EVALUATION OF SOIL COMPACTION AS AFFECTED BY DIFFERENT TILLAGE PRACTICES

Thesis

Submitted to the Punjab Agricultural University
in partial fulfillment of the requirements
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in

FARM MACHINERY AND POWER ENGINEERING
(Minor Subject: Computer Science and Engineering)

By
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CERTIFICATE – I

This is to certify that the thesis entitled **"Evaluation of soil compaction as affected by different tillage practices"** submitted for the degree of **Master of Technology** in the subject of **Farm Machinery and Power Engineering (Minor Subject: Computer Science and Engineering)** of the Punjab Agricultural University, Ludhiana is a bonafide research work carried out by **Er. Abhishek Kumar (L-2015-AE-176-M)** under my supervision and no part of this thesis has been submitted for any other degree.

The assistance and help received during the course of investigations have been fully acknowledged.

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CERTIFICATE – II

This is to certify that the thesis entitled **“Evaluation of soil compaction as affected by different tillage practices”** submitted by **Abhishek Kumar (L-2015-AE-176-M)** to the Punjab Agricultural University, Ludhiana in partial fulfillment of the requirements for the degree of **Master of Technology** in the subject of **Farm Machinery and Power (Minor Subject: Computer Science and Engineering)** has been approved by the Student’s Advisory Committee after an oral examination on the same.

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ABSTRACT

A study for evaluating the soil compaction caused by different tillage practices was undertaken. The independent parameters for the study were two soil types (sandy loam, S1 and silty loam, S2), six different tillage practices (conventional tillage practice as P1, P2, rotavator practices as P3, P4 and spading machine as P5, P6), two forward velocity ranges (V1 and V2) and two operation depth ranges (D1 and D2). Replicated (three) trials in factorial in RBD were adopted for the study. Soil bulk density and cone index values were taken at selected sampling depths for determining the initial soil compaction i.e before tillage treatments. Effect of irrigation on soil compaction was also noted at optimum moisture level after irrigation but before tillage treatments. Cone indices of both types of soils were found lesser, after irrigation, than that of before irrigation conditions. Bulk density of soil S1 was higher after irrigation, whereas of soil S2, it was lower than that of before irrigation, before tillage conditions. Cone indices in both types of soils were observed lesser than that of initial compaction, in top 10 cm of soil, after different tillage treatments. Cone indices, at sub-soil depths (at 15 cm and beyond) of both soil types, in P3, P4, P5 and P6 tillage practices were found to be comparatively more that of initial soil compaction for most of the treatments. Bulk density was observed lower than that of initial soil compaction for all the treatments in both soil types. Mean weight diameter of soil clods formed were minimum whereas fuel consumption (l/h) values were maximum in case of rotavator among all the treatment values.

Keyword : Soil compaction, tillage, irrigation, rotavator, spading machine, bulk density, cone index.

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ਵਿਦਿਆਰਥੀ ਦਾ ਨਾਂ ਅਤੇ ਦਾਖ਼ਲਾ ਨੰਬਰ	:	*ਅਭੀਸ਼ੇਕ ਕੁਮਾਰ* *(ਐੱਲ-2015-ਏਈ-176-ਐੱਮ)*
ਪ੍ਰਮੁੱਖ ਵਿਸ਼ਾ	:	*ਫਾਰਮ ਮਸ਼ੀਨਰੀ ਅਤੇ ਪਾਵਰ ਇੰਜੀਨੀਅਰਿੰਗ ਵਿਭਾਗ*
ਸਹਿਯੋਗੀ ਵਿਸ਼ਾ	:	*ਕੰਪਿਊਟਰ ਸਾਇੰਸ ਐਂਡ ਇੰਜੀਨੀਅਰਿੰਗ*
ਮੁੱਖ ਸਲਾਹਕਾਰ ਦਾ ਨਾਂ ਅਤੇ ਅਹੁੱਦਾ	:	ਡਾ. ਵਰਿੰਦਰ ਸਿੰਘ ਸੈਂਭੀ ਅਸਿਸਟੈਂਟ ਇੰਜੀਨੀਅਰ
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ਸਾਰ

ਵੱਖ-ਵੱਖ ਵਹਾਈ ਦੇ ਤਰੀਕਿਆਂ ਕਰਕੇ ਹੋਣ ਵਾਲੇ ਭੂਮੀ ਨਪਾਈ ਦੇ ਆਂਕਲਨ ਲਈ ਇੱਕ ਅਧਿਐਨ ਕੀਤਾ ਗਿਆ। ਅਧਿਐਨ ਲਈ ਜੋ ਸੁਤੰਤਰ ਮਾਪਦੰਡ ਰੱਖੇ ਗਏ ਉਹ ਇਸ ਪ੍ਰਕਾਰ ਸਨ; ਦੋ ਭੂਮੀ ਪ੍ਰਕਾਰ ਦੇ ਖੇਤ ਰੇਤਲੀ ਮੈਰਾ S1, ਸਿਲਟੀ ਮੈਰਾ S2), ਛੇ ਵਹਾਈ ਤਰੀਕੇ (ਰਵਾਇਤੀ ਵਹਾਈ ਦੇ ਤਰੀਕੇ, P1, P2, ਰੋਟਾਵੇਟਰ ਨਾਲ ਵਹਾਈ P3, P4 ਅਤੇ ਸਪੇਡਿੰਗ ਮਸ਼ੀਨ ਨਾਲ ਵਹਾਈ P5, P6), ਦੋ ਵੇਗ ਰੇਜ਼ (V1 ਅਤੇ V2), ਦੋ ਦੋ ਕਾਰਵਾਈ ਡੂੰਘਾਈ ਰੇਂਜ (D1 ਅਤੇ D2)। ਅਧਿਐਨ ਫੇਕਟੋਰੀਅਲ ਆਰ.ਬੀ.ਡੀ., ਵਿੱਚ ਤਿੰਨ ਵਾਰ ਦੁਹਰਾਇਆ ਗਿਆ। ਵਹਾਈ ਤੋਂ ਪਹਿਲਾਂ ਮਿੱਟੀ ਦੀ ਸ਼ੁਰੂਆਤੀ ਨਪਾਈ ਨਿਰਧਾਰਿਤ ਕਰਨ ਲਈ ਚੌਣਵੀ ਡੂੰਘਾਈ ਤੋਂ ਮਿੱਟੀ ਦੀ ਥੋਕ ਘਣਤਾ ਅਤੇ ਕੋਨ ਸੂਚਕਾਂਕ ਮਾਪੇ ਗਏ। ਸਿੰਚਾਈ ਤੋਂ ਬਾਅਦ ਪਰ ਵਹਾਈ ਤੋਂ ਪਹਿਲਾਂ ਸਿੰਚਾਈ ਦਾ ਭੂਮੀ ਨਪਾਈ ਉੱਪਰ ਪ੍ਰਭਾਵ ਢੁੱਕਵੀਂ ਨਮੀ ਪੱਧਰ ਤੇ ਲਿਆ ਗਿਆ। ਦੋਨਾਂ ਹੀ ਮਿੱਟੀਆਂ ਵਿੱਚ ਸਿੰਚਾਈ ਤੋਂ ਬਾਅਦ, ਕੋਨ ਸੂਚਕਾਂਕ, ਸਿੰਚਾਈ ਤੋਂ ਪਹਿਲਾਂ ਦੀ ਸਥਿਤੀ ਨਾਲੋਂ ਘੱਟ ਸੀ। S1 ਮਿੱਟੀ ਦੀ ਥੋਕ ਘਣਤਾ ਸਿੰਚਾਈ ਤੋਂ ਬਾਅਦ ਜ਼ਿਆਦਾ ਸੀ ਜਦਕਿ S2 ਵਿਚ ਇਹ ਸਿੰਚਾਈ ਤੋਂ ਪਹਿਲਾਂ ਜ਼ਿਆਦਾ ਸੀ। ਵੱਖ-ਵੱਖ ਵਹਾਈ ਉਪਚਾਰਾਂ ਤੋਂ ਬਾਅਦ ਉੱਪਰਲੀ 10 ਸੈਂਟੀਮੀਟਰ ਮਿੱਟੀ ਵਿੱਚ, ਦੋਨੋਂ ਖੇਤਾਂ ਵਿੱਚ, ਕੋਨ ਸੂਚਕਾਂਕ ਸ਼ੁਰੂਆਤੀ ਨਪਾਈ ਤੋਂ ਘੱਟ ਪਾਏ ਗਏ। ਹੇਠਲੀ ਮਿੱਟੀ ਵਿੱਚ (15 cm ਤੋਂ ਹੇਠਾਂ) ਦੋਨੋਂ ਖੇਤਾਂ ਵਿੱਚ ਕੀਤੇ ਗਏ ਉਪਚਾਰਾਂ ਵਿੱਚੋਂ P3, P4, P5 ਅਤੇ P6 ਵਿੱਚ ਸ਼ੁਰੂਆਤੀ ਨਪਾਈ ਦੇ ਮੁਕਾਬਲੇ ਕੋਨ ਸੂਚਕਾਂਕ ਜਿਆਦਾ ਪਾਏ ਗਏ। ਦੋਨੋਂ ਖੇਤਾਂ ਵਿੱਚ ਕੀਤੇ ਉਪਚਾਰਾਂ ਵਿਚ ਥੋਕ ਘਣਤਾ ਸ਼ੁਰੂਆਤੀ ਮਿੱਟੀ ਨਪਾਈ ਦੇ ਮੁਕਾਬਲੇ ਘੱਟ ਪਾਈ ਗਈ। ਸਾਰੇ ਉਪਚਾਰਾਂ ਵਿੱਚੋਂ ਰੋਟਾਵੇਟਰ ਵਾਹਈ ਅਤੇ ਸਪੇਡਿੰਗ ਮਸ਼ੀਨ ਨਾਲ ਵਹਾਈ ਬਾਅਦ ਨਿਰਮਿਤ ਮਿੱਟੀ ਦੇ ਡਲੇ ਦਾ ਔਸਤ ਵਿਆਸ ਘੱਟ ਸੀ ਪਰ ਈਂਧਨ ਖਪਤ (l/h) ਜ਼ਿਆਦਾ ਸੀ ।

ਮੁੱਖ ਸ਼ਬਦ: ਭੂਮੀ ਨਪਾਈ, ਵਹਾਈ, ਸਿੰਚਾਈ, ਰੋਟਾਵੇਟਰ, ਸਪੇਡਿੰਗ ਮਸ਼ੀਨ, ਥੋਕ ਘਣਤਾ, ਕੋਨ ਸੂਚਕਾਂਕ

ਮੁੱਖ ਸਲਾਹਕਾਰ ਦੇ ਹਸਤਾਖਰ

ਵਿੱਦਿਆਰਥੀ ਦੇ ਹਸਤਾਖਰ

CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATION

ANOVA	Analysis of Variance
avg	Average
cc	cubic centimeter
cm	Centimeter
CV	Coefficient of variation
db	Dry basis
Engg.	Engineering
g	Gram
g/cc	Gram/centimeter cube
h	Hour
kg	Kilogram
km/h	Kilometer/hour
kPa	Kilopascal
l	Litre
m	Metre
m-ha	Million hectare
mm	Millimeter
No.	Number
Pa	Pascal
PTO	Power take off
RBD	Randomized block design
rpm	Revolution per minute
s	Second
%	Percent
&	And

CHAPTER I

INTRODUCTION

In India, the total geographical area is 328.7 million hectare out of which 141.6 million hectare is net sown area. The net irrigated and gross cropped area is 63.6 million hectare and 198.9 million hectare, respectively, with the cropping intensity of 140.5 per cent. Punjab has total geographical area of about 5.0 million hectare out of which 4.1 million hectare is cultivated area. The net irrigated and gross cropped area of Punjab is 4.1 million hectare and 7.9 million hectare, respectively, with the cropping intensity of 191.0 per cent (Anonymous 2014). The population in India and Punjab stands at 1210.9 million and 27.7 million, respectively, as per census 2011. The percentage increase in population of India and Punjab from 2001 to 2011 is 17.7 per cent and 13.9 per cent, respectively. The total food grain production in India and Punjab is 265043.2 million tonne and 26703.0 million tonne, respectively (Anonymous 2015). With ever increasing population, limited land resources and stagnating or lower productivity gains of crops, there has been an increasing pressure of intensive agriculture.

All the countries in the world are switching over to intensive farming, shorter crop rotations and heavier machinery use. In intensive agriculture, all these have led to the increase in soil compaction (Poesse 1992). Intensive agriculture has been possible today because of improved farming systems but there have been certain drawbacks related to it such as degradation of the soil structure, which further leads to reduced crop yields. The soil compaction decreases porosity of the soil, thereby soil particles come closer to one another, therefore increasing the bulk density. Due to soil compaction, the shape, size and spatial arrangement has been changed (Defossez and Richard 2002). Soil compaction affects the hydraulic conductivity and in consequence affects infiltration rates. Tillage changes the way how water and air moves within the soil that alters infiltration rate. Reduction in the infiltration rates will increase runoff and flooding potential. Groundwater recharge also decreases consequently (Norman 1996).

Tillage is performed primarily for seedbed preparation so as to place seeds at suitable depth, which is appropriate for crop or plant growth. For this purpose, different tillage implements have been used. Tillage also retards the growth of weeds which makes the land favorable for plant growth. The manipulation of soil done by the tillage implements also loosens the tilled soil, therefore provides aeration and better conditions for growth of the crops or plants. There are different tillage implements which have different working depths, pulverization power, etc. which in turn affects crop yield and quality. Time and frequency of tillage also affects crop yield as the tillage implements loosens the top soil but tends to cause sub soil compaction. Important soil physical properties such as bulk density, penetration resistance, and soil pulverization are affected by tillage (Kumar 2015).

Tillage, an important field operation, handles largest soil volumes among others. Energy consumption and cost expenditure in soil manipulation has been enormous. Soil tillage consumes highest energy after irrigation operation (Singh 1983). The work of the tillage implements is to break the soil into smaller fragments. Some implements such as rotavators excessively pulverize the soil, which alters the soil structure and therefore altering the pore space in between the soil particles. The implements increase the porosity and infiltration rates at the surface but may form a compacted layer below the tillage depth. The compacted layer is often referred to as hard pan (Donald 1996). A study was conducted to compare the effects of deep ripping tillage (tilling up to 50 cm), spading tillage and mouldboard ploughing on sub-soil compaction alleviation and wheat yield. Deep subsoil tilling helps removing sub-soil compaction and showed 45 per cent yield benefit with spading and 39 per cent yield benefit with mould-board ploughing as compared with the deep ripping treatment (Davies and Johnston 2012).

In recent years, some alternative tillage systems such as multi-powered ones like rotary tilling, spading, powered harrowing etc. and minimum tilling and no-tilling has been preferred for reduced cost and environmental effects of tillage vis-a-vis maximizing the crop production. This paved the way for the use of alternative machinery other than the plough. (Giordano *et al.* 2015). But there has been some reported pros and cons of multi-powered implements. Whereas, the rotavators not only compacted the 0-20 cm layer, but also lead to the compaction of the 20-30 cm layer. There was a reduction in the microbial count due to the reduction in the plant material, which in turn indicated negative effects of rotary tillage, causing soil compaction. Therefore, some other tillage practice must be selected other than the rotary tillage to prevent compaction of the soil (Knut 1997). The spading machines has also been used in tillage for their inherent advantages. The fundamental aspect of spading machine is its ability to avoid the formation of a hard layer. The spading machine also enables operators to break the soil into uniform clods (Dhiman 2016).

Sub soil compaction is not easily accessed. Existence of sub soils that are too loose is very rare. One method that helps to access sub soil compaction may be to determine pre compression stress on· individual layers in the soil profile at various water conditions. This may allow valuable conclusions concerning cumulative influences of previous compactive stresses as well as concerning the resistance to changes in sub soil properties during subsequent loading. This requires extensive work. An alternative is to measure some other physical soil characteristics that are affected by compaction and are easy to determine. The parameter that is easiest to measure is the penetration resistance. The difference in the resistance values will give an idea as to what extent does the loading of equipment causes soil compaction (Donald 1972).

With the above said information, there arises a need to determine soil compaction effected by different tillage implements. Therefore, a study has been undertaken to ascertain the soil compaction caused due to the operation of tillage implements such as harrow-cultivator-planker (practice of conventional tillage), rotavator and spading tillage machines. The study would help in deciding the appropriate tillage tools so as to minimize soil compaction and energy expenditure during the tillage operations for sustainable agriculture. The extent of depth wise soil compaction caused by different tillage practices/implements are not available. The study would generate information on depth wise soil compaction in quantitative manner as affected by the tillage practices/implements. The objectives of the present study were:

I. To quantify soil compaction caused by selected tillage implements.
II. To calculate the energy required in terms of fuel consumption by the tillage practices under study.

CHAPTER II

REVIEW OF LITERATURE

In this chapter, information about the studies related to tillage carried out by different researchers in India and abroad has been briefly reviewed and compiled. The review has been presented under the following sub heads:

2.1 Effect of tillage operations on soil compaction
2.2 Effect of field traffic on soil compaction
2.3 Effect of soil compaction on plant growth and crop yield
2.4 Energy expenditure in various tillage operations
2.5 Soil compaction measuring devices
2.6 Salient findings of review

2.1 Effect of tillage operations on soil compaction

Cassel (1983) concluded changes in soil physical parameters caused due to tillage practices are rarely available. Nine physical soil parameters were taken under study after tillage in loamy sand type of soil. Mouldboard plough was used to till at 25cm depth one month before seeding. After seeding, the physical properties measured three times were bulk density (Db), weight per cent soil water (PW), cone index (CI), total porosity (P), macro porosity (M), saturated hydraulic conductivity (K) and soil water characteristic at soil water pressures of 0.4, 1.0, and 10.0 kPa within the 0 to 14, 14 to 28 and 28 to 41 cm depth. After seeding, changes in the soil physical characteristics were significantly different at 0 to 14 cm depth for six soil properties out of nine soil properties. There was small significant difference in the hydraulic conductivity values and it was difficult to measure it at low bulk density and nearly structure less loamy soil.

Radcliffe *et al* (1985) studied the effect of two tillage practices on soil compaction with the help of tractor mounted cone penetrometer for measuring the cone index values. The interval between the successive readings were 2.5 cm and the maximum depth of penetration of the instrument was 40 cm. After tillage operations, for the tilled depth zone, the cone index values were lesser as compared to the no tilled condition. Therefore, they concluded that tillage eliminated the compaction at the tilled depths (10-30cm).

Henderson *et al* (1988) investigated the four parameters taken into account were soil water content, bulk density, compactibility and soil penetration resistance. Thirteen subsoil sites from western Australian sand-plain soils were selected for compaction analysis. The effect of water content and bulk density on the penetration resistance values was observed for five of the soil types. Penetration resistance values were only slightly affected even when the water content was reduced to less than 70% of the water content at field capacity. Penetration resistance increased exponentially when the soil was dried further. Increase in bulk density increased the penetration resistance at all water contents.

Larney and Kladivko (1989) examined the continuous effect of conservation tillage that may increase surface soil strength or soil compaction, which reduces crop yield and root growth. Two dependent parameters vane shear strength (VS) and cone index (CI) were measured at three row positions: in non-wheel-track-interrow (NW), in row (R) and in wheel track-interrow (WT), with four tillage practices: chisel plow (CH), ridge-till-planter (RT), conventional moldboard plow (PL) and no-till (NT). The soil texture was of silty type. The 'Mollisols' and 'Alfisols' (two soil types) studies had been under the regular tillage treatments for 13, 8, and 4 years respectively. The order of the cone index values for the three row positions were found as: RT > CH and NT > PL. The zone of maximum strength was closer to the soil surface when less tillage was performed. The order of the cone index values for the different tillage practices are as follows PL > CH > NT=RT. Soil strength in the non-tramcked positions (NW and R) on the two Alfisols was the lowest for no-till, especially below 15 cm at the formerly tilled zone. Higher values of strength were recorded at 23 to 40 cm and 15 to 22 cm on the PL and CH treatments, respectively. The compaction severity was more in RT and NT than in PL and CH.

