter, per cent water stable aggregates (>0.25 mm) and per cent aggregate stability were improved by the long-term application of FYM @ 5 t ha^{-1} (T_2) once in three years for the past 41 years compared to other treatments.

The treatmental combinations *viz.,* NPK+gypsum+$ZnSO_4$ (T_{11}), NPK+lime (T_{10}), NPK+gypsum (T_9) and NPK (T_8) were showed improvement in soil physical properties *viz.,* bulk density, porosity, water holding capacity and structural indices compared to the control, whereas long-term application of K fertilizers alone showed deterioration in soil physical properties compared to the control.

Long-term application of manure and fertilizers to groundnut showed a slight decrease in soil pH compared to initial soil pH recorded during 1981. Whereas the accumulation of salts was not observed over a period of 41 years of experimentation in surface and sub-surface layers. However, soil organic carbon (SOC) content was improved in all the treatments including control over 41 years of cropping and application of manure and fertilizers. However the SOC was higher at surface layer than sub-surface layer in all the treatments.

Long-term application of FYM @ 5 t ha^{-1} (T_2) once in three years was recorded significantly highest SOC stocks, build-up (%) and carbon sequestration rate at surface and sub-surface layers and which was comparable with other treatmental combinations *viz.,* NPK+gypsum+$ZnSO_4$ (T_{11}), NPK+lime (T_{10}), NPK+gypsum (T_9) and NPK (T_8). Whereas the application of single nutrient fertilizers *viz.,* N alone (T_3), P alone (T_4) and K alone (T_5) treated plot showed negative SOC stock build-up (%) compared to control in both the soil layers.

Soil aggregate fractions under long-term application of FYM @ 5 t ha^{-1} (T_2) and treatmental combinations *viz.,* NPK+gypsum+$ZnSO_4$ (T_{11}), NPK+lime (T_{10}) and NPK+gypsum (T_9) were showed significantly higher proportion of large and small macro-aggregates fractions compared to control. Whereas, single nutrient fertilizer treatments showed higher micro-aggregates fractions.

The aggregate associated-C was significantly higher in large macro-aggregates compared to small macro and micro-aggregate fractions in both the soil layers. However, aggregate associated-C was higher in surface layer compared to sub-surface layer.

The significantly highest pod and haulm yields were recorded with FYM alone (T_2) and NPK+gypsum+$ZnSO_4$ (T_{11}), respectively compared to all other treatments. However, comparable with other treatments *viz.*, NPK+lime, NPK+gypsum and NPK treated plots.

The treatments received with single nutrient fertilizers *viz.*, N or P or K alone were inferior interms of soil structure, organic carbon stability and pod yield as compared to the combined application of nutrients. The study clearly indicated that application of FYM and treatmental combinations *viz.*, NPK+lime, NPK+gypsum+$ZnSO_4$ and NPK+gypsum would be better for the improvement of soil structure, organic carbon stability and groundnut pod yield on sustainable basis.

Chapter –I

Introduction

Chapter-I

INTRODUCTION

Groundnut (*Arachis hypogaea* L.) is the major oil seed crop in India and mainly growning in six states *viz*., Andhra Pradesh, Gujarat, Karnataka, Maharashtra, Rajasthan and Tamil Nadu, which accounts for about 90 per cent of the total groundnut area of the country. In India, groundnut is cultivated over an area of 4.89 m ha, with a total production and productivity of 10.1 MT and 2065 kg ha^{-1}, respectively. In Andhra Pradesh, it is being grown in an area of 6.6 lakh hectares with a production and productivity of 0.85 MT and 1282 kg ha^{-1}, respectively (*www.indiastat.com*, 2020).

Groundnut being a legume crop, leaves lot of residual fertility which inturn helps the succeeding crop under rainfed farming situations. Further, incorporation of organic manures (farmyard manure, vermicompost *etc*.) helps to improve soil structure, soil microbial activity and soil moisture conservation, which inturn helps to stabilize the production and productivity of the crops in rainfed farming situations (Lourduraj, 1999).

Aggregate formation is considered to happen by cohesion and adhesion mediated by organic matter (Bucka *et al*., 2019). The progress of aggregate formation is regulated by natural (e.g. soil structure, soil organic carbon and soil organisms) and human factors (e.g. fertilization, tillage and irrigation). The stability of soil aggregates is regarded as an evaluation indicator of aggregate formation, which is closely related to the organic carbon stability. While organic carbon stability is complex phenomenon, resulting from interactions among physical, chemical and biological processes (Rossel *et al*., 2019).

Sustaining the soil quality is the most appropriate method to ensure self sufficient in food production in any agro-ecosystem. Hence, maintenance of soil organic carbon pool is considered as essential for long-term sustainable productivity. Soil organic matter consider as a store house of all essential plant nutrients and plays a pivotal role in crop production. The soil organic carbon together with physical properties has been proposed as indicator of soil quality (Doran and Parkin, 1994). The important indicators of soil quality in relation to soil organic carbon content are mean weight diameter (MWD) of aggregates, available water holding capacity, cation exchange capacity (CEC) and bulk density (BD). The relative importance of these indicators varies among different soils and therefore, site-specific information is needed on these properties for quantitative assessment of soil quality (Lai *et al.,* 1998). In view of the significance of soil organic carbon in determining soil quality, adoption of judicious management practices to restore and upgrade soil organic carbon pool is essential.

Increasing carbon sequestration in agricultural soils by making soil a net sink for atmospheric carbon could be achieved by adoption of the best management practices, *viz.,* conservation tillage, application of fertilizers and bio-solids or organic amendments, crop rotation and improved residue management (Lai, 2003). Among these practices, the benefits of balanced application of mineral fertilizers and manures to maintain and increasing soil organic carbon levels in agricultural soils have been well documented (Rudrappa *et al.,* 2006).

Soil structure and soil organic carbon (SOC) are interrelated. SOC acts as a binding agent for the formation of soil aggregates and soil aggregate stability is important in maintaining soil structure. The pore region associated with aggregates often holds SOC, thereby contributing to carbon stabilization. More precisely, preferential accumulation of carbon in aggregates (intra-aggregate C) may indicate relative benefits of soil management practices. Aggregates provide physical protection to SOC and delays its degradation thereby it has a significant contribution on improving SOC stock. Aggregate associated-C is an important carbon source and accounts for nearly half of the total SOC in some soils (Sarkhot *et al.,* 2007).

Mineral fertilizer and organic manure are the important factors for maintenance and improvement of soil fertility and aggregation. Application of inorganic fertilizers results in higher SOC accumulation and biological activity due to increased plant biomass production and through decaying roots, litter and crop residues. Addition of organic manures enhances SOC content, which is an important indicator of soil quality and crop productivity. The combined application of mineral fertilizers and organic manures could affects the soil physical properties such as soil aggregation, aggregate stability, water holding capacity, porosity, infiltration rate, hydraulic conductivity and bulk density directly or indirectly due to increased SOC content. Organic manures and compost applications resulted in higher SOC content compared to inorganic fertilizers applications. Although, the accumulation of SOC through applied organic manures depends upon the rate of decomposition process.

Long-term fertilizer experiments (LTFE) plays an important role in understanding the changes in physical, physico-chemical properties and productivity of the crops. The decline in soil fertility due to the imbalanced fertilizer use has been recognized as one of the most important factors limiting crop yield (Nambiar and Abrol, 1989). The LTFE trails also provides valuable information on impact of continuous use of fertilizers with varying combination of organics and inorganics on soil physical and chemical properties and became good platform for monitoring the changes over period of time. In the long-term, formation of stable soil aggregates are related to soil carbon dynamics. The present study was initiated with the hypothesis of long-term fertilization and manuring on monocropping groundnut has a significant impact on aggregate properties and stabilization of SOC in aggregates, which further helps in protecting SOC from rapid degradation over time.

It is difficult to detect changes in SOC due to short-term effect of chemical fertilizers and manures. Hence, long-term experiments are more useful for studying the changes in soil properties and processes over time and for obtaining information on sustainability of agricultural systems for developing future strategies to maintain soil health. Keeping the above facts in view, present investigation on **“Soil structure and organic carbon stability of rainfed *Alfisols* under long-term application of manure and fertilizers”** is undertaken with the following objectives.

1. To study soil aggregate size distribution and associated organic carbon influenced by long-term application of manure and fertilizers.
2. To evaluate the soil structure based on different soil structural indices as influenced by long-term application of manure and fertilizers.
3. To study the carbon sequestration and SOC stocks under long-term application of manure and fertilizers.

Chapter – II

Review of Literature

Chapter-II

REVIEW OF LITERATURE

The available literature pertaining to the present study entitle **"Soil structure and organic carbon stability of rainfed Alfisols under long-term application of manure and fertilizers''** was reviewed in this chapter with the following sub headings. The literature on certain aspects pertaining to other crops were also included.

2.1 EFFECT OF LONG-TERM APPLICATION OF MANURE AND FERTILIZERS ON PHYSICAL AND PHYSICO-CHEMICAL PROPERTIES OF SOIL

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2.1 EFFECT OF LONG-TERM APPLICATION OF MANURE AND FERTILIZERS ON PHYSICAL AND PHYSICO-CHEMICAL PROPERTIES OF SOIL

2.1.1 Physical Properties

2.1.1.1 Soil texture

Soil texture refers to the relative proportion of the various soil separates *viz*., sand, silt and clay content present in the given soil mass. It determines the suitability of soils for growing different crops and nutrient supplying ability. The textural class of the soil could not be altered by the long-term application of organic or inorganic fertilizers.

Majority of the groundnut growing soils of Chittoor district were sandy loam in texture and to some extent loamy sands (Munaswamy *et al.*, 1989).

Six *et al.* (2000) stated that stabilization capacity was dictated by silt and clay content, the surface area and reactivity of mineral soil particles for increasing soil aggregation. Soil clay content indirectly affects SOC storage by occluding organic carbon, making them inaccessible to decomposing organisms and their enzymes.

The texture of the groundnut growing soils of Nellore district of Andhra Pradesh was loamy sand to sandy clay (Venkatesu *et al.*, 2002).

Basavaraju (2003) stated that the texture of surface horizons in pedons of Chandragiri mandal in Chittoor district of Andhra Pradesh varied from sandy to silty clay loam.

Ogunwole and Ogunleye (2004) reported soil texture under the various treatments was ranged from sandy loam to loam. The clay and silt fraction was significantly ($p \leq 0.01$) higher under the dung + phosphorous treatment over control from long-term experiment at Samaru, Northern Guinea Savanna of Nigeria.

Reddy *et al*. (2004) reported that the pod yield of groundnut was significantly reduced when the coarse fraction was above 50 per cent in red sandy loam soils.

Chatterjee *et al*. (2005) reported that the groundnut growing *Alfisols* of Dokhla in Maharashtra are clay loam in texture.

Kuntal *et al*. (2008) observed that texture has not played any significant role in the variation of soil properties among the long-term fertilization treatments.

Leelavathi *et al*. (2009) reported that the texture of the groundnut growing soils of Yerpedu mandal of Chittoor district was ranged from loamy sand to sandy clay loam.

Srinivasarao *et al.* (2013) reported that experimental site was classified as *Alfisol (Rhodustalfs)* and sandy loam textural class with sand, silt, clay contents of 72.0, 5.8 and 22.2 per cent, respectively under long-term experiment at Agricultural Research Station, Anantapur, Andhra Pradesh.

2.1.1.2 Bulk density

Bulk density is the mass of the soil per unit bulk volume. It is influenced by soil texture, organic matter, compaction, nature of crops, management practices and tillage. The ideal bulk density was 1.33 Mg m^{-3}. For coarse and fine textured soils, it ranged from 1.40 to 1.75 Mg m^{-3} and 1.10 to 1.40 Mg m^{-3}, respectively. Bulk density has negative relationship with soil organic matter.

Mahimairaja *et al.* (1986) revealed that long-term application of graded doses of NPK fertilizers did not showed significant influence on bulk density but the combined application of organics (FYM @ 10 Mg ha^{-1}) and inorganics improved the physical condition of the soil by reducing the bulk density. Similar trend was also reported by Bharadwaj and Omanwar (1992).

Sudhir *et al.* (1996) reported that the beneficial effect of the long-term integrated use of inorganic and organic manures to *Alfisol* by improving soil physical condition by decreasing bulk density from 1.51 Mg m^{-3} to 1.44 Mg m^{-3}.

Chandravanshi *et al.* (2001) reported that bulk density of *Alfisol* decreased significantly with FYM and lime in combination of NPK fertilizers in optimum dosage. However, incorporation of organic manure *viz.*, FYM and coirpith in the surface layer prior to sowing did not influenced the bulk density of sub-surface layers (Rajkannan *et al*., 2001). While, Sheeba and Kumaraswamy (2001) observed a significant decrease in bulk density with increase in organic matter content.

Bhagat *et al.* (2003) reported that bulk density was decreased in surface layer (0-15 cm) by lantana incorporation when compared to control due to increased total porosity.

Selvi *et al.* (2003) observed that application of inorganic fertilizers over a period of 26 years increased the bulk density of *Inceptisols* significantly under finger millet-cowpea cropping system.

Arvind and Kanthaliya (2004) noticed the decreased bulk density with increased organic carbon of the soil through the addition of the FYM alone or in combination with chemical fertilizers.

Bhattacharyya *et al.* (2004) reported that long-term application of FYM @ 10 t ha^{-1} for 29 years in soyabean-wheat cropping system had improved the soil porosity, which led to decline in the soil bulk density significantly in *Inceptisols* of Almora district in North-Western Himalayas. Similar results were also observed with application of FYM @ 20 Mg ha^{-1} in Rajasthan by Gathala *et al.* (2007).

Kumar *et al*. (2007) reported that the application of FYM and blue green algae along with recommended dose of fertilizers has reduced the bulk density of soil due to increased pore space.

Sultani *et al*. (2007) reported that higher reduction (7 %) in soil bulk density with incorporation of sesbania as green manure crop by the addition of greater amounts of organic matter and loosening of soil by root action.

Continuous application of FYM @ 10 Mg ha^{-1} over a period of 7 years has decreased the bulk density from 1.54 Mg m^{-3} to 1.45 Mg m^{-3} in sandy loams of Tirupati (*Annual report*, Regional Agricultural Research Station, 2010).

Verma *et al.* (2010) reported lowest bulk density with FYM incorporation @ 20 Mg ha^{-1} followed by 100 % NPK+FYM @ 10 Mg ha^{-1}. The lowering of bulk density might be due to increase in water stable aggregates and higher organic carbon, which resulted in more pore space and good soil aggregation in *Typic Haplustept* at Udaipur, Rajasthan.

Shahid *et al.* (2013) reported lower bulk density (1.40 Mg m^{-3}) in NPK (80-40-40 kg ha^{-1}) + FYM @ 5 Mg ha^{-1} compared to control (1.54 Mg m^{-3}). The reduction of bulk density with continuous application of NPK along with FYM might be due to the increase in soil organic carbon.

Yaduvanshi *et al.* (2013) noticed that the use of organic manures (FYM or green manure) with combination of inorganic fertilizers significantly improved the bulk density at 0-15 cm depth soil layer compared to inorganic fertilizers treatments alone.

The lowest bulk density was observed in long-term application of FYM @ 5 Mg ha^{-1} compared to the application of 100 % recommended dose of fertilizers to rainfed groundnut (Srinivasarao *et al*., 2013).

Roshan *et al.* (2014) observed decreasing trend in bulk density by improving total porosity. The highest porosity lowest bulk density was obtained from the application of FYM @ 21 Mg ha^{-1} in first season and FYM @ 10.5 Mg ha^{-1} during second season. The crop yields and biomass production were also differed significantly compared to other treatments.

Nagar *et al.* (2016) reported that long-term application of organic manures and crop residue resulted in significant reduction in bulk density. The lowest bulk density was noticed with combined application of FYM +

phosphocompost (1.29 Mg m^{-3}) and pigeonpea stalk + phosphocompost (1.29 Mg m^{-3}) compared to recommended dose of fertilizers alone.

2.1.1.3 Soil porosity

Soil porosity is the space occupied by the air and/or water. It was determined by the soil texture, soil structure, organic matter, depth and soil compaction. An increase in clay conten resulted in increase in total pore space.

Mahimairaja *et al.* (1986) indicated that long- term application of FYM in combination with NPK resulted in increased porosity of *Vertisol*. However only FYM application to *Alfisols* showed similar effects (Katile *et al*., 1992).

Prabakaran (2006) observed that the total porosity of soil was significantly increased due to the application of organic nitrogen in the form of press mud cake.

Saha and Mishra (2007) noticed the higher soil porosity in forestry system compared to the long-term shifting cultivation. This might be attributed to higher percentage of macro-aggregates (54.5 %), organic carbon content (2.95 %) and biotic activity in forest ecosystem.

Verma *et al*. (2010) reported more pore space with FYM incorporation @ 20 t ha^{-1} followed by 100 % NPK + FYM @ 10 Mg ha^{-1} due to the lowering of bulk density.

Prasad and Prasadini (2013) observed that the porosity was increased significantly by substitution of 50 % recommended N with FYM compared to recommended fertilizer application in the *kharif* and *rabi* reasons during both the years. This was obviously due to an increase in the volume of pore space by the addition of organic matter to the soil.

Babar and Dongale (2013) reported that organic treatments contributed significantly to the enhanced porosity compared to control. This might be due to lowering of bulk density value of soil.

Roshan *et al.* (2014) observed decreasing trend of bulk density with increasing porosity. The highest porosity was obtained from the application of FYM @ 21 Mg ha^{-1} in first season and also from residual FYM level @ 10.5 Mg ha^{-1}.

Karmakar *et al.* (2015) reported that application of vermicompost alone has resulted, highest porosity (46 %) and maximum water holding capacity (45.02 %) followed by RDF and mixed organic manures. Further, observed that the higher porosity at surface layer compared to sub-surface layer.

2.1.1.4 Maximium water holding capacity

Maximum water holding capacity is the average soil water content (expressed in percentage on oven dry weight basis) of a disturbed soil sample, measured by keen's cups method. It depends on texture, amount and nature of organic and inorganic colloidal materials.

Pernes and Tessier (2004) observed that continuous application of organic matter over a period of 70 years increased water retention at high water potential in soils of Versailles in France.

Bhattacharayya *et al.* (2004) observed the maximum soil water retention in the NPK+FYM treatment in rainfed system. The inclusion of P and FYM in the above said treatment might be attributed to the improvement of aggregates and favourable pore geometry in the soil.

Sarawad *et al.* (2005) observed that the improvement in maximum water holding capacity of the soil with sunhemp incorporation or compost application. The improvement could be due to increased organic matter content of the soils, which inturn improved soil structure.

Prasad and Prasadini (2013) reported that the water retention of the soil improved significantly by substituting 25 or 50 per cent recommended level of N with FYM. The water holding capacity relatively low at 15-30 cm than 0-15 cm soil depth irrespective of the treatment during both the years.

Tadesse *et al*. (2013) reported that application of 15 Mg ha^{-1} FYM increased the available water holding capacity by 17.6 per cent and reduced the soil bulk density by 0.31 g cm^{-3}.

Dubey and Datt (2014) noticed that the maximum water holding capacity was highest in organic treatment. Addition of organic matter content which resulted in the improvement in stable soil aggregates and macro and micro pores spaces might have resulted to increase in water holding capacity of the soil.

Gabhane *et al*. (2014) observed that among long-term integrated nutrient management treatments, significantly highest water holding capacity was noticed in treatment of 50 % recommended dose of fertilizers along with FYM @ 15 Mg ha^{-1} compared to rest of the treatments.

Parewa *et al*. (2014) noticed that combined application of 100 % NPK fertilizers and FYM has numerically more water holding capacity values as compared to control and 100 % NPK fertilizer treatments.

2.1.1.5 Soil structural indices

2.1.1.5.1 Mean weight diameter (MWD)

Rasool *et al*. (2008) reported that application of FYM @ 20 Mg ha^{-1} showed highest MWD in maize (0.160 mm) and wheat (0.172 mm) compared to control and decreased with increasing depth after 32 years of long-term experiment in sandy loam soil (*Typic Ustipsament*).

Bhattacharyya *et al.* (2009) studied the effect of FYM with N or NPK fertilizers application on soil properties in soybean-wheat sequence. The mean weight diameter, of soil was highest in the NPK+FYM treatment and lowest in the control, whereas mineral fertilizer treatments showed intermediate effect.

Bandyopadhyay *et al.* (2010) reported that effect of sole application of different levels of inorganic fertilizers and combined application with FYM significantly increased the MWD of water stable aggregate compared to control.

Aulakh *et al.* (2013) reported that application of fertilizer N, P and FYM significantly increased the MWD of water stable aggregates through the formation of macroaggregates, and highest in both surface (85 %) and sub-surface (81 %) soil layers, with 20 kg N + 60 kg P_2O_5 + 10 Mg ha^{-1} FYM applied to soybean and 120 kg N + 60 kg P_2O_5 to wheat crop, respectively.

Kharche *et al.* (2013) observed the improvement of MWD from 0.62 mm (control) to 0.68 mm (chemical fertilizers alone) and further increased to 0.72 mm under integrated nutrient management and bulk density was considerably reduced from 1.32 to 1.20 Mg m^{-3} under long-term experiment indicating profound influence of organics on soil structure at research farm of Mahatma Phule Krishi Vidyapeeth, Rahuri, Maharashtra.

Mazumdar *et al.* (2015) reported higher MWD (1.36 mm) in treatment received with 50 % NPK along with 50 % N through FYM as compared to control (0.89 mm) under 31 years of long-term experiment on rice-wheat cropping system in Middle Gangetic Plains of India.

Mazumdar *et al.* (2021) reported that the treatment receiving NPK along with FYM had higher MWD (1.2 mm) and GMD (0.5 mm) as compared to control (0.7 mm and 0.2 mm, respectively) under 44 year long-term experiment on rice-wheat-jute cropping sequence.

Niu *et al.* (2022) showed that combined application of organic and inorganic fertilizer treatments promoted the formation of macro-aggregates and thereby MWD increased from 0.24 to 0.45 mm in a 15 years long-term experiment in *aeolian* sandy soil.

2.1.1.5.2 Per cent water stable aggregates (% WSA ≥ 0.25 mm)

Gathala *et al.* (2007) noticed that the integrated use of FYM and chemical fertilizer increased the water stable aggregates (WSA), which could be attributed to the beneficial effects of certain polysaccharides formed during decomposition of organic residues by microbial activity and as cementing action of bacteria and fungi.

Ogunwole (2008) reported higher water stable aggregates (WSA) of >2.0 mm with FYM amended soil than all the other amended soils. Aggregates of <0.1 mm size range was higher in FYM+NPK amended soil than the other treatments. The MWD of the WSA was significantly lower in control. While, MWD values for the FYM and NPK amended soils were similar in surface layers of sandy loam soils (*Typic Haplustalf*) of Northern Guinea Savanna ecology of Nigeria.

Verma *et al.* (2010) showed maximum WSA under 20 Mg ha^{-1} FYM treatment and the application of 100 % NPK + 10 Mg ha^{-1} FYM significantly increased the soil aggregation over 100 % NPK treatment.

Sui *et al.* (2012) observed that WSA ≥0.25 mm and aggregate associated-C contents in the aggregates were greater in treatment with fertilizer along with manure application than chemical fertilizers alone under 5 years experiment in an eroded black soil (*Mollisol*) of North-East China.

Tripathi *et al.* (2014) reported that the WSA ranged from 71.6 % under control to 91.1 % under NPK+FYM in the surface soil (0–15 cm). The MWD varied from 0.43 to 0.78 mm in 0–15 cm and 0.40 to 0.72 mm in 15–30 cm soil layer. MWD was higher under FYM treated plots compared to inorganic fertilizers alone and unfertilized control.

Yazdanpanah *et al.* (2016) reported that soils with higher organic carbon resulted in higher per cent of WSA and more macropore fraction leading to higher hydraulic conductivity.

Tuo *et al.* (2017) showed that the continuous application of manure, either alone or in combination with N and/or P, increased WSA by 12.6 to 25.9 per cent, MWD by 22.8 to 43.3 per cent, GMD by 4.3 to 20.0 per cent, compared to the unfertilized control (CK). In contrast, the long-term application of NP, or N and P individually has lower values of these indices than CK over a 19 years of long-term experiment under a soybean-maize rotation in the Loess Plateau region in China.

2.1.1.5.3 Per cent aggregate stability (% AS)

Mishra and Sharma (1997) noticed that continuous application of 100 % NPK showed significant increase in aggregate stability (both fine and coarse aggregates) compared to half NPK and unfertilized treatments.

Sheeba and Chellamuthu (2002) reported that significant improvement in properties of *Vertic Ustropept* by continuous use of FYM @ 10 Mg ha^{-1} over twenty two years of application and reported significant increase in aggregate stability (68.49 %), % WSA (78.22 %) and total porosity (55.73 %) with application of FYM @ 10 Mg ha^{-1} as compared to application of 100 per cent NPK through inorganic fertilizers *i.e.* 64.3, 75.7 and 51.0 per cent, respectively.

Chakraborty *et al.* (2010) observed higher aggregate stability with 100 % NPK+FYM, where macroaggregates (2-0.25 mm) were greater than 50 per cent of total soil mass. Aggregation index was positively correlated with SOC in 8-4 mm aggregates.

Long *et al.* (2013) found that organic manure incorporation increased soil aggregate stability. On average, the soil macroaggregate proportion increased by 14 %, the microaggregate proportion increased by 3 % and MWD increased by 20 %. Soil silt+clay particles contained the largest part of total organic carbon, whereas the small macroaggregate fraction was the most sensitive to organic manure application.

Hati *et al.* (2015) reported that the aggregate stability was significantly higher in 150 % N compared to 50 % N level under soybean-wheat rotation in *Vertisols* of Central India from long-term experiment.

Aziz and Karim (2016) reported that aggregates of 0.75-0.125 mm were positively correlated to fine, very fine sand and silt fractions and organic matter. The stability of aggregates showed a positive correlation with clay content (r = 0.94) and organic matter content. Further, observed that lower percentage of large macro-aggregates (>2 mm) in control plot (12.83 and 16.77 %) in surface and sub-surface soil, respectively.

Chaitanya *et al.* (2017) showed that the aggregate stability was higher in FYM (93.8 %) treatment compared to control (54.35 %), but at par with other treatments and the mean weight diameter was higher in FYM @ 10 t ha^{-1} (2.08 mm) treatment compared to control (1.94 mm) under 25 year long-term field experiment in rice-rice cropping system.

Zhang *et al.* (2021) reported that fertilization with manure enhanced aggregate stability, large aggregate proportion and microaggregate-associated carbon under 13 year long-term experiment in the Hexi Corridor, Gansu Province, North-Western China.

2.1.2 Physico-Chemical Properties

2.1.2.1 Soil pH

Stalin *et al*. (2006) showed a slight increase in the soil pH due to application of organic and inorganic fertilizers in a long-term fertility experiment conducted for a period of 10 years in Cauvery delta of Tamil Nadu.

Singh *et al*. (2007) reported that continuous application of inorganic fertilizers showed slight increase in soil pH with increasing soil depth.

Urkurkar *et al*. (2010) reported that pH slightly decreased due to continuous application of green manure/ FYM/ rice-straw residue compared to inorganic fertilizers alone.

Hemalatha and Chellamuthu (2011) reported non significant changes in pH of the soil among the treatments, however, slight reduction in pH of the soil was noticed in 100 % NPK+FYM. This reduction might be attributed to the release of organic acids produced during the decomposition of FYM.

Kumari *et al*. (2013) reported that the continuous application of 100 % N, 100 % NP and 100 % NPK significantly decreased the pH, whereas the application of FYM alone or 100 % NPK with lime recorded significantly higher pH over control. The increase in soil pH by 1.0 unit might be due to ameliorative effect of lime on soil acidity. While fall in soil pH might be due to continuous application of inorganic fertilizers alone.

Kumara *et al*. (2014) showed that decrease in pH was more with the addition of FYM compared to poultry manure and pressmud cake. Highest soil pH (7.87) was observed in plots received with only NP fertilizers, which might be due to the leaching of soluble salts from surface soil.

Brar *et al*. (2015) reported that the soil pH was decreased with application of different combinations of manure and fertilizers in maize-wheat cropping system under long-term experiment conducted at PAU, Ludhiana. The decline in pH might have resulted from build-up of organic matter over a period of 36 years in manure and fertilizer treated plots. The pH was significantly reduced with 150 % NPK application as compared to 50 % NPK treatment, whereas FYM treatment showed no significant changes in soil pH.

Kundu *et al*. (2017) reported that the soil health after 42nd cropping cycle of jute-rice-wheat showed that pH of the surface soil increased from initial status (pH 7.1). The increase in pH may be attributed to more intake of anions like nitrate, phosphate, borate and molybdate besides H^+ ions by roots and inturn excretion of HCO_3 and OH^- ions to the soil solution. Increase in pH was less with application of FYM along with chemical fertilizers as compared to application of chemical fertilizers alone in sandy loam soil.

Madhuri *et al.* (2017) reported a least variation in pH in FYM applied plot followed by control in a long-term experiment on groundnut crop grown on *Alfisols*. The continuous cropping with fertilization over 34 years resulted in decrease in the soil pH by 0.1 to 0.2 units.

2.1.2.2 Electrical conductivity (EC)

Bhaskara *et al.* (1992) reported that EC of the soil did not changed over a period of ten years of continuous manuring and fertilization to rainfed groundnut crop in *Alfisols* of Tirupati in Andhra Pradesh.

Stalin *et al.* (2006) reported that EC was increased slightly in treatments received with organic and inorganic fertilizers for 10 years. This might be due to the dissolved salts contributed from soil and release of ionic species in reduction process.

Kumar *et al.* (2008) reported that integrated management of FYM, green manure and crop residues with inorganic fertilizers in rice-wheat system at Punjab Agricultural University, Ludhiana on a loamy sand soil, incorporation of the crop residue along with 100 % NPK application reduced the EC significantly.

Brar *et al.* (2015) in a long-term field experiment at Punjab Agricultural University, Ludhiana reported a significant increase in EC with the combined application of organic manures and NP fertilizers over application of NP fertilizer alone.

Long-term impact of manure and fertilizer application on soil properties at Akola, under sorghum-wheat cropping system was studied and reported that EC was the lowest under treatment received only FYM and on par with 100 % NPK+FYM application. Highest EC was observed in 150 % NPK followed by 100 % NPK (Metkari and Kharat, 2015).

Kundu *et al.* (2017) from a long-term fertilizer experiment in sandy loam soil (*Eutrochrept*) of Barrackpore, West Bengal reported that the EC of the soil varied from 0.16 dS m^{-1} to 0.23 dS m^{-1} and the highest was recorded in 100 % NPK+FYM @10 kg ha^{-1} in jute-rice-wheat cropping system.

In a long-term experiment on *Alfisols* conducted at Regional Agricultural Research Station, Tirupati showed that the soluble salt content was not influenced by the application of manure and fertilizers for over 34 years of groundnut cropping in both the surface and sub-surface soil layers (Salma *et al*., 2017).

Shivashankar *et al.* (2018) in a long-term field experiment at Regional Agricultural Research Station, Tirupati reported that EC of the soil was not influenced by different treatments in both the surface and sub-surface soils.

2.1.2.3 Soil organic carbon (SOC)

2.1.2.3.1 SOC content

Suresh *et al.* (1999) indicated that FYM application @ 5 Mg ha^{-1} increased the SOC status from 4.3 g kg^{-1} (control) to 5.9 g kg^{-1}.

Yaduvanshi (2001) noticed that continuous application of FYM or green manuring significantly increased the organic carbon from 3.2 to 4.0 g kg^{-1} over a period of 5 years.

Dwivedi and Dixit (2002) reported that the continued application of fertilizers alone also helped in increasing the SOC content, which could be attributed to higher contribution of biomass to soil in the form of crop stubbles and residues.

Singh and Chauhan (2002) reported higher organic carbon, available N and P with continuous application of FYM for 3 years.

Nalatwadmath *et al*. (2003) reported significant increase in organic carbon from 4.8 to 5.2 g kg^{-1} by the application of NPK fertilizers along with FYM in a long-term fertilizer experiment in *Vertisols* of Bellary.

Bhattacharyya *et al.* (2004) revealed that oxidisable soil organic carbon content at 0-15 cm depth was maximum in NPK+FYM treatment due to root biomass accumulation over a period of 29 years, whereas the non-oxidisable SOC content was highest at 15-30 cm depth in soils of Hawalbagh, Uttaranchal.

Balaguravaiah *et al.* (2005) reported that highest organic carbon in groundnut growing red sandy loam soil was recorded in application of FYM or groundnut shells alone compared to other treatments in long-term integrated nutrient management trial at ARS, Anantapur.

Singh *et al.* (2011) revealed that SOC content after crop harvest was significantly increased due to integrated application of biofertilizers and FYM as compared to chemical fertilizer alone.

The SOC increased in the plots treated with FYM and RDF over the control after 20 years of experimentation in groundnut growing *Alfisols*. (Srinivasarao *et al*., 2013).

Application of 75 % RDF (90-19-25) + 25 % RDN through FYM and green gram residues has recorded higher SOC content (12.4 to 18.4 g kg^{-1}) at 0-7.5cm soil layer, but no difference was recorded in 7.5-15 cm soil layer at Modipuram, Meerut, Uttar Pradesh (Das *et al*., 2014).

Boraiah *et al*. (2015) observed that SOC increased from 4.0 to 5.3 g kg^{-1} with FYM application in an experiment conducted in red sandy loam soils of Arsikere, Karnataka.

Meshram *et al.* (2016) reported that SOC was higher in treatment received with 100 % NPK + FYM @ 5 Mg ha^{-1} compared to other treatments whereas the lowest organic carbon (5.43 g kg^{-1}) was noted in absolute control in a long-term fertilizer experiment conducted at Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani under soybean-safflower cropping system in *Vertisols*.

Application of inorganic fertilizers along with compost significantly increased SOC content (13.89 g kg^{-1}) when compared to inorganic fertilizer treated plots (11.15 g kg^{-1}) (Adewole *et al.,* 2016).

Singh *et al.* (2016) reported that the treatments received with organic sources of nutrients along with chemical fertilizers has maintained high levels of organic carbon under integrated nutrient supply system in a permanent plot experiment.

Kundu *et al.* (2017) reported that the continuous application of fertilizers and organic manures in jute-rice-wheat cropping system resulted in significantly higher SOC content over control in sandy loam soil (*Eutrochrept*) of Barrackpore, West Bengal after 46 years of long-term fertilizer experiment.

Salma *et al.* (2017) reported slightly higher organic carbon (5.3 g kg^{-1}) with the application of FYM @ 5 Mg ha^{-1} once in three years for the past 34 years in the surface soil, compared to other treatments under long-term fertilizer experiment in groundnut at RARS, Tirupati, Andhra Pradesh.

Ahmady *et al.* (2020) reported that SOC content after harvest was significantly influenced by the different treatments in the surface layer, but not influenced in the sub-surface layer. The SOC content of surface soil ranged from 3.7 to 4.9 g kg^{-1}. However, the highest was observed in NPK+lime (4.9 g kg^{-1}) followed by only FYM treatment (4.8 g kg^{-1}) and NPK (4.6 g kg^{-1}), whereas the lowest SOC was observed in control (3.7 g kg^{-1}) followed by only K treatment and gypsum (3.8 g kg^{-1}) under long-term fertilizer experiment in groundnut at RARS, Tirupati, Andhra Pradesh.

2.1.2.3.2 Aggregate associated-C

Ferro *et al.* (2010) conducted a study on SOC and structural stability in a long-term experiment in North-Eastern Italy and revealed that the organic carbon played a pivotal role in aggregate stabilization, by exerting positive affects on soil microporosity by reducing the widening effect towards small pores. This was confirmed by the positive relationship ($p<0.05$) between SOC and ultra micro pores (5-0.1µm).

Aggregate formation was associated with increased carbon storage with aggregate size in most cases and carbon contents in all aggregate fractions of >53 µm size were greater than the silt and clay fraction (<53 µm). The soil amended by FYM contained significantly higher particulate organic carbon than inorganic fertilizer or control treatments (Liang *et al.,* 2012).

Yu *et al.* (2012) reported that the addition of mineral fertilizer increased carbon accumulation in free silt+clay fraction, whereas the addition of compost increased organic carbon concentrations in all aggregates under 23 year long-term experiment of *fluvo-aquic* soil in the North China Plain.

Zou *et al.* (2018) conducted a study on a flue-cured tobacco in China. The study was found that integrated nutrient management and crop rotation significantly affected bulk SOC, small macroaggregate and microaggregate associated-C, while fertilizer and rotation had no significant effect on SOC in large macroaggregates and silt-clay size fractions.

Li *et al.* (2020) reported that the SOC concentrations in the bulk soil and >2.0 mm and 0.25–2.0 mm aggregates increased by 20, 18 and 23 per cent, respectively in manure treatment compared to the fertilizer treatments. Whereas, increase was not observed in the <0.25 mm aggregates under 9 years experimentation on wheat-maize rotation in North China Plain.

Zhang *et al.* (2021) reported that organic carbon was more abundant in large aggregates and microaggregates than the other fractions, whereas the organic carbon in the macroaggregates with combined application of manure and chemical fertilizers was 2.23 to 2.67 times higher compared to manure application alone and the organic carbon in the large aggregates and silt+clay under application of manure and chemical fertilizer was 21.85 to 21.88 % lower when compared to other treatments under 13 year long-term experiment in Gansu Province, North-Western China.

Niu *et al.* (2022) showed that combined application of organic and inorganic fertilizers increased the amount of organic carbon in macro-aggregates from 92 to 103 % over 15 years long-term experiment in *aeolian* sandy soil.

2.1.2.3.3 SOC stocks

Munoz *et al.* (2007) reported that SOC stock decreased with the soil depth and it was 68 Mg ha^{-1} at 0-15 cm and declined to 11 Mg ha^{-1} for 20-40 cm depth.

Hati *et al.* (2008) reported that application of nitrogenous fertilizers alone decreased the SOC by 28.3 per cent from the initial level (92 Mg ha^{-1}), whereas the reduction was only 8.7 per cent and 10.9 per cent, respectively in NPK+FYM (10 Mg ha^{-1}) and NPK+lime (2.5 Mg ha^{-1}) treatments under long-term soyabean-wheat crop rotation in Ranchi, India.

Gattinger *et al.* (2012) found significant differences and higher values for organically farmed soils of 0.18 ± 0.06 % for SOC concentrations, 3.50 ± 1.08 Mg C ha^{-1} for stocks and 0.45 ± 0.21 Mg ha^{-1} yr^{-1} for sequestration rates compared with non organic management.

Kumara *et al.* (2014) reported that the SOC stock decreased with greater magnitude (26.1 Mg ha^{-1}) in 75 kg N + 30 kg P_2O_5 ha^{-1} for 16 years, whereas it was 71.1 Mg ha^{-1}, 36.2 Mg ha^{-1} and 49.4 Mg ha^{-1} under 15 Mg FYM ha^{-1}, poultry manure and pressmud cake, respectively. Increase in carbon sequestration rate of soil with the addition of organic manures along with NP fertilizers might be due to better crop growth with concomitant higher root biomass generation and higher return of plant residues.

Thennarasu *et al.* (2014) concluded that application of enriched FYM and vermicompost sequestered higher SOC stocks (4.16 and 4.01 Mg ha^{-1}) compared to other treatments.

Parmar *et al.* (2016) reported that maximum SOC stock (12.5 Mg ha^{-1} yr^{-1}), carbon sequestration (3 Mg ha^{-1} yr^{-1}), total carbon stock (78.3 Mg ha^{-1}

yr^{-1}) were observed in treatments receiving 50 % N supplemented with FYM enriched rock phosphate and 50 % N supplemented with vermicompost under tomato–cauliflower–radish or pea cropping pattern.

Hema *et al.* (2019) studied the soil carbon pools and carbon stocks as influenced by different cropping and nutrient management practices in *Vertic Ustropept* at TNAU, Coimbatore. Application of 100 % organics in brinjal recorded higher SOC (12.3 g kg^{-1}), labile carbon (1.31 g kg^{-1}), water soluble carbon (193 mg kg^{-1}) and SOC stocks (18.5 Mg ha^{-1}).

Mohan *et al.* (2020) studied the variability in SOC stocks influenced by existing major land use and cropping systems of the Chittoor district. The organic carbon status of the study area was significantly lowest (2.9 g kg^{-1}) under rainfed groundnut cropping system.

Trivedi *et al.* (2020) reported that FYM and lime (FYML) treated plots showed 83 % higher in total SOC content than unfertilized control plots. The FYML plots had 11 % more total SOC concentration than plots treated with mineral fertilizer and lime in the 0–30 cm soil layer. Labile-C was more in plots with FYM than NPKL plots, whereas the recalcitrant C stock was more in NPKL than FYML treated plots. In the 0–60 cm soil layer, the labile C stock was highest in FYML plots, but the recalcitrant C stock was highest in NPKL. Total SOC accumulation rate (over control plot) was highest for FYML plots (0.38 Mg ha^{-1} year^{-1}) in the surface soil layer, whereas SOC sequestration rate was highest in NPKL plots (0.18 Mg ha^{-1} year^{-1}) in the 0–60 cm layer.

Nandan (2021) worked on carbon stocks under diverse rainfed production systems in Tropical India and revealed that soybean and groundnut based systems harnessed higher SOC stocks than other production systems.

2.1.2.3.4 Carbon sequestration

Mandal and Sharma (2008) reported that incorporation of crop residues increased soil organic carbon levels. Long-term studies have showed that organic matter application increases the carbon sequestration capacity of soil in the range of 70 to 551 kg C ha^{-1} compared with mineral fertilizer use.

Bolan *et al*. (2008) reported that application of bio-solids like FYM, green manure has resulted higher C-sequestration when compared to fertilizer application and conservation tillage, which was attributed to increased microbial biomass and Fe and Al-oxides induced immobilization of carbon.

Benbi and Senapati (2010) reported that FYM along with NPK fertilization resulted in increased SOC stock over a period of seven years in rice-wheat system. Carbon sequestration was greater (1.53 Mg ha^{-1}) when both rice straw and FYM along with inorganic fertilizers were applied annually.

Carbon sequestration has potential for mitigating global warming and increasing agricultural productivity. Compared to the control treatment, NPK+FYM treatment sequestered 0.33 Mg C ha^{-1} yr^{-1}, whereas NPK treatment sequestered only 0.16 Mg C ha^{-1} yr^{-1} (Pathak *et al*., 2011).

Brar *et al*. (2012) reported that the rice-wheat cropping system even without any fertilization (control) contributed towards carbon sequestration (1.94 Mg C ha^{-1}). The SOC pools, carbon sequestration and carbon sequestration rate as observed in balanced fertilization (100 % NPK) were significantly increased from 9.19 to 9.99 g kg^{-1}, 3.30 to 4.10 Mg ha^{-1} and 0.37 to 0.46 Mg ha^{-1} yr^{-1}, respectively upon FYM application in conjunction with 100 % NPK.

Srinivasarao *et al*. (2012) reported that continuous use of chemical fertilizer and organic manures is essential to enhance SOC sequestration in semi-arid tropical condition from 20 year long-term experiment on rainfed groundnut monocropping in *Alfisols* of Ananthpur.

Rodrick and Lehrsch (2014) reported that the mean annual total C input was 15.7 Mg ha^{-1}, 10.8 Mg ha^{-1} and 10.4 Mg ha^{-1} for manured, fertilized and controled plots, respectively. But total C outputs for the above three treatments were similar with average of 12.2 Mg ha^{-1}. Manure plots showed a mean net gain of 3.3 Mg ha^{-1} (a positive net C flux) compared to a net loss for chemical fertilized (−1.6 Mg ha^{-1}) and control treatment (−1.5 Mg ha^{-1}).

Dou *et al*. (2016) reported that carbon sequestration rate was significantly higher in treatment with FYM (122 kg ha^{-1} year^{-1}) when compared with control and RDF under long-term fertilization. He also reported higher carbon sequestration rate in surface soil.

Firouzi *et al*. (2017) evaluated carbon sequestration efficiency of groundnut monocropping and groundnut-bean intercropping system in Guilan province, Iran and reported higher efficiency was observed in groundnut-bean intercrop system than groundnut monocropping system.

Ghosh *et al*. (2019) reported that the plots received with NPK+FYM (10 Mg ha^{-1}) (NPKF) showed 50 % higher SOC than NPK+lime (NPKL) in surface layer (0–15-cm). In 0–90 cm profile, SOC accumulation and sequestration rates in NPKF were 0.15 and 0.11 Mg ha^{-1} yr^{-1} higher than NPKL plots, respectively in wheat based cropping system in *Alfisols* over 43 years.

Hazra *et al*. (2020) reported that legume based crop rotations and integrated nutrient management promoted higher carbon sequestration compared with cereal-cereal-wheat rotation in a long-term experiment in *Typic Ustochrept* soils of Kanpur, India.

2.2 EFFECT OF LONG-TERM APPLICATION OF MANURE AND FERTILIZERS ON YIELD AND YIELD ATTRIBUTES

Jagadeeswaran *et al.* (2001) revealed that the application of ferrogypsum equivalent to recommended dose of gypsum (400 kg ha^{-1}) was significantly increased the pod and haulm yield, quality, nutrient content and uptake in groundnut grown on calcareous soil.

In long-term field trial conducted during 1985 to 1995 demonstrated that application of FYM @ 10 Mg ha^{-1} significantly increased pod and haulm of yield of groundnut by 13.48 and 43 per cent, respectively. But combined application of FYM and P did not influenced the pod and haulm yield significantly (Akbari *et al.,* 2002).

Balaguravaiah *et al.* (2005) reported highest pod yield in half recommended dose of fertilizers (20-40-40) + FYM @ 4 Mg ha^{-1} in *Alfisols* of Ananthpur.

Stalin *et al.* (2006) revealed that the treatment received with NPK @ 125:50:50 kg ha^{-1} during *kharif* and 150-60-60 kg ha^{-1} during *rabi* season along with green manure @ 6.25 Mg ha^{-1} in *kharif* and 12.5 Mg ha^{-1} of FYM in *rabi* and gypsum at 500 kg ha^{-1} both in *kharif* and *rabi* seasons, respectively recorded significantly higher grain yields in both the seasons consecutively for ten years.

Babu *et al.* (2007) reported highest 100 pod weight, pod and haulm yield of groundnut in the treatment NPK+gypsum+$ZnSO_{4}$,. However, shelling per cent was highest in the NPK+lime treatment in the long-term application of manure and fertilizers to rainfed groundnut.

Prakash *et al.* (2007) found that combined application of recommended dose of NPK and 10 Mg FYM ha^{-1} to soyabean-wheat system was better nutrient management option in *Typic Haplaquept* at the experimental farm of Vivekananda Institute of Hill Agriculture, Almora, Uttarakhand.

Application of poultry manure along with the inorganic fertilizer and press mud cake with inorganic fertilizers showed higher sugarcane yield, whereas FYM along with inorganic fertilizer followed by pressmud cake alone has resulted in the highest cane yield in the ratoon crop (Shankarbabu *et al.,* 2007).

Yeledhalli *et al.* (2007) reported that the pod yield of groundnut increased significantly by the application of K and Ca in the ratio of 1.5:1 *i.e.*, 75 kg K ha^{-1} and 50 kg Ca ha^{-1} over absolute control. However, recommended dose of NPK + 500 kg gypsum ha^{-1} at 30 DAS showed significantly highest pod yield in sandy clay loam soils of Raichur, Karnataka.

Balwinder *et al.* (2008) reported that the continuous application of FYM along with 100 % NPK for 8 years in a loamy sand soils of Ludhiana has recorded higher grain yield compared to 100 % NPK alone applied treatment and crop residues incorporated treatments in rice.

Kanu *et al.* (2008) observed that the application of phosphate rich organic manure (double the recommended dose of P_2O_5 through phosphate rock and FYM in 1:4 ratio) showed significantly highest pod and haulm yield of groundnut.

The long-term experiment revealed that treatment received with FYM 10 Mg ha^{-1}+100 % recommended dose of fertilizers has recorded highest sorghum yield. Hence, the application of fertilizer along with manure might be affective for harnessing higher and sustained sorghum grain yield (Kuligod *et al.*, 2008).

Akbari *et al.* (2010) reported that the application of FYM @ 10 Mg ha^{-1} has improved the plant height, number of branches, number of pods per plant, 100 kernel weight, shelling percentage and haulm yield. However, its effect was non-significant on pod yield of groundnut.

Sharma *et al.* (2010) observed that among the nutrient treatments, 100 % organic treatment was found superior with sustainability quality index (SQI) of 2.62 followed by conjuctive nutrient application *viz.*, 50 % organic + 50 % inorganic (SQI 2.35).

Thakur *et al.* (2011) showed that application of RDF with FYM @ 15 Mg ha^{-1} significantly increased soybean and wheat yields by 145 and 292 per cent, respectively compared control plot after 36 years of intensive cropping.

In a long-term experiment carried at Udaipur on sandy clay loam soils showed that application of NPKS+Zn significantly enhanced the pod and haulm yields by 25.9 and 2.4 per cent, respectively over 100 % NPK alone (Sharma *et al.*, 2011).

Srinivasarao *et al.* (2012) reported that the application of organics in the form of FYM or groundnut shells along with chemical fertilizer has significant improvement in sustainable yeild index of groundnut compared to recommended NPK, which might be due to high moisture retention capacity and better nutrient supply through integrated nutrient management treatment in rainfed groundnut.

Kumari *et al.* (2013) concluded that continuous application of 100 % NPK along with lime, FYM were beneficial for maintaining soil fertility and yield sustainability of maize-wheat cropping system in *Alfisol.*

Gabhane *et al.* (2014) showed that integrated application of FYM @ 10 Mg ha^{-1} along with 50 % recommended dose of chemical fertilizers was beneficial in improving soil quality index and sustaining the cotton productivity in rainfed *Vertisols* under semi-arid region of Maharashtra.

Sharma *et al.* (2014) observed significant linear relationships between soil quality indices (physical, physico-chemical, chemical properties) and crop yield (sorghum and castor) in long-term application of fertilizers and manures.

Shirale *et al.* (2014) reported that application of NPK+FYM under soyabean-safflower system was significantly superior over rest of the treatments with respect to grain yield, B:C ratio and buildup of soil fertility.

Brar *et al.* (2015) observed that the long-term effect of inorganic fertilizers along with organic manure (100 % NPK+FYM) had resulted in maximum infiltration rate, cumulative infiltration and MWD of aggregates. Improved soil physical conditions and increase in soil organic matter might have resulted in higher maize and wheat yields.

Parvathi *et al*. (2015) in a long-term experiment on *Alfisols* in groundnut at Regional Agricultural Research Station, Tirupati showed that the highest pod yield of 1499 kg ha^{-1} was obtained with application of NPK+gypsum+$ZnSO_4$, whereas lowest yield was obtained in the control (1204 kg ha^{-1}). However, the highest haulm yield (2593 kg ha^{-1}) was noticed with the application of FYM alone treatment, whereas lowest haulm yield was obtained in gypsum alone treated plot.

Amruth *et al.* (2017) noticed that significantly higher pod (1980 kg ha^{-1}) and haulm yield (3050 kg ha^{-1}) were obtained with the application of 75 % of recommended P (30 kg P_2O_5 ha^{-1}) through FYM+PSB and shelling percentage was significantly higher with application of 50 kg P_2O_5 ha^{-1} in sandy loam soils of Shivamogga, Karnataka during *kharif*.

Vala *et al.* (2017) observed significantly highest pod (2324 kg ha^{-1}) and haulm yield (3080 kg ha^{-1}) with the application of 75 % RDF + 50 % N through FYM + Biofertilizer at Gwalior, Madhya Pradesh.

The groundnut was showed greater response to the organic treatments 50 % N (FYM) + 25 % N (vermicompost) + *Rhizobium* + PSB (seed treatment) and with higher pod (2891 kg ha^{-1}) and haulm yield (4622 kg ha^{-1}) than inorganic treatments under loamy sandy soils (*Typic Haplustalf*) of Anand, Gujarat (Kulkarni *et al.,* 2018).

Rao *et al.* (2019) reported highest pod yield of 2542 and 2453 kg ha^{-1} with the application of 125 % RDF + FYM 5 Mg ha^{-1} + *Rhizobium* + PSB + VAM during 2015-16 and 2016-17, respectively in sandy loam soils of Viziayanagaram, Andhra Pradesh.

Yadav *et al.* (2019) concluded that the combined application of 5 Mg ha^{-1} FYM + 50 % inorganic phosphorus + PSB significantly enhanced the pod yield of groundnut under semi-arid conditions of Rajasthan.

Significantly highest pod yield (2875 kg ha^{-1}) of groundnut was recorded with the combined application of 50 kg P_2O_5 ha^{-1} and PSB in clay soils of Junagadh, Gujarat (Solanki *et al*., 2020).

Chapter – III

Material and Methods

Chapter III

MATERIAL AND METHODS

Long-term fertilizer experiment at Regional Agricultural Research Station, Acharya N.G Ranga Agricultural University, Tirupati, Andhra Pradesh was started in the year 1981 with the objective of studying long-term effects of continuous application of fertilizers and manures in rainfed groundnut under *Alfisols* of Southern agro-climatic zone. The present study entitled "**SOIL STRUCTURE AND ORGANIC CARBON STABILITY OF RAINFED ALFISOLS UNDER LONG-TERM APPLICATION OF MANURE AND FERTILIZERS"** was carried out as part of the long-term experiment during *kharif,* 2021. The experimental details are furnished here under.

3.1 LOCATION OF THE EXPERIMENTAL SITE

Experiment was laid out in field No.04, Dryland farm of Regional Agricultural Research Station, Tirupati, Chittoor district of Andhra Pradesh which is geographically situated at an altitude of 189.2 m above mean sea level (MSL) on 13.27° North latitude and 79.36° East longitude in the Southern Agroclimatic Zone of Andhra Pradesh and according to Troll's classification, study area falls under semi-arid tropics (SAT) region.

3.2 WEATHER DURING THE CROP GROWTH PERIOD

The weather data during the cropping season (09.7.2021 to 23.10.2021) was recorded at S.V.Agricultural college meteorological observatory, Regional Agricultural Research Station, Tirupati and presented in Table 3.1 and depicted in Fig 3.1. The study area receives rainfall from South-West (June-September) and North-East monsoon (October-December).

The weekly mean maximum temperature was ranged from 31.6 to 35.6 °C with an average of 33.5 °C, while the weekly mean minimum temperature ranged between 22.6 to 25.7 °C with an average of 24.5 °C. The weekly mean relative humidity ranged between 57.4 to 79.1 per cent with an

Table 3.1. Weekly meteorological data during the crop growth period of groundnut (09-07-2021 to 23-10-2021)

Standard Week	Date & Month	Temparature				Relative Humidity (%)		Rainfall (mm)		Number of rainy days		Evaporation (mm day-1)		Bright sun shine (hours day-1)	
		Maximum		Minimum											
		A	DN	A	DN	A	DN	A	DN	A	DN	A	DN	A	DN
28	09 Jul – 15 Jul	33.9	0.2	24.8	-0.2	71.5	8.1	37.8	-13	3.0	0.5	4.7	-1.0	1.9	2.8
29	16 Jul – 15 Jul	32.8	0.3	24.4	-0.4	69.8	12.1	30	-16	3.0	0.3	2.7	-1.2	2.3	2.3
30	23 Jul – 29 Jul	35.6	0.4	25.2	-0.1	59.7	6.8	24.0	-10.4	2.0	0.2	4.3	-1.5	8.0	3.2
31	30 Jul – 05 Aug	35.2	0.5	25.7	-0.1	57.4	6.0	0.0	-24.5	0.0	-1.4	4.8	-0.9	7.0	3.8
32	06 Aug – 12 Aug	35.2	0.3	25.4	-0.1	63.0	9.7	47.0	20.6	3.0	1.5	4.3	-1.6	7.1	3.1
33	13 Aug – 19 Aug	33.2	-1.0	25.4	0.9	64.9	8.2	9.0	-38.6	2.0	-0.7	3.7	-1.0	3.4	-0.5
34	20 Aug – 26 Aug	32.9	-1.2	24.0	-0.9	71.0	13.9	129.2	85.1	3.0	1.0	4.0	-1.3	4.1	-0.8
35	27 Aug – 02 Sep	31.6	-2.4	23.8	-0.5	73.2	13.9	43.4	12.6	3.0	1.0	3.4	-1.3	2.0	-2.0
36	03 Sep – 09 Sep	32.9	-0.9	24.0	0.0	69.8	12.1	28.0	-14.8	3.0	1.0	3.0	-1.8	3.9	-0.9
37	10 Sep – 16 Sep	35.5	2.3	25.5	1.5	60.7	1.2	0.0	-49.4	0.0	-2.4	5.2	-1.8	6.4	1.6
38	17 Sep – 23 Sep	34.7	1.5	24.9	0.5	65.1	4.6	28.0	-8.9	2.0	-0.1	4.6	0.4	5.2	0.8
39	24 Sep – 30 Sep	32.6	-1.2	24.0	-0.2	74.3	18.1	127.0	96.5	4.0	2.5	2.9	-1.6	3.6	-0.9
40	01 Oct – 07 Oct	32.3	-0.7	23.2	-0.2	79.1	17.8	71.0	12.3	5.0	2.7	2.7	-1.8	5.9	0.6
41	08 Oct – 14 Oct	32.4	1.5	24.5	1.7	74.6	14.0	10.0	-24.6	2.0	0.2	4.3	0.0	5.3	-0.1
42	15 Oct – 21 Oct	33.2	0.8	24.2	1.5	74.0	10.7	85.8	62.9	5.0	3.3	3.2	-0.8	4.5	-0.3
43	22 Oct – 28 Oct	31.7	-0.5	22.6	0.8	73.3	10.3	94.4	68.2	2.0	0.5	3.8	-5.3	4.9	-0.4
Mean		33.5		24.5		68.8		764.6		42.0		3.8		4.7	

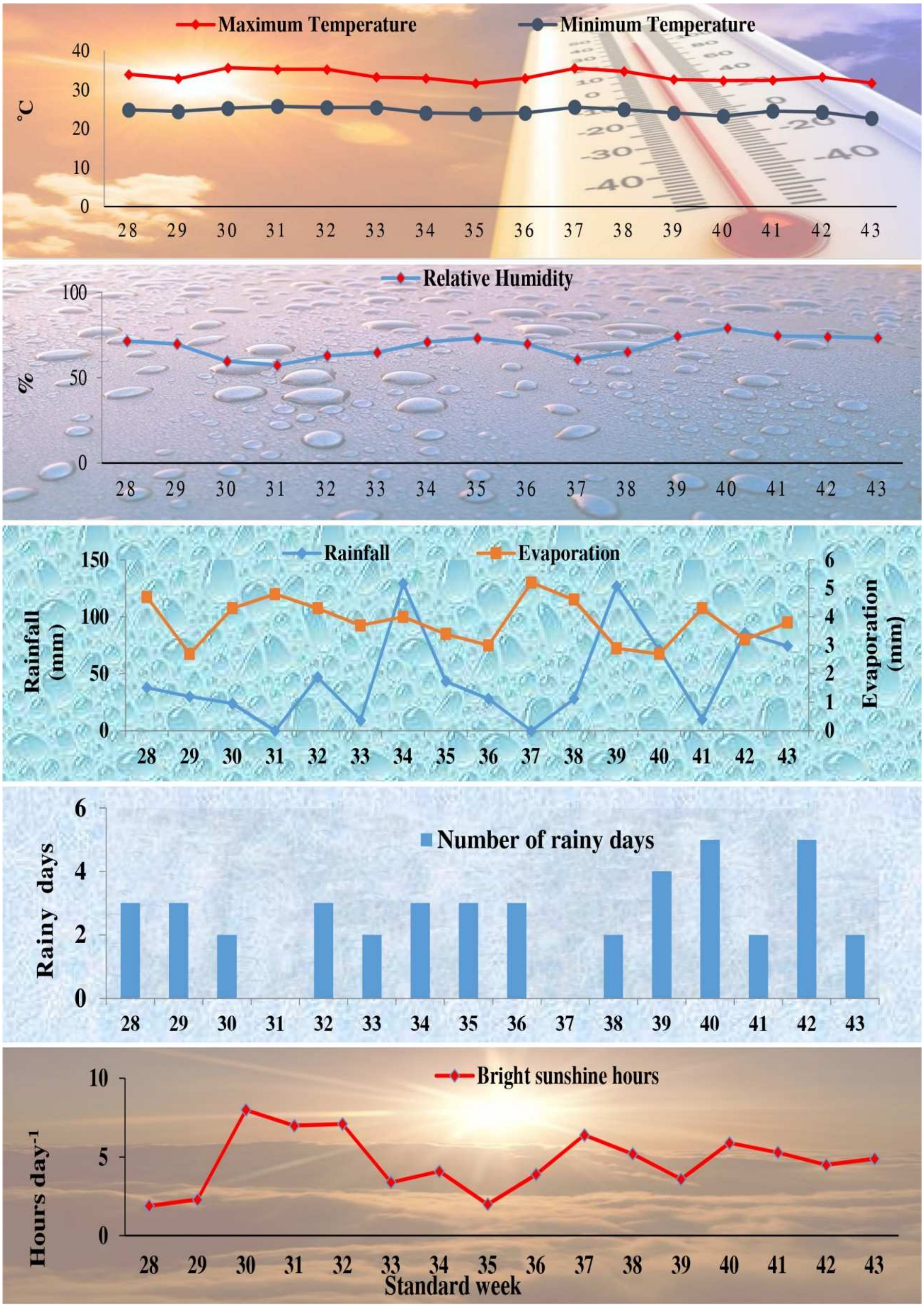

Fig. 3.1 Weekly meteorological data during the crop growth period of groundnut during *kharif*, 2021 (09-07-2021 to 23-10-2021).

average of 68.8 per cent. The weekly mean sunshine hours during the crop period ranged between 1.9 to 8.0 h day^{-1} with an average of 4.71 h day^{-1}. The weekly mean evaporation ranged between 2.7 to 4.8 mm day^{-1} with an average of 3.8 mm day^{-1}. A total rainfall of 764.6 mm was received in 42 rainy days during the crop growth period.