Panayiotopoulos *et al* (1994) indicated that soil bulk density is the mass of dry soil/volume. Bulk density can be used as a measure for measuring soil compaction. In turn, the degree of compaction determines the capacity to store water or air within the soil. Sullivan *et al* (1999) observed that changes in soil strength, void ratio, soil pore space and the pore distribution accounts for soil compaction. Compression and shearing of the soil also accounts for soil compaction. The model helps in determining the propagation of stress in the soil. Hakansson and Lipiec (2000) reported that moisture conditions needs to be monitored to fully understand soil compaction with relation to crop responses. As compared to the season with average rainfall, soil compaction was more significant in the dry season. Sharda (2001) reported that for one whole rotation of the rotary tiller blade, the reaction force varies from 0 to maximum when horizontal edge of the cutting tool enters the soil, the force of friction and reaction due to normal pressure of soil on the tool's working surface appears. The soil is compressed and compacted due to the normal forces. As the internal bonds of the soil particles does not break, the process of soil compression continues.

Prasad (1996) compared four tillage treatments viz. two operations of sweep type cultivator followed by one operation of a disc harrow (Tl), mouldboard ploughing followed by two operations of a disc harrow (T2), one operation of a rotavator (T3) and two operations of rotavator (T4). In the winter wheat crop, soil bulk density after tillage in treatments T3 and T4 was significantly lower in comparison with Tl and T2, although soil bulk densities in Tl and T2 as well as T3 and T4 were similar before tillage. The mean mass diameter of clods in seedbeds for wheat in treatments T3 and T4 was significantly lower than in T1. However, there was no significant difference between T2, T3 and T4. For soybean, the mean mass diameter in T3 and T4 was significantly lesser than in Tl and T2.

Blanco-Canqui *et al* (2017) measured ponded water infiltration (positive soil water pressure) and tension (-1 kPa matric potential) infiltration to exclude macro pore (>125 mm diameter) flow. They concluded that tillage treatments affected ponded infiltration only. The objective of this study was to specifically measure soil hydraulic properties (total porosity, water infiltration, saturated hydraulic conductivity, and water retention characteristics) in no-till, chisel plow, disk, and moldboard plow systems under rain fed continuous corn (*Zea mays* L.) after 35 yr. on silty clay loam soils in eastern Nebraska. Moldboard plow significantly increased ponded infiltration rate by 21.6 cm/h at 5 min and by 8.8 cm/h at 60 min compared with no-till. However, when compared with disk and chisel, moldboard plow increased ponded infiltration rates at all measurements times, which lasted 3 h. Regarding cumulative infiltration, moldboard plow increased cumulative infiltration by 26.9 cm to 39.0 cm after 3 h compared with other tillage systems. Similarities in tension infiltration suggest that the higher ponded infiltration for moldboard plow was most likely due to the presence of voids or fractures (>125 mm) created by full inversion tillage. Total porosity, saturated hydraulic conductivity, and water retention among the treatments did not differ. Overall, soil hydraulic properties did not differ among tillage systems except water infiltration in these silty clay loam soils after 35 years of management.

Reichert *et al* (2017) observed the compressive, shear, and hydraulic soil properties in a sandy clay loam ‘Hapludalf’, under continuous no-tillage and tillage operations to ameliorate soil physical conditions. The studied tillage systems were long-term (13 years) continuous no-tillage (NTc); chisel tillage two years before the experiment (CH2); inverting tillage performed on NT soil, 2 years before and just-before the experiment (IT2,0); and chisel tillage performed on NT soil 3 years before and just-before the experiment (CH3,0). Soil pre-compression stress, compressibility coefficient, cohesion, angle of internal friction, aggregate resistance, bulk density, porosity (total, macro porosity, micro porosity), and water retention (field capacity, permanent wilting point, available water, and drainable water) were determined for 0.01–0.03 m (surface) and 0.10–0.12 m (subsurface) soil layers. The results show inverting and chisel tillage of soil previously under long-term no-tillage has little and/or short-lasting effect on soil composition and functional physical properties. Soil reconsolidation over time significantly affects soil structural condition. Thus, soil tillage is not needed to improve soil structure of sandy clay loam subtropical soil. Furthermore, the terms capacity and intensity properties should not be used as synonyms to composition and functional properties, but they should rather be reserved to the thermodynamically basic quantity-intensity-capacity concept.

2.2 Effect of field traffic on soil compaction

Lowery and Schuler (1991) investigated about the sub soil compaction caused due to the heavy farm machinery. Experiments were carried out on a 'Kewaunee' (fine, mixed) and 'Rozetta' (fine-silty, mixed) soil for the determination of soil strength and corn growth for analyzing the effect of sub soil compaction. Two loads of 8 Mg (P1) and 12.5 Mg (P2) were applied at the two sites in the springs. Cone index values for the sub soil, was higher for the compacted plot. The cone index was significantly higher at the compaction fields as compared with the control.

Arvidsson and Hakansson (1996) studied that due to compaction, pore spaces reduced significantly and tensile strength increased. In Sweden, soil compaction effect was measured for 21 long term field experiments with 259 location years. Soil physical properties, plant growth and crop yield was observed. Two treatments were taken under study: control (no extra traffic) and compacted by 350 Mg km/ha (product of load and distance covered per hectare) of traffic load in the autumn prior to ploughing, with the help of a tractor and trailer with conventional wheel equipment and axle load limited to 4 Mg. The two treatments were conventionally and equally tilled for the remaining part of the year. The treatments for soil compaction was applied for seven long years and crop yield was determined five years after stopping of the compaction treatment, then the readings became constant. Crop yield loss of 11.4% was measured during the constant phase averaged over 107 location years. The yield returned to control level four to five years after stopping of the compaction treatment. For clayey type soils, the yield loss was increased. In case of winter wheat, there was no decrease in yield at a few location years.

Arvidsson and Ristic (1996) studied for four different tractor tires with 3 inflation pressures as sixty-seven, hundred and one hundred fifty per cent of the recommended pressure and with a load on the wheels of 2590 kg. The three tires were radial and the fourth one was a bias ply tire. With the increase in inflation pressure, penetration resistance and soil stress increased with significant difference at 20 and 40 cm depth. For 18.4 R 38, soil stress was the highest followed by 650/6CV38. With low inflation pressure, the low profile tires reduced compaction with 18.4-38 tires. The compaction was significant when the low profile tires were used at a higher inflation pressure. For the same inflation pressure, the radial tires caused a lower stress in the soil than the bias ply tires. The penetration resistance was lesser for the bias ply tires as compared to the radial tires.

Hakansson and Lipiec (2000) also observed that with an increase in soil moisture, the compaction effects were more pronounced at the time of tractor traffic. The compaction effect was more with an increase of number of passes of the tractor. Repeated heavy traffic was found to cause sub soil compaction.

Botta *et al* (2004) reported that harvest operations, tire ground pressure, high wheel load and traffic intensity tends to cause compaction, especially when the soil is clayey or the inflation pressure for the tires is high (140-218 kPa). Water content plays a major role for the soil strength as wet soils in case of soil compaction are more vulnerable than the dry soils.

Arvidsson and Keller (2007) investigated the wheel load effect (11, 15 and 33 kN) at three tire pressures of 50, 70 and 150 kPa on soil stress in Sweden. At 10 cm, the tyre pressure had a strong influence on soil stress but the soil stress below 30 cm was not significant but the wheel load had a significant effect on subsoil stress.

Chamen *et al* (2015) observed and concluded that when the soils are wetter than field capacity, traffic should be restricted just mainly considering the top most layer of soil. The layer below the annual cultivated layer is called the sub soil part. The intensity and type of compaction decides the layer part affected. The part of the sub soil which remains undisturbed by the tillage operations is called the unloosened subsoil.

2.3 Effect of soil compaction on plant growth and crop yield

Taylor *et al* (1966) observed the relation between the root growth for cotton plant and cone resistance, which quantified soil compaction. The measurements for cone index was taken with the help of a cone penetrometer. When the cone resistance approached 2 MPa, root growth was noted to be retarded whereas above 2 MPa, no root growth was seen at all.

Lowery and Schuler (1991) reported that there was a significant reduction in the crop height of 13 and 26 per cent for the 8 and 12.5 Mg compaction loads, respectively, compared with the control. After 3 years since applied compaction, the plant heights reduced by 3.1 and 4.3 per cent compared with the control for the 8 and 12.5 Mg compacted sites. Although Nitrogen and Potassium uptake reduced in case of compacted plot, but Iron, Aluminum and Manganese uptake increased with the compaction level rise on the ‘Kewaunee’ soil. The yields reduced by 4 and 14% for the 8 and 12.5 Mg treatments respectively on the ‘Rozetta’ soil as compared to the control. In the same year, yields for the ‘Kewaunee’ soil reduced 14 and 43% for the 8 and 12.5 Mg treatments respectively as compared with the control.

Prasad (1996) compared the performance of tractor operated rotavator with that of conventional tillage equipment for seedbed preparation under a wheat and soybean crop rotation. In the wheat crop, soil bulk density after tillage in all rotavator treatments were significantly lower in comparison with other implement treatments, although soil bulk densities in all treatments were similar before tillage. The mean mass diameter of clods in seedbeds for wheat in all rotavator treatments were significantly lower than first one, but there was no significant difference between others. For soybean, the mean mass diameter in all rotavator treatments were significantly lesser than others treatments. Neither wheat nor soybean yield was affected by tillage treatment.

Gregory *et al* (2007) found that the compaction effects were significant for sandy loam and sandy clay loam soil. But in case of clayey type of soil, the effects were of compaction was negligible possibly due to buoyancy effect of pore water pressure. It was also observed that in a sandy loam soil, the yield reduction was about 50%, when an 11 kN tractor was given 8 passes but there was no change in yield for the same tractor in case of clayey soil.

Glab (2011) observed that the yields of both annual and perennial plants decreased with the increase in soil compaction with reference to tractor traffic. Changes in root morphology was also observed. Root dry matter for the investigated soil layers was uniform for the case of un-compacted soil whereas the main root matter was limited to the upper layers of the soil only. Roots were seen to be longer at the depth of 0-10 cm, where it tended to decrease below 10 cm. As the degree of compaction increased, the root length density decreased. Also, the roots were observed to be thinner in case of compacted soil whereas thicker in case of un-compacted soil. The yield was found to decrease with compaction increase for the first year (2007) but was found to increase for the next two subsequent years (2008 and 2009).

Tolon-Becerra *et al* (2011) reported that there was yield reductions (10.7–15.2%), inadequate root growth and retarded emergence of maize seedlings for cone index values greater than 1.7MPa in the top layers of the soil.

Lipiec (2012) studied the two zones Europe (humid) and USA (temperate). He found that the compaction effect was pronounced for 5 years. The compaction effects in the 25–40 cm layer were alleviated over a 10-year period, whereas compaction effects on layers deeper than 40 cm were persistent despite annual winter soil freezing.

Ranjbarian *et al* (2015) concluded that the number of plant roots get reduced when there was an increase in the penetration resistance. Factors affecting compaction can be high wheel load, tire ground pressure and traffic intensity. There was reduction in yield for the crops, whose fields were in compacted state. It was further seen that wet soils were more susceptible to compaction than the dry soils.

Shah *et al* (2017) reported that agricultural production has always been affected due to soil compaction caused due to various factors such as tillage operations at high soil moisture, animal trampling and engine vibrations. Soil compaction leads to decrease in porosity, soil hydraulic conductivity and nutrient availability, and therefore reduces soil health and consequently lowers crop performance such as reduced root growth. The negative impacts of soil compaction were reduction in plant height, discoloration of the leaves, stunted growth and shallow root penetration, reduced uptake of the nutrients, reduced leaf gas exchange, carbon assimilation and less translocation of photosynthates.

2.4 Energy expenditure in various tillage operations

Prasad (1996) compared four tillage treatments viz. two operations of sweep type cultivator followed by one operation of a disc harrow (Tl), mouldboard ploughing followed by two operations of a disc harrow (T2), one operation of a rotavator (T3) and two operations of rotavator (T4). The specific energy utilized in seedbed preparation for both the crops was lowest with one pass of the rotavator (T3) compared with conventional tillage treatments Tl and T2.

Poje and Filipovic (1998) studied the energy expenditure of the various tillage implements for the loamy soil type. The power requirement for rotary harrow in driving, pulling and control of rolling resistance was 63.8, 28.5 and 7.7 per cent, respectively. In the case of rotary tiller used on ploughed soil, the power requirement for driving and control of tractor rolling resistance was 85.2 and 14.8 per cent, respectively. When the rotary tiller was operated on unploughed soil, 71.838 kW power was engaged, but there was a return of power of magnitude 24.8 kW from the rotary tiller to the tractor due to negative draught. Energy consumption/ volume of soil tilled was 238-276 kJ/m^3.

Ranjbarian *et al* (2015) also developed mobile instrumentation system was mounted on MF-285 tractor to measure the performance parameters of the tractor and attached implements. The system measures implement draft, fuel consumption, real forward velocity, tillage depth and engine speed. Other parameters such as wheel slippage, drawbar power and traction efficiency would be calculated by ASABE standard. Overall energy efficiency for the tractor-implement system was calculated, too. Three implements included of moldboard plow, disk plow and chisel plow at four forward velocities (1.5, 2.3, 3 and 4 km/h) in 23 cm depth and 1500 rpm engine speed was examined. Analysis of variance (ANOVA) of resulted data revealed that increase of forward velocity results in increase of implement draft, wheel slippage, drawbar power and overall energy efficiency but results in decrease of traction efficiency. Furthermore, fuel consumption decreased by increase of velocity from 1.5 km/h to 3 km/h but increased by increase of velocity from 3 km/h to 4 km/h. Moreover, it was observed that draft requirement for implements in tests ranged from 8.2 kN for the disk plow to 13 kN for the chisel plow and fuel consumption ranged from 10.72 l/ha for the chisel plow to 26.5 L/ha for the moldboard plow. The ranges in mentioned parameters indicate that energy saving can be readily done by selecting energy-efficient implements and by proper matching of the tractor size and operating parameters to the implements. It can be concluded that the no of plant roots gets reduced when there was an increase in the penetration resistance. Factors affecting compaction can be high wheel load, tire ground pressure and traffic intensity. There was reduction in yield for the crops, whose fields were in compacted state. It was further seen that wet soils were more susceptible to compaction than the dry soils.

Sarauskis *et al* (2017) studied that hourly fuel consumption for the strip tillage machine was effected by the depth of operation of the narrow tine and the forward speed of the tillage machine. The experiment was carried out to inspect the influence of depth of operation of a narrow tine, forward speed of the strip tillage machine, row cleaner attack angle and spacing between discs on the tractor's fuel consumption and greenhouse gas emissions. The observations were taken for the four different factors with varying ranges such as depth of operation range of a narrow tine was taken between 0 to 200mm, forward speed range of the tillage machine was taken from 1.4 m/s to 3.1 m/s, row cleaner attack angle range was from 10 to 22.5 and the spacing between the discs' range was taken in between 105 mm to 135 mm at 44 different scenarios. Increase in the depth of operation of the narrow tine from 0 to 200 mm, there was an increase in tractor's fuel consumption from 10.3 to24.3% depending on the forward speed. It was noted that least fuel consumption and CO_2 emissions were found at the forward speed of 2.5 m/s whereas the greenhouse gas emissions were found highest at the forward speed of 1.4 m/s. There was 20% increase in the CO_2 emissions from the tractors with the increase in the depth of operation from 0 to 200 mm. The most optimal parameters for lowest fuel consumption and CO_2 emissions from tractor were forward speed being 2.5 m/s, row cleaner attack angle being 10 degrees, gap between row cleaner discs being 105 mm and strip width being 135 mm but not depending on the depth of operation of the narrow tine.

2.5 Soil compaction measuring devices

Prather *et al* (1970) reported that depth-resistance curve was drawn automatically in the recording type cone penetrometers as the cone moves down the soil, but the limitation is only that the force needs to be applied manually. Williford *et al* (1972) developed a tractor mounted cone penetrometer, in which hydraulic system is used to push the cone down the soil. Force-depth graph is plotted and recorded automatically, the limitation being that 2 men are needed for the data collection work. Microcomputer based cone penetrometers have been developed for recording penetration resistance. Considering the time use efficiency, the tractor mounted penetrometers require only 25% time as compared to the operation of the hand held manually operated cone penetrometers.

Wilkerson *et al* (1982) developed a more advance instrument for the measurement of soil strength. The penetrometer was tractor mounted, which was hydraulically operated and could move to a depth of 61 cm over a 4-row width. A data logger automatically records the data and a microprocessor is there, which activates all moving mechanisms. Phillips and Perumpral (1983) modified the manually hand operated penetrometer by using strain gauges to be placed on the proving ring, which in turn sent electrical signals for the cone resistance values. The data recording work and operation required two operators.

Woodruff and Lenker (1984) designed a manual penetrometer, which can record data at 1.2 cm depth intervals up to a maximum depth of 100 cm on a data logger. The capacity for data storage ranges from 60-70 penetrations, each with 48 data readings. Ohmiya (1998) developed a three dimensional cone index recorder for measuring the soil strength. The penetrometer was different from conventional penetrometers as it could record cone resistance in all the three directions.

Sudduth *et al* (2004) reported that slower rates of insertion speeds for Veris penetrometer will not cause significant errors. The initial configuration of the insertion speed for the Veris penetrometer was 40 mm/s (1.6 in/s). The effect of insertion speed on cone index was to be noted at a site with silty clay loam texture. Both, EC tip and the ASAE small tip were used in the experiment with three replications. Data were collected in three positions relative to corn stubble rows: in the row, in the row middle, and at a point halfway between. The three nominal insertion speeds taken were 30, 40, and 50 mm/s, which was maintained by adjusting the oil flow rate to the hydraulic cylinder. The 50 mm/s insertion speed was the maximum achievable with the Veris hydraulic system.

Kotrocz *et al* (2016) studied the simulation of the soil cone penetrometer with the cohesive loamy sand soil with a three dimensional (3D) discrete element model (DEM). The purpose was to observe the variations of soil penetration resistance due to soil model's geometrical changes. The model area ratio was used to analyze the effects of cross sectional size while the height ratio values were used to analyze the model's height. The results of the discrete element model were compared with that of the in-situ measurements taken with cone penetrometer of same geometry. The model showed a good agreement between simulated and measured values. The mean error between the calculated penetration resistance with the model to that of in-situ measurements was found to be 14.74%. The two best performing models were a rectangular model and circular model. The rectangular model had an area ratio and height ratio of 72 and 1.33, respectively. The circular model had an area ratio and height ratio of 32 and 2, respectively. Using the direct shear box for loamy sand soils, the cohesion values and internal friction angle values were found between 6.61 to 8.66 kPa and 41.34 to 41.60 degrees, respectively.

2.6 Salient findings of the reviews

- The number of roots penetrating the soil were reduced drastically as the penetration resistance increased. When the cone resistance approached 2 MPa, root growth was noted to be retarded whereas above 2 MPa, no root growth was seen at all.
- Cone index was higher in the no till field as compared in the tilled field. It was concluded that tilling eliminated the compacted depth zone.
- Soil water contents, soil texture and structure, and soil organic matter were the main factors among others which effect the soil compaction. Generally, soils with very low moisture content have been less vulnerable to compaction than high moisture soils. Whereas, compaction effects have been likely more pronounced in dry seasons than in seasons with above average rainfall.
- The compaction effects were significant in case of sandy loam and clay sandy loam

soil unlike the clayey type of soil, where the effect of compaction was found to be negligible due to presence of excessive number of micro pores.

- Tractor or traffic movements on the soil also contributes to soil compaction.
- With the increase in the depth of operation of the narrow tine from 0 to 200 mm, there was an increase in tractor's fuel consumption from 10.3 to24.3% depending on the forward speed.
- The power requirement for rotary harrow in driving, pulling and control of rolling resistance was 63.8, 28.5 and 7.7 per cent, respectively.
- When a rotary tiller was operated on unploughed soil, 71.838 kW power was engaged, but there was a return of power of magnitude 24.8 kW from the rotary tiller to the tractor due to negative draught.
- Advanced penetrometers are tractor mounted, which is hydraulically operated and can move to a depth of 61 cm over a 4-row width. The main advantage of tractor mounted penetrometers is the constant insertion speed, which would provide a more accurate and reliable data.