3.3 INITIAL SOIL CHARACTERISTICS

Long-term fertilizer experiment has been conducting in a red sandy loam soil since *kharif,* 1981. Initial soil analysis (1981) revealed that soil was slightly acidic to neutral in reaction with pH of 6.7 and non-saline (0.08 dS m^{-1}). The organic carbon content was low (0.18 per cent). And also analysed for physical properties like bulk density, particle density, soil texture and soil fertility (Table 3.2).

Table 3.2 Soil physical, physico-chemical and chemical properties of experimental field at 0-15 cm depth recorded during 1981

S.No.	Parameters	Values
I	**Physical properties**	
1	Sand (per cent)	80.2
2	Silt (per cent)	8.3
3	Clay (per cent)	11.5
4	Textural class	Sand
5	Bulk density (Mg m^{-3})	1.55
6	Partical density (Mg m^{-3})	2.70
II	**Physico-chemical properties**	
1	pH	6.7
2	Electrical conductivity(dSm^{-1})	0.08
3	Organic carbon (%)	0.18
III	**Chemical properties**	
1	Nitrogen (kg ha^{-1})	180.3
2	Available phosphorus (kg ha^{-1})	47.6
3	Available potassium (kg ha^{-1})	216
4	Available sulphur (mg kg $^{-1}$)	12.5
5	Exchangeable Calcium{cmol (p^{+}) kg^{-1}}	2.0
6	Exchangeable Magnesium {cmol (p^{+}) kg^{-1}}	0.9

3.4 EXPERIMENTAL DETAILS

3.4.1 Design and Layout

The experiment was laid out in Randomized block design, replicated four times with eleven treatments. The layout plan of the experiment was shown in Fig. 3.2.

3.4.2 Treatment details

Design	:	Randomized Block Design (RBD)
Treatments	:	11
Replications	:	4
Season	:	*kharif*-2021
Crop	:	Groundnut
Variety	:	Dharani
Duration	:	110 days
Plot size	:	
Gross size	:	9.9 × 4.8 m = 47.52 m^2
Net size	:	7.8 × 4.2 m = 32.76 m^2
Spacing	:	30 cm × 10 cm

3.4.3 Details of treatments :

T_1 : Control (no manure and fertilizers)

T_2 : Farm yard manure @ 5 t ha^{-1} (once in 3 years)

T_3 : 20 kg nitrogen (N) ha^{-1}

T_4 : 10 kg phosphorus (P) ha^{-1}

T_5 : 25 kg potassium (K) ha^{-1}

T_6 : 250 kg gypsum ha^{-1} as top dress at flower initiation

T_7 : 20 kg N + 10 kg P ha^{-1}

T_8 : 20 kg N + 10 kg P + 25 kg K ha^{-1}

T_9 : 20 kg N + 10 kg P + 25 kg K + 250 kg gypsum ha^{-1}

RI	T_2	T_6	T_{11}	T_5	T_7	T_1	T_9	T_3	T_4	T_{10}	T_8
RII	T_5	T_8	T_{10}	T_2	T_6	T_4	T_{11}	T_9	T_7	T_1	T_3
RIII	T_{11}	T_6	T_5	T_7	T_8	T_3	T_2	T_1	T_4	T_9	T_{10}
RIV	T_1	T_4	T_3	T_6	T_{10}	T_5	T_8	T_{11}	T_7	T_2	T_9

Design: **RBD** Replications : **Four** **Plot Size : Gross**: 9.9 x 4.8 m **Net:** 7.8 x 4.2 m

Treatments:

T_1 : Control (no manure and fertilizers)
T_2 : Farm yard manure @ 5 t ha^{-1} (once in 3 years)
T_3 : 20 kg Nitrogen (N) ha^{-1}
T_4 : 10 kg Phosphorus (P) ha^{-1}
T_5 : 25 kg Potassium (K) ha^{-1}
T_6 : 250 kg Gypsum ha^{-1} as top dressing at flower initiation
T_7 : 20 kg N + 10 kg P ha^{-1}
T_8 : 20 kg N + 10 kg P + 25 kg K ha^{-1}
T_9 : 20 kg N + 10 kg P + 25 kg K + 250 kg Gypsum ha^{-1}
T_{10} : 20 kg N + 10 kg P + 25 kg K + 100 kg lime ha^{-1} (lime as top dressing at flower initiation)
T_{11} : 20 kg N + 10 kg P + 25 kg K + 25 kg zinc sulphate ha^{-1} (as basal, once in 3 years) + 250 kg Gypsum ha^{-1} as top dressing

Fig. 3.2. Layout of the Experiment

T_{10} : 20 kg N + 10 kg P + 25 kg K + 100 kg lime ha^{-1} (lime as top dress at flower initiation)

T_{11} : 20 kg N + 10 kg P + 25 kg K + 25 kg zinc sulphate ha^{-1} (as basal, once in 3 years) + 250 kg gypsum ha^{-1} as top dress at flowering initiation.

3.4.4 Source of Nutrients

3.4.1.1 Inorganic sources

3.4.1.1.1 Nitrogen

It was supplied in the form of urea (46 per cent nitrogen) at the time of sowing.

3.4.1.1.2 Phosphorus

It was supplied in the form of single super phosphate (16 per cent water soluble phosphorus) at the time of sowing.

3.4.1.1.3 Potassium

It was supplied in the form of muriate of potash (60 per cent water soluble potassium) at the time of sowing.

3.4.1.1.4 Gypsum

Gypsum was applied in the form of $CaSO_4.2H_2O$ to the treatments T_6, T_9 and T_{11} at the time of flower initiation and mixed up well within the soil by hand weeding and earthing-up with hoe.

3.4.1.1.5 Lime

In the treatment T_{10}, commercially available lime was applied at the time of flower initiation and mixed up well within the soil by hand weeding and earthing-up with hoe.

3.5 CROP HUSBANDARY

3.5.1 Preparatory Cultivation

The experiment field was ploughed twice by working with mini tractor in both the directions immediately after the receipt of *kharif* rains during first week of June. This was repeated with subsequent rains and finally levelled with a plank and strengthened the treatmental bunds by working with spades as per the experimental layout.

3.5.2 Manure and Fertilizers

Fertilizers *viz*., N @ 20 kg ha^{-1}, P @ 10 kg ha^{-1} and K @ 25 kg ha^{-1} in the form of urea, single super phosphate and muriate of potash, respectively were applied to the plots as per treatments just before sowing in lines at a depth of 5 cm in the furrows made with hand hoes away from the seed rows. Amendments *viz*., gypsum and lime were applied at first bloom stage *i.e.* 30-35 DAS by row placement and get mixed up within the soil by hand weeding and earthing up with hoe. As FYM and $ZnSO_4$ must be applied once in 3 years, the last application was on *kharif*-2019, hence not applied in current season.

3.5.3 Seeds and Sowing

Bold and healthy groundnut kernels of Dharani variety with 95 per cent germination were selected for sowing. The seeds were treated with Mancozeb @ 3 g kg^{-1} seed against seed borne diseases. The seeds were hand dibbled in furrows by adopting a spacing of 30 cm x 10 cm and covered with soil and slightly compacted. The groundnut crop was sown on 09-07-2021.

3.5.4 Weed Management

Pre-emergence application of Pendimethalin @ 5 ml L^{-1} was sprayed on next day after sowing of the crop with knapsack sprayer which controlled the weeds up to one month. Manual hand weeding was done at 35 DAS and tall weeds were removed manually at 65 DAS during crop growing period. No irrigation was provided to the crop even during dry spells.

3.5.5 Plant Protection

Monocrotophos @ 1.6 ml L^{-1} was sprayed against sucking pests like leaf miner and thrips at 20 DAS as prophylactic measure. Imidacloprid @ 0.3 ml L^{-1} was sprayed against aphids and jassids at 40 DAS. Monocrotophos and Imidacloprid were sprayed with the help of tractor mounted spraying assembly set.

3.5.6 Harvesting

The crop was harvested on 23-10-2021. The plants in the border rows in each plot were removed and net plots of size 32.76 m^2 were harvested by hand pulling and kept separately for each treatment. The pods were stripped off manually in the field itself and sun dried till a constant dry weight was obtained and recorded yield per plot. Similarly, haulm from individual plots was dried to a constant weight and recorded haulm yield per plot.

3.6 COLLECTION AND PROCESSING OF SOIL SAMPLES

Soil samples were collected from 0-15 and 15-30 cm depth after harvest of the crop. While collecting the samples two pits were dug in each plot with the help of spade. The two soil samples were mixed separately depth wise, dried under shade and labelled. The soil samples collected were analyzed for physical and physico-chemical properties by using standard procedures as furnished below.

3.6.1 Procedures of Soil Analysis

3.6.1.1 Physical analysis

3.6.1.1.1 Soil texture

Soil textural analysis was carried out by Bouyoucos hydrometer method (Bouyoucos, 1951) after destroying organic matter using hydrogen peroxide (H_2O_2), calcium carbonate ($CaCO_3$) with dilute hydrochloric acid (HCl) and followed by dispersed with sodium hexameta phosphate as discribed by Piper (1950) and finally expressed in percentage for individual soil separates.

3.6.1.1.2 Bulk density and pore space

The Bulk density was determined by core sampler method at two depths *i.e.* 0–15 cm and 15–30 cm. The core sampler (3 inch diameter ring placed) was driven into the soil directly by using hand sledge and then, it was carefully lifted to prevent any compaction and without loss of soil from ring. The excess soil from the core was carefully removed by using flat bladed knife. The sample was transferred from core sampler to a pre-weighed labeled aluminium box and placed in an oven for 36 to 48 hours at 105 ^{o}C until constant weight was obtained. The weight of soil was recorded by subtracting the empty aluminium box weight. The bulk density and pore space was calculated by the formula given by Blake and Hartge (1986).

$$\text{Bulk Density}\left(\text{Mg m}^{-3}\right)=\frac{\text{Oven dry weight soil}\left(\text{Mg}\right)}{\text{Sample volume}\left(\text{m}^{3}\right)}$$

$$\text{Soil Porosity}\left(\%\right)=100\times\left\{1-\frac{\text{Soil bulk density}}{\text{Particle density}}\right\}$$

3.6.1.1.3 Maximum water holding capacity

The maximum water holding capacity of the soil was determined with Keen-boxes as per the procedure laid down by Piper (1950).

3.6.1.1.4 Aggregate analysis

Aggregate analysis was done by wet sieving method (Yoder, 1936) at two depths *i.e.* 0–15 cm and 15–30 cm. The Yoder apparatus have a vertical stroke of 45 mm and was operated for 10 min at a speed of 30 strokes per min (Mohan and Prabhuprasadini, 2019). A set of sieves comprising of six sieves *viz.*, 5 mm, 2 mm, 1 mm, 0.5 mm, 0.25 mm, 0.125 mm secured to a holder, through a distance of 3.18 cm arranged in assembly at a descending order.

The soil sample of 5 to 8 mm size was placed on the top of 5 mm sieve and allowed to wet in water for 10 min. The sieves were then swayed vertically and rhythmically, so that water was made to flow up and down throughout the screens and the assemblage of aggregates. After 10 minutes time period, the nest of sieves were removed carefully from the water and aggregates retained on the each sieve was back washed into a pre-weighed beakers (500 ml) and oven dried at 105 °C for 24 hrs. After drying, weight of aggregate retained on each sieve was measured and expressed as total aggregation, percentage of water-stable aggregates (WSA) >0.25 mm. The aggregates retained on each size sieve, after correction for sand content was used to calculate the mean weight diameter (MWD) and geometric mean diameter (GMD) of the water stable aggregates as given by Van (1950).

$$\% \text{ Total aggregation} = [(W_1 + W_2 + W_3 + W_4 + W_5 + W_6) / W_0] \times 100$$

$$\%\text{WSA} > 0.25 \text{ mm} = [(W_1 + W_2 + W_3 + W_4 + W_5) / W_0] \times 100$$

W_0 – Total weight of sample taken

W_1 – weight of aggregates retained on 5 mm sieve

W_2 – weight of aggregates retained on 2 mm sieve

W_3 – weight of aggregates retained on 1 mm sieve

W_4 – weight of aggregates retained on 0.5 mm sieve

W_5 – weight of aggregates retained on 0.25 mm sieve

W_6 – weight of aggregates retained on 0.125 mm sieve

$$\text{MWD} = \sum_{i=1}^{n} X_i \times W_i$$

$$\text{GMD} = \exp \frac{\left(\sum_{i=1}^{n} W_i \log \times X_i \right)}{\left(\sum_{i=1}^{n} W_i \right)}$$

n = number of size fraction,

X_i = mean diameter of each size fractions

W_i = fraction weight of aggregate in that size range of total dry weight of the sample analyzed.

3.6.1.2 Physico-chemical analysis

3.6.1.2.1 Soil reaction (pH)

The soil pH was determined in 1:2.5 soil-water suspension using Systronics pH system 361 with a glass electrode as described by Jackson (1973).

3.6.1.2.2 Electrical conductivity (EC)

The electrical conductivity of the soil was determined in 1:2.5 soil-water suspension with the help of Systronics digital electrical conductivity meter as described by Jackson (1973) and expressed as dS m^{-1}.

3.6.1.2.3 Organic carbon (OC)

The organic carbon content was estimated by Walkley and Black wet oxidation method (1934) as outlined by Jackson (1973) and was expressed in percentage. 1 g soil was digested with 10 ml 1 *N* potassium dichromate ($K_2Cr_2O_7$) and 20 ml of concentrated H_2SO_4 in dark condition for 30 min. After digestion, excess dichromate was determined by titration with 0.5 *N* ferrous ammonium sulphate [$Fe(NH_4)(SO_4)_2.6H_2O$] after adding 10 ml H_3PO_4 in presence of diphenyl amine indicator. The organic carbon percentage was calculated from the following formula:

$$\%\,\text{Organic Carbon} = 10 \times \frac{\text{B-T}}{\text{B}} \times 0.003 \times \frac{100}{\text{Weight of sample}}$$

B = Volume (ml) of ferrous ammonium sulphate solution required for blank titration

T = Volume (ml) of ferrous ammonium sulphate solution required for titration of soil sample

3.6.1.2.4 Soil organic carbon stock

Soil organic carbon stock was estimated by multiplying SOC content with soil bulk density and soil depth according to the equation given by Brar *et al*. (2015), Poeplau *et al*. (2017) and was expressed as Mg ha^{-1}.

$$\text{SOC stock}\left(\text{Mg ha}^{-1}\right)=\text{SOC}(\%)\times\text{Bulk density}\left(\text{Mg m}^{-3}\right)\times\text{depth}(\text{m})\times 10$$

$$\text{SOC stocks build-up}(\%)=\frac{\text{SOC stocks}(\text{tre})-\text{SOC stocks}(\text{con})}{\text{SOC stocks}(\text{con})}\times 100$$

Where, SOC stocks (tre) is SOC stocks (Mg ha^{-1}) in individual treatments and SOC stocks (con) is SOC stocks (Mg ha^{-1}) in control treatment.

3.6.1.2.5 Carbon sequestration

The carbon sequestration rate (Mg ha^{-1} $year^{-1}$) under various long-term fertilization treatments was calculated with formula given by Zhang *et al.* (2014). The positive and negative values indicates gain and loss in SOC stocks.

$$\text{Carbon sequestration rate (Mg ha}^{-1}\text{ yr}^{-1}\text{)}=\frac{\left(\text{SOCSc-SOCSi}\right)}{\text{T}}$$

Where, SOCSc is soil organic carbon stocks (Mg ha^{-1}) in current year (2021) and SOCSi was the initial soil organic carbon stocks (Mg ha^{-1}) during 1981 and T is years of experimentation (41 years).

3.7 YIELD ATTRIBUTES

3.7.1 Pod Yield

After harvest, the pods were seperated by manual stripping operation and sun dried the pods per plot wise seperately. The recorded pod yield per plot was expressed in kg ha^{-1} for all the treatments.

3.7.2 Haulm Yield

Dry haulm yield from each net plot after harvest was recorded after separating the pods followed by sun drying for period of one week and expressed as kg ha^{-1}.

3.7.3 100 Pod Weight

One hundred pods were counted at random from the whole net plot produce, weighed and expressed in grams per 100 pods.

3.7.4 100 Kernel Weight (Test weight)

One hundred kernels were counted at random from the whole net plot produce, weighed and expressed in grams per 100 seeds.

3.7.5 Shelling Percentage

Kernels were separated from 100 gm of pods and weighed. The percentages of kernels to pods were worked out for each treatment.

$$\text{Shelling percentage} = \frac{\text{Weight of kernels}}{\text{Weight of pods}} \times 100$$

3.8 STATISTICAL ANALYSIS

The collected data was analysed statistically for test of significance following the Fisher’s method of analysis of variance as outlined by Panse and Sukhatme (1985). Statistical significance was tested by ‘F’ value at 5 per cent level of probability and wherever the ‘F’ values were found significant, critical difference were worked out at 5 per cent level of probability and the values are furnished. Treatmental differences that were not significant were denoted as NS.

Chapter – IV

Results & Discussion

Chapter-IV

RESULTS AND DISCUSSION

A long-term field experiment on application of manure and fertilizers in rainfed groundnut monocropping system was initiated in the year 1981 to study the long-term changes in soil properties at Regional Agricultural Research Station, Acharya N.G. Ranga Agricultural University (ANGRAU), Tirupati. The same experiment was selected for the present study during *kharif*, 2021. The soil samples were collected after harvest from both surface (0-15 cm) and sub-surface (15-30 cm) layers and analyzed for various physical and physico-chemical properties. The data on soil properties after harvest was used to compare and discuss with the initial soil data (recorded in 1981). Data on yield and yield attributes were recorded after harvest of the groundnut crop. The results obtained were presented, analyzed statistically and discussed briefly in this chapter under the following sub heads.

4.1 EFFECT OF LONG TERM APPLICATION OF MANURE AND FERTILIZERS ON SOIL PHYSICAL PROPERTIES

4.1.1 Soil Texture

The data pertaining to soil texture was presented in Table 4.1. The sand content of experimental plots in the surface layer ranged from 68.6 to 74.3 per cent with the mean of 72.4 per cent, whereas the silt content varied from 11.7 to 16.7 per cent with the mean of 13.6 per cent. The clay content ranged from 12.0 to 16.3 per cent with the mean of 14.1 per cent.

In sub-surface, sand content was ranged from 67.9 to 71.7 per cent with the mean of 70.3 per cent, whereas the silt content varied from 12.9 to 15.4 per cent with the mean of 14.3 per cent and clay content ranged from 13.7 to 18.1 per cent with the mean of 16.7 per cent. The soil texture of experimental field was categorized as sandy loam (SL) as per USDA textural triangle. The available literature revealed that majority of the groundnut soils are sandy loam in texture. The physical fractionation revealed that, no textural changes

Table 4.1. Effect of long-term application of manure and fertilizers on soil texture at surface and sub-surface layers after harvest, *kharif*, 2021

Treatments	Sand (%)		Silt (%)		Clay (%)		Textural Class
	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	
T_1 : Control	72.9	70.3	12.9	12.9	14.2	16.9	SL
T_2 : FYM @ 5 t ha^{-1} (once in 3 years)	73.7	71.5	14.3	13.7	12.0	14.9	SL
T_3 : N @ 20 kg ha^{-1}	73.6	71.2	12.2	15.4	14.2	13.6	SL
T_4 : P @ 10 kg ha^{-1}	72.0	68.9	11.7	15.0	16.3	16.2	SL
T_5 : K @ 25 kg ha^{-1}	73.7	70.8	13.6	14.5	12.7	15.3	SL
T_6 : Gypsum @ 250 kg ha^{-1}	71.0	71.4	13.7	14.3	15.3	15.9	SL
T_7 : NP	68.6	70.6	16.7	14.9	14.7	14.8	SL
T_8 : NPK	74.2	69.7	13.3	14.9	12.5	15.5	SL
T_9 : NPK + gypsum	70.5	67.9	14.1	14.1	15.4	18.1	SL
T_{10} : NPK+ lime @ 100 kg ha^{-1}	74.3	71.7	13.7	13.2	12.1	15.1	SL
T_{11} : NPK+gypsum +$ZnSO_4$ @ 25 kg ha^{-1}	71.7	69.3	13.2	14.0	15.2	17.0	SL
Mean	**72.4**	**70.3**	**13.7**	**14.3**	**14.1**	**16.7**	
Range	**68.6-74.3**	**67.9-71.7**	**11.7-16.7**	**12.9-15.4**	**12.0-16.3**	**13.6-18.1**	

Note : SL – Sandy loam

were observed among the long-term treatments. These results are in agreement with the findings of Srinivasarao *et al.* (2013). Several scientists were also studied the groundnut crop grown on sandy loam soils (Munaswamy *et al.* 1989, Venkatesu *et al.* 2002 and Reddy *et al.* 2004).

4.1.2 Bulk Density

The data on soil bulk density at surface and sub-surface layer as influenced by various treatments under long-term application is presented in Table 4.2 and depicted in Fig. 4.1.

The bulk density was significantly influenced by various treatments used in the long-term experiment at surface layer (0-15 cm). The bulk density of the surface layer was ranged from 1.37 to 1.51 Mg m^{-3}. The highest bulk density was recorded with K alone treated plot (T_5) (1.51 Mg m^{-3}) which was on a par with control (T_1) (1.49 Mg m^{-3}) and NPK+gypsum+$ZnSO_4$ (T_{11}) (1.49 Mg m^{-3}), followed by NP (T_7) (1.45 Mg m^{-3}), NPK (T_8) (1.44 Mg m^{-3}), NPK+lime (T_{10}) (1.44 Mg m^{-3}), gypsum alone treated plot (T_6) (1.44 Mg m^{-3}). Among all the treatments studied, the lowest bulk density was observed in FYM alone treated plot (T_2) (1.37 Mg m^{-3}).

However, the lowest bulk density obtained with the FYM alone treated plot which might be attributed to the accumulation of organic matter due to the continuous application of FYM @ 5 Mg ha^{-1} once in three years for the past 41 years. The organic matter per se or its decomposed products of FYM might have bounded the primary soil particles to form soil aggregates resulting an increase in total pore space as evident from the data presented in Table 4.2. These results are in relevance with the findings of Sheeba and Kumaraswamy (2001), Bhattacharyya *et al.* (2004), Verma *et al.* (2010), Srinivasarao *et al.* (2013) and Roshan *et al.* (2014).

In sub-surface layer (15-30 cm), bulk density was not significantly influenced by various treatments and ranged from 1.50 to 1.57 Mg m^{-3}. The higher bulk density was recorded in NPK+gypsum+$ZnSO_4$ (T_{11}) (1.57 Mg

m^{-3}) and NPK (T_8) (1.57 Mg m^{-3}) followed by control (T_1) (1.55 Mg m^{-3}), N alone treated plot (T_3) (1.54 Mg m^{-3}) and P alone treated plot (T_4) (1.54 Mg m^{-3}). Whereas the lowest bulk density was observed in NP (T_7) (1.50 Mg m^{-3}).

Interestingly, the lower bulk density values were also obtained in P, lime and gypsum treatmental combinations in both surface and sub-surface soils and the values were comparable with FYM treated plot. The main reason for decreasing the bulk density values due to the supply of P, Ca through respective fertilizers, which might have improved the aggregation of the soil particles which inturn improved the soil structure. The lowest bulk density values of surface and subsurface soil with P, lime and gypsum treatmental combinations in the study were relevance to the studies of Mahimairaja *et al.* (1986) and Bharadwaj and Omanwar (1992).

4.1.3 Soil Porosity

The soil porosity was significantly influenced by the different treatments in surface and sub-surface layers and the data was presented in Table 4.2.

The porosity of the surface soil (0-15 cm) was ranged from 44.0 to 49.4 %. The higher porosity was recorded with FYM alone (T_2) (49.4 %) followed by P alone treated plot (T_4) (47.8 %), N alone treated plot (T_3) (47.5 %), NPK+ gypsum (T_9) (47.3 %), gypsum alone treated plot (T_6) (46.8 %), NPK (T_8) (46.5 %), NP (T_7)(46.3 %) and NPK+lime (T_{10}) (46.3 %) Among all the treatments studied, the lowest porosity was observed in K alone treated plot (T_5) (44.0 %).

In sub-surface layer (15-30 cm), it was ranged from 41.2 to 44.0 %. The significantly highest porosity was recorded with FYM alone (T_2) (44.0 %) which was on a par with NPK+lime (T_{10}) (43.9 %) and NP (T_7) (43.8 %), followed by K alone treated plot (T_5) (43.5 %), gypsum alone treated plot (T_6) (43.0 %), P alone treated plot(T_4) (42.8 %) and NPK+gypsum (T_9) (42.5 %). The lowest porosity in sub-surface layer was observed in NPK (T_8) (41.2 %).

The highest porosity were observed in FYM alone treated plot in both the soil layers, which was mainly attributed to the presence of higher organic matter content as compared to the other treatments. The higher organic matter content might have helped in formation of stable soil aggregates, which inturn resulted in the higher porosity. The improvement of the soil structure was also evidenced by obtaining significantly higher values of structural indices *viz.*, MWD, GMD, per cent water stable aggregates, water holding capacity in this study with the application of FYM (Table 4.3 and 4.4.). Similarly, increased porosity was observed on application of FYM (Katile *et al.*, 1992 and Verma *et al.,* 2010) and pressmud cake (Prabakaran, 2006).

The lower porosity was observed in sub-surface layer in all the treatments studied compared to surface layer, which might be attributed to higher compaction apart from presence of low organic matter content and aggregates. Similar findings were also reported by Prabakaran (2006) and Karmakar *et al.* (2015). The higher porosity was also obtained with gypsum, lime treated plots in combination with other inorganic fertilizers, mainly due to the addition of calcium might have played a significant role in the formation of the soil aggregates by acting as flocculating and cementing agents. Similar results were also reported by Mahimairaja *et al.* (1986).

4.1.4 Maximium Water Holding Capacity

The data on maximium water holding capacity (MWHC) of soil as influenced by various treatments in the long-term for both surface and sub-surface layers was presented in Table 4.2 and depicted in Fig. 4.2.

The MWHC of soil was not significantly influenced by the different treatments in the surface layer but it was differed in the sub-surface layer. The MWHC of surface layer (0-15 cm) was ranged from 39.2 to 44.1 %. The highest was observed in NPK+lime (T_{10}) (44.1 %) followed by FYM alone treated plot (T_2) (42.7 %), control (T_1) (41.7 %) and NPK (T_8) (41.5 %). Whereas, the lowest maximum water holding capacity was observed with N alone treated plot (T_3) (39.2 %) followed by NP (T_7) (39.4 %).