CHAPTER III

MATERIAL AND METHODS

This Chapter deals with the material and methods employed for the experimental investigations. The tests were carried out in the fields of research farms of Department of Farm Machinery and Power Engineering, Punjab Agricultural University, Ludhiana.

The complete methodology used for the present study has been given under the following sub heads:

3.1 Independent parameters of the study
3.2 Effect of irrigation
3.3 Dependent parameters of the study
3.4 Lay out of experimental plots
3.5 Statistical analysis

3.1 Independent parameters of the study

Different independent parameters were selected for determining the soil compaction caused by different tillage practices and the parameters that express the degree of soil compaction caused are discussed as per following sub heads:

3.1.1 Soil type
3.1.2 Tillage practices
3.1.3 Forward velocity
3.1.4 Depth of operation

3.1.1 Soil type

Field plots at two different locations of varied soil texture described henceforth as S1 and S2 were selected. The soil texture has been characterized by ascertaining the soil physical parameters. i.e. per cent sand, silt and clay. Soil samples were taken from at least four different locations of the selected plot i.e. from S1 and S2 separately. Samples taken from fields S1 and S2 were mixed separately and part of soil samples (S1 and S2) were taken to soil testing laboratory of the Department of Soil Science, Punjab Agricultural University, Ludhiana for analysis work.

3.1.2 Tillage practices

Three different tillage practices were taken for the present study and described as per following sub heads:

3.1.2.1 Conventional tillage practice
3.1.2.2 Tillage with rotavator
3.1.2.3 Tillage with spading machine

3.1.2.1 Conventional tillage practice

Three tillage implements, viz. disc-harrow, cultivator and planker, used commonly for conventional tillage were selected. All implements were operated once, one after the other i.e. first disc-harrow, then cultivator and then planker (one pass each) and this practice has been designated as P1. Another tillage practice has been considered for the present study by using two passes each one after the other, of all the selected implements and designated as P2. The specific but brief information regarding the different implements has been given as follows.

A semi mounted double action disc harrow (Amsons) was used with 16 discs arranged on two gangs as shown in Fig. 3.1. Mild steel angle welded frame structure was mounted on the individual gang of discs. Curved discs with plane sharp cutting edge were used. The disc harrow was hydraulically lifted for locomotion.

Fig 3.1 A stationary view of Disc harrow.

An 11 Tyne cultivator with spring loaded tynes (Amsons) was used shown in Fig. 3.2. Heavy springs provide safety to the tynes against shock and impact loads encountered during field operations. Width of cultivator was 2.4 m.

Fig 3.2 A stationary view of 11 Tyne cultivator.

A mild steel planker of width 3 m (Amsons) was used for the top finishing operation of the soil shown in Fig. 3.3.

Fig 3.3 A stationary view of Planker.

3.1.2.2 Tillage with rotavator

A horizontal shaft forward rotary rotavator with L-shaped blades has been used for the study. Two tillage practices of rotavator were taken in the study viz. one pass of rotavator designated as P3 and two passes of rotavator designated as P4. The specific but brief information about rotavator has been given as follows. The rotavator (Dasmesh) used for the study comprise of 36 L-type blades, as shown in Fig. 3.4. The rotavator was designed to operate at 540 PTO rpm and had a rotor speed of 270 rpm. Physical dimensions of the rotavator viz. width x height x length were 1.77 m x 0.94 m x 1.35 m. Working width of the rotavator was 1.52 m. The rotavator has adjustable skids for varying the depth of operation.

Fig 3.4 A stationary view of the rotavator with L type blades.

3.1.2.3 Tillage with spading machine

A spading machine (Selvatici, 150.75 series, 1105 model) having 1.1m width has been used for the study. Two tillage practice of spading machine were taken i.e. one pass of spading machine designated as P5 and two passes of spading machine designated as P6. The spading machine manufactured by Bologna (Italy) based farm machinery manufacturing company, Selvatici was used in the present investigation as shown in Fig. 3.5. This is a compact machine equipped with five spades and works on a width of 110 cm. The depth of working has been adjustable up to a maximum of 30 cm.

Fig 3.5 A view of spading machine used in the study.

Tractor selected in the experiment was JOHN DEERE 55 hp equipped with a fuel flow meter shown in Fig. 3.6.

Fig 3.6 A view of tractor equipped with the fuel meter.

3.1.3 Forward velocity

Two different ranges of forward velocities hence-forth described as V1 and V2, for the tillage implements has been taken. V1 has been taken as the lower manageable velocity range while V2 has been taken as the higher manageable velocity range. Appropriate velocity ranges have been selected so that all implements could confirm the selected ranges. The forward velocity of implements was measured by standard velocity measurement relationship given in equation 3.1.

$$v = d/t \qquad \ldots 3.1$$

where

v = forward speed, m/s
d = distance in meters, m
t = time taken to cover the designated distance in seconds.

3.1.4 Depth of operation

Two different depth ranges, henceforth described as (D1 and D2) for operating each of the tillage implements has been taken. The shallower depth range has been designated as D1 and the deeper depth range of operation as D2. The required depth of operation was maintained by the hydraulic control of lower links and the top link adjustment of three-point linkage system of tractor. Test runs were conducted for the depth adjustment of different implements before actual experimental runs. Appropriate depth ranges have been selected so that all implements could confirm the selected ranges. A ruler (30 cm length) was used to measure the depth of operation of various implements, as shown in Fig. 3.7.

Figure 3.7 A view of depth of operation measurement using a ruler.

3.2 Effect of Irrigation

The effect of irrigation on soil hardness/compaction has also been included in the present study. Soil compaction has been noted by taking cone index and bulk density samples before irrigation before the tillage treatments. Soil compaction has also been recorded after applying irrigation to fields by taking cone index readings and bulk density values, when fields were at optimum moisture content, depending upon different soil types. Before irrigation condition has been denoted as BI and after irrigation condition has been denoted as AI.

3.3 Dependent parameters of the study

The dependent parameters that are measured to quantify the soil compaction are discussed as per the following sub heads:

3.3.1 Cone Index (penetration resistance)
3.3.2 Soil bulk density
3.3.3 Mean weight diameter of soil clods
3.3.4 Fuel consumption of tillage practices

3.3.1 Cone index (penetration resistance)

A hand-held digital cone penetrometer described in section 3.3.1.1, was used to measure soil hardness or penetration resistance. The Cone index or penetration resistance, in kPa was measured as an indicator of soil compaction. To quantify soil compaction caused by different tillage practices, cone index of experimental plots was recorded, as shown in Fig. 3.8 before and after the operation of each tillage practice, discussed in detail in section 3.1.2.

Fig 3.8 Soil hardness being measured using a digital cone penetrometer.

3.3.1.1 Digital cone penetrometer

A digital cone penetrometer used in the experiment was Rimik CP40II. It consists of a rigid, steel rod, with a cone tip attached to one end, fixed to a force transducer, through the other end. The force transducer has been fixed to the unit at lower portion and the force sensor has been connected to the microcomputer based circuitry of the unit with a display at upper portion, as shown in fig. 3.9.

Fig 3.9 A view of Cone penetrometer.

The penetrometer can be used up to a depth of 75cm and has a maximum force limit of 75 kgf. Depth measurements were made by the unit with ultrasonic proximity sensor fixed at its lower portion. The cone tip of penetrometer has been exchangeable with other different size tips. Cone penetrometer was operated at a uniform speed range of 0.2m/min to 2m/min by placing the cone tip at the designated place of sampling with penetrometer rod held at near vertical orientation as possible. The cone index readings were automatically logged by the unit’s data logger. An RS-232 interface connection has been provided with the unit along with software for downloading the logged data to a computer in an xls file format for further analysis. The unit logs the cone index data for every 1 cm, 1.5 cm, 2 cm or 2.5 cm travel of penetrometer rod, as per customized requirements.

3.3.2 Soil Bulk Density

Soil compaction has also been characterized by recording the soil bulk density of the experimental plots. Bulk density of soils was recorded at three different depths 0-5 cm, 0-10 cm and 0-20 cm by using three different core samplers, shown in Fig. 3.10. The core samplers were hammered in the soil and samples were drawn without disturbing the soil, as shown in Fig 3.11. The samples were weighed using the platform type electronic weighing balance (Oras Tech, India). Bulk density values for 0-5 cm, 0-10 cm and 0-20 cm depth has been calculated by using relative density separation method of corresponding depths. For calculating bulk density for depth 0-10 cm, relative weight and volume of 0-5 cm depth were subtracted from 0-10 cm depth values. Bulk density for 0-20 cm has also been calculated by using similarly technique.

The soil samples from the core were used for working out the wet bulk density. Standard core sampling technique was used to determine soil bulk density (wet basis) by using the relation given in equation 3.2.

$$D_w = W/V \qquad \ldots 3.2$$

where

D_w = Bulk density (wet basis) in g/cc,
W = weight of soil taken by sampler in g,
V = volume of specific sampler in cc.

Fig 3.10 Core samplers along with the hammer.

Fig 3.11 Core samplers excavated out of the soil.

3.3.2.1 Soil bulk density at dry basis

The extent of soil moisture influences the soil bulk density at wet basis, so bulk density values have been determined at standard moisture i.e. at dry level. The dry bulk density of soil sample (D_d) has been calculated using the relation between the soil bulk density at wet basis and moisture content. A part of the soil sample has been collected in plastic envelops while recording wet bulk density of soil. The soil samples were then put for moisture determination at department laboratory using standard oven drying method. The soil samples were weighed with weighing balance (Denver instrument, TP-3102) having precision of 0.01g. The soil moisture fraction has been calculated by using relation given in equation 3.3.

$$w = (W_w - W_d) / W_d \qquad \ldots 3.3$$

where,

w = soil moisture in fraction of given soil sample,

W_w = wet weight of soil in g,

W_d = dry weight of soil in g.

Then, the soil bulk density at dry basis was calculated using the relation given in equation 3.4.

$$D_d = D_w/(1+w) \qquad \ldots 3.4$$

where,

D_d = dry bulk density in g/cc,

D_w = wet bulk density in g/cc,

w = soil moisture in fraction of given soil sample

Soil bulk density at dry basis for 0-5 cm, 0-10 cm and 0-20 cm has been used for comparing the results obtained in the present study.

3.3.3 Mean weight diameter of soil clods

The Mean weight diameter, henceforth described as MWD, of the soil aggregates have been considered as index of soil pulverization caused by different tillage practices considered under the present study. The degree of soil pulverization was measured by determining the MWD of soil clods after tillage practices by using sieve analysis technique. For this, sieves of appropriate mesh size were selected to assess the degree of pulverization. A set of 10 sieves of different sizes (75, 19, 8, 4.75, 2.8, 2, 1, 0.6, 0.425 and 0.15 mm) were used with size decreasing downwards up to the pan. The set consisted of sieve sizes according to BIS standards IS 2720-4 (1985). After performing different tillage practices, samples were drawn in three replications randomly, using soil sampler (length 150 mm x width 150 mm x height 300 mm) shown in fig 3.12. The soil samples were shade dried for 24 hours before carrying out the sieve analysis. The sieve analysis was done by using mechanical sieve shaker, as shown in fig 3.13. The weighted mean of the soil restrained in different sieves was found. The weight of soil retained by each sieve was also determined. The mean weight diameter of soil clods formed after tillage treatments were calculated by using equation 3.4.

$$MWD = (\sum W_i{*}d_i)/W_T \qquad \ldots 3.4$$

where,

d_i = average diameter of i and $(i+1)^{th}$ sieve in mm, such that $d_i<d_{i+1}$,
W_i = weight of soil retained on the i^{th} sieve in g,
W_T= total weight of soil sample in g.

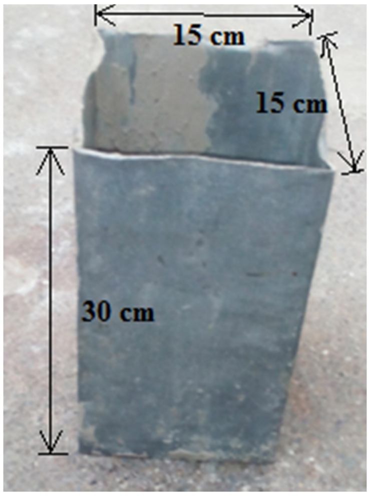

Fig 3.12 A view of the soil sampler used for MWD determination.

Fig 3.13 A view of the sieve shaker.

3.3.4 Fuel Consumption

Fuel consumption of each of the tillage practices were recorded with the help of the tractor mounted fuel flow meter shown in Fig. 3.14. A volume flow meter (Aqua Metro VZO 4, Swiss made) was installed between the diesel tank and fuel filters of the tractor to ascertain the fuel consumption of the tractor. Bypass fuel from filters and injectors was returned downstream of flow meter instead of being returned to the fuel tank. Thus all fuel passing through the flow meter was consumed by the tractor engine. An additional fuel filter was also installed upstream of flow meter to rule out choking. The fuel meter gives only the quantity of fuel passed through the meter. The quantity of fuel metered was accurate up to 1 ml. A stopwatch was used to record the time of run of tractor for the measurement of fuel consumption.

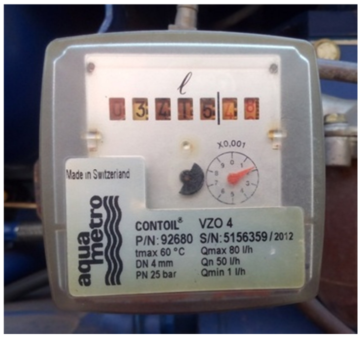

Fig. 3.14 Tractor mounted fuel meter.

3.4 Layout of experimental plots

The experiments have been laid out by using factorial in randomized block design, henceforth designated as $_f$RBD, of statistical methods to minimize variation in soil properties on the treatments. In order to find out the soil compaction caused by different tillage practices taken in the present study, each treatment was replicated three times.

Paper chits with the name of different treatments were prepared by writing designated tillage practices, forward velocities and depth of operations as factors. The paper chits were thoroughly mixed and random draw of lot was performed one by one till the end of lot. Then, accordingly the names of the treatments were written for one block. This process was repeated for a total of six times for the two soils, each comprising of three randomized blocks i.e. three replications.

3.5 Statistical analysis

Different statistical methods have been formulated to quantify the soil compaction affected by different tillage practices adopted in the present study. Factorial in randomized block design ($_f$RBD) was formulated on soil types, tillage practices, forward speeds and depths as independent parameters. Analysis of variance in $_f$RBD was performed to show the significance of each parameter. Coefficient of variance and t-tests were performed to signify the consistency of recorded parameters of the treatments, before and after the tillage practices. Dependent variables, i.e. cone index, bulk density, pulverization in terms of MWD of soil clods and fuel consumption, in terms of their respective general means were compared on the basis of the tests.

CHAPTER IV

RESULTS AND DISCUSSION

This Chapter deals with the results of different experiments conducted to study soil compaction under selected conditions. The results have been presented and discussed under the following sub-heads:

4.1 Layout of experimental plots

4.2 Independent parameters of the study

4.3 Effect of irrigation on soil compaction

4.4 Dependent parameters of the study

4.1 Layout of experimental plots

The experiments, as described in chapter 3, section 3.1, were laid on fields of research farms of department of farm machinery and power engineering, PAU, Ludhiana by using randomized block design of statistical methods and given in Table 4.1.

Table 4.1 The experimental layout, on two different soils viz. soil S1 (Sandy Loam), soil S2 (Silty Loam), replications; R1, R2 and R3, tillage practices P1 to P6, velocity ranges V1, V2 and depth ranges D1, D2 adopted in the study.

Sr. No.	S1 (Sandy Loam)			S2 (Silty Loam)		
	R1	**R2**	**R3**	**R1**	**R2**	**R3**
1	P1V2D2	P1V2D2	P1V1D1	P5V2D1	P3V2D1	P3V2D2
2	P5V1D2	P1V1D1	P6V2D2	P3V1D2	P1V1D2	P5V1D1
3	P1V1D1	P5V1D1	P2V2D1	P6V1D2	P1V2D1	P2V1D2
4	P6V2D2	P6V2D2	P6V1D2	P3V1D1	P5V2D2	P6V2D2
5	P4V1D2	P1V1D2	P4V2D1	P6V1D1	P4V1D1	P3V1D2
6	P6V2D1	P5V2D2	P5V2D2	P2V1D1	P3V1D2	P1V1D2
7	P2V1D1	P6V2D1	P5V1D1	P4V2D2	P1V2D2	P4V2D1
8	P6V1D1	P4V1D2	P1V2D1	P2V1D2	P6V1D2	P5V2D1
9	P3V2D2	P1V2D1	P5V1D2	P5V1D2	P3V1D1	P1V2D2
10	P2V2D1	P3V1D2	P2V1D1	P1V1D2	P6V2D2	P3V1D1
11	P3V1D2	P2V2D2	P3V1D2	P6V2D1	P2V1D2	P2V2D2
12	P3V1D1	P3V1D1	P6V1D1	P4V1D1	P4V1D2	P6V1D1
13	P5V2D2	P6V1D2	P2V2D2	P5V2D2	P2V2D1	P5V1D2
14	P3V2D1	P3V2D2	P1V1D2	P4V1D2	P4V2D2	P4V2D2
15	P6V1D2	P5V2D1	P4V1D2	P3V2D2	P6V2D1	P6V1D2
16	P2V1D2	P2V1D2	P5V2D1	P2V2D1	P2V2D2	P5V2D2
17	P5V1D1	P2V1D1	P3V1D1	P6V2D2	P5V2D1	P1V2D1
18	P5V2D1	P6V1D1	P4V1D1	P1V2D1	P2V1D1	P4V1D1
19	P4V1D1	P3V2D1	P3V2D1	P5V1D1	P1V1D1	P2V2D1
20	P1V2D1	P4V1D1	P4V2D2	P2V2D2	P5V1D2	P2V1D1
21	P2V2D2	P5V1D2	P6V2D1	P3V2D1	P3V2D2	P3V2D1
22	P4V2D1	P4V2D1	P2V1D2	P1V1D1	P4V2D1	P1V1D1
23	P4V2D2	P2V2D1	P3V2D2	P1V2D2	P6V1D1	P4V1D2
24	P1V1D2	P4V2D2	P1V2D2	P4V2D1	P5V1D1	P6V2D1

The experimental layout adopted was according to section 3.4 given in chapter 3. The fields were demarcated as per the experimental layout. The two soil types were divided into 3 blocks, separately, for the 3 replications, and each block was further divided into 24 plots for the tillage treatments. Length of run was 27m and 25m for S1 and S2, respectively.

4.2 Independent parameters of the study

Different operating ranges were selected for different independent parameters depending upon nature of tillage implements used in the present study. The soil samples of two different sites, selected for the experimentation, were analyzed for particle size distribution (soil texture). The S1 soil composes of 76% sand, 12% silt and 12% clay, hence termed as sandy loam texture whereas S2 soil composes 20% sand, 55% silt and 25% clay, hence falls under silty loam texture.

Six different tillage practices, viz. one pass each of harrow followed by cultivator and planker (P1), two passes each of harrow followed by cultivator and planker (P2), one pass of rotavator (P3), two passes of rotavator (P4), one pass of spading machine (P5) and two passes of spading machine (P6), were considered for the present study. A total of five different tillage implements were used for the experimental study. As per section 3.1.3 and 3.1.4 of previous chapter, all the implements have their own recommended speed of operation. For experimental study, two different forward speed ranges, suitable to every implement, were selected. The lower speed range (V1) of all tillage implements were maintained between 1.63 km/h to 5 km/h. The lower speed of operation in the conventional tillage practices P1 and P2, disc harrow, cultivator and plankers were operated at about 3.9-5 km/h, in practices P3 and P4, rotavator was operated at about 1.63–2.46 km/h and in practices P5 and P6, spading machine was operated at about 1.92–2.31 km/h. The higher speed range (V2) of all tillage implements were maintained between 2.37 km/h to 7.47 km/h. In the conventional tillage practice P1 and P2, disc harrow, cultivator and plankers were operated at about 5.4–7.47 km/h, in practices P3 and P4, rotavator was operated at about 2.37–2.85 km/h and in practices P5 and P6, spading machine was operated at about 2.5–3 km/h.