Table 4.2. Effect of long-term application of manure and fertilizers on soil physical properties at surface and sub-surface layers after harvest, *kharif*, 2021

Treatments	Bulk density ($Mg\ m^{-3}$)		Soil porosity (%)		Water holding capacity (%)	
	0-15 cm	**15-30 cm**	**0-15 cm**	**15-30 cm**	**0-15 cm**	**15-30 cm**
T_1 : Control	1.49	1.55	44.6	42.0	41.7	39.7
T_2 :FYM @ 5 t ha^{-1} (once in 3 years)	1.37	1.53	49.4	44.0	42.7	44.7
T_3 :N @ 20 kg ha^{-1}	1.42	1.54	47.5	42.4	39.2	40.5
T_4 :P @ 10 kg ha^{-1}	1.43	1.54	47.8	42.8	39.9	40.2
T_5 :K @ 25 kg ha^{-1}	1.51	1.53	44.0	43.5	40.5	41.6
T_6 :Gypsum @ 250 kg ha^{-1}	1.44	1.53	46.8	43.0	40.0	43.4
T_7 :NP	1.45	1.50	46.3	43.8	39.4	39.8
T_8 :NPK	1.44	1.57	46.5	41.2	41.5	43.2
T_9 :NPK + gypsum	1.41	1.53	47.3	42.5	40.1	42.6
T_{10} : NPK + lime @ 100 kg ha^{-1}	1.44	1.52	46.3	43.9	44.1	44.4
T_{11} : NPK + gypsum + $ZnSO_4$ @ 25 kg ha^{-1}	1.49	1.57	44.3	41.7	40.8	41.8
SEm±	**0.01**	**0.03**	**0.08**	**0.11**	**0.77**	**1.11**
CD (P=0.05)	**0.03**	**NS**	**0.23**	**0.33**	**NS**	**3.30**
CV	**1.38**	**3.60**	**0.29**	**0.45**	**9.00**	**4.60**

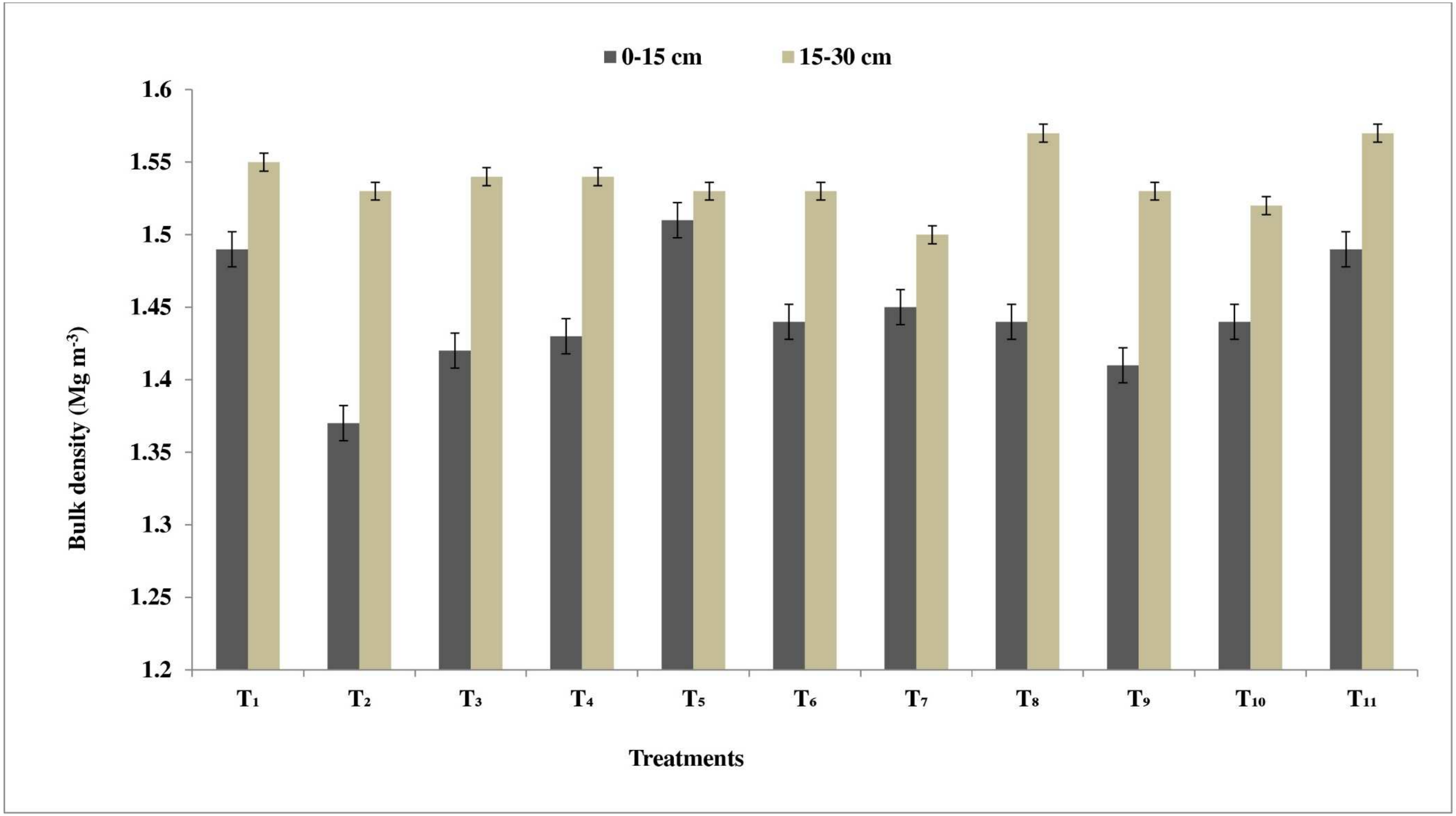

Fig. 4.1. **Effect of long-term application of manure and fertilizers on bulk density (Mg m^{-3}) at surface and sub-surface layers**

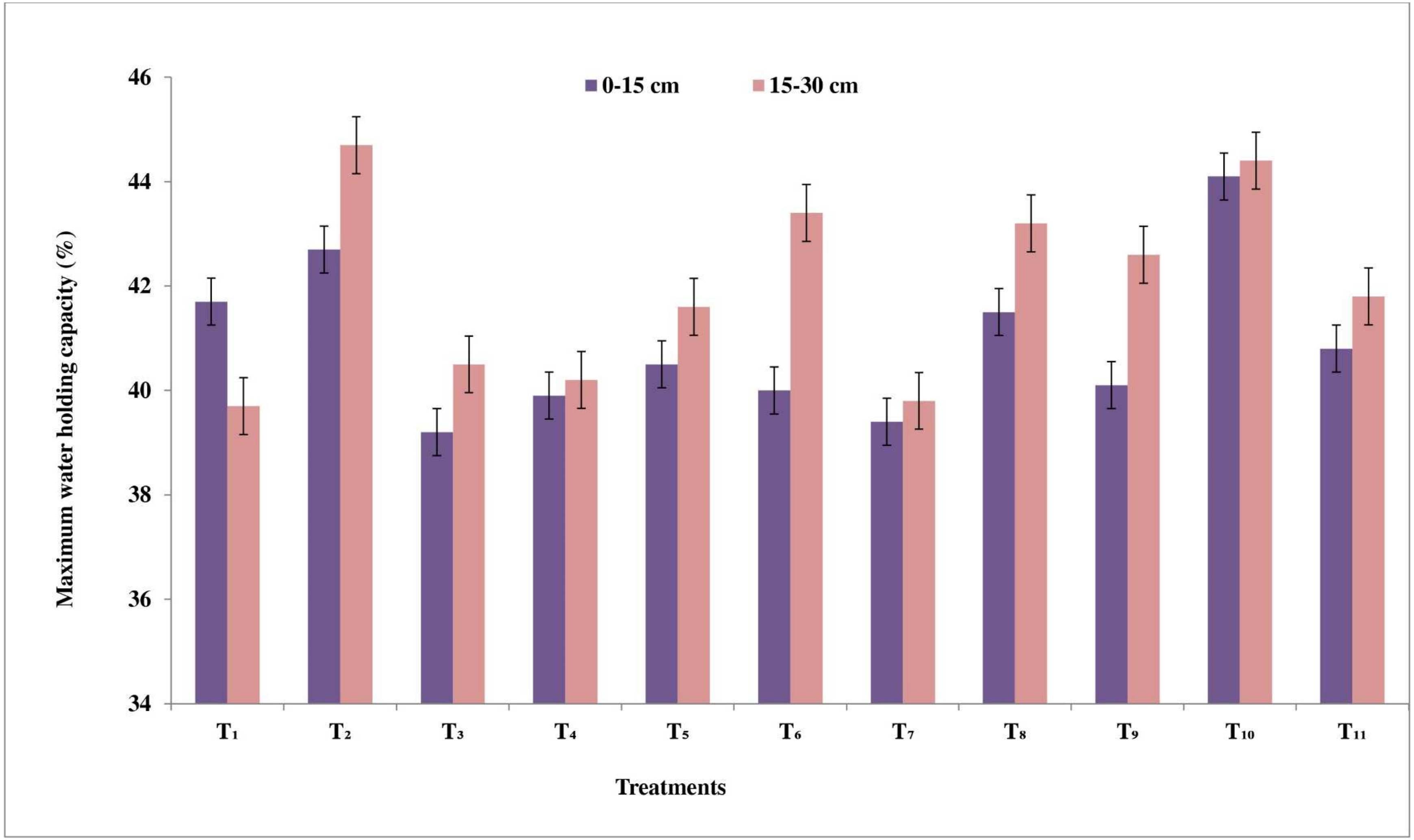

Fig. 4.2. Effect of long-term application of manure and fertilizers on maximum water holding capacity (%) at surface and sub-surface layers

In sub-surface layer (15-30 cm), MWHC was ranged from 39.7 to 44.7 % and significantly highest was observed in FYM alone (T_2) (44.7 %) which was on par with NPK+lime (T_{10}) (44.4 %), gypsum alone treated plot (T_6) (43.4 %), NPK (T_8) (43.2 %), NPK+gypsum (T_9) (42.6 %) and NPK+gypsum+$ZnSO_4$ (T_{11}) (41.8 %). The lowest MWHC was observed in control (T_1) (39.7 %) followed by NP (T_7) (39.4 %).

The higher MWHC was obtained with the FYM alone which was on par with NPK+lime (T_{10}), NPK+gypsum+$ZnSO_4$ (T_{11}), NPK (T_8) and NPK+gypsum (T_9) and they were significantly superior over the rest of the treatments. The higher MWHC of these treatments might be due to the improvement of the soil structure by the inclusion of P, gypsum, lime, which might have helped in the formation of soil aggregates which inturn decreased the macro pore space and increased the micro pore space of sandy loam soil, which lead to increased MWHC of aforesaid treatments. Similarly, Bhattacharayya *et al.* (2004) observed improvement of the aggregates in the soils with application of P and FYM in rainfed ecosystem. The higher values of MWHC in FYM alone treated plot in both the soil layers was due to accumulation of organic matter, which resulted in the improvement in stable soil aggregates and macro and micro pores spaces caused the free movement of water within the soil might have resulted to increase in water holding capacity of the soil. These results are in confirmity with the findings of Pernes and Tessier (2004), Sarawad *et al.* (2005), Tadesse *et al*. (2013) and Dubey and Datt (2014).

4.1.5 Soil Structural Indices

4.1.5.1 Mean weight diameter

The mean weight diameter (MWD) of soil aggregates was significantly influenced by the different treatments at surface and sub-surface layers and the data was presented in Table 4.3 and 4.4 and depicted in Fig. 4.3.

In surface layer (0-15 cm), the MWD of soil aggregates in different treatments ranged from 1.03 to 1.36 mm. The highest MWD of soil aggregates was recorded with FYM alone treated plot (T_2) (1.36 mm) and which was on par with NPK+gypsum+$ZnSO_4$ (T_{11}) (1.35 mm), NPK+lime (T_{10}) (1.34 mm), NPK+gypsum (T_9) (1.25 mm), NPK (T_8) (1.24 mm), gypsum alone treated plot (T_6) (1.22 mm), NP (T_7) (1.20 mm) and P alone treated plot (T_4) (1.17 mm). Whereas, significantly lowest MWD of soil aggregates was observed with control (T_1) (1.03 mm), followed by application of K alone (T_5) (1.12 mm) and N alone (T_3) (1.13 mm).

In sub-surface layer (15-30 cm), the MWD of soil aggregates in different treatments ranged from 1.22 to 1.44 mm. The highest MWD of soil aggregates recorded with FYM alone treated plot (T_2) (1.44 mm) which was on par with NPK+gypsum+$ZnSO_4$ (T_{11}) (1.43 mm), NPK+lime (T_{10}) (1.41 mm), NPK+gypsum (T_9) (1.38 mm), NP (T_7) (1.36 mm), P alone treated plot (T_4) (1.36 mm), gypsum alone treated plot (T_6) (1.33 mm) and NPK (T_8) (1.32 mm). Whereas, significantly lowest MWD of soil aggregates was observed with K alone treated plot (T_5) (1.22 mm), followed by control (T_1) (1.24 mm)

The higher MWD observed in FYM alone treatment might be due to the effect of organic matter as binding agent and helped in formation of stable aggregates with primary particles and clay domains through cementation. These results are in agreement with the findings of Rasool *et al.* (2008) who recorded highest MWD with the application of FYM @ 20 Mg ha^{-1}.

4.1.5.2 Geometric mean diameter

The geometric mean diameter (GMD) of soil aggregates was significantly influenced by the different treatments at surface and sub-surface layers. The data was presented in Table 4.3 and 4.4 and depicted in Fig. 4.4.

The GMD of soil aggregates in different treatments at surface layer (0-15 cm) was varied from 0.72 to 0.81 mm. The highest GMD was observed in FYM alone treated plot (T_2) (0.81 mm) and it was on par with NPK+lime (T_{10}) (0.80 mm), NPK+gypsum (T_9) (0.79 mm), NPK+gypsum+$ZnSO_4$ (T_{11})

(0.78 mm), NP (T_7) (0.78 mm), gypsum alone treated plot (T_6) (0.77 mm) and P alone treated plot (T_4) (0.76 mm). Whereas, the lowest GMD of soil aggregates was observed with control (T_1) (0.72 mm), followed by application of K fertilizer alone (T_5) (0.73 mm)

In sub-surface layer (15-30 cm), the GMD of soil aggregates in different treatments ranged was from 0.77 to 0.83 mm. The highest GMD was observed in NPK+gypsum+$ZnSO_4$ (T_{11}) (0.83 mm) and FYM alone treated plot (T_2) (0.83 mm), which was on par with NPK+gypsum (T_9) (0.82 mm), NPK+lime (T_{10}) (0.81 mm), NP treatment (T_7) (0.81 mm) and P alone treated plot (T_4) (0.80 mm) followed by gypsum alone treated plot (T_6) (0.79 mm) and N alone treated plot (T_3) (0.79 mm). Whereas, the significantly lowest GMD of soil aggregates was observed with control (T_1) (0.77 mm).

The increase in GMD with addition of FYM helped in formation of stable soil aggregates due to higher organic matter content which inturn resulted in the higher GMD. The present result are in agreement with the findings of Tuo *et al*. (2017) and Mazumdar *et al.* (2021) who reported higher GMD with continuous application of FYM alone.

4.1.5.3 Per cent water stable aggregates (≥0.25 mm)

The water stable aggregates (%WSA ≥0.25 mm) was significantly influenced by the different treatments at surface and sub-surface layers. The data was presented in Table 4.3 and 4.4 and depicted in Fig. 4.5.

The %WSA (≥0.25 mm) in different treatments at surface layer (0-15 cm) was ranged from 20.7 to 24.0 %. The highest was observed in FYM alone treated plot (T_2) (24.0 %) and which was on par with NPK+gypsum (T_9) (23.8 %), NP (T_7) (23.3 %), NPK+lime (T_{10}) (23.3 %), gypsum alone treated plot (T_6) (22.5 %) and P alone (T_4) (22.5 %) followed by NPK+gypsum+$ZnSO_4$ (T_{11}) (22.4 %) and NPK (T_8) (21.9 %). Whereas, the significantly lowest %WSA (≥0.25 mm) of soil aggregates was recorded with control (T_1) (20.7 %) and which was on par with application of K alone (T_5) (21.6 %) and N alone (T_3) (21.7 %).

In sub-surface layer (15-30 cm), the %WSA (≥0.25 mm) in different treatments was ranged from 21.6 to 24.0 %. The highest was observed in FYM alone treated plot (T_2) (24.0 %) which was on par with NPK+gypsum (T_9) (23.8 %), NPK+gypsum +$ZnSO_4$ (T_{11}) (23.5 %), NP (T_7) (23.2 %), N alone (T_3) (23.2 %), NPK+lime (T_{10}) (23.2 %). Whereas, the significantly lowest %WSA (≥0.25 mm) of soil aggregates was recorded with control (T_1) (21.6 %).

The higher %WSA (≥0.25 mm) of FYM treated plot in both the soil layers might be due to accumulation of organic matter, which resulted in the improvement in stable soil aggregates. These results are in agreement with the findings of Verma *et al.* (2010) and Yazdanpanah *et al*. (2016).

4.1.5.4 Per cent aggregate stability

The per cent aggregate stability (% AS) was significantly influenced by the different treatments at surface and sub-surface layers. The data was presented in Table 4.3 and 4.4 and depicted in Fig. 4.6.

The %AS in different treatments at surface layer (0-15 cm) was ranged from 26.7 to 28.3 %. The highest % AS was observed in NPK+gypsum (T_9) (28.3 %) and which was on par with P alone (T_4) (27.9 %), NPK+lime (T_{10}) (27.8 %), NP (T_7) (27.8 %), gypsum alone (T_6) (27.8 %), FYM alone (T_2) (27.7 %). Whereas, the significantly lowest % AS of soil aggregates was recorded with K alone treated plot (T_5) (26.7 %).

In sub-surface layer (15-30 cm), the %AS in different treatments was ranged from 27.1 to 28.2 %. The highest % AS was observed in NPK+gypsum +$ZnSO_4$ (T_{11}) (28.2 %) and which was on par with NPK+gypsum (T_9) (28.1 %), FYM alone (T_2) (27.9 %), NPK (T_8) (27.7 %), NP (T_7) (27.6 %), P alone (T_4) (27.6 %) and N alone treated plot (T_3) (27.6 %). Whereas, the significantly lowest % AS of soil aggregates was recorded with K alone treated plot (T_5) (27.1 %).

From the data presented Table 4.3 and 4.4. related the soil structural indices *viz.*, MWD, GMD, % WSA (≥0.25 mm) and % AS ranged between

1.03 to 1.36 mm, 0.72 to 0.81 mm, 20.7 to 24.0 per cent and 26.7 to 28.3 per cent, respectively at surface layer. However, MWD and % WSA were higher in sub-surface layer compared to surface layer, which might be due to absence of ploughing induced disruption of soil aggregates in sub-surface soil layer and subsequent compaction due to over burden pressure. The structural indices obtained with long-term application of FYM were relatively higher when compared with other long-term treatments indicating the profound influence of FYM on soil structure. Soil organic matter is the major binding agent and aggregation is hierarchial in which primary particles and clay domains are cemented together. FYM is a good source of organic matter which played an important role in the formation of the water stable aggregates. The present results were in accordance with Verma *et al.* (2010) and Tuo *et al.* (2017) who reported that increased soil structural indices *viz.,* MWD, GMD, % WSA ($\geq$0.25 mm) with application of FYM. The sole application of N, P, K fertilizers alone seperately recorded significantly lower soil structural indices compared with treatmental combinations *viz.,* NPK+gypsum+$ZnSO_4$, NPK+gypsum, NPK+lime and NPK. However application of gypsum @ 250 kg ha^{-1} continuously was also recorded significantly higher indices when compared with control. The lowest structural indices were recorded with K alone treated plot when compared with all other treatments.

Inclusion of the P, gypsum and lime and $ZnSO_4$ in the treatmental combinations or alone attributed to the development of the soil structure. The polyvalent anions ($H_2PO_4^-$, HPO_4^{-2}, PO_4^{-3}, SO_4^{-2}) which played a significant role in soil aggregation by bonding with the colloidal soil particles through Fe and Al. Similar results were reported by Mishra and Sharma, (1997). The Ca which is the constituent of lime and gypsum might be acted as a flocculating agent and phosphate ion, organic matter acted as cementing agents, hence the soil structural indices were significantly higher in FYM treated plot and lime or gypsum in combination with NPK. The foregoing discussion clearly indicated that FYM alone and integrated use of chemical

Table 4.3. Effect of long term application of manure and fertilizers on soil aggregation indices at surface layer (0-15 cm)

Treatments	Mean Weight Diameter (mm)	Geometric Mean Diameter (mm)	Water stable aggregates(%)	Aggregate stability (%)
T_1 : Control	1.03	0.72	20.7	27.4
T_2 :FYM @ 5 t ha^{-1} (once in 3 years)	1.36	0.81	24.0	27.7
T_3 : N @ 20 kg ha^{-1}	1.13	0.75	21.7	27.5
T_4 : P @ 10 kg ha^{-1}	1.17	0.76	22.5	27.9
T_5 : K @ 25 kg ha^{-1}	1.12	0.73	21.6	26.7
T_6 : Gypsum @ 250 kg ha^{-1}	1.22	0.77	22.5	27.8
T_7 : NP	1.20	0.78	23.3	27.8
T_8 : NPK	1.24	0.75	21.9	27.2
T_9 : NPK + gypsum	1.25	0.79	23.8	28.3
T_{10} : NPK + lime @ 100 kg ha^{-1}	1.34	0.80	23.3	27.8
T_{11} : NPK + gypsum + $ZnSO_4$ @ 25 kg ha^{-1}	1.35	0.78	22.4	27.4
SEm ±	**0.06**	**0.02**	**0.53**	**0.25**
CD (P=0.05)	**0.19**	**0.05**	**1.57**	**0.75**
CV	**9.18**	**3.94**	**4.09**	**1.59**

Table 4.4. Effect of long-term application of manure and fertilizers on soil aggregation indices at sub-surface layer (15-30 cm)

Treatments	Mean Weight Diameter (mm)	Geometric Mean Diameter (mm)	Water stable aggregates (%)	Aggregate stability (%)
T_1 : Control	1.24	0.77	21.6	27.5
T_2 : FYM @ 5 t ha^{-1} (once in 3 years)	1.44	0.83	24.0	27.9
T_3 : N @ 20 kg ha^{-1}	1.29	0.79	23.2	27.6
T_4 : P @ 10 kg ha^{-1}	1.36	0.80	22.4	27.6
T_5 : K @ 25 kg ha^{-1}	1.22	0.78	22.2	27.1
T_6 : Gypsum @ 250 kg ha^{-1}	1.33	0.79	22.3	27.5
T_7 : NP	1.36	0.81	23.2	27.6
T_8 : NPK	1.32	0.78	22.4	27.7
T_9 : NPK + gypsum	1.38	0.82	23.8	28.1
T_{10} : NPK + lime @ 100 kg ha^{-1}	1.41	0.81	23.2	27.4
T_{11} : NPK + gypsum + $ZnSO_4$ @ 25 kg ha^{-1}	1.43	0.83	23.5	28.2
SEm±	**0.04**	**0.01**	**0.38**	**0.19**
CD (P=0.05)	**0.13**	**0.03**	**1.12**	**0.56**
CV	**5.74**	**2.54**	**2.86**	**1.17**

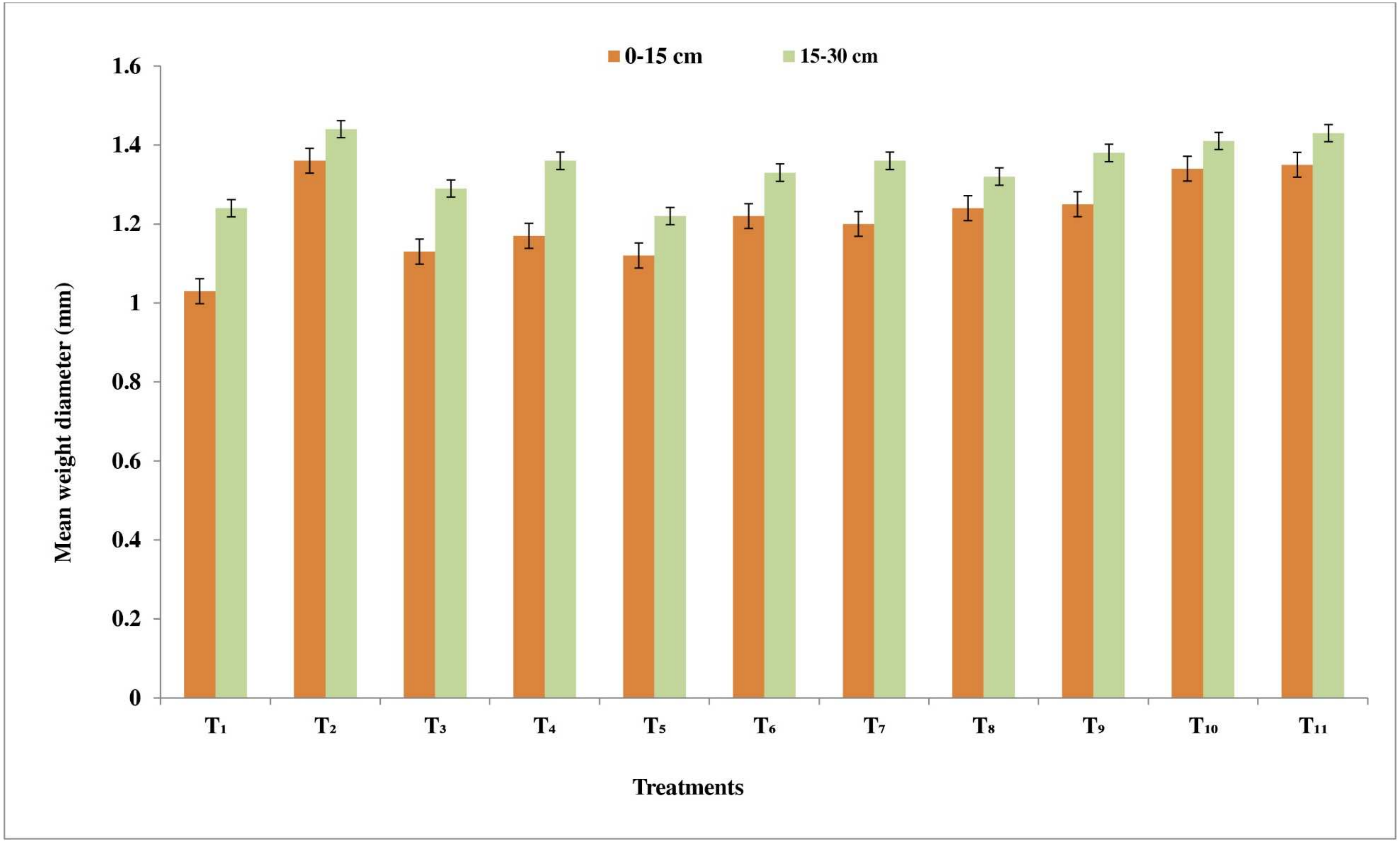

Fig. 4.3. Effect of long-term application of manure and fertilizers on mean weight diameter (mm) at surface and sub-surface layers

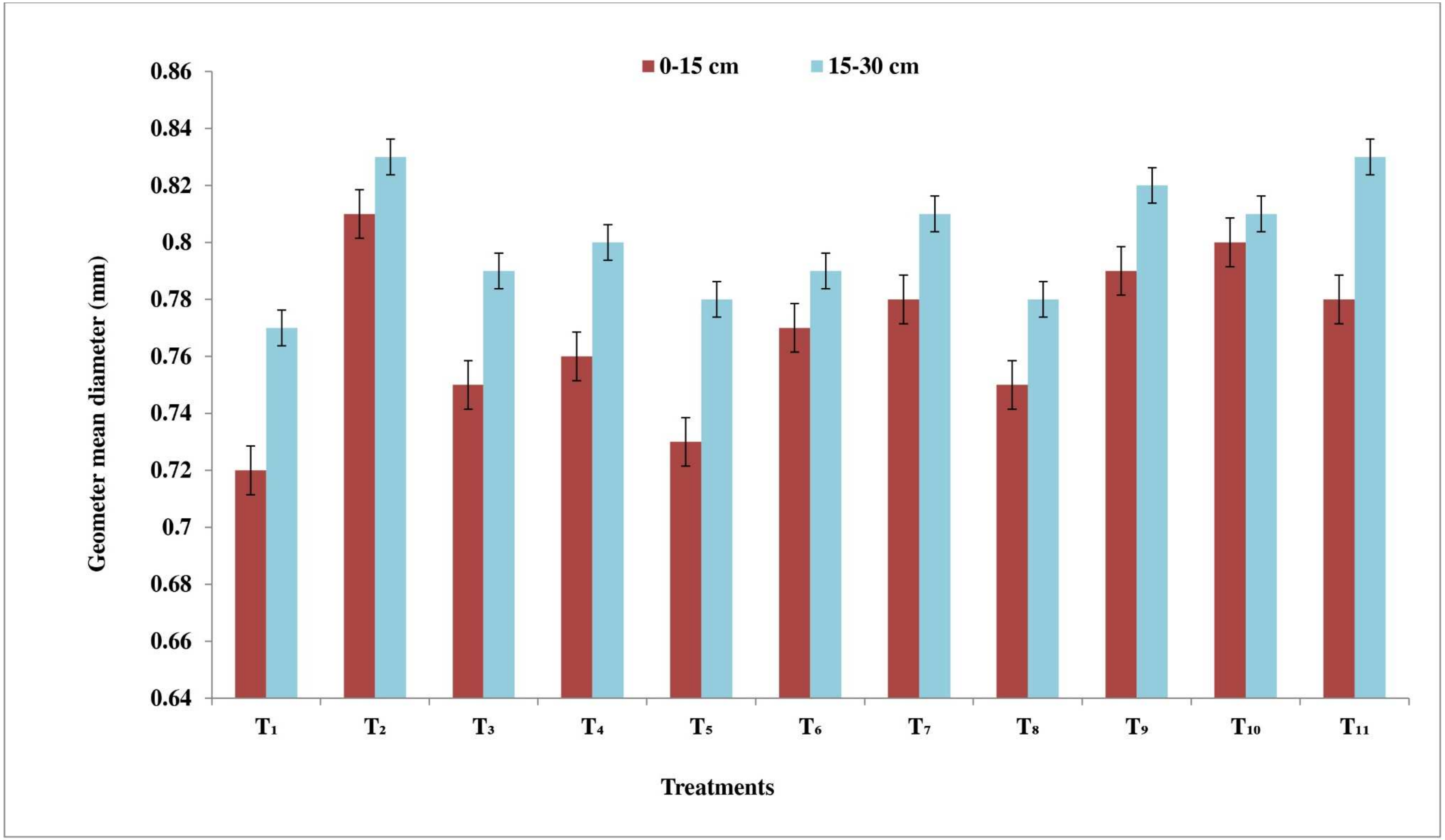

Fig. 4.4. Effect of long- term application of manure and fertilizers on geometer mean diameter (mm) at surface and sub-surface layers