Similarly, different implements have different depth of operation. For the experimental study, two different ranges of depth of operation were selected. The shallower depth ranges of operation (D1) maintained for the selected implements were between 5 cm to 10 cm. For the lower depth, the conventional tillage practices P1 and P2, disc harrow, cultivator and plankers were operated at about 10 cm, in practices P3 and P4, rotavator was operated at about 5 cm and in practices P5 and P6, spading machine was operated at about 5 cm. The deeper depth ranges of operation (D2) were maintained between 10 cm to 15 cm for all the implements under study. For the deeper depth, the conventional tillage practices P1 and P2, disc harrow, cultivator and plankers were operated at about 15 cm, in practices P3 and P4, rotavator was operated at about 10 cm and in practices P5 and P6, spading machine was operated at about 10 cm. The total number of test runs were 144 including three replications and two soil types.

4.3 Effect of irrigation on soil compaction

Cone index and bulk density values were taken at initial compacted condition of both types of soils. Cone index values were recorded for sandy loam soil (S1) in kPa at 5, 10 and 15 cm sampling depths. The cone index values beyond 15 cm depth could not be recorded due to excessive hardness encountered at sub-soil level of the soil. A total number of cone insertions were 432 (24 plots x 6 insertions x 3 replications). The average cone index values were found to be 1816, 2059 and 2568 kPa at 5, 10 and 15 cm depths, respectively.

Bulk density values for 0-5 cm, 0-10 cm and 0-20 cm depth were calculated in g/cc for the soil. A total of 24 samples (24 plots x 1 reading) were taken. The reading value was the averaged value obtained over the three replications. The average bulk density values were found to be 1.69, 1.71 and 1.56 g/cc at 0-5 cm, 0-10 cm and 0-20 cm depths, respectively.

Coefficient of variation (CV) for cone index values for soil S1 were analyzed for variation of data within the experimental plots and between the experimental plots. The CV for the cone index values at 5 cm depth was found to vary from 9.3 to 14.91 % among all values within the plots. The CV at 10 cm depth varied between 4.98 to 14.88% and at 15 cm depth it varied between 8.46 to 14.75% among all the sample values within the plots. The CV for the cone index between the plots for soil S1 at 5, 10 and 15 cm depths were found to be 4.34, 3.61 and 7.57 %, respectively. The maximum variation in the cone index value was 14.91 % within the plots and 7.57 % between the plots. The CV for the bulk density values for 0-5, 0-10 and 0-20 cm depths were calculated between the plots and were found to be at 5.36, 7.05 and 4.20 %, respectively. The variation in the values may be due the heterogeneous nature & physical properties of the soil and manual operation of the sampling equipment.

The T-test for the cone index values of soil S1 at sampling depths of 5, 10 and 15 cm is given in Table 4.2. No significant variation has been found, at 5 % level of significance (p>0.05), among cone index values at all the reported depths.

Table 4.2 The T-test for the cone index values, before the irrigation, for soil S1 at different sampling depths.

Depth in cm	Test value	t value	d.f.	Mean difference	p (2-tailed)
5	1816	0.022	431	0.2399	NS
10	2059	0.089	431	0.9087	NS
15	2568	0.021	431	0.3546	NS

The T-test for the bulk density values at sampling depths for 0-5, 0-10 and 0-20 cm of soil S1 is given in Table 4.3. No significant variation has been found, at 5 % level of significance (p>0.05), among bulk density values at all the reported depths.

Table 4.3 The T-test for the bulk density values, before the irrigation, for soil S1 at different sampling depths.

Depth in cm	Test value	t value	d.f.	Mean difference	p (2-tailed)
0-5	1.69	0.028	23	0.0005	NS
0-10	1.71	0.141	23	0.0034	NS
0-20	1.56	0.447	23	0.0059	NS

Cone index values were recorded at initial compacted condition for silty loam soil (S2) in kPa at 5, 10 and 15 cm sampling depths. The cone index values beyond 15 cm depth could not be recorded due to excessive hardness encountered at the sub-soil level of this soil, also. A total number of cone insertions were 432 (24 plots x 6 insertions x 3 replications). The average cone index values were found to be 2071, 1557 and 1968 kPa at 5, 10 and 15 cm depths, respectively.

Bulk density values for 0-5 cm, 0-10 cm and 0-20 cm depths were also calculated in g/cc for the S2 soil. A total of 24 samples (24 plots x 1 reading) were taken. The reading value was the averaged value obtained over the three replications. The average bulk density values were found to be 1.82, 1.83 and 1.50 g/cc at 0-5 cm, 0-10 cm and 0-20 cm depth, respectively.

CV for cone index values for S2 soil were also analyzed for variation of data within the experimental plots and between the experimental plots. The CV for the cone index values at 5 cm depth was found to vary from 8.46 to 14.82 % among all samples within the plots. The CV at 10 cm depth varied between 8.78 to 14.86 % and at 15 cm depth it varied between 7.09 to 14.59 % among all the sample values within the plots. The CV for the cone index between the plots for soil S2 at 5, 10 and 15 cm depths were found to be 4.00, 4.91 and 2.39 %, respectively. The maximum variation in the cone index value was 14.86 % within the plots and 4.91 % between the plots. The CV for the bulk density values for 0-5, 0-10 and 0-20 cm depths were calculated between the plots and were found to be at 4.1, 6.33 and 6.84 %, respectively. The variation in the values may be due the heterogeneous nature & physical properties of the soil and manual operation of the sampling equipment.

The T-test for the cone index values of soil S2 at sampling depths of 5, 10 and 15 cm is given in Table 4.4. No significant variation has been found, at 5 % level of significance ($p>0.05$), among cone index values at all the reported depths.

Table 4.4 The T-test for the cone index values, before the irrigation, for soil S2 at different sampling depths.

Depth in cm	Test value	t value	d.f.	Mean difference	p (2-tailed)
5	2071	0.065	431	0.8352	NS
10	1557	0.06	431	0.6326	NS
15	1968	0.065	431	0.8958	NS

The T-test for the bulk density values at sampling depths for 0-5, 0-10 and 0-20 cm of soil S2 is given in Table 4.5. No significant variation has been found, at 5 % level of significance ($p>0.05$), among bulk density values at all the reported depths.

Table 4.5 The T-test for the bulk density values, before the irrigation, for soil S2 at different sampling depths.

Depth in cm	Test value	t value	d.f.	Mean difference	p (2-tailed)
0-5	1.82	0.429	23	0.0064	NS
0-10	1.83	0.244	23	0.0057	NS
0-20	1.5	0	23	0.0001	NS

Cone index and bulk density values were taken at optimum moisture condition after irrigating the both types of soils. Cone index values were recorded for sandy loam soil (S1) in kPa at 5, 10 and 15 cm sampling depths. The cone index values beyond 15 cm depth could not be recorded, even after the irrigation, due to excessive hardness still being maintained at sub-soil level of the soil. A total number of cone insertions were 432 (24 plots x 6 insertions x 3 replications). The average cone index values were found to be 398, 973 and 2081 kPa at 5, 10 and 15 cm depths, respectively.

Bulk density values for 0-5 cm, 0-10 cm and 0-20 cm depth were also recorded in g/cc for the soil, after the irrigation. A total of 24 samples (24 plots x 1 reading) were taken. The reading value was the averaged value obtained over the three replications. The average bulk density values were found to be 1.79, 1.80 and 1.67 g/cc at 0-5 cm, 0-10 cm and 0-20 cm depths, respectively.

CV for cone index values for soil S1 were analyzed for variation of data within the experimental plots and between the experimental plots, after the irrigation. The CV for the cone index values at 5 cm depth was found to vary from 8.76 to 14.77 % among all samples within the plots. The CV at 10 cm depth varied between 7.96 to 14.93 % and at 15 cm depth it varied between 6.79 to 14.75% among all samples within the plots. The CV for the cone index between the plots for soil S1 at 5, 10 and 15 cm depths were found to be 8.87, 13.82 and 6.02 %, respectively. The maximum variation in the cone index value was 14.93 % within the plots and 13.82 % between the plots. The CV for the bulk density values for 0-5, 0-10 and 0-20 cm depths were calculated between the plots and were found to be at 4.31, 3.94 and 4.91 %, respectively. The variation in the values may be due the heterogeneous nature & physical properties of the soil and manual operation of the sampling equipment.

The T-test for the cone index values of soil S1 at sampling depths of 5, 10 and 15 cm, after the irrigation, is given in Table 4.6. No significant variation has been found, at 5 % level of significance ($p>0.05$), among cone index values at all the reported depths.

Table 4.6 The T-test for the cone index values, after the irrigation, for soil S1 at different sampling depths.

Depth in cm	Test value	t value	d.f.	Mean difference	p (2-tailed)
5	393	0.182	431	0.5298	NS
10	973	0.092	431	0.7805	NS
15	2220	0.034	431	0.5141	NS

The T-test for the bulk density values at sampling depths for 0-5, 0-10 and 0-20 cm of soil S1 after the irrigation is given in Table 4.7. No significant variation has been found, at 5 % level of significance ($p>0.05$), among bulk density values at all the reported depths.

Table 4.7 The T-test for the bulk density values, after the irrigation, for soil S1 at different sampling depths.

Depth in cm	Test value	t value	d.f.	Mean difference	p (2-tailed)
0-5	1.79	0.512	23	0.008	NS
0-10	1.80	0.122	23	0.0017	NS
0-20	1.67	0.025	23	0.0004	NS

The cone index values were plotted across the sampling depth for the soil S1, before and after the irrigation, shown in Fig. 4.1. The cone index values of the soil were found to be lower after irrigation than that of before irrigation conditions. This was due to the presence of moisture in the soil, which allowed the easy penetration of the cone, and thus lower cone index values.

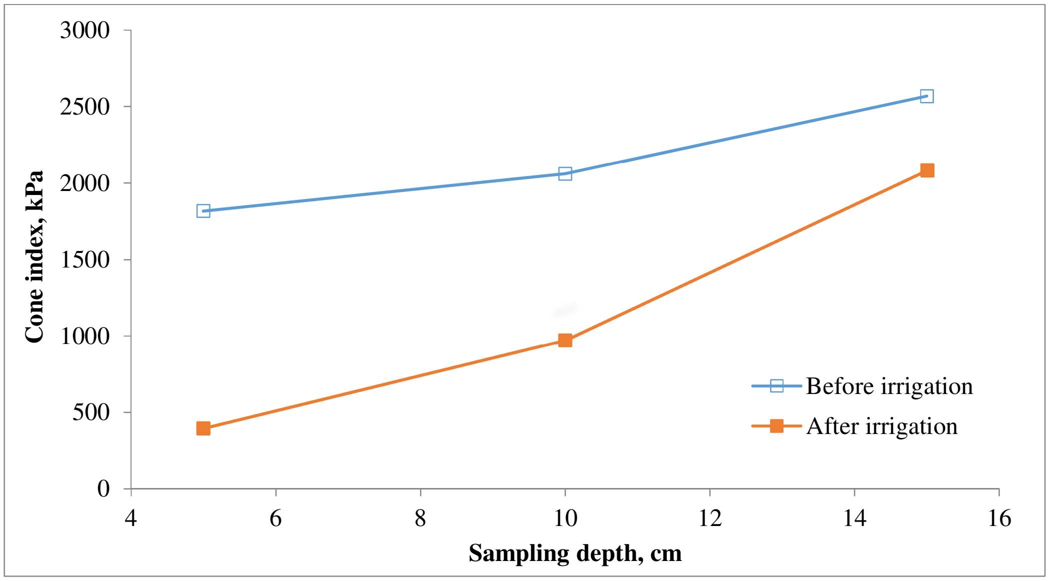

Fig. 4.1 Cone index values of soil S1 before and after irrigation.

The bulk density values were plotted across the sampling depth for the soil, before and after irrigation, shown in Fig. 4.2. The bulk density values of the soil were found to be higher after irrigation than that of before irrigation conditions. This was due to the presence of moisture in the soil. The average moisture fractions of the soil samples, before and after the irrigation, were 7.5 % and 15.0 %, respectively. More moisture fraction may be attributed to more weight gain by same volume of the soil, leading to high bulk density.

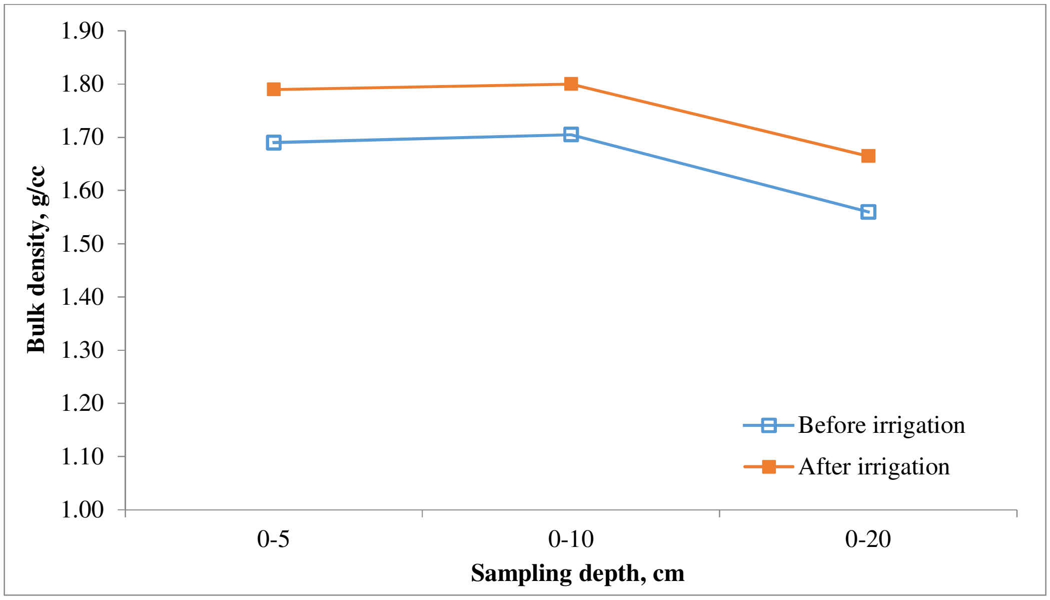

Fig. 4.2 Bulk density values of soil S1 before and after irrigation.

Cone index values were recorded for silty loam soil (S2) in kPa at 5, 10, 15, 20, 25, 30, 35, 40, 45 and 50 cm sampling depths after the irrigation. The cone index values were recorded beyond 15 cm depth after the irrigation due to influence of irrigation moisture at sub-soil level of the soil. A total number of cone insertions were 432 (24 plots x 6 insertions x 3 replications). The average cone index values were found to be 740, 1010, 1698, 1841, 1732, 1857, 2137, 2417, 2755 and 3021 kPa at 5, 10, 15, 20, 25, 30, 35, 40, 45 and 50 cm depths, respectively.

Bulk density values for 0-5 cm, 0-10 cm and 0-20 cm depth were also recorded in g/cc for the soil, after the irrigation. A total of 24 samples (24 plots x 1 reading) were taken. The reading value was the averaged value obtained over the three replications. The average bulk density values were found to be 1.71, 1.71 and 1.45 g/cc at 0-5 cm, 0-10 cm and 0-20 cm depths, respectively.

CV for cone index values for soil S2 were analyzed for variation of data within the experimental plots and between the experimental plots, after the irrigation. The CV for the cone index values at different sampling depths were found to vary from 3.94 to 14.80 % among all samples within the plots. The CV for the bulk density values for 0-5, 0-10 and 0-20 cm depths were calculated between the plots and were found to be at 3.86, 5.89 and 6.32 %, respectively. The variation in the values may be due the heterogeneous nature & physical properties of the soil and manual operation of the sampling equipment.

The T-test for the cone index values of soil S2 at sampling depths of 5, 10 and 15 cm is given in Table 4.8. No significant variation has been found, at 5 % level of significance (p>0.05), among cone index values at all the reported depths.

Table 4.8 The T-test for the cone index values, after the irrigation, for soil S2 at different sampling depths.

Depth in cm	Test value	t value	d.f.	Mean difference	p (2-tailed)
5	740	0.75	431	0.3411	NS
10	1010	0.187	431	0.6499	NS
15	1698	0.039	431	0.2048	NS

The T-test for the bulk density values at sampling depths for 0-5, 0-10 and 0-20 cm of soil S2 is given in Table 4.9. No significant variation has been found, at 5 % level of significance (p>0.05), among bulk density values at all the reported depths.

Table 4.9 The T-test for the bulk density values, after the irrigation, for soil S2 at different sampling depths.

Depth in cm	Test value	t value	d.f.	Mean difference	p (2-tailed)
0-5	1.71	0.216	23	0.0029	NS
0-10	1.71	0.238	23	0.0048	NS
0-20	1.45	0.261	23	0.0048	NS

The cone index values were plotted across the sampling depth for the soil S2, before and after the irrigation and shown in Fig. 4.3. The cone index values of the soil were found to be lower after irrigation than that of before irrigation conditions. This was due to the presence of moisture in the soil, which allowed the easy penetration of the cone, and thus lower cone index values.

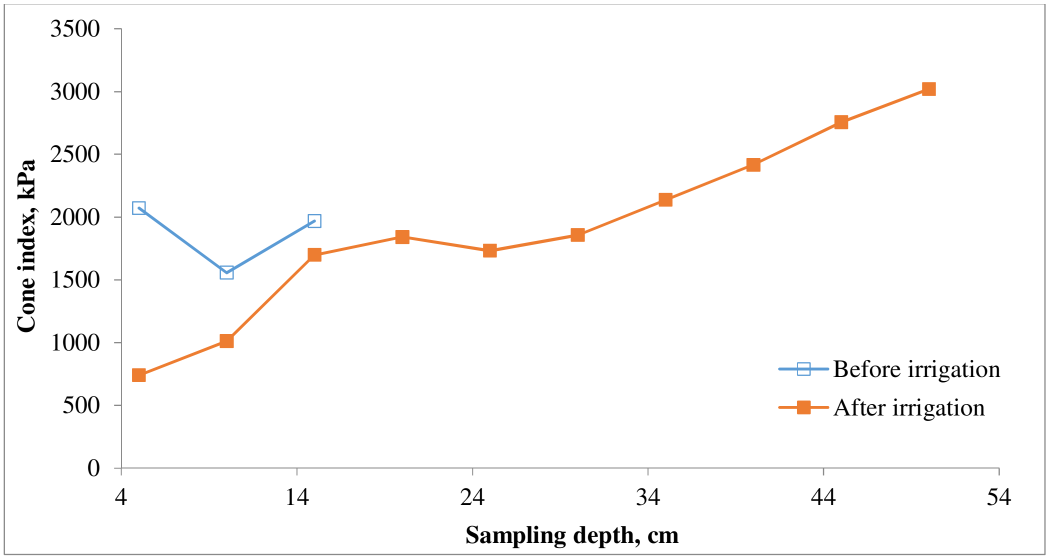

Fig. 4.3 Cone index values of soil S2 before and after irrigation.

The bulk density values were plotted across the sampling depth for the soil, before and after irrigation and shown in Fig. 4.4. The bulk density values of the soil were found to be lower after irrigation than that of before irrigation conditions. The reason may be due to presence of large number of micro pores in the soil which leads to more sample volume gain as compared to weight gain, after the irrigation conditions (moisture fractions were 17.0 % and 21.0 %, before and after irrigation, respectively). This may be due to shrinking/swelling behaviour of fine textured soils.