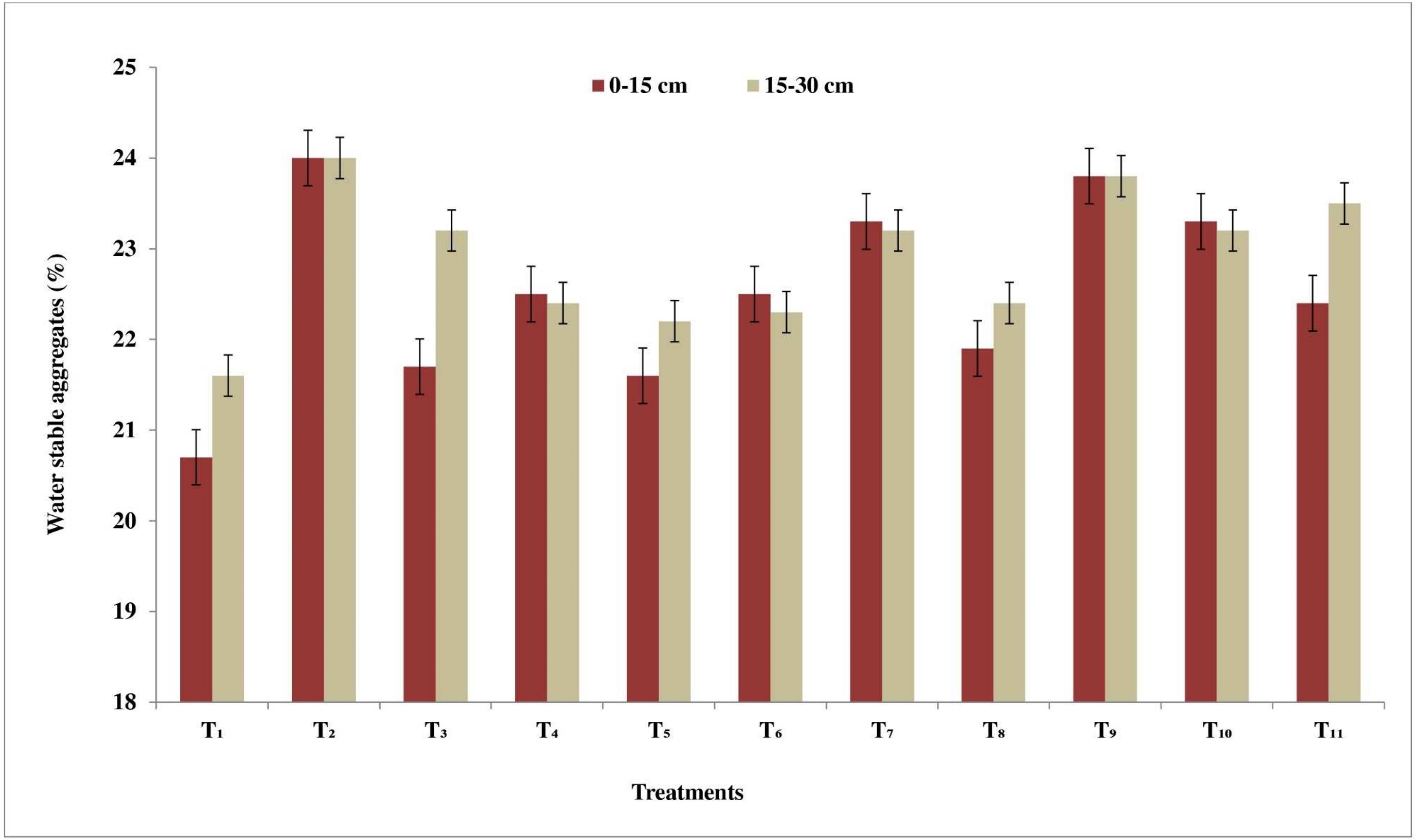

Fig. 4.5. **Effect of long-term application of manure and fertilizers on water stable aggregates (%) at surface and sub-surface layers**

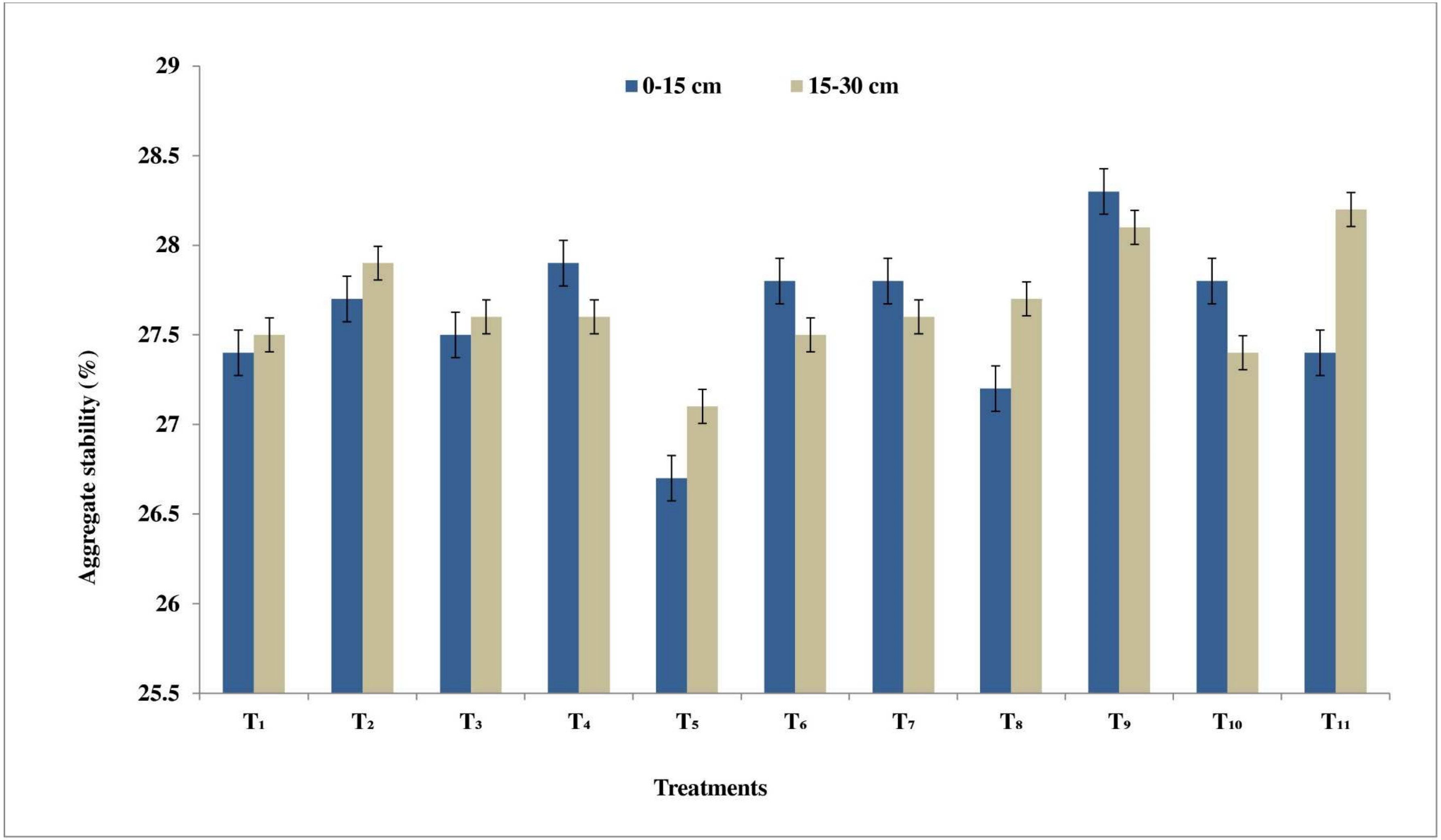

Fig. 4.6. Effect of long-term application of manure and fertilizers on aggregate stability (%) at surface and sub-surface layers

fertilizers increased the structural indices *viz.,* MWD (mm), GMD (mm), %WSA (≥0.25mm) and %AS. This could be attributed to the beneficial effects of certain polysaccharides by microbial activity as well as cementing action of bacteria and fungi (Kharche *et al.,* 2013).

4.2 EFFECT OF LONG TERM APPLICATION OF MANURE AND FERTILIZERS ON SOIL PHYSICO-CHEMICAL PROPERTIES

4.2.1 Soil Reaction (pH)

The data on soil pH as influenced by various treatments under long-term application is presented in Table 4.5 and depicted in Fig. 4.7.

The soil pH was significantly influenced by various treatments used in the long-term experiment in surface layer (0-15 cm) and ranged from 6.11 to 6.59. The highest soil pH was recorded in FYM alone (T_2) (6.59), which was on par with P alone (T_4) (6.57), NPK+lime (T_{10}) (6.48) and N alone treated plot (T_3) (6.46). Whereas the lowest soil pH was observed in NPK (T_8) (6.11) and NPK+gypsum (T_9) (6.13).

The soil pH was not significantly influenced by different treatments in the sub-surface layer (15-30 cm) and ranged from 5.94 to 6.21. The highest soil pH was recorded in NPK (T_8) (6.21), followed by FYM alone (T_2) (6.19), NP (T_7) (6.18) and N alone treated plot (T_3) (6.15). Whereas the lowest was observed in NPK+gypsum (T_9) (5.94), gypsum alone treated plot (T_6) (5.96) and K alone treated plot (T_5) (5.97).

Long-term application of manure and fertilizers showed a slight decrease in soil pH including control when compared to the initial (1981) soil pH (6.7). However, the soil pH in treatmental plots varied from 6.11 to 6.59 and 5.94 to 6.21 in surface and sub-surface layers, respectively. The slight variations with respect to pH among the treated plots might be due to the acidifying effect of different chemical fertilizers and organic matter. This was in accordance with the findings of Urkurkar *et al.* (2010), Hemalatha and Chellamuthu (2011), Brar *et al.* (2015), Salma *et al.* (2017) and Madhuri *et al.*

(2017). However, significant changes in the pH of the surface and sub-surface layers were not observed compared to control. This might be due to lower dose of chemical fertilizers applied apart from the buffering capacity of the soil.

4.2.2 Electrical Conductivity

The data on electrical conductivity (EC) as influenced by various treatments at surface and sub-surface layers is presented in Table 4.5 and depicted in Fig. 4.8.

The soil EC was not significantly influenced by different treatments in the surface and sub-surface layers. The EC of surface layer (0-15 cm) was ranged from 0.054 to 0.082 dS m^{-1} (Non-saline). The higher EC was recorded in gypsum alone treated plot (T_6) (0.082 dS m^{-1}) followed by NPK+gypsum+$ZnSO_4$ (T_{11}) (0.075 dS m^{-1}), P alone treated plot (T_4) (0.074 dS m^{-1}), only N treatment (T_3) (0.070 dS m^{-1}), K alone treated plot (T_5) (0.067 dS m^{-1}) and NPK+gypsum (T_9) (0.065 dS m^{-1}). The lowest soil EC was recorded in NPK (T_8) (0.054 dS m^{-1}) and NP (T_7) (0.054 dS m^{-1}).

In sub-surface layer (15-30 cm), EC was ranged from 0.050 to 0.088 dS m^{-1} (Non-saline). The higher EC was recorded in gypsum alone treated plot (T_6) (0.088 dS m^{-1}) followed by P alone treated plot (T_4) (0.081 dS m^{-1}), NP (T_7) (0.079 dS m^{-1}), only N treatment (T_3) (0.069 dS m^{-1}), control (T_1) (0.063 dS m^{-1}) and K alone treated plot (T_5) (0.063 dS m^{-1}). Whereas the lowest soil EC was recorded in the NPK+gypsum+$ZnSO_4$ (T_{11}) (0.050 dS m^{-1}), followed by FYM alone (T_2) (0.052 dS m^{-1}).

The perusal from the data presented in Table 4.5. revealed that the variation in EC among the treatments in both the soil layers were negligible and statistically non-significant. Similarly, EC values obtained with different treatments were comparable with initial EC (0.08 dS m^{-1}) recorded at the starting of the experiment in the year 1981. Similar results were also noticed by several workers *viz*., Bhaskara *et al*. (1992), Stalin *et al*. (2006), Yamini *et* *al.* (2015) and Shivashankar *et al.* (2018). Similarly, Salma *et al.* (2017) also reported that the accumulation of salts was not observed due to continuous application of manure and inorganic fertilizers to rainfed groundnut over a period of 34 years in both the surface and sub-surface soil layers.

4.2.3 Soil Organic Carbon

Soil organic carbon (SOC) as influenced by various treatments in the long-term at surface and sub-surface layers is presented in Table 4.5 and depicted in Fig. 4.9.

The SOC content was significantly influenced by the different treatments in surface and sub-surface layers. The SOC content in surface horizon (0-15 cm) was ranged from 3.31 to 5.94 g kg^{-1}. The highest SOC content was observed in FYM alone (T_2) (5.94 g kg^{-1}) followed by NPK+lime (T_{10}) (5.07 g kg^{-1}), NPK+gypsum (T_9) (5.03 g kg^{-1}), NPK (T_8) (4.95 g kg^{-1}), NPK+gypsum+$ZnSO_4$ (T_{11}) (4.58 g kg^{-1}), gypsum alone treated plot (T_6) (4.50 g kg^{-1}) and NP treatment (T_7) (4.18 g kg^{-1}). Whereas the lowest SOC content was observed in K alone treated plot (T_5) (3.31 g kg^{-1}), which was on par with sole application P (T_4) (3.51 g kg^{-1}), N (T_3) (3.76 g kg^{-1}) and control (T_1) (3.85 g kg^{-1}).

In sub-surface layer (15-30 cm), the SOC content was ranged from 3.24 to 4.91 g kg^{-1}. The highest SOC content was observed in FYM alone (T_2) (4.91 g kg^{-1}), which is on par with NPK+lime (T_{10}) (4.54 g kg^{-1}) followed by NPK+gypsum (T_9) (4.22 g kg^{-1}), N treatment (T_3) (4.14 g kg^{-1}) and NPK+gypsum+$ZnSO_4$ (T_{11}) (4.12 g kg^{-1}). Whereas the lowest SOC content was observed in only K alone treated plot (T_5) (3.24 g kg^{-1}).

The results indicated that SOC content was significantly influenced by the different treatments in surface and sub-surface layers. Among the treatments, FYM applied treatment showed significant higher in SOC content which was on par with NPK+lime. This might be due to the increased organic carbon content by addition of FYM. The above said data clearly indicated that

Table 4.5. Effect of long-term application of manure and fertilizers on soil physico-chemical properties at surface and sub-surface layers after harvest, *kharif*, 2021

Treatments	pH		Electrical conductivity (dSm^{-1})		Organic carbon ($g\ kg^{-1}$)	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
T_1 : Control	6.43	6.04	0.063	0.063	3.85	3.64
T_2 : FYM @ 5 t ha^{-1} (once in 3 years)	6.59	6.19	0.064	0.052	5.94	4.91
T_3 : N @ 20 kg ha^{-1}	6.46	6.15	0.070	0.069	3.76	4.14
T_4 : P @ 10 kg ha^{-1}	6.57	6.03	0.074	0.081	3.51	3.44
T_5 : K @ 25 kg ha^{-1}	6.36	5.97	0.067	0.063	3.31	3.24
T_6 : Gypsum @ 250 kg ha^{-1}	6.21	5.96	0.082	0.088	4.50	3.89
T_7 : NP	6.31	6.18	0.054	0.079	4.18	4.03
T_8 : NPK	6.11	6.21	0.054	0.059	4.95	3.60
T_9 : NPK + gypsum	6.13	5.94	0.065	0.058	5.03	4.22
T_{10} : NPK + lime @ 100 kg ha^{-1}	6.48	5.99	0.061	0.057	5.07	4.54
T_{11} : NPK + gypsum + $ZnSO_4$ @ 25 kg ha^{-1}	6.26	5.98	0.075	0.050	4.58	4.12
SEm±	**0.05**	**0.15**	**0.014**	**0.021**	**0.24**	**0.18**
CD (P=0.05)	**0.13**	**NS**	**NS**	**NS**	**0.70**	**0.54**
CV	**1.44**	**4.79**	**19.79**	**16.42**	**9.26**	**7.90**

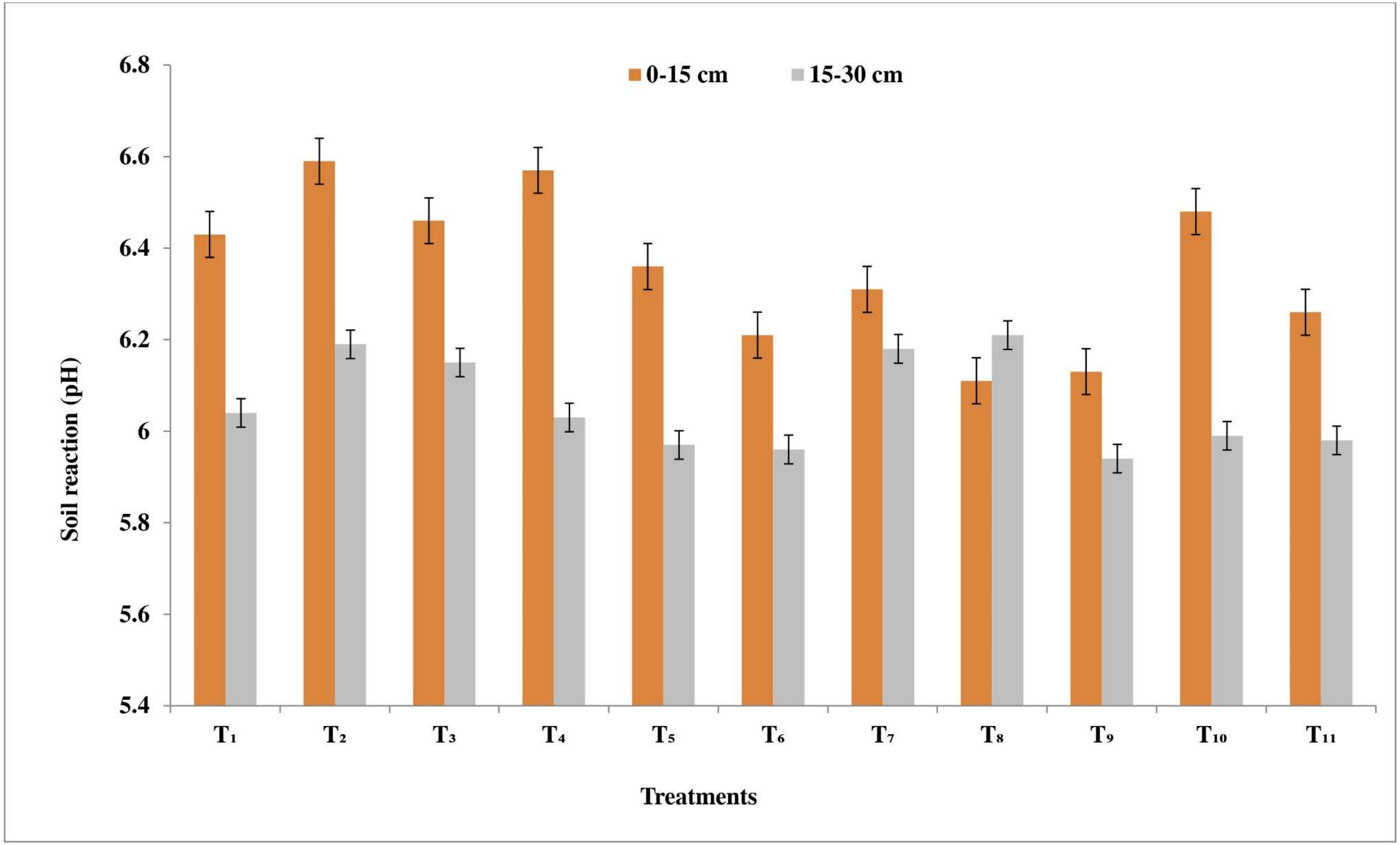

Fig. 4.7. Effect of long-term application of manure and fertilizers on soil pH at surface and sub-surface layers

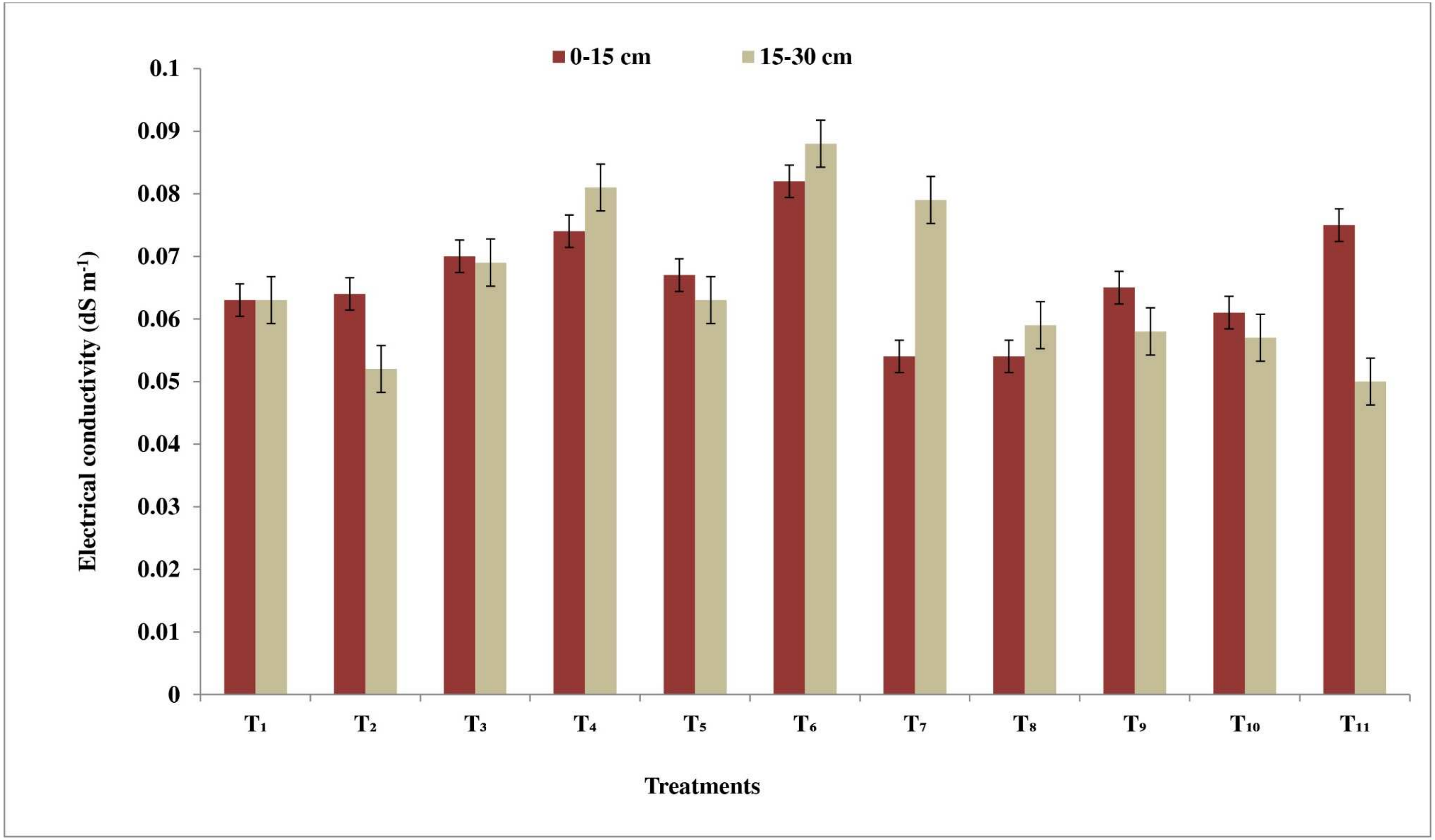

Fig. 4.8. Effect of long-term application of manure and fertilizers on electrical conductivity (dS m^{-1}) at surface and sub-surface layers

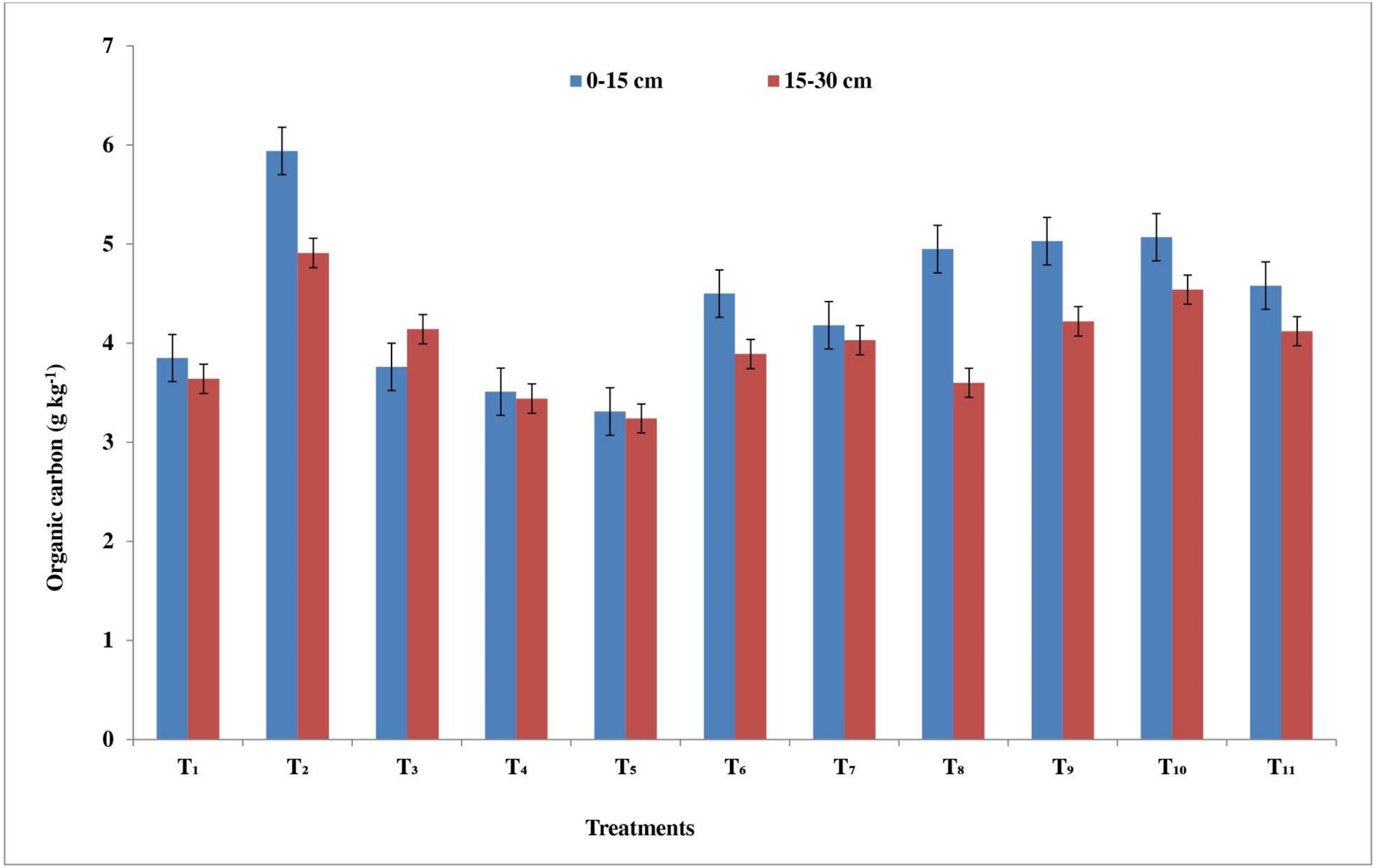

Fig. 4.9. Effect of long-term application of manure and fertilizers on SOC (g kg^{-1}) at surface and sub-surface layers

the increase in organic carbon content in the surface layer as compared to the initial SOC content recorded in 1981 was mainly due to the accumulation of organic residues over a period of time. This was in accordance with the findings of Yaduvanshi (2001), Bhattacharya *et al.* (2004), Kundu *et al.* (2017), Ahmady *et al*. (2020) and Mohan *et al.* (2021). The data also revealed that the SOC content was increased in all the treatments including control. Similarly, Dwivedi and Dixit (2002) also reported that the continued application of fertilizers alone helped in increasing the SOC content, due to contribution of biomass in the form of crop stubbles and residues.

4.2.4 Effect of Long-Term Application of Manure and Fertilizers on Carbon Stocks

4.2.4.1 Soil organic carbon stocks

The soil organic carbon stocks (SOC stocks) was significantly influenced by various treatments at surface and sub-surface layers and the data was presented in Table 4.6 and depicted in Fig. 4.10.

The SOC stocks at surface layer (0-15 cm) was ranged from 7.40 to 12.12 Mg C ha^{-1} with the mean of 9.54 Mg C ha^{-1}. Significantly higher SOC stocks was recorded in FYM alone (T_2) (12.12 Mg C ha^{-1}) which was on par with NPK+lime (T_{10}) (11.02 Mg C ha^{-1}) followed by NPK treatment (T_8) (10.58 Mg C ha^{-1}), NPK+gypsum (T_9) (10.57 Mg C ha^{-1}), NPK+gypsum+$ZnSO_4$ (T_{11}) (10.28 Mg C ha^{-1}), gypsum alone treatment (T_6) (9.72 Mg C ha^{-1}) and NP treatment (T_7) (9.13 Mg C ha^{-1}). Whereas the lowest SOC stock was observed in K alone (T_4) (7.47 Mg C ha^{-1}) and on par with application of P alone (T_4) (7.50 Mg C ha^{-1}), N alone (T_3) (8.09 Mg C ha^{-1}) and control (T_1) (8.49 Mg C ha^{-1}).

The SOC stocks at sub-surface layer (15-30 cm) was ranged from 7.34 to 11.24 Mg C ha^{-1} with the mean of 9.11 Mg C ha^{-1}. Significantly higher SOC stocks was recorded in FYM alone (T_2) (11.24 Mg C ha^{-1}) which was on par with NPK+lime (T_{10}) (10.26 Mg C ha^{-1}) followed by

NPK+gypsum+$ZnSO_4$ (T_{11}) (9.65 Mg C ha^{-1}), NPK+gypsum (T_9) (9.64 Mg C ha^{-1}) and N alone treated plot (T_3) (9.47 Mg C ha^{-1}). Whereas the lowest SOC stocks was observed in K alone treated plot (T_5) (7.34 Mg C ha^{-1}), which was on par with application of P alone (T_4) (7.58 Mg C ha^{-1}) and control (T_1) (8.37).

The results revealed that the SOC stocks was decreased with increase in soil depth. The mean SOC stock at surface soil and sub-surface layers was recorded as 9.24 Mg C ha^{-1} and 9.11 Mg C ha^{-1}, respectively. The higher SOC stock in the surface layer as compared to sub-surface layers might be due to addition of organic matter through FYM or crop biomass. The present results are in agreement with the findings of Bhattacharyya *et al.* (2006), Munoz *et al*. (2007) and Bhattacharyya *et al.* (2007).

The SOC stocks both in surface and sub-surface layers are greater in FYM treated plot compared to other treatments, but on par with NPK+lime, NPK+gypsum+$ZnSO_4$ and gypsum alone treated plots compared to sole nutrient fertilizers treatments and control. The higher amount of large macroaggregates present in aforesaid treatments might be one of the major reasons for higher SOC stocks, as macroaggregates provide better biophysical and chemical protection to SOC from microbial breakdown. The increase in SOC stock in FYM might be due to availability of more organic matter, reduced bulk density, increased porosity which inturn increased soil carbon stock. These results are in line with the findings of Thennarasu *et al.* (2014), Trivedi *et al*. (2020) and Mohan *et al.* (2020) who reported that application of FYM sequestered higher SOC stocks compared to other treatments.

4.2.4.2 SOC stocks build-up

The SOC stocks build-up (%) was significantly influenced by various treatments over the long-term application both in surface and sub-surface layers and the data was presented in Table 4.6 and depicted in Fig. 4.11.

SOC stocks build-up (%) at surface layer (0-15 cm) was ranged from -11.76 to 43.13 % with the mean of 13.88 %. The higher SOC stock build-up (%) was recorded in FYM alone (T_2) (43.13 %) followed by NPK+lime (T_{10}) (30.19 %), NPK treatment (T_8) (24.70 %), NPK+gypsum (T_9) (24.42 %) and NPK+gypsum +$ZnSO_4$ (T_{11}) (21.05 %). Whereas the SOC stock build-up (%) was negative in K alone (T_5) (-11.76 %), P alone (T_4) (-11.61 %) and N alone (T_3) (-4.29 %) treated plots compared to control (T_1).

The SOC stock build-up (%) at sub-surface layer (15-30 cm) was ranged from -12.16 to 35.24 % with the mean of 10.42 %. The higher SOC stock build-up (%) was recorded in FYM alone (T_2) (35.24 %) followed by NPK+lime (T_{10}) (23.43 %), NPK+gypsum+$ZnSO_4$ (T_{11}) (16.33 %), NPK+gypsum (T_9) (15.54 %) and N alone treated plot (T_3) (14.14 %). Whereas the SOC stock build-up (%) was negative in K alone (T_5) (-12.16 %) and P alone (T_4) (-5.95 %) treated plots compared to control.

The results indicated that the SOC stock build-up (%) was significantly influenced by the different treatments in surface and sub-surface layers. Among the treatments, FYM applied treatment showed significant increase in SOC stock build-up (%) followed by NPK+lime treatment both in surface and sub-surface layers. This might be due to the residual effect of organic manures on soil which increased organic carbon content. The single nutrient fertilizers treated plots showed significantly negative build-up (%) which might be due to lesser biomass addition to the soil surface. These findings are in comfirmity with the earlier reports by Pedababu (2009) who recorded that the inorganic treatments did not showed any significant effect on carbon stocks build-up (%).

4.2.4.3 Carbon sequestration rate

Carbon sequestration rate (Mg ha^{-1} yr^{-1}) was significantly influenced by various treatments over the long-term application both in surface and sub-surface layers and data was presented in Table 4.6 and depicted in Fig. 4.12.

Carbon sequestration rate at surface layer (0-15 cm) was ranged from 0.08 to 0.20 Mg ha^{-1} yr^{-1} with the mean of 0.13 Mg ha^{-1} yr^{-1}. Significantly higher carbon sequestration rate was recorded in FYM alone (T_2) (0.20 Mg ha^{-1} yr^{-1}) which was on par with NPK+lime (T_{10}) (0.17 Mg ha^{-1} yr^{-1}) followed by NPK treatment (T_8) (0.16 Mg ha^{-1} yr^{-1}), NPK+gypsum (T_9) (0.16 Mg ha^{-1} yr^{-1}) and NPK+gypsum +$ZnSO_4$ (T_{11}) (0.15 Mg ha^{-1} yr^{-1}). Whereas the lowest Carbon sequestration rate was observed in K alone (T_5) and P alone (T_4) (0.08 Mg ha^{-1} yr^{-1}) treated plots.

Carbon sequestration rate at sub-surface layer (15-30 cm) was ranged from 0.08 to 0.18 kg C ha^{-1} with the mean of 0.12 Mg ha^{-1} yr^{-1}. Significantly higher Carbon sequestration rate was recorded in FYM alone (T_2) (0.18 Mg ha^{-1} yr^{-1}) which is on par with NPK+lime (T_{10}) (0.15 Mg ha^{-1} yr^{-1}) followed by NPK+ gypsum+$ZnSO_4$ (T_{11}) (0.14 Mg ha^{-1} yr^{-1}) and NPK+gypsum (T_9) (0.14 Mg ha^{-1} yr^{-1}). Whereas the lowest Carbon sequestration rate was observed in K alone (T_5) (0.08 Mg ha^{-1} yr^{-1}), P alone (T_4) (0.09 Mg ha^{-1} yr^{-1}) treated plots and control (T_1) (0.10 Mg ha^{-1} yr^{-1}).

The results indicated that, higher organic inputs in FYM treated plot resulted in higher carbon sequestration both in surface and sub-surface layers. Several studies revealed that the FYM contains of higher lignin content and recalcitrant form of carbon might resulted in higher carbon sequestration upon application in agricultural fields (Bronson *et al.*, 1998). The increase in carbon sequestration rate with the addition of FYM also attributed to better crop growth and concomitant high root biomass and crop residues (Kumara *et al*., 2014). The higher carbon sequestration was observed in surface layer compared to sub-surface layer, which might be due to addition of more plant biomass to the surface layer rather than sub-surface layer. These results are in agreement with the findings of Dou *et al*. (2016).

Table 4.6. Effect of long-term application of manure and fertilizers on SOC stocks, build-up and carbon sequestration rate at surface and sub-surface layers

Treatments	SOC stocks (Mg C ha^{-1})		SOC stocks build-up (%)		Carbon sequestration rate (Mg ha^{-1} $year^{-1}$)	
	0-15 cm	**15-30 cm**	**0-15 cm**	**15-30 cm**	**0-15 cm**	**15-30 cm**
T_1 : Control	8.49	8.37	_	_	0.11	0.10
T_2 : FYM @ 5 t ha^{-1} (once in 3 years)	12.12	11.24	43.13	35.24	0.20	0.18
T_3 : N @ 20 kg ha^{-1}	8.09	9.47	-4.29	14.14	0.10	0.13
T_4 : P @ 10 kg ha^{-1}	7.50	7.85	-11.60	-5.95	0.08	0.09
T_5 : K @ 25 kg ha^{-1}	7.47	7.34	-11.76	-12.16	0.08	0.08
T_6 : Gypsum @ 250 kg ha^{-1}	9.72	8.95	15.47	7.93	0.14	0.12
T_7 : NP	9.13	9.00	7.45	8.19	0.12	0.12
T_8 : NPK	10.58	8.48	24.70	1.53	0.16	0.11
T_9 : NPK +gypsum	10.57	9.64	24.42	15.54	0.16	0.14
T_{10} : NPK + lime @ 100 kg ha^{-1}	11.02	10.26	30.19	23.43	0.17	0.15
T_{11} : NPK +gypsum+$ZnSO_4$ @ 25 kg ha^{-1}	10.28	9.65	21.05	16.33	0.15	0.14
Mean	**9.54**	**9.11**	**13.88**	**10.42**	**0.13**	**0.12**
SEm±	**0.46**	**0.40**	**1.07**	**0.98**	**0.01**	**0.01**
CD (P=0.05)	**1.36**	**1.20**	**3.19**	**2.94**	**0.03**	**0.03**
CV	**8.35**	**7.69**	**13.36**	**16.37**	**14.86**	**14.27**

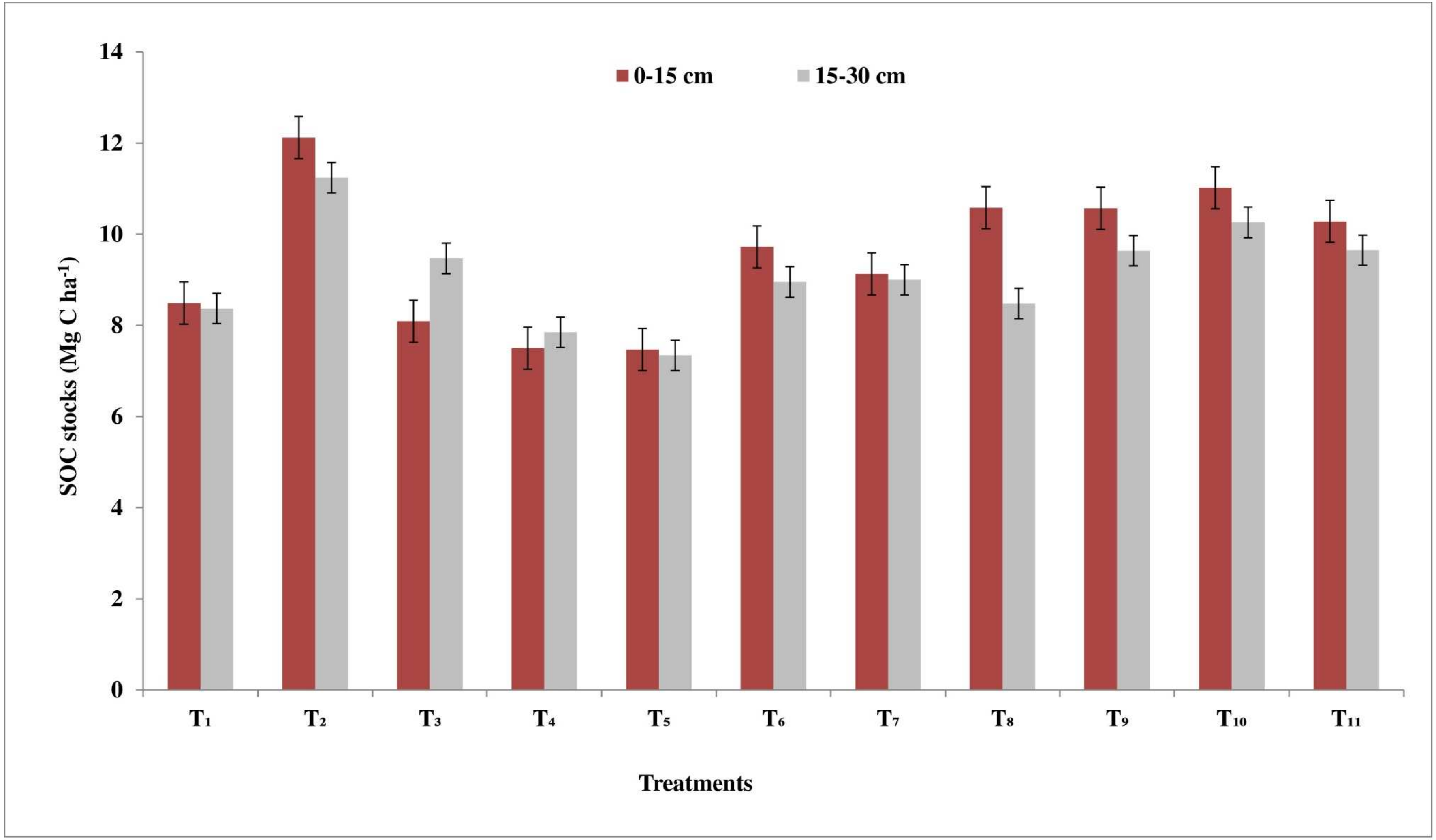

Fig. 4.10. Effect of long-term application of manure and fertilizers on SOC stocks (Mg C ha^{-1}) at surface and sub-surface layers

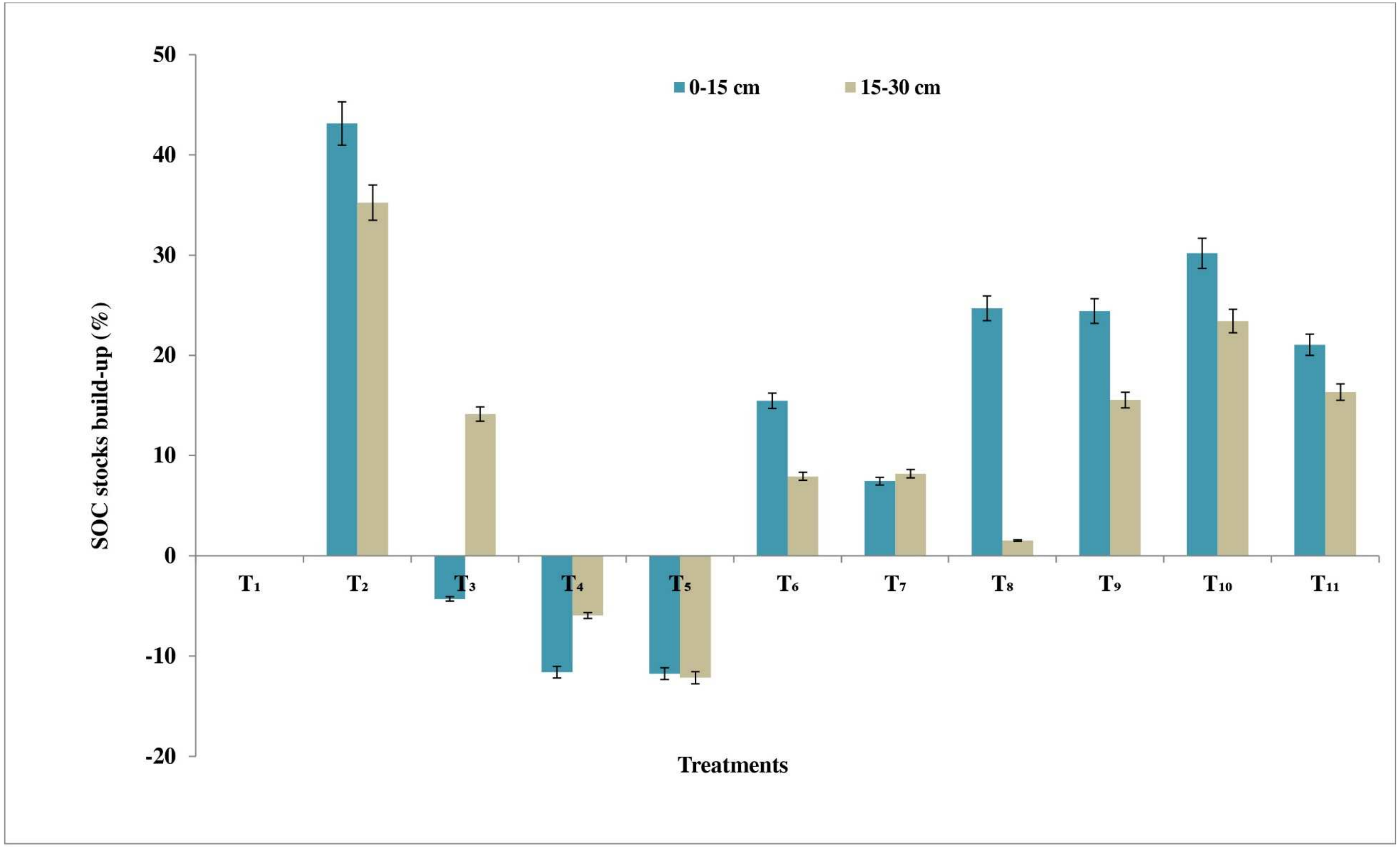

Fig. 4.11. Effect of long-term application of manure and fertilizers on SOC stocks build-up (%) at surface and sub-surface layers

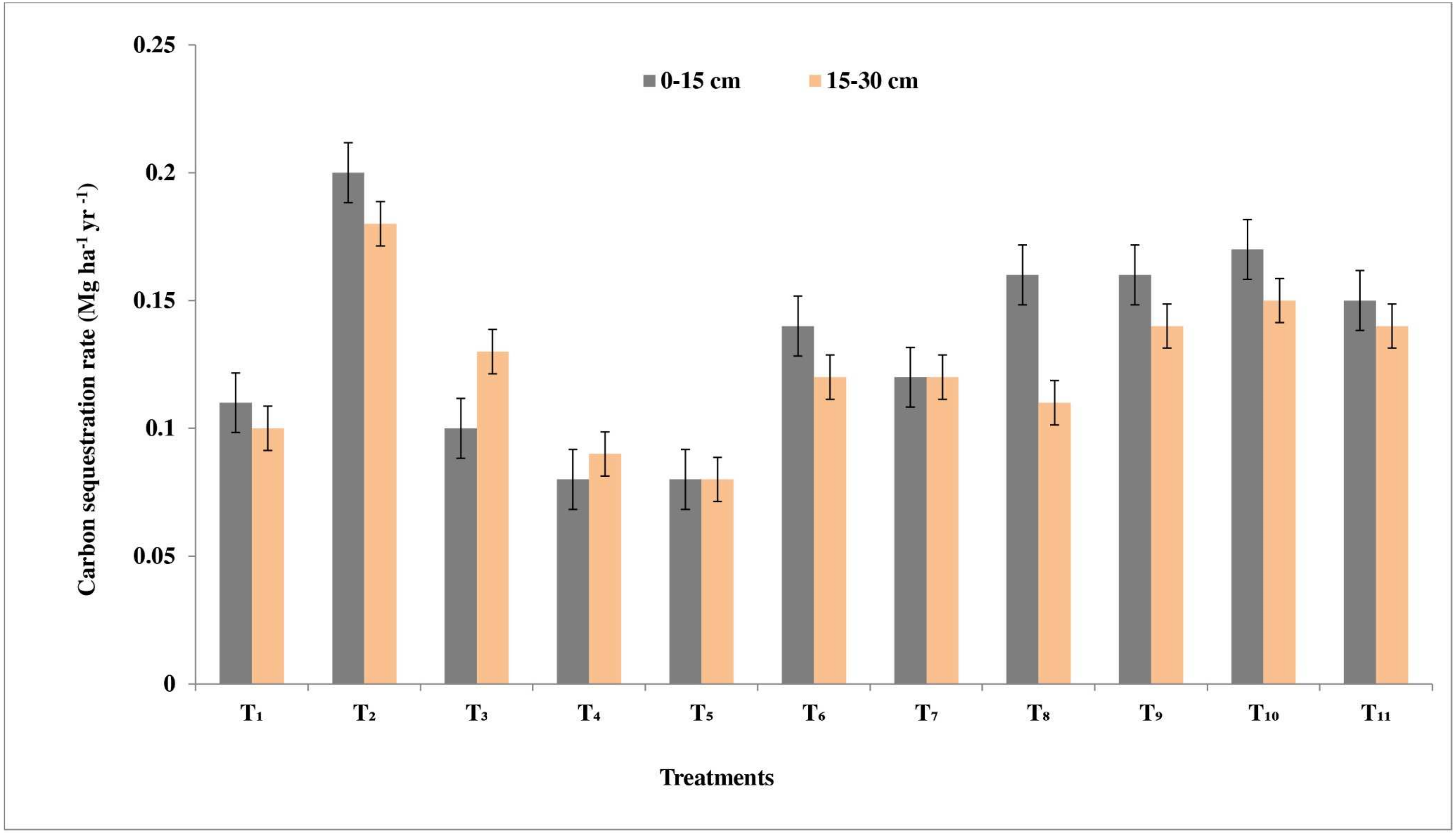

Fig. 4.12. Effect of long-term application of manure and fertilizers on carbon sequestration rate (Mg ha^{-1} yr^{-1}) at surface and sub-surface layers

4.2.5 Effect of Long-Term Application of Manure and Fertilizers on Soil Aggregation

The soil aggregate size fractions influenced by long-term application of manure and fertilizers at surface and sub-surface layers was presented in Table 4.7, 4.8 and 4.9 and depicted in Fig. 4.13 and 4.14.

The soil aggregate fractionation at surface horizon (0-15 cm) revealed that the soil aggregates of 8-5 mm size fraction was ranged from 5.53 to 9.83 % with the mean of 7.78 %. The highest was observed in NPK+lime (T_{10}) (9.83 %) and lowest was observed in control (T_1) (5.53 %). The soil aggregates of 5-2 mm size fraction was ranged from 7.30 to 9.53 % with the mean of 8.29 %. The highest was observed in NPK+gypsum+$ZnSO_4$ (T_{11}) (9.53 %) and lowest was observed in control (T_1) (7.30 %). The soil aggregates of 2-1 mm size fraction was ranged from 8.07 to 10.73 % with the mean of 9.38 % The highest was observed in FYM alone treated plot (T_2) (9.53 %) and lowest was observed in NPK+gypsum+$ZnSO_4$ (T_{11}) (8.07 %).

The soil aggregates of 1-0.5 mm size fraction was ranged from 13.40 to 20.27 % with the mean of 17.61 % The highest was observed in NP (T_7) (20.27 %) and lowest was observed in NPK (T_8) (13.40 %). The soil aggregates of 0.5-0.25 mm size fraction was ranged from 28.97 to 35.40 % with the mean of 32.02 %. The highest was observed in NPK+gypsum (T_9) (35.40 %) and lowest was observed in N alone treated plot (T_3) (28.97 %). The soil aggregates of 0.25-0.125 mm size fraction was ranged from 12.43 to 22.37 % with the mean of 16.95 %. The highest was observed in control (T_1) (22.37 %) and lowest was observed in FYM alone treated plot (T_2) (12.43 %). Whereas, soil aggregates of <0.125 mm size fraction was ranged from 5.67 to 10.97 % with the mean of 8.00 %. The highest was observed in P alone treated plot (T_4) (10.97 %) and lowest was observed in NPK+gypsum (T_9) (5.67 %) (Table 4.7).

In sub-surface layer (15-30 cm), the soil aggregates of 8-5 mm size fraction was ranged from 6.07 to 9.67 % with the mean of 7.92 %. The highest was observed in FYM alone treated plot (T_2) (9.67 %) and lowest was observed in K alone treated plot (T_5) (6.63 %). The soil aggregates of 5-2 mm size fraction was ranged from 10.13 to 12.10 % with the mean of 11.09 %. The highest was observed in P alone treated plot (T_4) (12.10 %) and lowest was observed in control (T_1) (10.13 %). The soil aggregates of 2-1 mm size fraction was ranged from 10.73 to 14.63 % with the mean of 12.08 %. The highest was observed in NP (T_7) (14.63 %) and lowest was observed in NPK (T_8) (10.73 %).

The soil aggregates of 1-0.5 mm size fraction was ranged from 13.97 to 17.27 % with the mean of 15.36 %. The highest was observed in K alone treated plot (T_5) (17.27 %) and lowest was observed in NP (T_7) (13.97 %). The soil aggregates of 0.5-0.25 mm size fraction was ranged from 26.23 to 34.50 % with a mean of 29.85 %. The highest was observed in NPK+gypsum (T_9) (34.50 %) and lowest was observed in NPK (T_8) (26.23 %). The soil aggregates of 0.25-0.125 mm size fraction was ranged from 13.10 to 20.53 % with the mean of 15.88 %. The highest was observed in NPK (T_8) (20.53 %) and lowest was observed in FYM alone treated plot (T_2) (13.10 %). Whereas, soil aggregates of <0.125 mm size fraction was ranged from 6.07 to 9.67 % with the mean of 7.82 %. The highest was observed in gypsum alone treated plot (T_6) (9.67 %) and lowest was observed in NPK+gypsum+$ZnSO_4$ (T_{11}) (6.07 %) (Table 4.8).

The data pertaining to soil aggregate fractions in aggregate class (%) *i.e.* micro-aggregates (<0.25 mm), small macro-aggregates (2-0.25 mm) and large macro-aggregates (>2 mm) was presented in Table 4.9 and depicted in Fig. 4.13 and 4.14. The soil aggregate fractions was significantly influenced by various treatments in the long-term at surface and sub-surface layers.

In surface layer (0-15 cm), the micro-aggregates (<0.25 mm) ranged from 19.93 to 31.03 % with the mean of 24.92 %. The highest was observed in control (T_1) (31.03 %) and which was on par P alone (T_4) (27.97 %), N alone treated plot (T_3) (27.80 %) and NPK (T_8) (26.97 %). Whereas, the lowest was observed in FYM alone treated plot (T_2) (19.93 %). The small macro-aggregates (2-0.25 mm) ranged from 55.73 to 62.77 % with the mean of 59.01 %. The highest was observed in NPK+gypsum (T_9) (62.77 %) and which was on par with FYM alone (T_2) (62.27 %), NP (T_7) (61.60 %) and NPK+lime (T_{10}) (60.23 %). Whereas, the lowest was observed in NPK+gypsum+$ZnSO_4$ (T_{11}) (55.73 %). The large macro-aggregates (>2 mm) ranged from 12.83 to 19.10 % with the mean of 16.07 %. The highest was observed in NPK+gypsum+$ZnSO_4$ (T_{11}) (19.10 %) and which was on par with FYM alone (T_2) (17.80 %), NPK+lime (T_{10}) (17.60 %) and NPK (T_8) (16.73), whereas lowest was observed in control (T_1) (12.83 %).

In sub-surface layer (15-30 cm), the micro-aggregates (<0.25 mm) ranged from 20.00 to 28.13 % with the mean of 23.70 %. The highest was observed in NPK (T_8) (28.13 %) and which was on par with gypsum alone (T_6) (26.07 %), K alone (T_5) (25.73 %) and P alone treated plot (T_4) (25.30 %), whereas lowest was observed in FYM alone treated plot (T_2) (20.00 %). The small macro-aggregates (2-0.25 mm) ranged from 52.83 to 59.97 % with the mean of 57.28 %. The highest was observed in NPK+gypsum (T_9) (59.97 %) and which was on par with FYM alone (T_2) (59.67 %), N alone (T_3) (59.60 %) and NP (T_7) (58.30 %), whereas lowest was observed in NPK (T_8) (52.83 %). The large macro-aggregates (>2 mm) ranged from 16.77 to 20.50 % with the mean of 19.01 %. The highest was observed in NPK+lime (T_{10}) (20.50 %) followed by NPK+gypsum+$ZnSO_4$ (T_{11}) (20.40 %) and FYM (T_2) (20.33 %), whereas lowest was observed in control (T_1) (16.77 %).