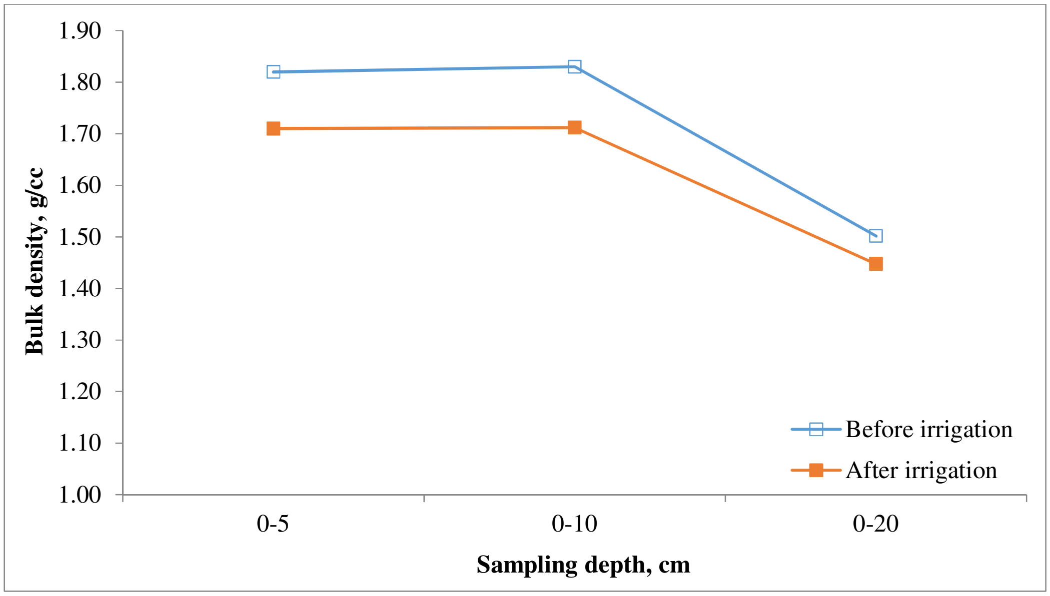

Fig. 4.4 Bulk density values of soil S2 before and after irrigation.

4.4 Dependent parameters of the study

The dependent parameters were measured after operating the various tillage practices under selected operating conditions as given in section 4.2. The results obtained are discussed as per the following sub heads:

- **4.4.1 Cone Index**
- **4.4.2 Soil Bulk Density**
- **4.4.3 Mean weight diameter of soil clods**
- **4.4.4 Fuel Consumption in tillage practices**

4.4.1 Cone Index

Cone index values, measured after operating the selected tillage practices within V1 velocity range and D1 depth range in the soil S1, are given in Table 4.10.

Table 4.10 Effect of tillage practices on cone index values for velocity range V1 and depth of operation range D1 for soil S1.

	Cone index values in kPa at given sampling depths		
Tillage practices	**5 cm**	**10 cm**	**15 cm**
P1	305	827	1973
P2	55	356	2110
P3	35	961	2783
P4	36	1303	2338
P5	57	559	2247
P6	114	656	1333

The cone index values at 5 cm of sampling depth under all tillage practices were found be to lowest for P3 (35 kPa) and highest in case of P1 (305 kPa). It may be due to the fact that rotavator over pulverizes the top soil (5 cm) which results in lower cone index values. At 10 cm sampling depth, the cone index values were found to be lowest for P2 (356 kPa) and highest in case of P4 (1303 kPa). At 15 cm sampling depth, the cone index values were found to be lowest for P2 (2109 kPa) and highest in case of P4 (2337 kPa). At 10 and 15 cm of sampling depths, cone index values were found comparatively higher for P3 and P4.

The cone index values for soil S1 were plotted across the sampling depths for all tillage practices along with cone index values of initial compacted condition after irrigation and is given in Fig. 4.5. Cone index values of P2, P3, P4 and P5 practices were found to be more than the initial compacted condition at sub soil depths.

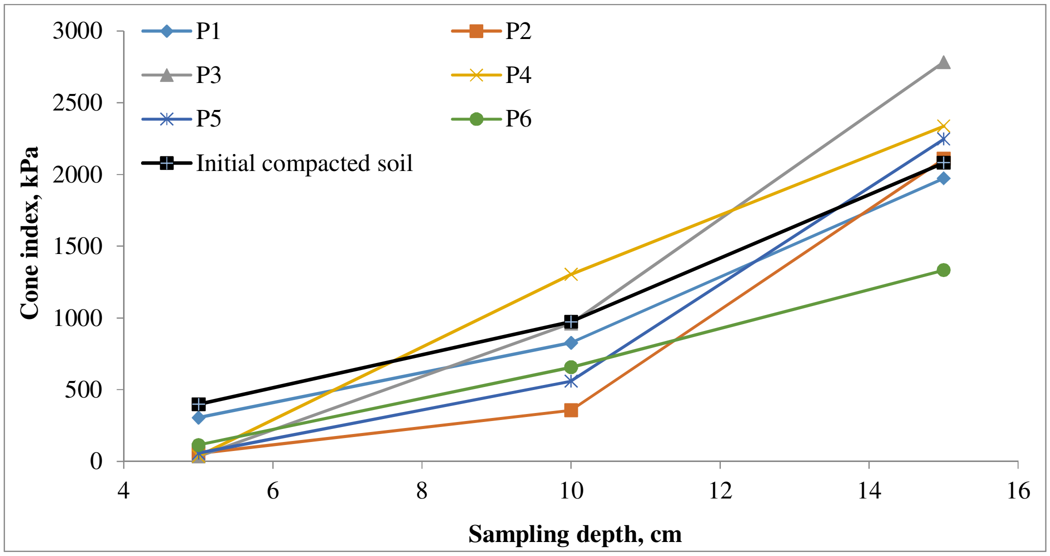

Fig. 4.5 Effect of tillage practices on cone index values at different sampling depths for soil S1 at velocity range V1 and depth range D1.

Cone index values, measured after operating the selected tillage practices within V1 velocity range and D2 depth range in the soil S1, are given in Table 4.11.

Table 4.11 Effect of tillage practices on cone index values for velocity range V1 and depth of operation range D2 for soil S1.

	Cone index values in kPa at given sampling depths		
Tillage Practices	**5 cm**	**10 cm**	**15 cm**
P1	101	449	1212
P2	162	518	2057
P3	38	95	1436
P4	23	78	2434
P5	130	156	1937
P6	71	55	2214

The cone index values at 5 cm of sampling depth under all tillage practices were found be to lowest for P4 (23 kPa) and highest in case of P2 (162 kPa). It may be due to the fact that rotavator over pulverizes the top soil (5 cm) which results in lower cone index values. At 10 cm sampling depth, the cone index values were found to be lowest for P6 (55 kPa) and highest in case of P2 (518 kPa). At 15 cm sampling depth, the cone index values were found to be lowest for P1 (1212 kPa) and highest in case of P4 (2434 kPa). At 15 cm of sampling depth, cone index values were found comparatively higher for P4.

The cone index values for soil S1 were plotted across the sampling depths for all tillage practices along with cone index values of initial compacted condition after irrigation and is given in Fig. 4.6. Cone index values of P4 and P6 practices were found to be more than the initial compacted condition at sub soil depths.

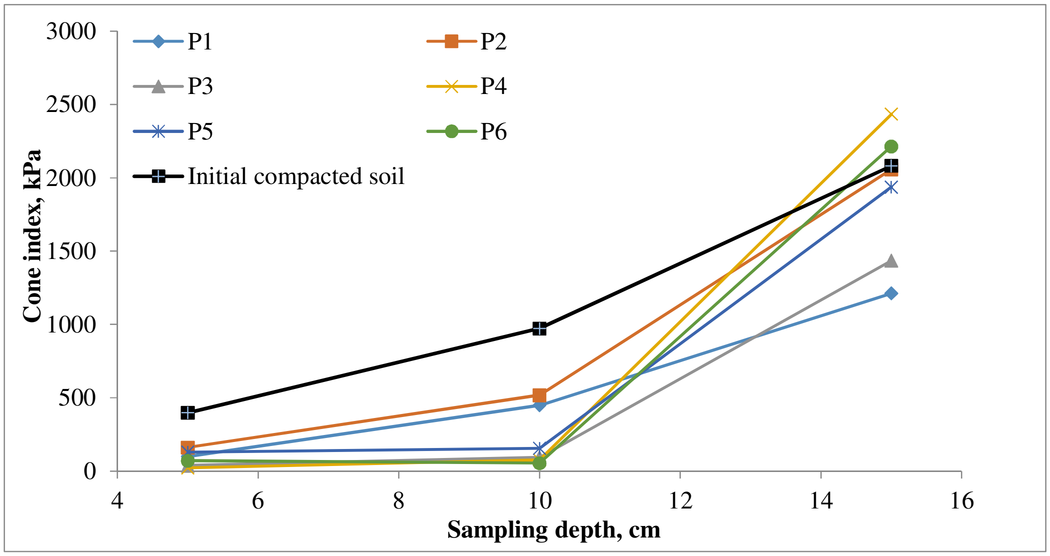

Fig. 4.6 Effect of tillage practices on cone index values at different sampling depths for soil S1 at velocity range V1 and depth range D2.

Cone index values, measured after operating the selected tillage practices within V2 velocity range and D1 depth range in the soil S1, are given in Table 4.12.

Table 4.12 Effect of tillage practices on cone index values for velocity range V2 and depth of operation range D1 for soil S1.

	Cone index values in kPa at given sampling depths		
Tillage Practices	**5 cm**	**10 cm**	**15 cm**
P1	144	763	2330
P2	120	917	2363
P3	17	946	2767
P4	22	1391	1892
P5	77	1259	2315
P6	20	1624	2214

The cone index values at 5 cm of sampling depth under all tillage practices were found be to lowest for P3 (17 kPa) and highest in case of P1 (144 kPa). It may be due to the fact that rotavator over pulverizes the top soil (5 cm) which results in lower cone index values. At 10 cm sampling depth, the cone index values were found to be lowest for P1 (763 kPa) and highest in case of P6 (1624 kPa). At 15 cm sampling depth, the cone index values were found to be lowest for P4 (1892 kPa) and highest in case of P3 (2767 kPa). At 15 cm of sampling depth, cone index values were found comparatively higher for P3.

The cone index values for soil S1 were plotted across the sampling depths for all tillage practices along with cone index values of initial compacted condition after irrigation and is given in Fig. 4.7. Cone index values of P1, P2, P3, P5 and P6 practices were found to be more than the initial compacted condition at sub soil depths.

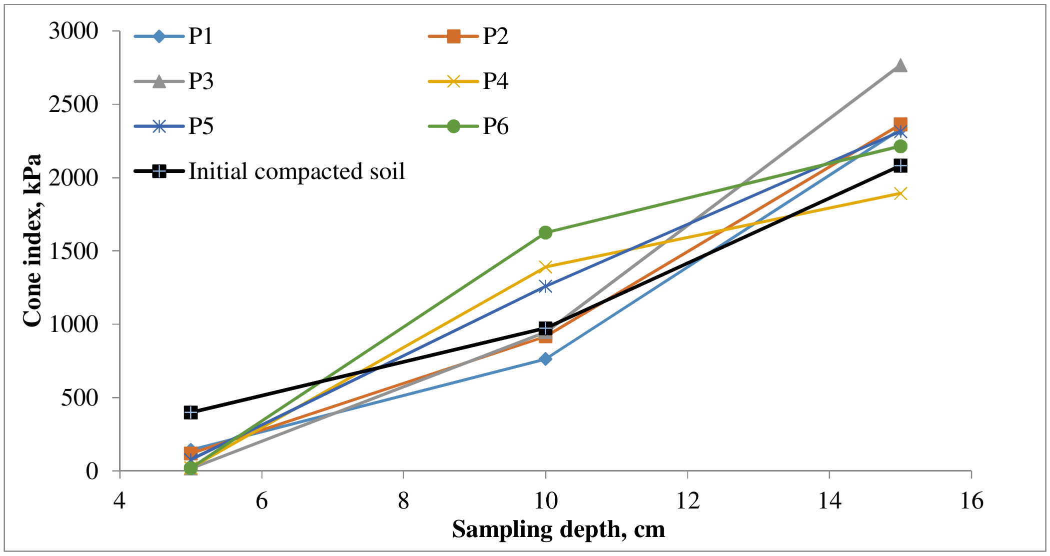

Fig. 4.7 Effect of tillage practices on cone index values at different sampling depths for soil S1 at velocity range V2 and depth range D1.

Cone index values, measured after operating the selected tillage practices within V2 velocity range and D2 depth range in the soil S1, are given in Table 4.13.

Table 4.13 Effect of tillage practices on cone index values for velocity range V2 and depth of operation range D2 for soil S1.

	Cone index values in kPa at given sampling depths		
Tillage Practices	**5 cm**	**10 cm**	**15 cm**
P1	283	907	1993
P2	102	834	1610
P3	55	457	1793
P4	24	69	2556
P5	27	66	2493
P6	68	124	1837

The cone index values at 5 cm of sampling depth under all tillage practices were found be to lowest for P4 (24 kPa) and highest in case of P1 (283 kPa). It may be due to the fact that rotavator over pulverizes the top soil (5 cm) which results in lower cone index values. At 10 cm sampling depth, the cone index values were found to be lowest for P5 (66 kPa) and highest in case of P1 (907 kPa). At 15 cm sampling depth, the cone index values were found to be lowest for P2 (1610 kPa) and highest in case of P4 (2556 kPa). At 15 cm of sampling depth, cone index values were found comparatively higher for P4.

The cone index values for soil S1 were plotted across the sampling depths for all tillage practices along with cone index values of initial compacted condition after irrigation and is given in Fig. 4.8. Cone index values of P4 and P5 practices were found to be more than the initial compacted condition at sub soil depths.

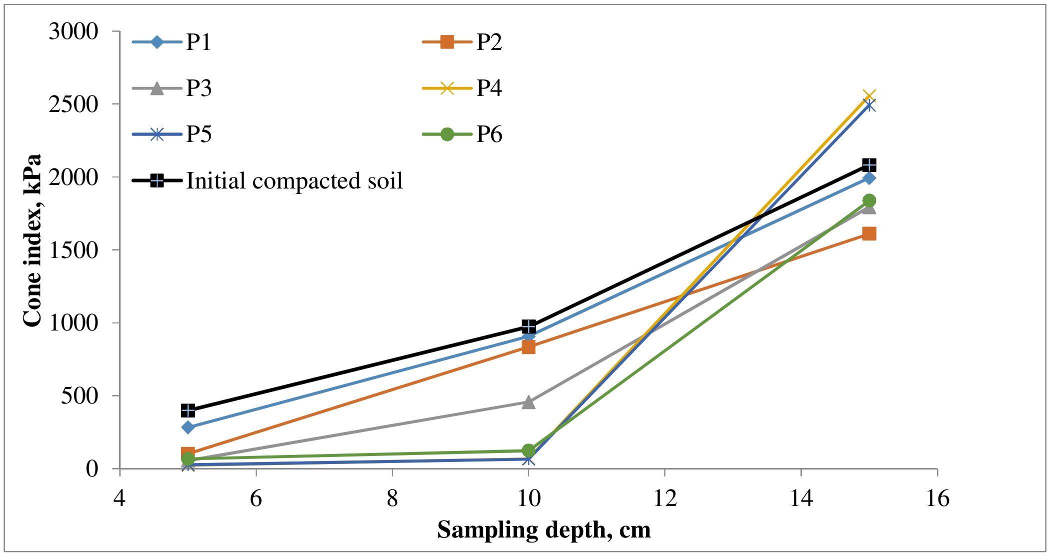

Fig. 4.8 Effect of tillage practices on cone index values at different sampling depths for soil S1 at velocity range V2 and depth range D2.

Cone index values, measured after operating the selected tillage practices within V1 velocity range and D1 depth range in the soil S2, are given in Table 4.14.

Table 4.14 Effect of tillage practices on cone index values for velocity range V1 and depth of operation range D1 for soil S2.

Tillage Practices	Cone index values in kPa at given sampling depths									
	5 cm	10 cm	15 cm	20 cm	25 cm	30 cm	35 cm	40 cm	45 cm	50 cm
P1	107	363	1058	1252	1606	1699	1385	1557	1624	1755
P2	124	384	1227	1411	1772	1892	1760	1963	2035	2005
P3	148	718	1632	2499	2534	2493	2542	2420	2330	2186
P4	96	482	1620	2885	2676	2904	2888	2511	3275	3193
P5	122	603	1918	2207	2311	2439	2569	2107	1849	2097
P6	124	613	2065	2066	2344	2498	2278	2476	2913	3065

The cone index values at 5 cm of sampling depth under all tillage practices were found be to lowest for P4 (96 kPa) and highest in case of P3 (148 kPa). It may be due to the fact that rotavator over pulverizes the top soil (5 cm) which results in lower cone index values. At 10 cm sampling depth, the cone index values were found to be lowest for P1 (363 kPa) and highest in case of P3 (718 kPa). At 15 cm sampling depth, the cone index values were found to be lowest for P1 (1058 kPa) and highest in case of P6 (2065 kPa). At 20 cm sampling depth, the cone index values were found to be lowest for P1 (1252 kPa) and highest in case of P4 (2885 kPa). At sampling depths beyond 20 cm, cone index values were found comparatively higher for P3, P4, P5 and P6 at most of the sub-soil depths.

The cone index values for soil S2 were plotted across the sampling depths for all tillage practices along with cone index values of initial compacted condition after irrigation and is given in Fig. 4.9. Cone index values of P3, P4, P5 and P6 practices were found to be more than the initial compacted condition at most of the sub-soil depths.

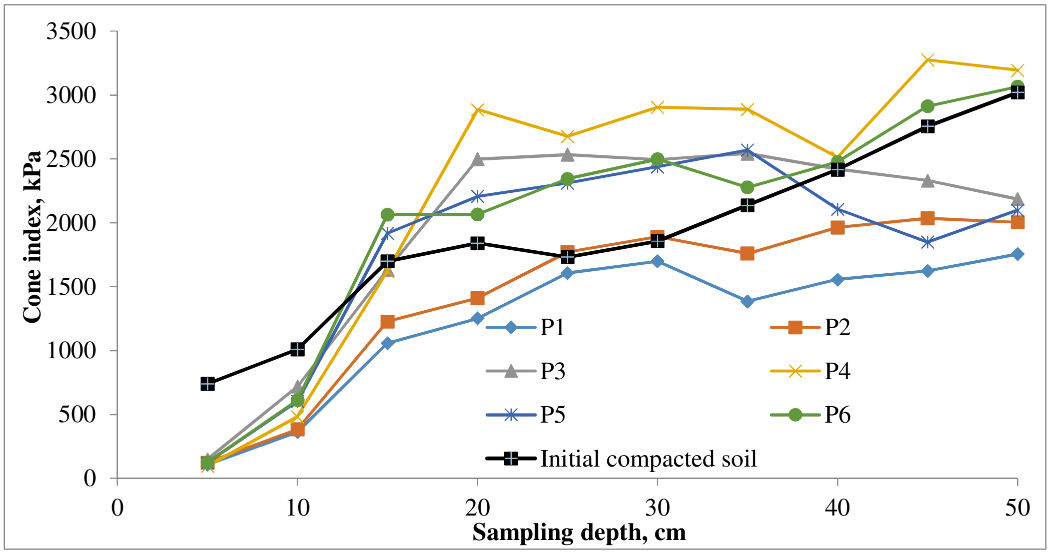

Fig. 4.9 Effect of tillage practices on cone index values at different sampling depths for soil S2 at velocity range V1 and depth range D1.

Cone index values, measured after operating the selected tillage practices within V1 velocity range and D2 depth range in the soil S2, are given in Table 4.15.

Table 4.15 Effect of tillage practices on cone index values for velocity range V1 and depth of operation range D2 for soil S2.

Tillage Practices	Cone index values in kPa at given sampling depths									
	5 cm	10 cm	15 cm	20 cm	25 cm	30 cm	35 cm	40 cm	45 cm	50 cm
P1	143	489	816	1584	1708	1991	2095	2216	2100	1717
P2	97	480	781	2127	1553	1870	2363	2130	2057	1982
P3	136	264	1528	2466	2835	2262	2956	2955	2985	2748
P4	105	269	2272	3085	2982	2605	3059	2769	2709	2265
P5	115	182	1996	2169	2381	2328	2605	2843	2846	2967
P6	150	219	1797	2216	766	1650	2492	2563	2500	2080

The cone index values at 5 cm of sampling depth under all tillage practices were found be to lowest for P2 (97 kPa) and highest in case of P6 (150 kPa). At 10 cm sampling depth, the cone index values were found to be lowest for P5 (182 kPa) and highest in case of P1 (489 kPa). At 15 cm sampling depth, the cone index values were found to be lowest for P2 (781 kPa) and highest in case of P4 (2272 kPa). At 20 cm sampling depth, the cone index values were found to be lowest for P1 (1584 kPa) and highest in case of P4 (3085 kPa). Beyond 20 cm of sampling depths, cone index values were found to be comparatively higher for P3, P4 and P5.

The cone index values for soil S2 were plotted across the sampling depths for all tillage practices along with cone index values of initial compacted condition after irrigation and is given in Fig. 4.10. Cone index values of P3, P4 and P5 practices were found to be more than the initial compacted condition at most of the sub-soil depths.

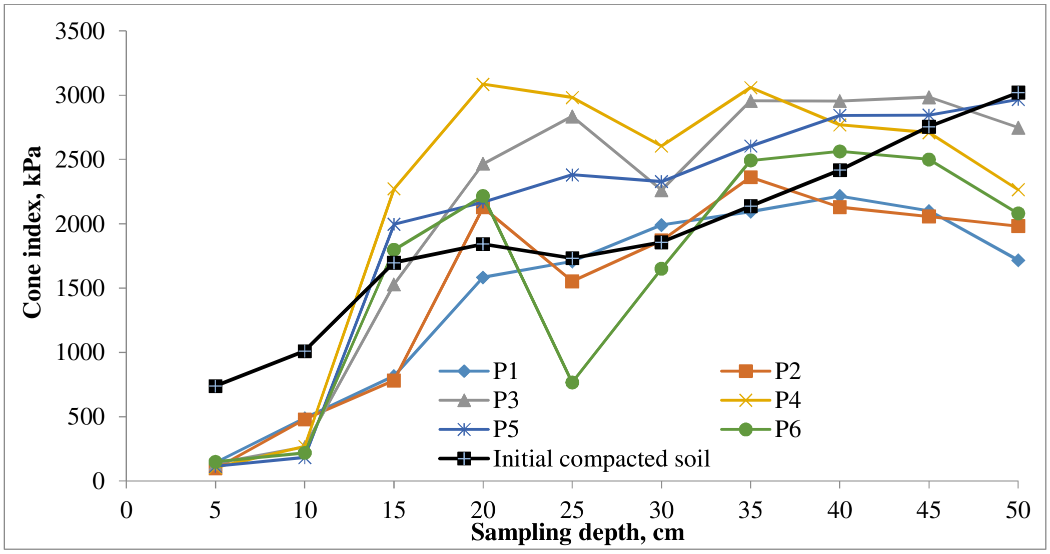

Fig. 4.10 Effect of tillage practices on cone index values at different sampling depths for soil S2 at velocity range V1 and depth range D2.

Cone index values, measured after operating the selected tillage practices within V2 velocity range and D1 depth range in the soil S2, are given in Table 4.16.

Table 4.16 Effect of tillage practices on cone index values for velocity range V2 and depth of operation range D1 for soil S2.

Tillage Practices	Cone index values in kPa at given sampling depths									
	5 cm	10 cm	15 cm	20 cm	25 cm	30 cm	35 cm	40 cm	45 cm	50 cm
P1	98	386	1175	1367	1926	1662	1793	2049	1890	1935
P2	118	423	1234	1500	1299	1179	1014	1344	1639	1755
P3	131	723	1511	2622	2395	2613	2460	2612	2928	2764
P4	100	541	1715	2983	2855	2278	2416	2412	2088	2003
P5	133	628	2086	2173	2133	2131	2160	2643	2826	2923
P6	161	720	1748	2244	685	1936	2247	2841	2713	3177

The cone index values at 5 cm of sampling depth under all tillage practices were found be to lowest for P1 (98 kPa) and highest in case of P6 (161 kPa). At 10 cm sampling depth, the cone index values were found to be lowest for P1 (386 kPa) and highest in case of P3 (723 kPa). At 15 cm sampling depth, the cone index values were found to be lowest for P1 (1175 kPa) and highest in case of P5 (2086 kPa). At 20 cm sampling depth, the cone index values were found to be lowest for P1 (1367 kPa) and highest in case of P4 (2983 kPa). Beyond 20 cm of sampling depths, cone index values were found to be comparatively higher for P3, P4, P5 and P6.

The cone index values for soil S2 were plotted across the sampling depths for all tillage practices along with cone index values of initial compacted condition after irrigation and is given in Fig. 4.11. Cone index values of P3, P4 and P5 practice were found to be more than the initial compacted condition at most of the sub soil depths.

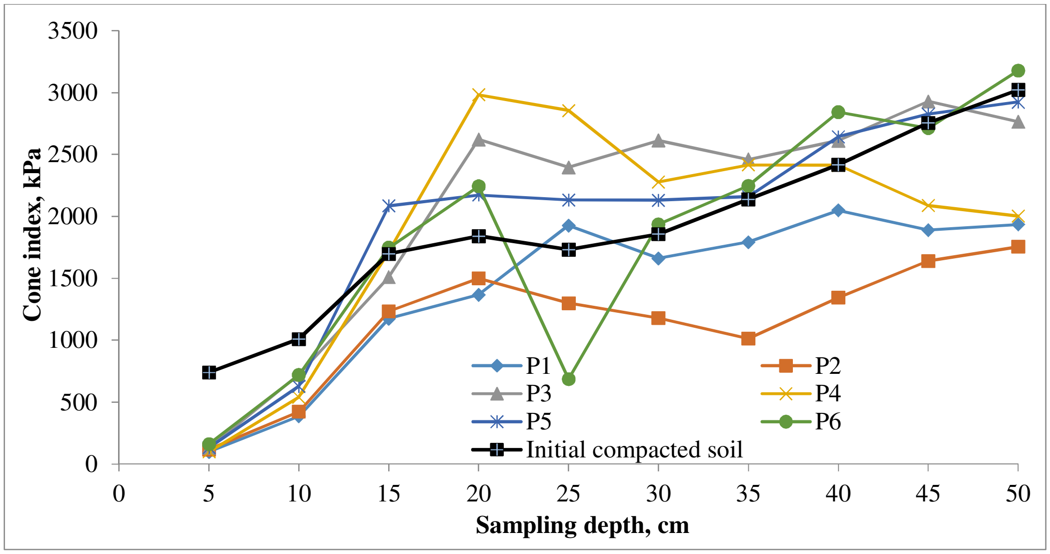

Fig. 4.11 Effect of tillage practices on cone index values at different sampling depths for soil S2 at velocity range V2 and depth range D1.

Cone index values, measured after operating the selected tillage practices within V2 velocity range and D2 depth range in the soil S2, are given in Table 4.17.

Table 4.17 Effect of tillage practices on cone index values for velocity range V2 and depth of operation range D2 for soil S2.

Tillage Practices	Cone index values in kPa at given sampling depths									
	5 cm	10 cm	15 cm	20 cm	25 cm	30 cm	35 cm	40 cm	45 cm	50 cm
P1	108	526	815	1640	1415	2138	2638	2694	2224	2199
P2	109	388	882	2140	2389	2128	2585	2390	2218	866
P3	159	361	1508	2624	2271	2473	2780	2990	2920	2378
P4	146	97	2104	2457	2514	2423	2464	2664	2691	2520
P5	155	200	1563	2432	2299	2784	2991	3132	2922	2725
P6	114	194	1795	2029	1427	2211	2498	2826	2790	2921

The cone index values at 5 cm of sampling depth under all tillage practices were found be to lowest for P1 (108 kPa) and highest in case of P3 (159 kPa). At 10 cm sampling depth, the cone index values were found to be lowest for P4 (97 kPa) and highest in case of P1 (526 kPa). At 15 cm sampling depth, the cone index values were found to be lowest for P1 (815 kPa) and highest in case of P4 (2104 kPa). At 20 cm sampling depth, the cone index values were found to be lowest for P1 (1640 kPa) and highest in case of P3 (2624 kPa). Beyond 20 cm of sampling depths, cone index values were found to be comparatively higher for P3, P5 and P6.

The cone index values for soil S2 were plotted across the sampling depths for all tillage practices along with cone index values of initial compacted condition after irrigation and is shown in Fig. 4.12. Cone index values of P2, P3, P4, P5 and P6 practice were found to be more than the initial compacted condition at most of the sub soil depths.

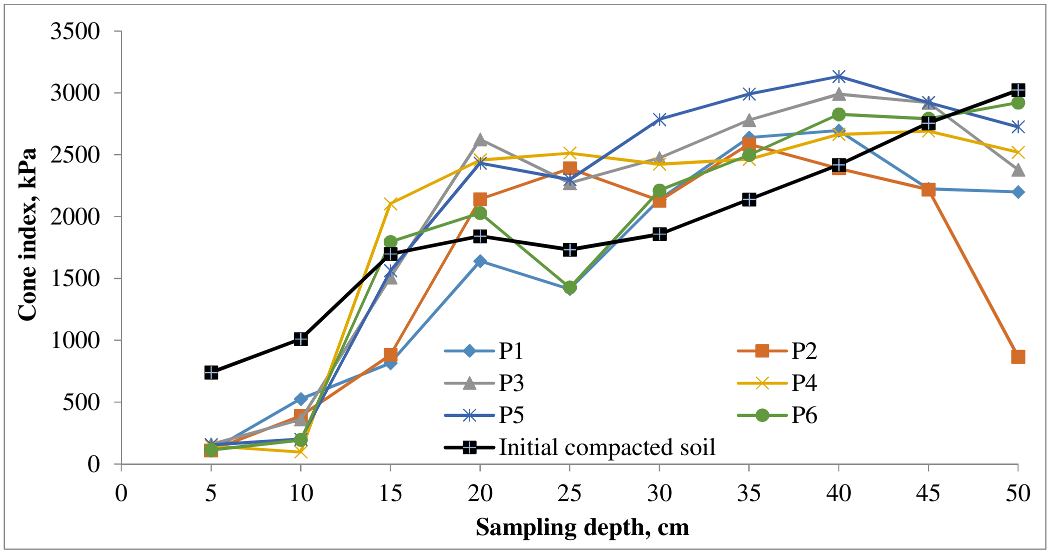

Fig. 4.12 Effect of tillage practices on cone index values at different sampling depths for soil S2 at velocity range V2 and depth range D2.

The analysis of variance (ANOVA) for cone index values were calculated at 5 cm sampling depth for all tillage practices, at given velocity and depth of operation ranges and for selected soil types, as given in Table 4.18.

Table 4.18 ANOVA for cone index values at 5 cm sampling depth.

FACTOR MEANS						
Practice(P1, P2, P3, P4, P5, P6)	161.1^{a}	110.7^{b}	89.9^{bc}	68.9^{d}	101.9^{b}	102.7^{b}
Velocity(V1, V2)	108.1^{a}	103.7^{a}				
Depth of operation(D1, D2)	102.6^{a}	109.1^{a}				
Soil Type(S1, S2)	86.8^{b}	124.9^{a}				

ANOVA TABLE

Source	Sum of Squares	df	Mean Square	F	p
S	52368.763	1	52368.763	48.078	0.000
P	113318.179	5	22663.636	20.807	0.000
V	669.343	1	669.343	0.614	NS
D	1496.013	1	1496.013	1.373	NS
S * P	163259.146	5	32651.829	29.976	0.000
S * V	3378.128	1	3378.128	3.101	NS
S * D	3.103	1	3.103	0.003	NS
P * V	3815.248	5	763.050	0.701	NS
P * D	2204.498	5	440.900	0.405	NS
V * D	4322.332	1	4322.332	3.968	0.049
S * P * V	9600.722	5	1920.144	1.763	NS
S * P * D	12670.644	5	2534.129	2.326	0.049
S * V * D	2790.774	1	2790.774	2.562	NS
P * V * D	44069.648	5	8813.930	8.092	0.000
S * P * V * D	74735.521	5	14947.104	13.722	0.000
Error	104568.325	96	1089.253		
Total	2208053.36	144			
Corrected Total	593270.388	143			

Tukey's test has been applied to see the difference in cone index values at 5 cm sampling depth. Figures with different superscripts are found to be significantly different ($p < 0.05$).

The ANOVA for cone index values at 5 cm sampling depth were found to be statistically significant for the factors of tillage practices and soil types whereas it becomes non-significant for other factors i.e. velocity and depth of operation ranges. The factor interactions of tillage practices and soil types, velocities and depths, tillage practices with soil types and depths, tillage practices with velocities and depths and all factors combinations were found to be statistically significant for variation in cone index values.

The analysis of variance (ANOVA) for cone index values were calculated at 10 cm sampling depth for all tillage practices, at given velocity and depth of operation ranges and for selected soil types, as given in Table 4.19.

Table 4.19 ANOVA for cone index values at 10 cm sampling depth.

FACTOR MEANS						
Practice (P1, P2, P3, P4, P5, P6)	588.6^{a}	537.5^{ab}	565.6^{ab}	528.5^{b}	456.7^{c}	525.5^{b}
Velocity (V1, V2)	461.6^{b}	605.9^{a}				
Depth of operation (D1, D2)	756.1^{a}	311.5^{b}				
Soil Type (S1, S2)	640.4^{a}	427.1^{b}				

ANOVA TABLE					
Source	**Sum of Squares**	**df**	**Mean Square**	**F**	**P**
S	1636970.268	1	1636970.268	409.652	0.000
P	241508.112	5	48301.622	12.087	0.000
V	749504.305	1	749504.305	187.563	0.000
D	7114778.250	1	7114778.250	1780.473	0.000
S * P	333442.584	5	66688.517	16.689	0.000
S * V	648784.158	1	648784.158	162.358	0.000
S * D	1463722.908	1	1463722.908	366.297	0.000
P * V	287167.048	5	57433.410	14.373	0.000
P * D	4176117.744	5	835223.549	209.015	0.000
V * D	145664.144	1	145664.144	36.452	0.000
S * P * V	216400.236	5	43280.047	10.831	0.000
S * P * D	812676.335	5	162535.267	40.674	0.000
S * V * D	33974.170	1	33974.170	8.502	0.004
P * V * D	775556.748	5	155111.350	38.817	0.000
S * P * V * D	554986.314	5	110997.263	27.777	0.000
Error	383616.365	96	3996.004		
Total	60604620.246	144			
Corrected Total	19574869.688	143			

Tukey's test has been applied to see the difference in cone index values at 10 cm sampling depth. Figures with different superscripts are found to be significantly different ($p < 0.05$).

The ANOVA for cone index values at 10 cm sampling depth were found to be statistically significant for all the factors. i.e. soil type, tillage practice, velocity and depth of operation. All the factor interactions were also found to be statistically significant for variation in cone index values.

The analysis of variance (ANOVA) for cone index values were calculated at 15 cm sampling depth for all tillage practices, at given velocity and depth of operation ranges and for selected soil types, as given in Table 4.20.

Table 4.20 ANOVA for cone index values at 15 cm sampling depth.

FACTOR MEANS						
Practice (P1, P2, P3, P4, P5, P6)	1421.4^{d}	1532.8^{c}	1869.7^{b}	2116.2^{a}	2069.3^{a}	1875.3^{b}
Velocity (V1, V2)	1782.6^{b}	1845.7^{a}				
Depth of operation (D1, D2)	1902.2^{a}	1726.1^{b}				
Soil Type (S1, S2)	2093.1^{a}	1535.1^{b}				

ANOVA TABLE					
Source	**Sum of Squares**	**df**	**Mean Square**	**F**	**p**
S	11208562.747	1	11208562.747	2044.587	0.000
P	9517453.621	5	1903490.724	347.221	0.000
V	143333.543	1	143333.543	26.146	0.000
D	1115602.449	1	1115602.449	203.500	0.000
S * P	3986071.201	5	797214.240	145.422	0.000
S * V	443714.744	1	443714.744	80.939	0.000
S * D	239746.514	1	239746.514	43.733	0.000
P * V	584114.565	5	116822.913	21.310	0.000
P * D	4516332.484	5	903266.497	164.767	0.000
V * D	20676.762	1	20676.762	3.772	NS
S * P * V	641367.888	5	128273.578	23.399	0.000
S * P * D	1954184.333	5	390836.867	71.294	0.000
S * V * D	8335.842	1	8335.842	1.521	NS
P * V * D	608922.201	5	121784.440	22.215	0.000
S * P * V * D	1997747.579	5	399549.516	72.883	0.000
Error	526278.501	96	5482.068		
Total	511453508.759	144			
Corrected Total	37512444.974	143			

Tukey's test has been applied to see the difference in cone index values at 15 cm sampling depth. Figures with different superscripts are found to be significantly different ($p < 0.05$).

The ANOVA for cone index values at 15 cm sampling depth were found to be statistically significant for all the factors. i.e. soil type, tillage practice, velocity and depth of operation. All the factor interactions were also found to be statistically significant except for factor interactions of velocities with depths and soil type with velocity and depth of operation for variation in cone index values.

4.4.2 Soil bulk density

Bulk density values, measured after operating the selected tillage practices within V1 velocity range and D1 depth range in the soil S1, are given in Table 4.21.

Table 4.21 Effect of tillage practices on bulk density values for velocity range V1 and depth of operation range D1 for soil S1.

	Bulk density values in g/cc at given sampling depths		
Tillage Practices	0-5 cm	0-10 cm	0-20 cm
P1	1.36	1.42	1.40
P2	1.21	1.36	1.35
P3	1.23	1.25	1.30
P4	1.25	1.25	1.28
P5	1.35	1.42	1.44
P6	1.29	1.30	1.28

The bulk density values for 0-5 cm of sampling depth under all tillage practices were found be to lowest for P2 (1.21 g/cc) and highest in case of P1 (1.36 g/cc). At 0-10 cm sampling depth, the bulk density values were found to be lowest for P3&P4 (1.25 g/cc) and highest in case of P1&P5 (1.42 g/cc). At 0-20 cm sampling depth, the bulk density values were found to be lowest for P4&P6 (1.28 g/cc) and highest in case of P5 (1.44 g/cc).

The bulk density values for soil S1 were plotted across the sampling depths for all tillage practices along with bulk density values of initial compacted condition after irrigation and is shown in Fig. 4.13. The bulk density values for all the tillage practices were found to be lesser than the initial compacted condition at all sampling depths.

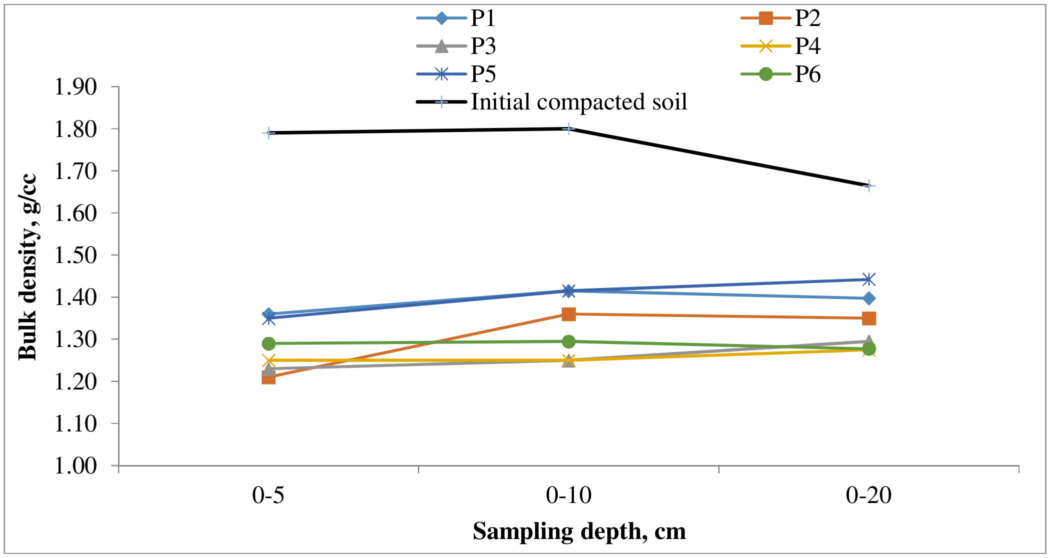

Fig. 4.13 Effect of tillage practices on bulk density values at different sampling depths for soil S1 at velocity range V1 and depth range D1.

Bulk density values, measured after operating the selected tillage practices within V1 velocity range and D2 depth range in the soil S1, are given in Table 4.22.

Table 4.22 Effect of tillage practices on bulk density values for velocity range V1 and depth of operation range D2 for soil S1.