The results revealed that, among the soil aggregate fractions (%) small macro-aggregates are higher compared to large macro and micro-aggregates in both surface and sub-surface layers. The data revealed that aggregate fraction of size >0.25 mm were in higher in treatments received with FYM alone, NPK+lime, NPK+gypsum and NPK+gypsum+$ZnSO_4$ treatments compared to other treatments. This might be due to the increased root biomass which indirectly helped in improvement of large and small macro-aggregates

Table 4.7. Effect of long-term application of manure and fertilizers on soil aggregate size class (%) at surface layer after harvest, *kharif*, 2021

Treatments	**Aggregate size class (mm)**						
	5-8	**2-5**	**1-2**	**0.5-1**	**0.25-0.5**	**0.125-0.25**	**<0.125**
T_1 : Control	5.53	7.30	8.87	17.17	30.10	22.37	8.67
T_2 :FYM @ 5 t ha^{-1} (once in 3 years)	9.67	8.13	10.73	17.83	33.70	12.43	7.50
T_3 :N @ 20 kg ha^{-1}	6.17	8.57	9.63	18.87	28.97	19.83	8.30
T_4 :P @ 10 kg ha^{-1}	6.60	8.00	8.77	16.93	31.73	17.00	10.97
T_5 :K @ 25 kg ha^{-1}	6.93	8.00	10.47	16 .40	33.17	18.00	7.03
T_6 :Gypsum @ 250 kg ha^{-1}	7.47	8.33	10.71	17.57	30. 87	17.80	7.23
T_7 :NP	7.10	8.90	8.53	20.27	32.80	15.03	7.37
T_8 :NPK	8.90	7.83	8.40	13.40	34.50	17.57	9.40
T_9 :NPK + gypsum	7.80	8.80	9.60	17.77	35.40	14.97	5.67
T_{10} :NPK + lime @ 100 kg ha^{-1}	9.83	7.77	9.43	19.17	31.63	15.00	7.17
T_{11} : NPK + gypsum + $ZnSO_4$ @ 25 kg ha^{-1}	9.57	9.53	8.07	18.30	29.37	16.47	8.70
Mean	**7.78**	**8.29**	**9.38**	**17.61**	**32.02**	**16.95**	**8.00**
SEm±	**0.84**	**0.62**	**0.65**	**1.52**	**1.55**	**1.45**	**0.76**
CD (P=0.05)	**2.48**	**NS**	**NS**	**NS**	**NS**	**4.29**	**2.26**

Table 4.8. **Effect of long-term application of manure and fertilizers on soil aggregate size class (%) at sub-surface layer after harvest, *khari*, 2021**

Treatments	Aggregate size class (mm)						
	5-8	**2-5**	**1-2**	**0.5-1**	**0.25-0.5**	**0.125-0.25**	**<0.125**
T_1 : Control	6.63	10.13	12.53	15.53	29.97	16.90	8.30
T_2 :FYM @ 5 t ha^{-1} (once in 3 years)	9.67	10.67	12.00	14.00	33.67	13.10	6.90
T_3 :N @ 20 kg ha^{-1}	7.37	10.23	12.40	16.77	30.43	14.83	7.97
T_4 :P @ 10 kg ha^{-1}	7.57	12.10	12.80	15.53	26.70	17.17	8.13
T_5 :K @ 25 kg ha^{-1}	6.07	10.90	11.83	17.27	28.23	17.40	8.33
T_6 :Gypsum @ 250 kg ha^{-1}	7.60	11.57	11.70	15.53	27.53	16.40	9.67
T_7 :NP	7.57	11.60	14.63	13.97	29.70	14.43	8.10
T_8 :NPK	7.93	11.10	10.73	15.87	26.23	20.53	7.60
T_9 :NPK + gypsum	8.83	10.70	10.87	14.60	34.50	14.10	6.40
T_{10} : NPK + lime @ 100 kg ha^{-1}	9.17	11.33	10.93	14.30	31.63	14.10	8.53
T_{11} : NPK + gypsum + $ZnSO_4$ @ 25 kg ha^{-1}	8.70	11.70	12.43	15.60	29.77	15.73	6.07
Mean	**7.92**	**11.09**	**12.08**	**15.36**	**29.85**	**15.88**	**7.82**
SEm±	**0.57**	**0.76**	**0.97**	**0.77**	**1.95**	**1.21**	**0.62**
CD (P=0.05)	**1.70**	**NS**	**NS**	**NS**	**NS**	**3.59**	**1.85**

Table 4.9. Effect of long-term application of manure and fertilizer on soil aggregate proportion mass in aggregate class (%) at surface and sub-surface layers after harvest, *kharif*, 2021

Treatments	Micro-aggregate (< 0.25 mm)		Small macro-aggregate (2-0.25 mm)		Large macro-aggregate (> 2 mm)	
	0-15 cm	**15-30 cm**	**0-15 cm**	**15-30 cm**	**0-15 cm**	**15-30 cm**
T_1 : Control	31.03	25.20	56.13	58.03	12.83	16.77
T_2 :FYM @ 5 t ha^{-1} (once in 3 years)	19.93	20.00	62.27	59.67	17.80	20.33
T_3 :N @ 20 kg ha^{-1}	27.80	22.80	57.47	59.60	14.73	17.60
T_4 :P @ 10 kg ha^{-1}	27.97	25.30	57.43	55.03	14.60	19.67
T_5 :K @ 25 kg ha^{-1}	25.03	25.73	60.03	57.30	14.93	16.97
T_6 :Gypsum @ 250 kg ha^{-1}	25.03	26.07	59.17	54.77	15.80	19.17
T_7 :NP	22.40	22.53	61.60	58.30	16.00	19.17
T_8 :NPK	26.97	28.13	56.30	52.83	16.73	19.03
T_9 :NPK + gypsum	20.63	20.50	62.77	59.97	16.60	19.53
T_{10} :NPK + lime @ 100 kg ha^{-1}	22.17	22.63	60.23	56.87	17.60	20.50
T_{11} : NPK + gypsum + $ZnSO_4$ @ 25 kg ha^{-1}	25.17	21.80	55.73	57.80	19.10	20.40
Mean	**24.92**	**23.70**	**59.01**	**57.28**	**16.07**	**19.01**
SEm±	**1.77**	**1.26**	**1.51**	**1.37**	**1.07**	**0.91**
CD (P=0.05)	**5.25**	**3.73**	**4.47**	**4.06**	**3.17**	**NS**

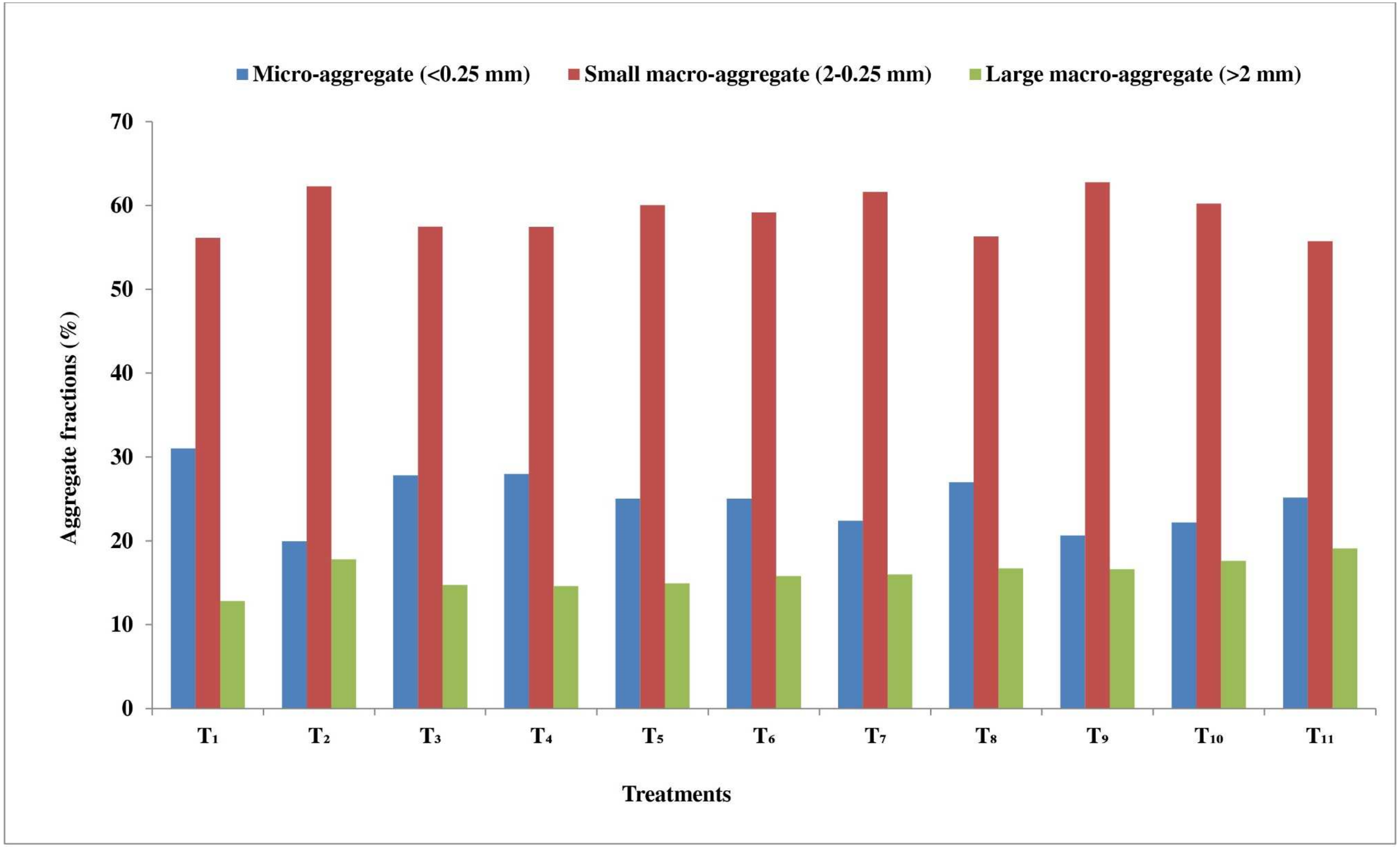

Fig. 4.13. Effect of long-term application of manure and fertilizers on aggregate fractions (%) at surface layer (0-15 cm)

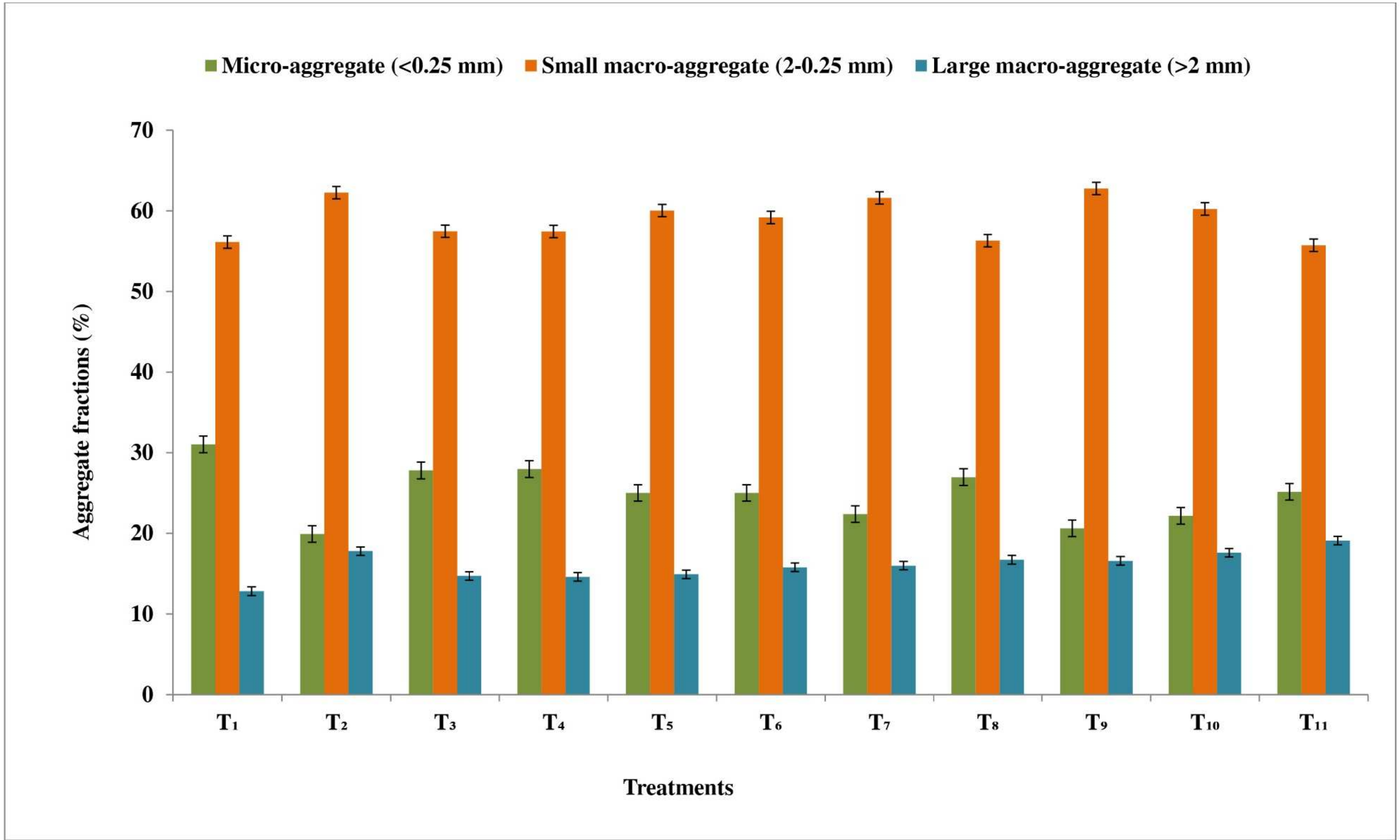

Fig. 4.14. **Effect of long-term application of manure and fertilizers on aggregate fractions (%) at sub-surface layer (15-30 cm)**

stabilization in aforesaid treatments. Whereas the aggregate fraction of <0.25 mm size was significantly higher in treatment received with only inorganic fertilizers and control treatments compared to the other treatments. Interestingly, microaggregates fraction was decreased with the application of FYM alone in both surface and sub-surface soils. This indicates that higher formation of larger aggregates with the supplimentation of organic matter. The present results are in agreement with the findings of Chakraborty *et al.* (2010) and Long *et al.* (2013) who reported that organic manure incorporation increased soil macro-aggregate proportion.

The higher percentage of aggregates <0.25 mm was evidenced under single nutrient treatments *viz.*, N, P, K and control in surface and sub-surface layers, which might be ascribed to comparatively low level of carbonates and organic matter. These results are in agreement with the findings of Manna *et al.* (2007) and Ghosh *et al.* (2010). The lower percentage of large macro-aggregates (>2 mm) in control plot in surface (12.83 %) and sub-surface (16.77 %) layers, respectively, might be due to comparatively lesser binding materials compared to other treatments. Similar findings were reported by Aziz and Karim (2016).

4.2.6 Long-Term Effect of Manure and Fertilizers on Aggregate Associated Carbon

The data on soil aggregate associated-C in different aggregate size fractions at surface and sub-surface layers was presented in Table 4.10, 4.11 and 4.12 and depicted in Fig. 4.15 and 4.16.

In surface layer (0-15 cm), the aggregate associated-C content in 8-5 mm aggregate size fraction was ranged from 3.70 to 5.08 g kg^{-1} with the mean of 4.36 g kg^{-1}. The highest was observed in NPK+lime (T_{10}) (5.08 g kg^{-1}) and lowest was observed in control (T_1) (3.70 g kg^{-1}). The aggregate associated-C content in 5-2 mm aggregate size fraction was ranged from 3.02 to 5.03 g kg^{-1} with the mean of 3.83 g kg^{-1}. The highest was observed in FYM alone (T_2) (5.03 g kg^{-1}) and lowest was observed in control (T_1) (3.02 g kg^{-1}). The aggregate associated-C content in 2-1 mm aggregate size fraction was ranged from 2.87 to 5.01 g kg^{-1} with the mean of 3.67 g kg^{-1}. The highest was observed in NPK (T8) (5.03 g kg^{-1}) and lowest was observed in K alone treated plot (T_5) (2.87 g kg^{-1}).

Whereas the aggregate associated-C content in 1-0.5 mm aggregate size fraction was ranged from 2.27 to 4.27 g kg^{-1} with the mean of 2.94 g kg^{-1}. The highest was observed in FYM alone (T_2) (4.27 g kg^{-1}) and lowest was observed in NP (T_7) (2.27 g kg^{-1}). The aggregate associated-C content in 0.5-0.25 mm aggregate size fraction was ranged from 2.13 to 3.73 g kg^{-1} with the mean of 3.03 g kg^{-1}. The highest was observed in gypsum alone treated plot (T_6) (3.73 g kg^{-1}) and lowest was observed in P alone treated plot (T_4) (2.13 g kg^{-1}). And finally the aggregate associated-C content in <0.25 mm aggregate size fraction was ranged from 2.47 to 4.18 g kg^{-1} with the mean of 3.06 g kg^{-1}. The highest was observed in gypsum alone treated plot (T_6) (4.18 g kg^{-1}) and lowest was observed in NP (T_7) (2.47 g kg^{-1}) (Table 4.10).

In sub-surface layer (15-30 cm), the aggregate associated-C content in 8-5 mm aggregate size fraction was ranged from 3.07 to 4.22 g kg^{-1} with the mean of 3.52 g kg^{-1}. The highest was observed in FYM alone (T_2) (4.22 g kg^{-1}) and lowest was observed in NPK+gypsum+$ZnSO_4$ (T_{11}) (3.07 g kg^{-1}). The aggregate associated-C content in 5-2 mm aggregate size fraction was ranged from 2.90 to 4.17 g kg^{-1} with the mean of 3.43 g kg^{-1}. The highest was observed in NPK (T_8) (4.17 g kg^{-1}) and lowest was observed in K alone treated plot (T_5) (2.90 g kg^{-1}). The aggregate associated-C content in 2-1 mm aggregate size fraction was ranged from 2.98 to 3.71 g kg^{-1} with the mean of 3.27 g kg^{-1}. The highest was observed in FYM alone (T_2) (3.71 g kg^{-1}) and lowest was observed in NP (T_7) (2.98 g kg^{-1}).

Whereas the aggregate associated-C content in 1-0.5 mm aggregate size fraction was ranged from 2.52 to 3.63 g kg^{-1} with the mean of 3.01 g kg^{-1}. The highest was observed in FYM alone (T_2) (3.63 g kg^{-1}) and lowest was observed in N alone treated plot (T_3) (2.52 g kg^{-1}). The aggregate associated-C content in 0.5-0.25 mm aggregate size fraction was ranged from 2.27 to 3.42 g kg^{-1} with the mean of 2.87 g kg^{-1}. The highest was observed in FYM alone (T_2) (3.42 g kg^{-1}) and lowest was observed in NPK+gypsum (T_9) (2.27 g kg^{-1}). And finally the aggregate associated-C content in <0.25 mm aggregate size fraction was ranged from 2.42 to 3.48 g kg^{-1} with the mean of 3.01 g kg^{-1}. The highest was observed in FYM alone (T_2) (3.48 g kg^{-1}) and lowest was observed in NP (T_7) (2.42 g kg^{-1}) (Table 4.11).

The data pertaining to aggregate associated-C in micro-aggregates (<0.25 mm), small macro-aggregates (2-0.25 mm) and large macro-aggregates (>2 mm) at surface and sub-surface layers was presented in Table 4.12 and depicted in Fig. 4.15 and 4.16. The aggregate associated-C in all aggregate size fraction was significantly influenced by various treatments in the long-term at surface and sub-surface layers.

In surface layer (0-15 cm), the aggregate associated-C in micro-aggregates (<0.25 mm) ranged from 2.47 to 4.18 g kg^{-1} with the mean of 3.06 g kg^{-1}. The highest was observed in gypsum alone treated plot (T_6) (4.18 g kg^{-1}) and the lowest was observed in NP (T_7) (2.47 g kg^{-1}). The aggregate associated-C in small macro-aggregates (2-0.25 mm) ranged from 2.80 to 3.95 g kg^{-1} with the mean of 3.22 g kg^{-1}. The highest was observed in FYM alone (T_2) (3.95 g kg^{-1}) and lowest was observed in NP (T_7) (2.80 g kg^{-1}). And the aggregate associated-C in large macro-aggregates (>2 mm) ranged from 3.36 to 5.01 g kg^{-1} with the mean of 4.10 g kg^{-1}. The highest was observed in FYM alone (T_2) (5.01 g kg^{-1}) and lowest was observed in control (T_1) (2.80 g kg^{-1}) (Table 4.12 and Fig. 4.15).

In sub-surface layer (15-30 cm), the aggregate associated-C in micro-aggregates (<0.25 mm) ranged from 2.42 to 3.48 g kg^{-1} with the mean of 3.01 g kg^{-1}. The highest was observed in FYM alone (T_2) (3.48 g kg^{-1}) and lowest was observed in NP (T_7) (2.42 g kg^{-1}). The aggregate associated-C in small macro-aggregates (2-0.25 mm) ranged from 2.68 to 3.58 g kg^{-1} with the mean of 3.05 g kg^{-1}. The highest was observed in FYM alone (T_2) (3.58 g kg^{-1}) and lowest was observed in control (T_1) (2.68 g kg^{-1}). And the aggregate associated-C in large macro-aggregates (>2 mm) ranged from 3.02 to 4.12 g kg^{-1} with the mean of 3.41 g kg^{-1}. The highest was observed in FYM alone (T_2) (4.12 g kg^{-1}) and lowest was observed in control (T_1) (3.02 g kg^{-1}) (Table 4.12 and Fig. 4.16).

The results indicated that SOC was significantly higher in large macro-aggregates when compared to small macro and micro-aggregates. The higher SOC within large macro-aggregates might be due to carbon associated with the formation of microaggregates inside macroaggregates, which better protects SOC from being lost to the atmosphere due to various soil physico-chemical properties. Even though microaggregate associated C concentration is low, it is important for protection of total SOC in soils having lower turnover rates. These results are in confirmity with the findings of Yu *et al.* (2012) and Liang *et al.*, (2012) who recorded that aggregate formation was associated with increased carbon storage in aggregate fractions >53 μm than in the silt and clay fraction (<53 μm).

The highest aggregate associated-C was found in the case of FYM alone treated plot compared to other treatments, which might be due to FYM application provides different organic carbon compounds to soil directly and increased root biomass and returning large amounts of carbon to the soil indirectly. The lowest aggregate association-C was observed in single nutrient treatments like N, P, K and control in surface and sub-surface layers, might be due to less addition organic matter thereby reduction in C accumulation in all aggregates fractions. The present results are in agreement with the findings of Zou *et al.* (2018). The aggregate associated-C content was decreased with decrease in aggregate size fractions. The results are similar to those of Li *et al.* (2020) who reported that the SOC content was decreased in <0.25 mm aggregates when compared to >0.25 mm aggregate sizes in 9 years long-term experiment. However, long-term amendment of manure significantly increased SOC in macro-aggregates. Similar results were also reported by Zhang *et al*. (2021) and Niu *et al*. (2022).

Table 4.10. Effect of long-term application of manure and fertilizers on aggregate associated-C (g kg^{-1}) at surface layer

Treatment	Aggregate size class (mm)					
	5-8	**2-5**	**1-2**	**0.5-1**	**0.25-0.5**	**< 0.25**
T_1 : Control	3.70	3.02	2.90	2.47	3.22	2.87
T_2 :FYM @ 5 t ha^{-1} (once in 3 years)	4.98	5.03	4.43	4.27	3.15	2.77
T_3 :N @ 20 kg ha^{-1}	4.02	3.37	3.01	2.77	2.95	2.70
T_4 :P @ 10 kg ha^{-1}	3.85	3.23	3.07	3.53	2.13	3.10
T_5 :K @ 25 kg ha^{-1}	3.98	3.83	2.87	2.93	2.8	3.23
T_6 :Gypsum @ 250 kg ha^{-1}	4.05	4.29	4.60	2.5	3.73	4.18
T_7 :NP	4.06	3.33	3.57	2.27	2.57	2.47
T_8 :NPK	4.88	4.02	5.01	3.37	3.03	2.60
T_9 :NPK +gypsum	4.98	4.05	3.80	2.60	3.50	3.25
T_{10} : NPK + lime @ 100 kg ha^{-1}	5.08	4.25	4.00	2.63	3.17	3.37
T_{11} : NPK+gypsum+$ZnSO_4$ @ 25 kg ha^{-1}	4.33	3.73	3.13	3.03	3.13	3.17
Mean	**4.36**	**3.83**	**3.67**	**2.94**	**3.03**	**3.06**
SEm±	**0.15**	**0.23**	**0.22**	**0.15**	**0.12**	**0.18**
CD (P=0.05)	**0.44**	**0.68**	**0.65**	**0.45**	**0.36**	**0.53**

Table 4.11. Effect of long-term application of manure and fertilizers on aggregate associated-C (g kg^{-1}) at sub-surface layer

Treatment	Aggregate size class (mm)					
	5-8	**2-5**	**1-2**	**0.5-1**	**0.25-0.5**	**< 0.25**
T_1 : Control	3.80	3.08	3.05	2.58	2.41	2.98
T_2 :FYM @ 5 t ha^{-1} (once in 3 years)	4.22	4.13	3.71	3.63	3.42	3.48
T_3 :N @ 20 kg ha^{-1}	3.15	3.53	3.00	2.52	2.96	2.72
T_4 :P @ 10 kg ha^{-1}	3.17	3.20	3.18	3.10	2.83	2.51
T_5 :K @ 25 kg ha^{-1}	3.37	2.90	3.20	2.78	2.59	3.28
T_6 :Gypsum @ 250 kg ha^{-1}	3.85	3.45	3.65	3.12	3.22	3.05
T_7 :NP	3.13	3.13	2.98	2.98	2.48	2.42
T_8 :NPK	4.00	4.17	3.47	3.10	3.28	3.33
T_9 :NPK +gypsum	3.20	3.47	3.30	2.83	2.27	3.15
T_{10} :NPK + lime @ 100 kg ha^{-1}	3.80	3.13	3.17	3.05	3.03	3.10
T_{11} : NPK+gypsum +$ZnSO_4$ @ 25 kg ha^{-1}	3.07	3.57	3.32	3.38	3.10	2.98
Mean	**3.52**	**3.43**	**3.27**	**3.01**	**2.87**	**3.01**
SEm±	**0.09**	**0.08**	**0.17**	**0.13**	**0.17**	**0.22**
CD (P=0.05)	**0.28**	**0.24**	**NS**	**0.39**	**0.52**	**NS**

Table 4.12. Effect of long-term application of manure and fertilizers on aggregate associated-C (g kg^{-1}) at surface and sub-surface layers after harvest, *kharif*, 2021

Treatments	Micro-aggregate (< 0.25 mm)		Small macro-aggregate (2-0.25 mm)		Large macro-aggregate (>2 mm)	
	0-15 cm	**15-30 cm**	**0-15 cm**	**15-30 cm**	**0-15 cm**	**15-30 cm**
T_1 : Control	2.87	2.98	2.86	2.68	3.36	3.02
T_2 : FYM @ 5 t ha^{-1} (once in 3 years)	2.77	3.48	3.95	3.58	5.01	4.12
T_3 : N @ 20 kg ha^{-1}	2.70	2.72	2.91	2.83	3.69	3.24
T_4 : P @ 10 kg ha^{-1}	3.10	2.51	2.91	3.04	3.54	3.53
T_5 : K @ 25 kg ha^{-1}	3.23	3.28	2.87	2.86	3.91	3.22
T_6 : Gypsum @ 250 kg ha^{-1}	4.18	3.05	3.61	3.33	4.17	3.65
T_7 : NP	2.47	2.42	2.80	2.82	3.70	3.04
T_8 : NPK	2.60	3.33	3.81	3.28	4.45	3.69
T_9 : NPK +gypsum	3.25	3.15	3.03	2.80	4.52	3.21
T_{10} : NPK + lime @ 100 kg ha^{-1}	3.37	3.10	3.27	3.08	4.67	3.47
T_{11} : NPK+gypsum+$ZnSO_4$ @ 25 kg ha^{-1}	3.17	2.98	3.10	3.27	4.04	3.32
Mean	**3.06**	**3.01**	**3.22**	**3.05**	**4.10**	**3.41**
SEm±	**0.18**	**0.22**	**0.11**	**0.08**	**0.15**	**0.14**
CD (P=0.05)	**0.53**	**0.66**	**0.33**	**0.24**	**0.45**	**0.42**

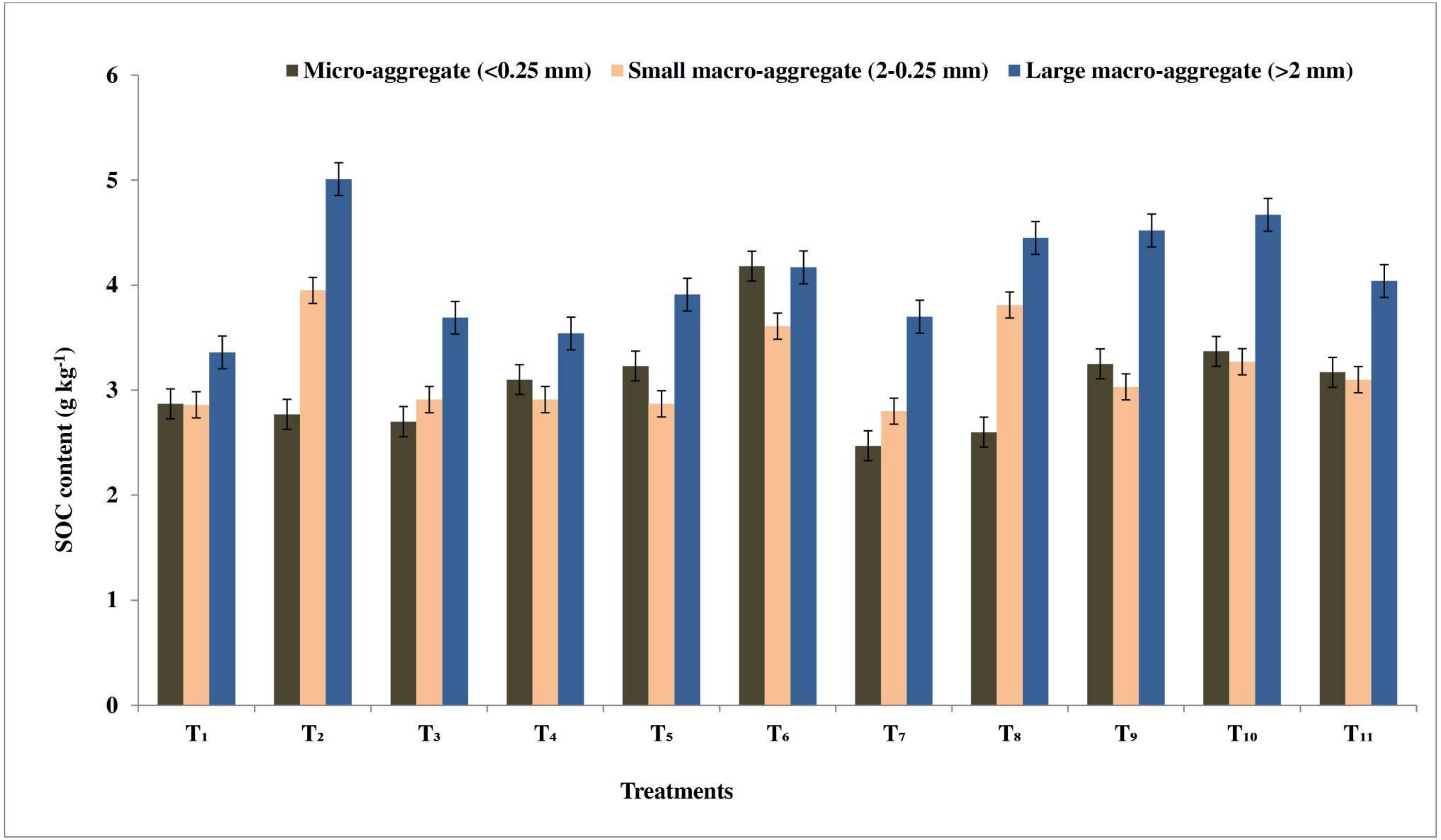

Fig. 4.15. **Effect of long-term application of manure and fertilizers on aggregate associated-C (g kg^{-1}) at surface layer (0-15 cm)**