	Bulk density values in g/cc at given sampling depths		
Tillage Practices	**0-5 cm**	**0-10 cm**	**0-20 cm**
P1	1.31	1.40	1.37
P2	1.31	1.24	1.25
P3	1.24	1.30	1.35
P4	1.25	1.24	1.28
P5	1.27	1.31	1.33
P6	1.35	1.35	1.34

The bulk density values for 0-5 cm of sampling depth under all tillage practices were found be to lowest for P3 (1.24 g/cc) and highest in case of P6 (1.35 g/cc). At 0-10 cm sampling depth, the bulk density values were found to be lowest for P2&P4 (1.24 g/cc) and highest in case of P1 (1.40 g/cc). At 0-20 cm sampling depth, the bulk density values were found to be lowest for P2 (1.25 g/cc) and highest in case of P1 (1.37 g/cc).

The bulk density values for soil S1 were plotted across the sampling depths for all tillage practices along with bulk density values of initial compacted condition after irrigation and is given in Fig. 4.14. The bulk density values for all the tillage practices were found to be lesser than the initial compacted condition at all sampling depths.

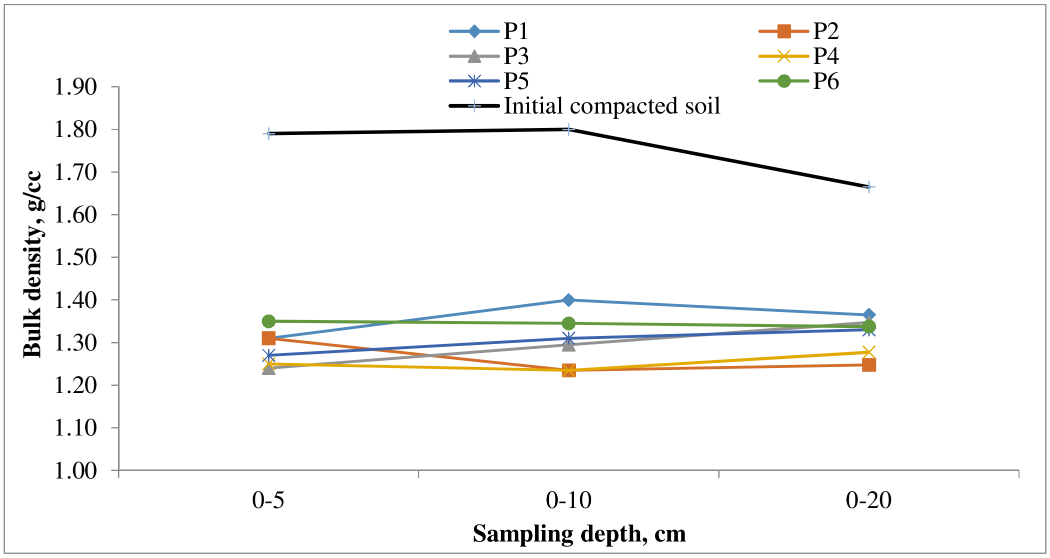

Fig. 4.14 Effect of tillage practices on bulk density values at different sampling depths for soil S1 at velocity range V1 and depth range D2.

Bulk density values, measured after operating the selected tillage practices within V2 velocity range and D1 depth range in the soil S1, are given in Table 4.23.

Table 4.23 Effect of tillage practices on bulk density values for velocity range V2 and depth of operation range D1 for soil S1.

	Bulk density values in g/cc at given sampling depths		
Tillage Practices	0-5 cm	0-10 cm	0-20 cm
P1	1.29	1.34	1.33
P2	1.37	1.35	1.36
P3	1.27	1.28	1.30
P4	1.24	1.23	1.26
P5	1.31	1.42	1.46
P6	1.37	1.31	1.32

The bulk density values for 0-5 cm of sampling depth under all tillage practices were found be to lowest for P4 (1.24 g/cc) and highest in case of P2 (1.37 g/cc). At 0-10 cm sampling depth, the bulk density values were found to be lowest for P4 (1.23 g/cc) and highest in case of P5 (1.42 g/cc). At 0-20 cm sampling depth, the bulk density values were found to be lowest for P4 (1.26 g/cc) and highest in case of P5 (1.46 g/cc).

The bulk density values for soil S1 were plotted across the sampling depths for all tillage practices along with bulk density values of initial compacted condition after irrigation and is given in Fig. 4.15. The bulk density values for all the tillage practices were found to be lesser than the initial compacted condition at all sampling depths.

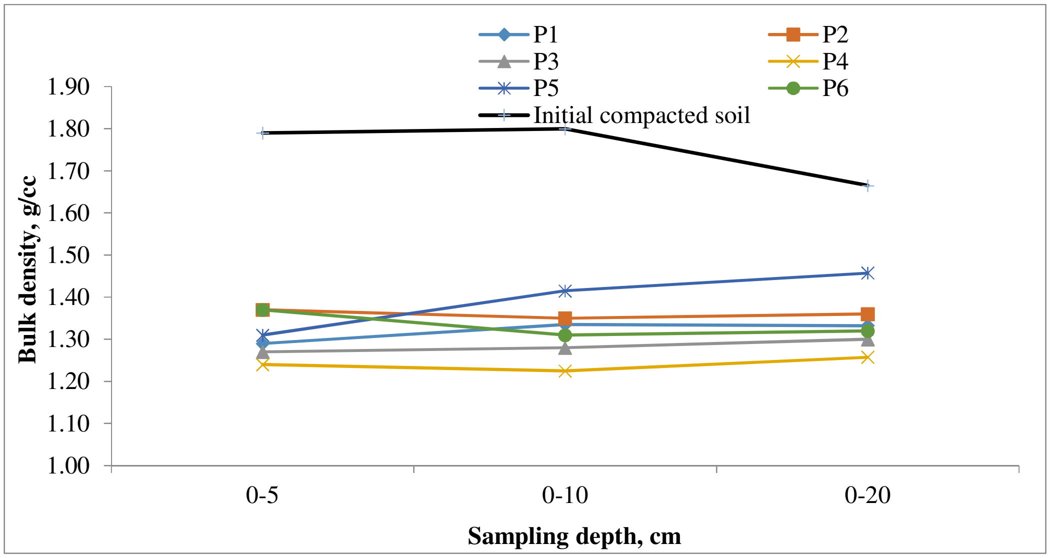

Fig. 4.15 Effect of tillage practices on bulk density values at different sampling depths for soil S1 at velocity range V2 and depth range D1.

Bulk density values, measured after operating the selected tillage practices within V2 velocity range and D2 depth range in the soil S1, are given in Table 4.24.

Table 4.24 Effect of tillage practices on bulk density values for velocity range V2 and depth of operation range D2 for soil S1.

	Bulk density values in g/cc at given sampling depths		
Tillage Practices	**0-5 cm**	**0-10 cm**	**0-20 cm**
P1	1.28	1.35	1.36
P2	1.38	1.32	1.28
P3	1.31	1.35	1.39
P4	1.26	1.24	1.27
P5	1.31	1.47	1.45
P6	1.36	1.30	1.26

The bulk density values for 0-5 cm of sampling depth under all tillage practices were found be to lowest for P4 (1.26 g/cc) and highest in case of P2 (1.38 g/cc). At 0-10 cm sampling depth, the bulk density values were found to be lowest for P4 (1.24 g/cc) and highest in case of P5 (1.47 g/cc). At 0-20 cm sampling depth, the bulk density values were found to be lowest for P6 (1.26 g/cc) and highest in case of P5 (1.45 g/cc).

The bulk density values for soil S1 were plotted across the sampling depths for all tillage practices along with bulk density values of initial compacted condition after irrigation and is given in Fig. 4.16. The bulk density values for all the tillage practices were found to be lesser than the initial compacted condition at all sampling depths.

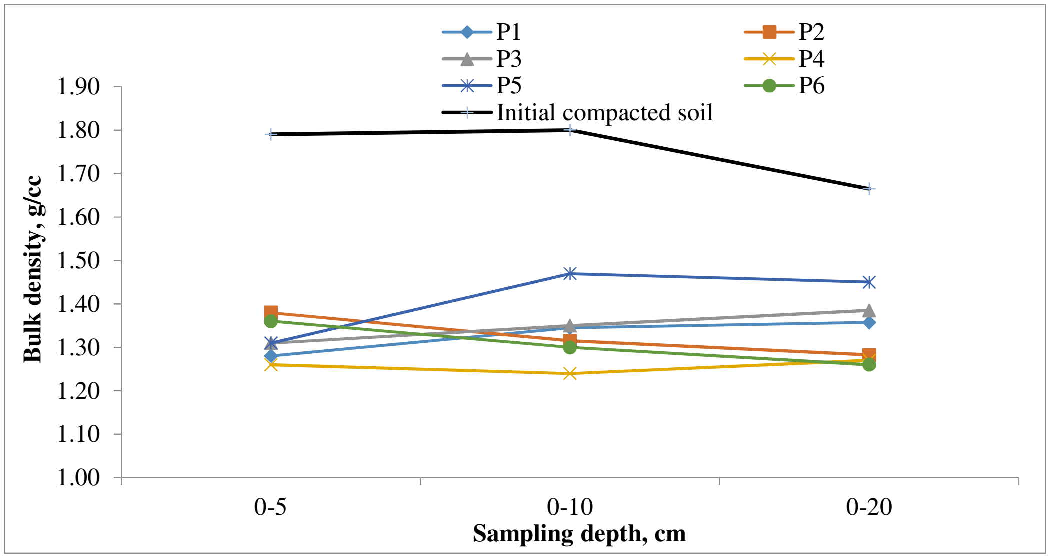

Fig. 4.16 Effect of tillage practices on bulk density values at different sampling depths for soil S1 at velocity range V2 and depth range D2.

Bulk density values, measured after operating the selected tillage practices within V1 velocity range and D1 depth range in the soil S2, are given in Table 4.25.

Table 4.25 Effect of tillage practices on bulk density values for velocity range V1 and depth of operation range D1 for soil S2.

	Bulk density values in g/cc at given sampling depths		
Tillage Practices	**0-5 cm**	**0-10 cm**	**0-20 cm**
P1	1.45	1.54	1.45
P2	1.27	1.38	1.36
P3	1.33	1.35	1.38
P4	1.28	1.26	1.24
P5	1.33	1.31	1.36
P6	1.42	1.39	1.43

The bulk density values for 0-5 cm of sampling depth under all tillage practices were found be to lowest for P2 (1.27 g/cc) and highest in case of P1 (1.45 g/cc). At 0-10 cm sampling depth, the bulk density values were found to be lowest for P4 (1.26 g/cc) and highest in case of P1 (1.54 g/cc). At 0-20 cm sampling depth, the bulk density values were found to be lowest for P4 (1.24 g/cc) and highest in case of P1 (1.45 g/cc).

The bulk density values for soil S2 were plotted across the sampling depths for all tillage practices along with bulk density values of initial compacted condition after irrigation and is given in Fig. 4.17. The bulk density values for all the tillage practices were found to be higher than the initial compacted condition between 0-20 cm of sampling depth. The reason may be due to presence of large number of micro pores in the soil and shrinking/swelling behaviour of fine textured soils.

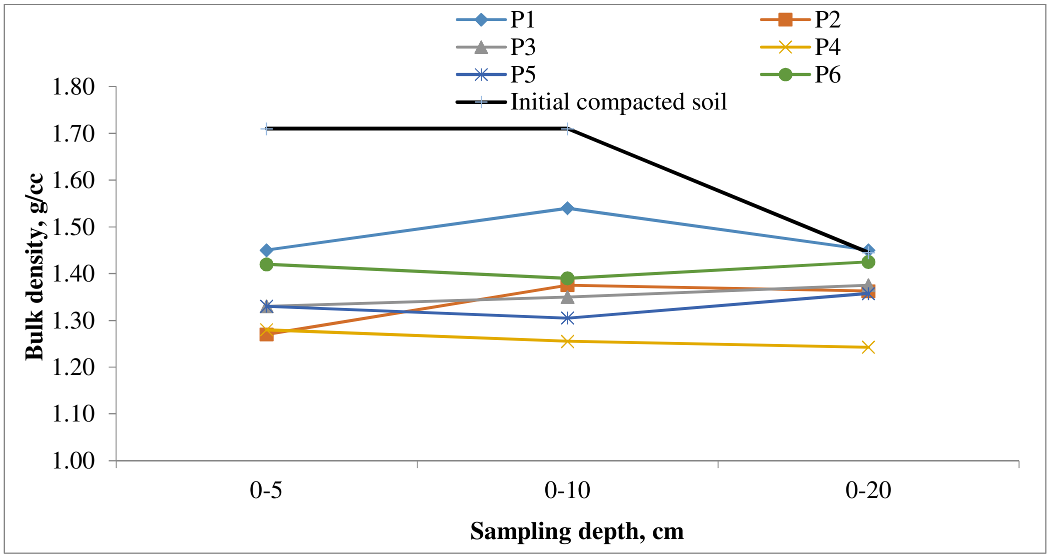

Fig. 4.17 Effect of tillage practices on bulk density values at different sampling depths for soil S2 at velocity range V1 and depth range D1.

Bulk density values, measured after operating the selected tillage practices within V1 velocity range and D2 depth range in the soil S2, are given in Table 4.26.

Table 4.26 Effect of tillage practices on bulk density values for velocity range V1 and depth of operation range D2 for soil S2.

	Bulk density values in g/cc at given sampling depths		
Tillage Practices	**0-5 cm**	**0-10 cm**	**0-20 cm**
P1	1.42	1.43	1.40
P2	1.31	1.32	1.30
P3	1.33	1.33	1.41
P4	1.34	1.22	1.24
P5	1.30	1.29	1.39
P6	1.25	1.25	1.28

The bulk density values for 0-5 cm of sampling depth under all tillage practices were found be to lowest for P6 (1.25 g/cc) and highest in case of P1 (1.42 g/cc). At 0-10 cm sampling depth, the bulk density values were found to be lowest for P4 (1.22 g/cc) and highest in case of P1 (1.43 g/cc). At 0-20 cm sampling depth, the bulk density values were found to be lowest for P4 (1.24 g/cc) and highest in case of P3 (1.41 g/cc).

The bulk density values for soil S2 were plotted across the sampling depths for all tillage practices along with bulk density values of initial compacted condition after irrigation and is given in Fig. 4.18. The bulk density values for all the tillage practices were found to be higher than the initial compacted condition between 0-20 cm of sampling depth. The reason may be due to presence of large number of micro pores in the soil and shrinking/swelling behaviour of fine textured soils.

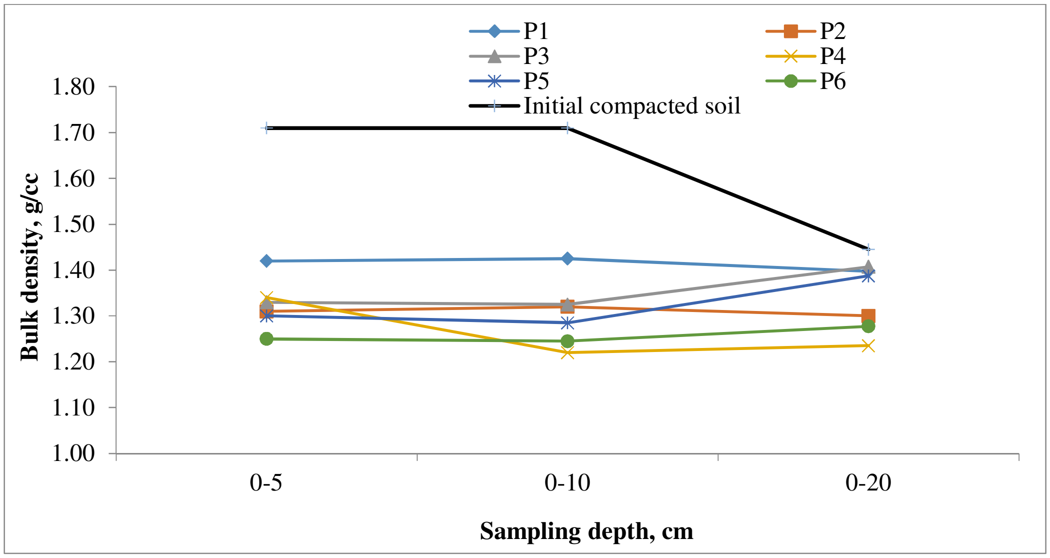

Fig. 4.18 Effect of tillage practices on bulk density values at different sampling depths for soil S2 at velocity range V1 and depth range D2.

Bulk density values, measured after operating the selected tillage practices within V2 velocity range and D1 depth range in the soil S2, are given in Table 4.27.

Table 4.27 Effect of tillage practices on bulk density values for velocity range V2 and depth of operation range D1 for soil S2.

	Bulk density values in g/cc at given sampling depths		
Tillage Practices	**0-5 cm**	**0-10 cm**	**0-20 cm**
P1	1.36	1.48	1.45
P2	1.36	1.41	1.34
P3	1.28	1.32	1.34
P4	1.28	1.20	1.21
P5	1.28	1.33	1.40
P6	1.39	1.33	1.35

The bulk density values for 0-5 cm of sampling depth under all tillage practices were found be to lowest for P3, P4 and P5 (1.28 g/cc) and highest in case of P6 (1.39 g/cc). At 0-10 cm sampling depth, the bulk density values were found to be lowest for P4 (1.20 g/cc) and highest in case of P1 (1.48 g/cc). At 0-20 cm sampling depth, the bulk density values were found to be lowest for P4 (1.21 g/cc) and highest in case of P1 (1.45 g/cc).

The bulk density values for soil S2 were plotted across the sampling depths for all tillage practices along with bulk density values of initial compacted condition after irrigation and is given in Fig. 4.19. The bulk density values for all the tillage practices were found to be higher than the initial compacted condition between 0-20 cm of sampling depth. The reason may be due to presence of large number of micro pores in the soil and shrinking/swelling behaviour of fine textured soils.

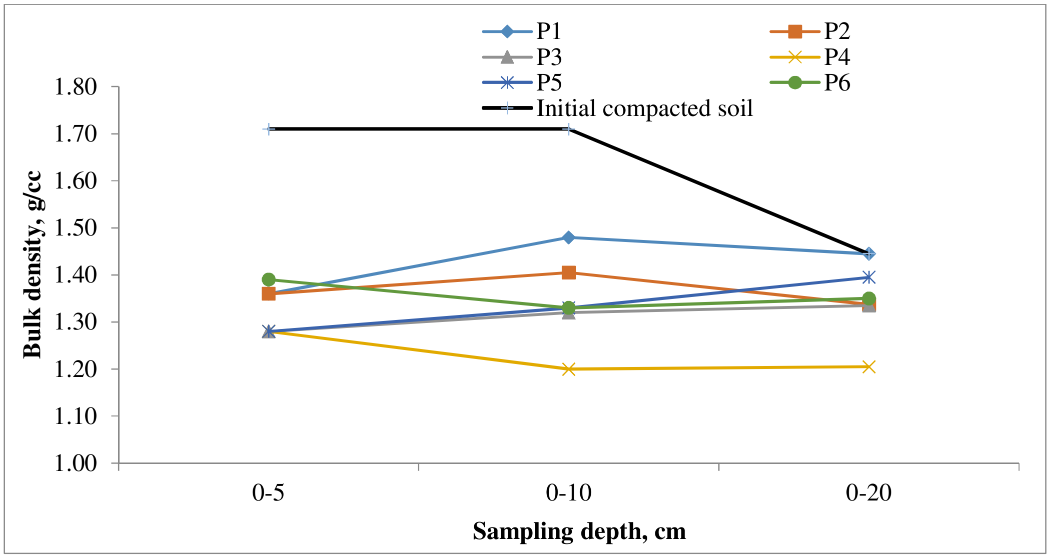

Fig. 4.19 Effect of tillage practices on bulk density values at different sampling depths for soil S2 at velocity range V2 and depth range D1.

Bulk density values, measured after operating the selected tillage practices within V2 velocity range and D2 depth range in the soil S2, are given in Table 4.28.

Table 4.28 Effect of tillage practices on bulk density values for velocity range V2 and depth of operation range D2 for soil S2.