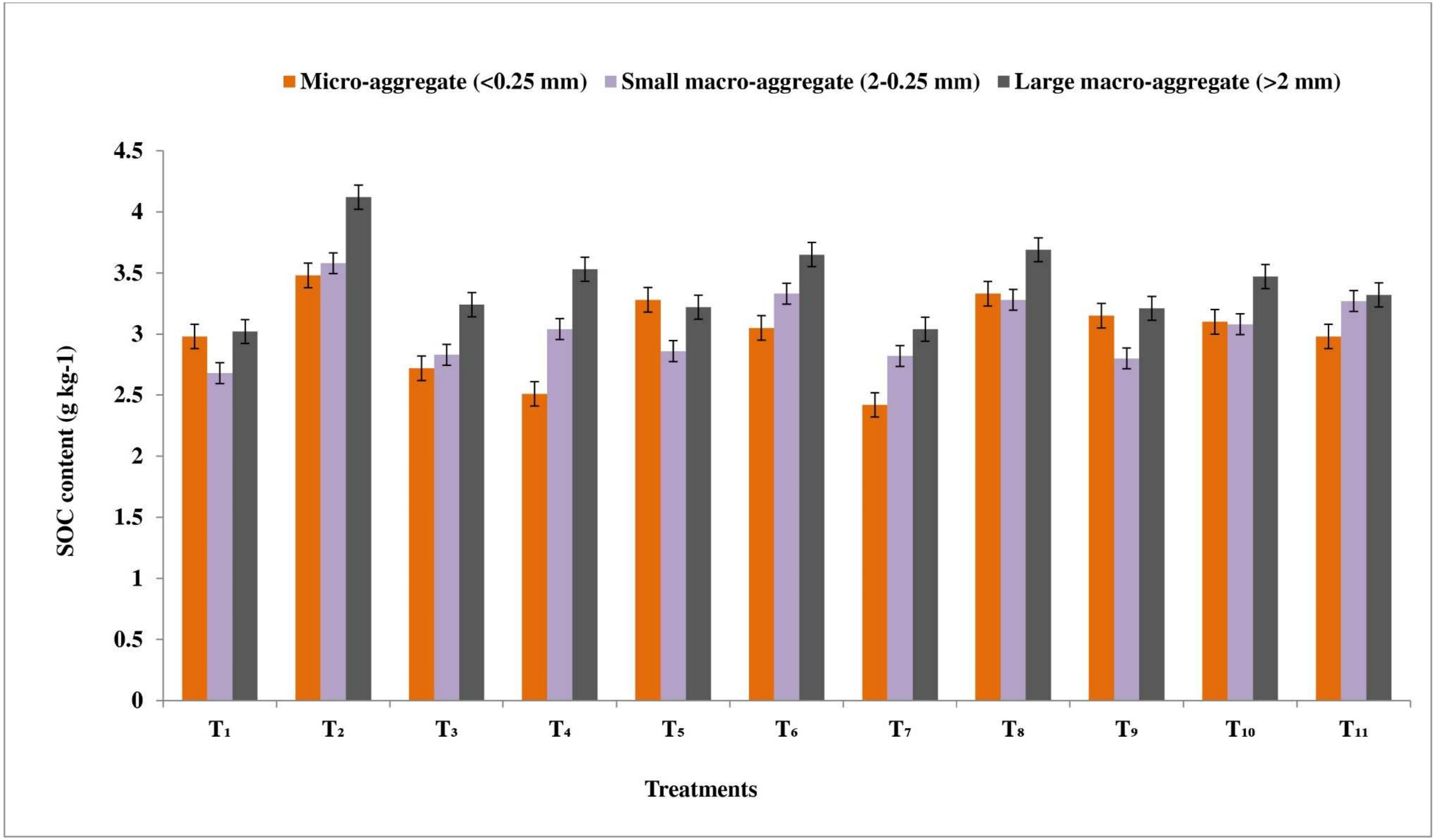

Fig. 4.16. Effect of long-term application of manure and fertilizers on aggregate associated-C (g kg^{-1}) at sub-surface layer (15-30 cm)

4.3 INFLUENCE OF LONG-TERM APPLICATION OF MANURE AND FERTILIZERS ON YIELD AND YIELD ATTRIBUTES OF GROUNDNUT

The data on yield attributes of groundnut as influenced by the different treatments was presented in table 4.13 and depicted in Fig. 4.17 and 4.18.

4.3.1 Plant Population

The plant population was not significantly influenced by different treatments and varied from 22 to 24 No. m^{-2}. However, the higher plant population was obtained in K alone treated plot (T_5) (28 No. m^{-2}) followed by NPK (T_8) (27 No. m^{-2}), NPK+lime (T_{10}) (26 No. m^{-2}), P alone treated plot (T_4) (26 No. m^{-2}) and only gypsum treatment (T_6) (26 No. m^{-2}) (Table 4.13).

4.3.2 100 Pod Weight

The 100 pod weight in groundnut was not significantly influenced by the different treatments and it ranged from 91 to 99 g. The higher 100 pod weight was obtained in NPK+gypsum+$ZnSO_4$ (T_{11}) (99 g) and control (T_1) (99 g) followed by NPK (T_8) (98 g) and NPK+lime (T_{10}) (97 g), whereas the lowest 100 pod weight was observed in NP (T_7) (91 g) (Table 4.13).

4.3.3 100 Kernel Weight (g)

The test weight of groundnut was not significantly influenced by the different treatments and varied from 40.0 to 42.0 g. The higher 100 kernel weight was obtained in NPK (T_8) (42.0 g) and NPK+lime (T_{10}) (42.0 g) and on par with rest of the long-term treatments. The higher kernel weight might be due to the stimulation of root development, synthesis of carbohydrates and translocation of photosynthates towards the sink development (pods) by combined application of NPK (Table 4.13).

4.3.4 Shelling Percentage

The shelling percentage was not significantly influenced by the different treatments and it was ranged from 76 to 79 per cent. However, the higher shelling percentage was obtained in only FYM (T_2) (79 %) and lower was noticed in P alone treated plot (T_4) (75 %) followed by control (T_1) (76 %). Similarly, higher shelling percentage was recorded in FYM plot compared to control (T_1) by Abraham and Thenua (2010) and Akbari *et al.* (2010) (Table 4.13).

4.3.5 Pod Yield

The pod yield of groundnut was significantly varied among the treatments and it was ranged from 2083 to 3100 kg ha^{-1}. The highest pod yield of groundnut was recorded in FYM alone treated plot (T_2) (3100 kg ha^{-1}) and which was on par wih NPK+gypsum+$ZnSO_4$ (T_{11}) (2854 kg ha^{-1}), NPK (T_8) (2802 kg ha^{-1}), NPK+lime (T_{10}) (2784 kg ha^{-1}) and NPK+gypsum (T_9) (2753 kg ha^{-1}). Whereas the lowest pod yield was recorded with N alone treated plot (T_3) (2083 kg ha^{-1}) and which was on par with control (T_1) (2155 kg ha^{-1}), K alone treated plot (T_5) (2254 kg ha^{-1}) and gypsum alone treated plot (T_6) (2285 kg ha^{-1}) (Table 4.13 and Fig. 4.17).

The highest pod yield was obtained with FYM alone @ 5 Mg ha^{-1} once in three years, which might be due to the balanced supply of all the nutrients including secondary and micronutrients and improved soil physical properties *viz.*, bulk density, hydraulic conductivity, infiltration rate, water holding capacity and porosity. Whereas the treatments *viz.*, NPK+lime, NPK+gypsum, NPK+gypsum+ $ZnSO_4$ and NPK were also recorded comparable yields with FYM alone treated plot which might be due to the adequate and balanced supply of the nutrients like N, P, K to meet the requirements of the crop during the crop growth period. The application of lime might have helped in creating the favourable chemical, physical and biological environment of the soil. Enrichment of the calcium in the soil was also another beneficial effect on pod yield due to the inclusion of lime or gypsum along with NPK application. The cumulative effect of balanced nutrition and good soil environment might favoured for the highest pod yield in the aforesaid treatments. The lowest pod yield of groundnut was obtained with N alone treated plot (T_3) (2083 kg ha^{-1}) which was on par with control (T_1). The low yield of these treatments might be attributed to poor soil fertility status. The results are similar to those of Akbari *et al.* (2002), Parvathi *et al.* (2015) and Kulkarni *et al.* (2018).

4.3.6 Haulm Yield

The haulm yield was significantly influenced by different treatments and ranged from 3367 to 7892 kg ha^{-1}. The highest haulm yield was recorded with NPK+gypsum+$ZnSO_4$ (T_{11}) (7892 kg ha^{-1}) which was on par with NPK+lime (T_{10}) (6966 kg ha^{-1}) followed by NPK+gypsum (T_9) (6629 kg ha^{-1}). The higher haulm yields might be due to application of nutrients in balanced proportion during the early stages of crop growth which produces vigorous plants due to better availability of nutrients which inturn contributed to haulm yield (Abraham and Thenua., 2010). Similar results were reported by Babu *et al.* (2007), Sharma *et al.* (2011) and Salma *et al.* (2017). Whereas the lowest haulm yield was recorded with K alone treated plot (T_5) (3367 kg ha^{-1}) which was on par with N alone treated plot (T_3) (4209 kg ha^{-1}) followed by control (T_1) (4419 kg ha^{-1}) and gypsum alone treated plot (T_6) (4419 kg ha^{-1}) (Table 4.13 and Fig. 4.18).

Table 4.13. Effect of long-term application of manure and fertilizers on yield and yield attributes of groundnut during *kharif*, 2021

Treatments	Plant population (No. m^{-2})	Pod yield (kg ha^{-1})	Haulm yield (kg ha^{-1})	100 pod wieght (g)	100 kernel wieght (g)	Shelling percentage (%)
T_1 : Control	25	2155	4419	99.0	40.0	76.0
T_2 :FYM @ 5 t ha^{-1} (once in 3 years)	25	3100	6418	94.0	40.0	79.0
T_3 :N @ 20 kg ha^{-1}	23	2083	4209	95.0	40.0	77.0
T_4 :P @ 10 kg ha^{-1}	26	2306	6418	95.0	40.0	75.0
T_5 :K @ 25 kg ha^{-1}	28	2254	3367	93.0	41.0	78.0
T_6 :Gypsum @ 250 kg ha^{-1}	26	2285	4419	93.0	41.0	78.0
T_7 :NP	25	2490	6524	91.0	41.0	78.0
T_8 :NPK	27	2802	5892	98.0	42.0	78.0
T_9 :NPK + gypsum	25	2753	6629	94.0	41.0	78.0
T_{10} :NPK + lime @ 100 kg ha^{-1}	26	2784	6966	97.0	42.0	78.0
T_{11} : NPK + gypsum + $ZnSO_4$ @ 25 kg ha^{-1}	25	2854	7892	99.0	40.0	77.0
SEm±	**0.95**	**195**	**303**	**2.12**	**0.91**	**1.03**
CD (P=0.05)	**NS**	**564**	**974**	**NS**	**NS**	**NS**
CV	**4.35**	**14.98**	**17.4**	**4.46**	**4.48**	**2.65**

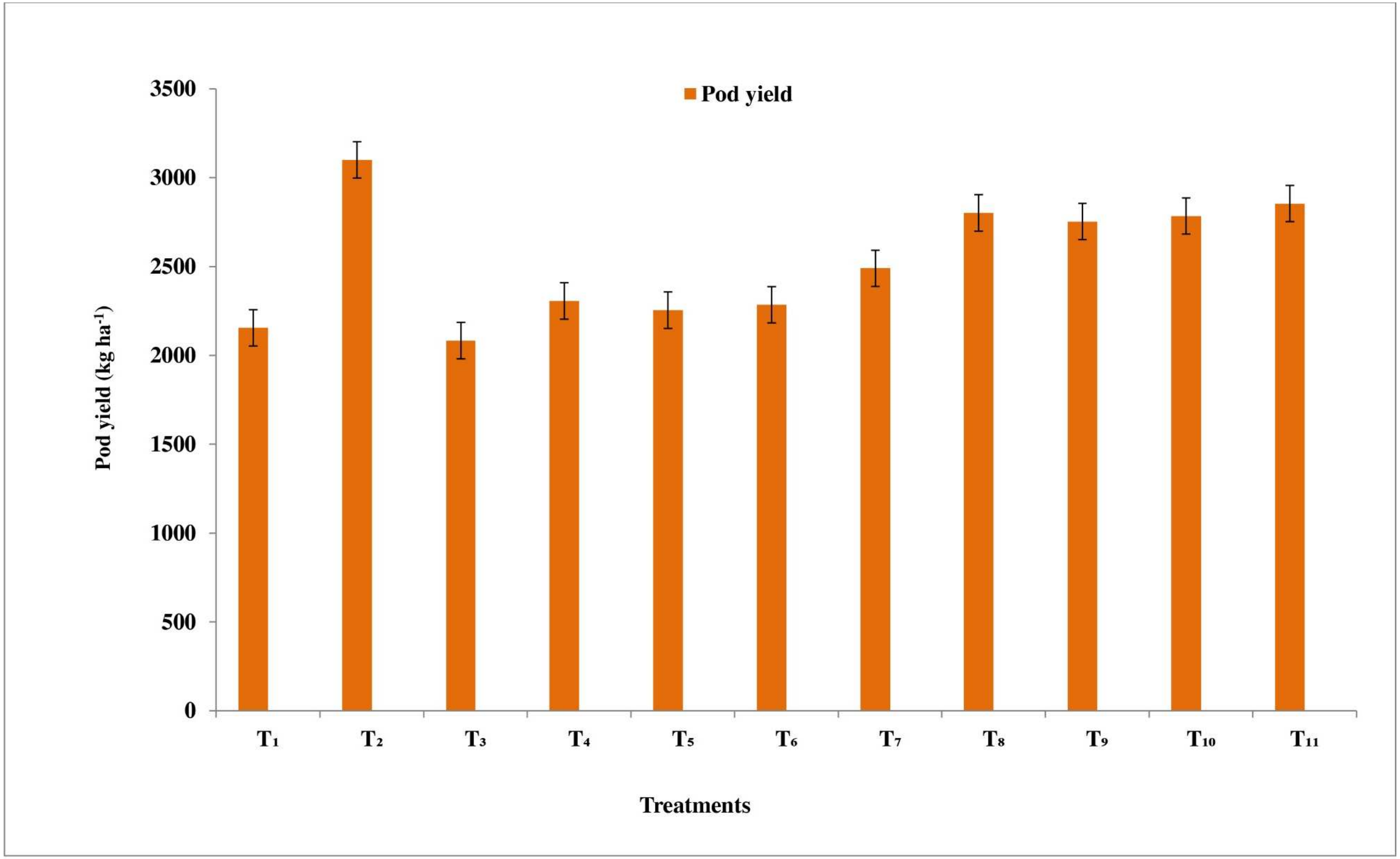

Fig. 4.17. Effect of long-term application of manure and fertilizers on pod yield (kg ha^{-1}) of groundnut

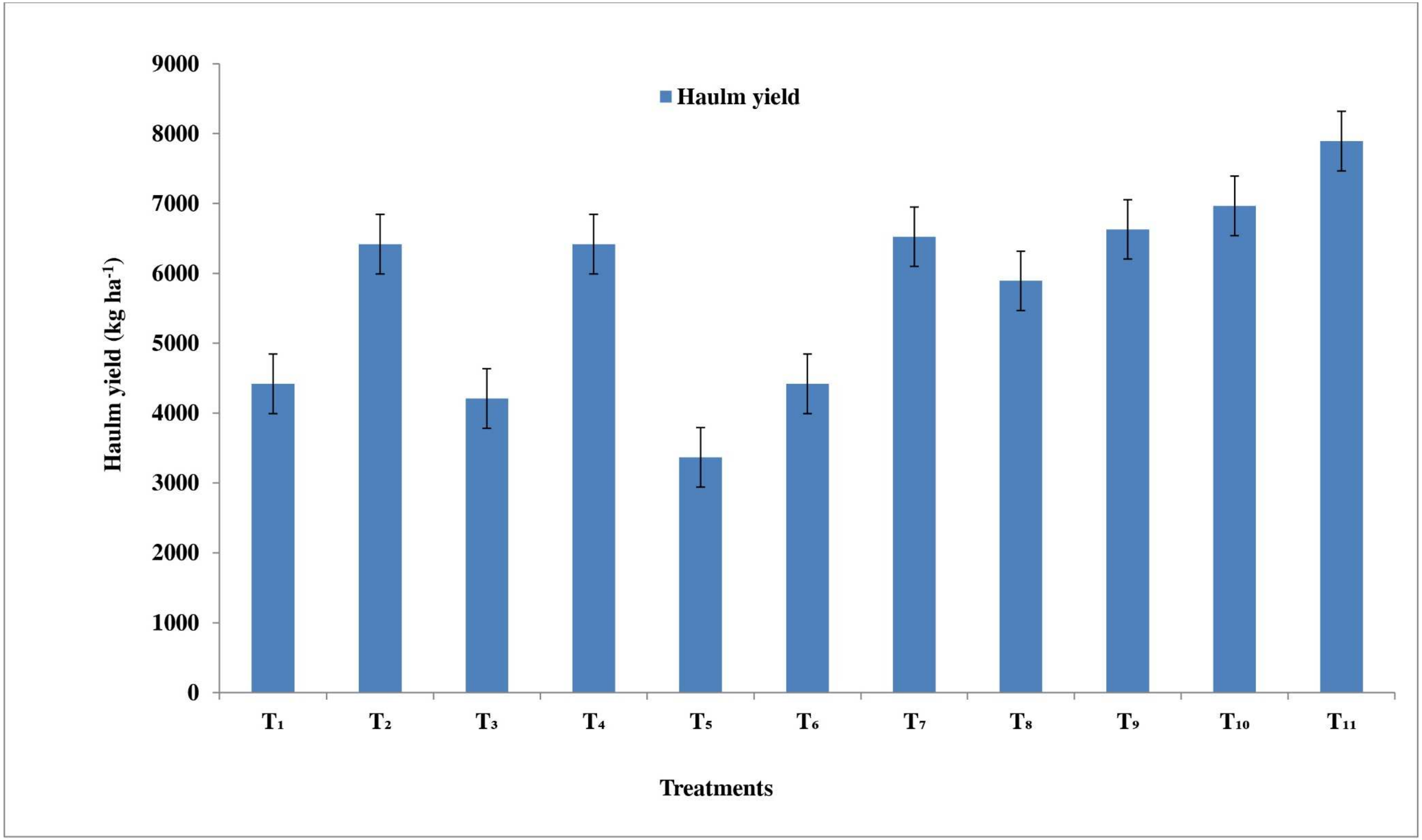

Fig. 4.18. Effect of long-term application of manure and fertilizers on haulm yield (kg ha^{-1}) of groundnut

Chapter – V

Summary & Conclusions

Chapter V

SUMMARY AND CONCLUSIONS

A field experiment entitled "**SOIL STRUCTURE AND ORGANIC CARBON STABILITY OF RAINFED ALFISOLS UNDER LONG-TERM APPLICATION OF MANURE AND FERTILIZERS"** was carried out as part of the long-term experiment during *kharif*, 2021 on red sandy loam (*Haplustalf*) soils at Regional Agricultural Research Station, Acharya N.G Ranga Agricultural University, Tirupati, Andhra Pradesh. The experiment was laid out in randomized block design with eleven treatments and four replications. The treatments includes T_1: control (no manure and fertilizers), T_2: Farm yard manure @ 5 t ha^{-1} (once in 3 years), T_3: 20 kg nitrogen (N) ha^{-1}, T_4: 10 kg phosphorus (P) ha^{-1}, T_5: 25 kg potassium (K) ha^{-1}, T_6: 250 kg gypsum ha^{-1}, T_7: 20 kg N + 10 kg P ha^{-1}, T_8: 20 kg N + 10 kg P + 25 kg K ha^{-1}, T_9: 20 kg N + 10 kg P + 25 kg K + 250 kg gypsum ha^{-1}, T_{10}: 20 kg N + 10 kg P + 25 kg K + 100 kg lime ha^{-1}, T_{11}: 20 kg N + 10 kg P + 25 kg K + 250 kg gypsum + 25 kg ha^{-1} zinc sulphate (once in 3 years).

Soil samples were collected from each treatment plot at two depths *viz.*, 0-15 and 15-30 cm after harvest of crop during *kharif*, 2021 and data was recorded on soil physical properties *viz.*, bulk density, porosity, maximum water holding capacity, soil texture and aggregate stability. Data was also recorded on soil physio-chemical properties *viz.*, soil reaction (pH), electrical conductivity, soil organic carbon (SOC), SOC stocks, carbon sequestration and aggregate associated-C. And observations were recorded on yield and yield attributes *viz.*, pod yield, haulm yield, 100 pod wieght, 100 kernel wieght and shelling percentage. All the above mentioned parameters of groundnut were influenced by manure and fertilizers and the salent findings were summarized here under.

- The soil texture was not influenced by different long-term fertilizer application treatments and all the treatments are grouped as sandy loam

(SL) texture. In surface layer, sand, silt and clay content was ranged from 68.6 to 74.3 per cent, 11.7 to 16.7 per cent and 12.0 to 16.3 per cent, respectively with the mean of 72.4, 13.6 and 14.1 per cent, respectively. Whereas in sub-surface layer, sand, silt and clay content ranged from 67.9 to 71.7 per cent, 12.9 to 15.4 per cent and 13.6 to 18.1 per cent, respectively with the mean of 70.3, 14.3 and 16.7 per cent, respectively.

- Application of FYM alone (T_2) resulted significantly lowest bulk density in surface layer, whereas the highest was recorded in K alone treated plot (T_5) and on par with control (T_1). In sub-surface layer, the lowest bulk density was observed in NP (T_7), whereas the highest was recorded in NPK+gypsum+ZnSO4 (T_{11}) and NPK (T_8) followed by control (T_1).
- The higher porosity was recorded with FYM alone (T_2) followed by P alone treated plot (T_4) in surface layer and the lowest porosity was observed in K alone treated plot (T_5). In sub-surface layer, significantly highest porosity was recorded with FYM alone (T_2) which was on a par with NPK+lime (T_{10}) and the lowest porosity was observed in NPK (T_8).
- The maximum water holding capacity (MWHC) was highest in NPK+lime (T_{10}) followed by FYM alone treated plot (T_2) and the lowest MWHC was observed with N alone treated plot (T_3) at surface layer. In sub-surface layer, the higher MWHC was observed in FYM alone (T_2) which was on par with NPK+lime (T_{10}) and the lowest MWHC was observed in control (T_1).
- The mean wieght diameter (MWD) of soil aggregates was highest with FYM alone treated plot (T_2) and on par with NPK+gypsum+$ZNSO_4$ (T_{11}) in surface and sub-surface layers. Whereas the lowest MWD was observed with control (T_1) and K alone treated plot (T_5) in surface and sub-surface layers, respectively.

- The geometric mean diameter (GMD) was highest in FYM alone treated plot (T_2) and on par with NPK+lime (T_{10}) in surface layer. In sub-surface layer, GMD was highest in NPK+gypsum+$ZnSO_4$ (T_{11}) and FYM alone (T_2). Whereas, the lowest GMD was observed with control (T_1) in both the soil layers.
- The water stable aggregates (% WSA ≥0.25 mm) was highest in FYM alone treated plot (T_2) and statistically on par with NPK+gypsum (T_9) and lowest % WSA (≥0.25 mm) was recorded with control (T_1) in surface and sub-surface layers.
- The per cent aggregate stability (% AS) was higher in NPK+gypsum (T_9) and which was on par with P alone (T_4) in surface layer. In sub-surface layer, highest % AS was observed in NPK+gypsum+$ZnSO_4$ (T_{11}) and on par with NPK+gypsum (T_9). Whereas the lowest % AS was recorded with K alone treated plot (T_5) in both the soil layers.
- The soil pH was higher in FYM alone (T_2) treated plot and on par with P alone (T_4), whereas the lowest soil pH was observed in NPK (T_8) in surface layer. In sub-surface layer, soil pH was highest with NPK (T_8) followed by FYM alone (T_2), whereas the soil pH was lowest in NPK+gypsum (T_9).
- The electrical conductivity (EC) was higher in gypsum alone treated plot (T_6) and lowest was recorded in NPK (T_8) at surface layer. In sub-surface layer, soil EC was higher in gypsum alone (T_6) and lowest soil EC was recorded in NPK+gypsum+$ZnSO_4$ (T_{11}).
- The soil organic carbon (SOC) content and SOC stocks were highest in FYM alone (T_2) followed by NPK+lime (T_{10}) and the lowest SOC content and stocks were observed in K alone treated plot (T_5) in surface and sub-surface layers.
- The SOC stocks build-up (%) was highest in FYM alone (T_2) treatment followed by NPK+lime (T_{10}). Whereas the SOC stock build-up (%) was negative with K alone (T_5) and P alone (T_4) treated plots compared to control in surface and sub-surface layers.

- The carbon sequestration rate was also highest in FYM alone (T_2) treatment, which was on par with NPK+lime (T_{10}) and the lowest rate was observed in K alone (T_5) and P alone (T_4) treated plots.
- The micro-aggregates (<0.25 mm) proportion was highest in control (T_1) treatment and lowest was observed in FYM alone treated plot (T_2). Whereas the small macro-aggregates (2-0.25 mm) fractions was highest in NPK+gypsum (T_9) and lowest in NPK+gypsum+$ZnSO_4$ (T_{11}) treatment. The large macro-aggregates (>2 mm) fraction was highest in NPK+gypsum+ $ZnSO_4$ (T_{11}) treatment and lowest in control (T_1) in surface layer. In sub-surface layer, micro-aggregates was highest in NPK (T_8) treatment and lowest in FYM alone treated plot (T_2). The small macro-aggregates was highest in NPK+gypsum (T_9) treatment and lowest in NPK (T_8) treatment. Whereas large macro-aggregates was highest in NPK+lime (T_{10}) treatment and lowest in control (T_1) treatment.
- In surface layer, the micro-aggregates (<0.25 mm) associated-C was highest in gypsum alone treated plot (T_6) and the lowest in NP (T_7) treatment. Whereas the small macro-aggregates (2-0.25 mm) associated-C was highest in FYM alone (T_2) and lowest in NP (T_7) treatment. The large macro-aggregates (>2 mm) associated-C was highest in FYM alone (T_2) treatment and lowest in control (T_1). In sub-surface layer, micro-aggregates associated-C was highest in FYM alone (T_2) treatment and the lowest in NP (T_7) treatment. Whereas the small macro-aggregates and large macro-aggregate associated-C was highest in FYM alone (T_2) treatment and lowest in control (T_1) treatment.
- The pod yield and shelling percentage were highest in FYM alone (T_2) treatment and lowest was recorded in N alone (T_3) and P alone (T_4) treatments, respectively. Whereas, the 100 pod weight and haulm yield were highest with application of NPK+gypsum+$ZnSO_4$ (T_{11}) and lowest in K alone treated plot (T_5).

In conclusion, the present study indicated that long-term application of FYM @ 5 t ha^{-1} once in three years was very effective in increasing the soil physical, physio-chemical environment and yield of the groundnut. The study also revealed that balanced nutrition treatments *viz.*, NPK+gypsum+$ZnSO_4$, NPK+lime, NPK+gypsum and NPK were also equally effective in obtaining good yield of the groundnut. These results also confirmed that application of any single nutrient fertilizers would not able to sustain the yield of groundnut. To conclude, long-term application of FYM @ 5 t ha^{-1} or NPK+lime improved the soil structure, aggregate and organic carbon stability of rainfed *Alfisols*. Whereas the long-term application of K fertilizers alone deteriorated the soil structure and organic carbon stability.

Suggestions for further research work

The results need to be continued by collecting the data for 3 to 4 more years in the same LTFE. The influence of long-term application of manure and fertilizers on soil structure and organic carbon stability has to be studied in future years also.

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Plate

Plate No. 1. Overall view of the experimental field at 30 days after sowing

Plate No. 2. Overall view of the experimental field at 90 days after sowing