	Bulk density values in g/cc at given sampling depths		
Tillage Practices	**0-5 cm**	**0-10 cm**	**0-20 cm**
P1	1.39	1.45	1.38
P2	1.37	1.35	1.31
P3	1.27	1.31	1.26
P4	1.28	1.23	1.22
P5	1.28	1.35	1.40
P6	1.31	1.26	1.27

The bulk density values for 0-5 cm of sampling depth under all tillage practices were found be to lowest for P3 (1.27 g/cc) and highest in case of P1 (1.39 g/cc). At 0-10 cm sampling depth, the bulk density values were found to be lowest for P4 (1.23 g/cc) and highest in case of P1 (1.45 g/cc). At 0-20 cm sampling depth, the bulk density values were found to be lowest for P4 (1.22 g/cc) and highest in case of P5 (1.40 g/cc).

The bulk density values for soil S2 were plotted across the sampling depths for all tillage practices along with bulk density values of initial compacted condition after irrigation and is given in Fig. 4.20. The bulk density values for all the tillage practices were found to be higher than the initial compacted condition between 0-20 cm of sampling depth. The reason may be due to presence of large number of micro pores in the soil and shrinking/swelling behaviour of fine textured soils.

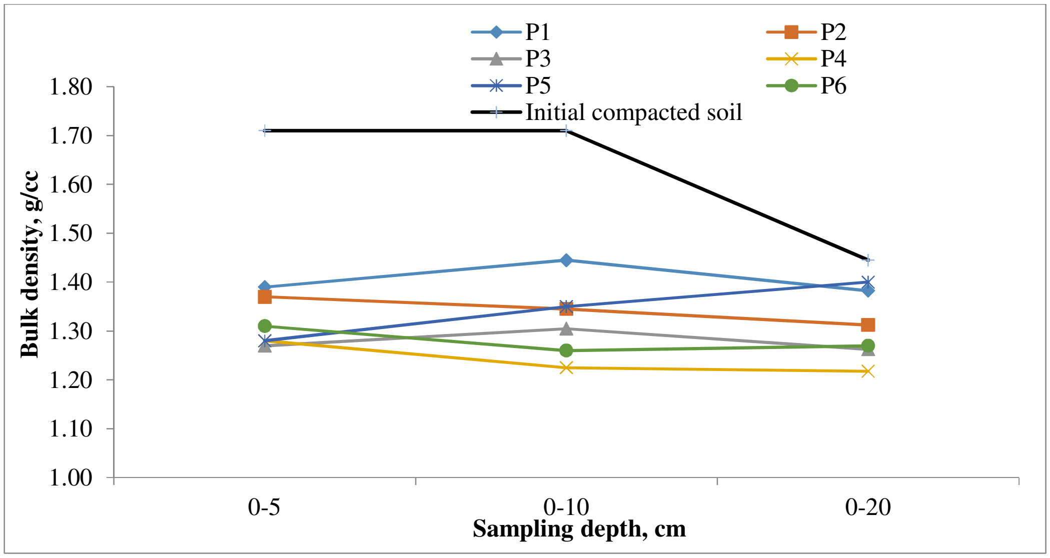

Fig. 4.20 Effect of tillage practices on bulk density values at different sampling depths for soil S2 at velocity range V2 and depth range D2.

The analysis of variance (ANOVA) for bulk density values were calculated at 0-5 cm sampling depth for all tillage practices, at given velocity and depth of operation ranges and for selected soil types, as given in Table 4.29.

Table 4.29 ANOVA for bulk density values at 0-5 cm sampling depth.

FACTOR MEANS						
Practice (P1, P2, P3, P4, P5, P6)	1.358^{a}	1.322^{bc}	1.283^{de}	1.272^{e}	1.303^{cd}	1.341^{ab}
Velocity (V1, V2)	1.311^{a}	1.317^{a}				
Depth of operation (D1, D2)	1.316^{a}	1.312^{a}				
Soil Type (S1, S2)	1.299^{b}	1.328^{a}				

ANOVA TABLE					
Source	**Sum of Squares**	**df**	**Mean Square**	**F**	**p**
S	0.031	1	0.031	24.680	0.000
P	0.135	5	0.027	21.371	0.000
V	0.001	1	0.001	0.984	NS
D	0.001	1	0.001	0.424	NS
S * P	0.046	5	0.009	7.198	0.000
S * V	0.016	1	0.016	12.560	0.001
S * D	0.004	1	0.004	2.825	NS
P * V	0.079	5	0.016	12.454	0.000
P * D	0.035	5	0.007	5.492	0.000
V * D	0.000	1	0.000	0.269	NS
S * P * V	0.009	5	0.002	1.478	NS
S * P * D	0.033	5	0.007	5.274	0.000
S * V * D	0.000	1	0.000	0.393	NS
P * V * D	0.012	5	0.002	1.932	NS
S * P * V * D	0.013	5	0.003	2.128	NS
Error	0.122	96	0.001		
Total	249.060	144			
Corrected Total	0.538	143			

Tukey's test has been applied to see the difference in bulk density values at 0-5 cm sampling depth. Figures with different superscripts are found to be significantly different ($p < 0.05$).

The ANOVA for bulk density values at 0-5 cm sampling depth were found to be statistically significant for the factors of tillage practices and soil types whereas it becomes non-significant for other factors i.e. velocity and depth of operation ranges. The factor interactions of tillage practices and soil types, velocities and soil type, tillage practice and velocity, tillage practice and depth of operation and tillage practices with soil types and depths were found to be statistically significant for variation in bulk density values.

The analysis of variance (ANOVA) for bulk density values were calculated at 0-10 cm sampling depth for all tillage practices, at given velocity and depth of operation ranges and for selected soil types, as given in Table 4.30.

Table 4.30 ANOVA for bulk density values at 0-10 cm sampling depth.

FACTOR MEANS						
Practice (P1, P2, P3, P4, P5, P6)	1.518^{a}	1.364^{a}	1.376^{a}	1.105^{b}	1.49^{a}	1.162^{b}
Velocity (V1, V2)	1.341^{a}	1.332^{a}				
Depth of operation (D1, D2)	1.368^{a}	1.304^{a}				
Soil Type (S1, S2)	1.341^{a}	1.331^{a}				

ANOVA TABLE

Source	**Sum of Squares**	**df**	**Mean Square**	**F**	**p**
S	0.002	1	0.002	0.709	NS
P	1.296	5	0.259	121.403	0.000
V	0.000	1	0.000	0.001	NS
D	0.073	1	0.073	34.114	0.000
S * P	0.282	5	0.056	26.401	0.000
S * V	0.002	1	0.002	0.925	NS
S * D	0.028	1	0.028	12.945	0.001
P * V	0.169	5	0.034	15.844	0.000
P * D	0.147	5	0.029	13.794	0.000
V * D	0.062	1	0.062	28.910	0.000
S * P * V	0.020	5	0.004	1.870	NS
S * P * D	0.071	5	0.014	6.646	0.000
S * V * D	0.000	1	0.000	0.190	NS
P * V * D	0.027	5	0.005	2.491	0.036
S * P * V * D	0.054	5	0.011	5.020	0.000
Error	0.205	96	0.002		
Total	262.415	144			
Corrected Total	2.436	143			

Tukey's test has been applied to see the difference in bulk density values at 0-10 cm sampling depth. Figures with different superscripts are found to be significantly different ($p < 0.05$).

The ANOVA for bulk density values at 0-10 cm sampling depth were found to be statistically significant for the factor of tillage practices and depth of operation whereas it becomes non-significant for other factors i.e. soil type and velocity. The factor interactions of soil types and velocities, soil type with velocities and tillage practices, soil type with depth of operation and velocities were found to be statistically non-significant for variation in bulk density values whereas the other factor interactions were found to be statistically significant for the bulk density values at 0-10 cm.

The analysis of variance (ANOVA) for bulk density values were calculated at 0-20 cm sampling depth for all tillage practices, at given velocity and depth of operation ranges and for selected soil types, as given in Table 4.31.

Table 4.31 ANOVA for bulk density values at 0-20 cm sampling depth.

FACTOR MEANS						
Practice(P1, P2, P3, P4, P5, P6)	1.248^{c}	1.274^{bc}	1.426^{ab}	1.403^{abc}	1.454^{a}	1.43^{a}
Velocity(V1, V2)	1.388^{a}	1.358^{a}				
Depth of operation(D1, D2)	1.367^{a}	1.380^{a}				
Soil Type(S1, S2)	1.33^{b}	1.416^{a}				

ANOVA TABLE					
Source	**Sum of Squares**	**df**	**Mean Square**	**F**	**p**
S	0.000	1	0.000	0.285	NS
P	0.481	5	0.096	103.195	0.000
V	0.018	1	0.018	19.412	0.000
D	0.018	1	0.018	19.669	0.000
S * P	0.070	5	0.014	14.993	0.000
S * V	0.025	1	0.025	27.284	0.000
S * D	0.001	1	0.001	0.615	NS
P * V	0.039	5	0.008	8.427	0.000
P * D	0.045	5	0.009	9.556	0.000
V * D	0.008	1	0.008	8.091	0.005
S * P * V	0.026	5	0.005	5.632	0.000
S * P * D	0.063	5	0.013	13.571	0.000
S * V * D	0.003	1	0.003	3.206	NS
P * V * D	0.010	5	0.002	2.230	NS
S * P * V * D	0.070	5	0.014	15.109	0.000
Error	0.090	96	0.001		
Total	260.359	144			
Corrected Total	0.969	143			

Tukey's test has been applied to see the difference in bulk density values at 0-20 cm sampling depth. Figures with different superscripts are found to be significantly different ($p < 0.05$).

The ANOVA for bulk density values at 0-20 cm sampling depth were found to be statistically non-significant for the factor soil types whereas it becomes significant for other factors i.e. tillage practices, velocity and depth of operation ranges. The factor interactions of soil type and depth of operation, soil type with velocity and depth of operation and tillage practices with velocities and depth of operation was found to be statistically non-significant for variation in bulk density values whereas the other factor interactions were found to be statistically significant for the bulk density values at 0-20 cm.

4.4.3 Mean weight diameter of soil clods

Mean weight diameter of soil clods were determined using method given in section 3.3.3 of chapter III. The average values of mean weight diameter of soil clods observed after different tillage practices are given in the Table 4.32.

Table 4.32 Effect of tillage practices, forward speed and depth of operation on mean weight diameter of soil clods in soil S1 and soil S2.

Treatment	Average mean weight diameter of soil clods, mm	
	Soil S1	Soil S2
P1V1D1	4.91	13.01
P1V1D2	3.44	28.72
P1V2D1	7.65	33.04
P1V2D2	7.24	39.56
P2V1D1	3.52	28.72
P2V1D2	4.49	22.39
P2V2D1	5.86	24.93
P2V2D2	6.17	29.85
P3V1D1	2.36	10.48
P3V1D2	2.66	23.04
P3V2D1	2.51	13.21
P3V2D2	4.02	11.30
P4V1D1	2.01	8.98
P4V1D2	3.26	12.14
P4V2D1	5.89	10.01
P4V2D2	2.71	10.99
P5V1D1	3.96	15.44
P5V1D2	6.90	19.41
P5V2D1	10.56	22.08
P5V2D2	4.09	14.59
P6V1D1	4.58	16.70
P6V1D2	6.84	12.37
P6V2D1	11.82	16.61
P6V2D2	6.81	15.86

The MWD of soil clods after different tillage practices was found to be between 2.01 mm, for tillage practice P4 at velocity V1 and depth D1, to 11.82 mm, for tillage practice P6 at velocity V2 and depth D1 in soil S1. For soil S2, it was found to vary between 8.98 mm, for tillage practice P4 at velocity V1 and depth D1, to 39.56 mm, for tillage practice P1 at velocity V2 and depth D2. The lower MWD in soil S1, may be due to the fact that sandy loam soil gets easily pulverized because of lesser binding forces between the soil particles whereas in case of silty loam soil, the binding forces are more and does not get pulverized easily hence resulting in bigger clods.

The analysis of variance (ANOVA) of mean weight diameter (MWD) values for all tillage practices, at given velocity and depth of operation ranges for selected soil types, is given in Table 4.33.

Table 4.33 ANOVA for mean weight diameter values.

FACTOR MEANS						
Practice (P1,P2, P3, P4, P5, P6)	19.874^a	15.738^b	7.519^e	6.572^f	14.363^c	12.250^d
Velocity (V1, V2)	11.958^b	13.481^a				
Depth of operation (D1, D2)	12.712^a	12.727^a				
Soil Type (S1, S2)	5.035^b	20.405^a				

ANOVA TABLE					
Source	**Sum of Squares**	**df**	**Mean Square**	**F**	**p**
S	8504.832	1	8504.832	11864.810	0.000
P	3074.021	5	614.804	857.693	0.000
V	83.506	1	83.506	116.496	0.000
D	0.008	1	0.008	0.012	NS
S * P	1967.544	5	393.509	548.971	0.000
S * V	5.506	1	5.506	7.681	0.007
S * D	3.531	1	3.531	4.926	0.029
P * V	60.708	5	12.142	16.938	0.000
P * D	28.755	5	5.751	8.023	0.000
V * D	0.895	1	0.895	1.248	NS
S * P * V	37.323	5	7.465	10.414	0.000
S * P * D	11.541	5	2.308	3.22	0.010
S * V * D	80.728	1	80.728	112.621	0.000
P * V * D	158.397	5	31.679	44.195	0.000
S * P * V * D	135.834	5	27.167	37.899	0.000
Error	68.814	96	0.717		
Total	37519.650	144			
Corrected Total	14221.940	143			

Tukey's test has been applied to see the difference in mean weight diameter values. Figures with different superscripts are found to be significantly different ($p < 0.05$).

The ANOVA for mean weight diameter values were found to be statistically significant for the factors of tillage practices, soil types and velocity and non-significant for depth of operation ranges. All the factor interactions were found to be statistically significant for variation in bulk density values except for the factor interaction of velocity and depth of operation.

4.4.4 Fuel consumption in tillage practices

The fuel consumed by tractor in different tillage practices selected under the study were determined using method given in section 3.3.4 of chapter III. The length of run for the different tillage treatments were 27 m and 25 m for soil S1 and soil S2, respectively. The average values of fuel consumption (rounded to nearest ml), time of run for different practices (s), volume of soil moved (m^3) and fuel consumed per unit of soil moved (ml/m^3) recorded in different tillage treatments are given in the Table 4.34.

Table 4.34 Fuel consumption for the tillage practices for both soil S1 and S2

Treatment	Soil S1				Soil S2			
	Fuel consumed, ml	**Time of run, s**	**Volume of soil moved, m^3**	**Fuel consumption, ml/m^3**	**Fuel consumed, ml**	**Time of run, s**	**Volume of soil moved, m^3**	**Fuel consumption, ml/m^3**
P1V1D1	85	57	16.20	5.25	90	60	15.00	6.00
P1V1D2	90	63	23.09	3.90	110	81	21.38	5.15
P1V2D1	94	50	16.20	5.80	110	53	15.00	7.33
P1V2D2	114	50	23.09	4.94	110	67	21.38	5.15
P2V1D1	190	160	32.40	5.86	210	175	30.00	7
P2V1D2	166	146	46.18	3.59	240	181	42.76	5.61
P2V2D1	262	138	32.40	8.08	280	179	30.00	9.33
P2V2D2	258	145	46.18	5.58	310	171	42.76	7.24
P3V1D1	50	42	2.03	24.69	50	47	1.88	26.67
P3V1D2	50	41	4.05	12.35	50	46	3.75	13.33
P3V2D1	60	35	2.03	29.63	60	38	1.88	32.00
P3V2D2	60	34	4.05	14.81	60	35	3.75	16.00
P4V1D1	120	102	4.06	29.55	120	110	3.76	31.91
P4V1D2	100	94	8.10	12.34	110	106	7.50	14.66
P4V2D1	130	86	4.06	32.01	140	88	3.76	37.23
P4V2D2	140	92	8.10	17.28	150	97	7.50	20.00
P5V1D1	40	44	1.49	26.94	40	36	1.38	29.09
P5V1D2	40	35	2.97	13.47	40	34	2.75	14.55
P5V2D1	50	34	1.49	33.67	50	31	1.38	36.36
P5V2D2	60	33	2.97	20.20	50	30	2.75	18.18
P6V1D1	100	101	2.98	33.55	90	74	2.76	32.60
P6V1D2	100	96	5.94	16.83	110	83	5.50	20.00
P6V2D1	110	84	2.98	36.91	110	69	2.76	39.85
P6V2D2	110	82	5.94	18.51	110	69	5.50	20.00

The fuel consumption, of certain tillage treatments that consists of two passes of implements, composes fuel consumed during headland turning. The fuel consumed varied between 40 ml for P5V1D1 and P5V1D2 tillage practices to 262 ml for P2V2D1 practice in soil S1 and from 40 ml for P5V1D1 and P5V1D2 practices to 310 ml for P2V2D2 practice. The time of run for different practice for soil S1 varied from 33 s in P5V2D2 practice to 160 s in P2V1D1 practice. It was observed that conventional tillage practices consumed more fuel and time as compared multi-powered tillage tools practices. The reason is due the fact of more number of implements in conventional practices. Similarly, the volume soil moved is considerably more in conventional practices as compared to rotavator and spading machine practices.

The fuel consumption per unit of soil moved by different practices were found to vary between 3.90 ml/m^3 for P1V1D2 practice to 74.07 for P6V2D1 ml/m^3 in soil S1 and from 5.15 ml/m^3 for P1V2D2 practice to 80 ml/m^3 for P6V2D1 practice in soil S2. Fuel consumption per unit of soil moved was found to lower for conventional practices as compared to rotavator and spading machine practices. This reason behind this is the amount of soil moved, which is considerably more in conventional practices.

CHAPTER V

SUMMARY AND CONCLUSIONS

A study for evaluating the soil compaction caused during different tillage practices, followed by most of farmers and a new tillage machine, like harrow-cultivator-planker; the conventional tillage practice, rotavator practice and spading tillage machine was undertaken in the fields. The experiment was carried out at the fields of two different soil types viz. sandy loam (S1) and silty loam (S2). Six tillage practices, designated as P1, P2, P3, P4, P5 and P6, were undertaken in the present study. The six practices were one pass of harrow-cultivator-planker combination (P1), two passes of harrow-cultivator-planker combinations (P2), one pass of rotavator (P3), two passes of rotavator (P4), one pass of spading tillage machine (P5) and two passes of spading tillage machine (P6).

Different implements have their own, i.e. different recommended speeds and depths of operation. For experimental study, two different depth of cut ranges, designated as D1 & D2 and two forward velocity ranges, designated as V1 & V2, suitable to every implement, were selected. The experiments have been laid out by using factorial in randomized block design, henceforth designated as $_f$RBD, of statistical methods to minimize variation in soil properties on the treatments. In order to find out the soil compaction caused by different tillage practices taken in the present study, each treatment was replicated three times. Coefficient of variance and t-tests were performed to signify the consistency of recorded parameters of the treatments, before and after the tillage practices.

The following conclusions were drawn on the basis of results obtained of the study:

1. The cone index of sandy loam soil and silty loam soil was found to be lower after irrigation was applied to the fields.
2. The bulk density of sandy loam soil was found to be higher after irrigation than that of before irrigation conditions, but in silty loam soil it was found to be lower after irrigation than that of before irrigation conditions.
3. Cone index of sandy loam soil was found to be comparative higher, than initial compaction, in rotavator and spading machine treatments for all velocity and depth ranges. However, in certain treatments, cone index was found at par with initial compaction of soil.
4. Cone index of silty loam soil was found to be comparative higher, than initial compaction, in rotavator and spading machine treatments for all velocity and depth ranges. However, in certain treatments, cone index was found at par with initial compaction of soil, except in one pass of harrow-cultivator-planker combination.
5. The bulk density values of both the soils after all the tillage practices at all velocity ranges and all depth ranges were found to be lesser than the initial compacted condition at all

sampling depths.

6. The mean weight diameter of soil clods formed after different tillage practices were found to be smaller in sandy soil as compared to silty soil, whereas, clods formed in sandy soil were comparatively bigger in rotavator and spading machine practices at higher velocity and lower depth range as compared to all other practices.
7. The conventional tillage practices consumed more fuel and time as compared multi-powered tillage tools practices but were found to move considerable volume of soil and show lower rate of fuel consumption per unit of soil moved than other practices, whereas, rotavator and spading machine takes lesser time and fuel for tillage operation.

SUGGESTIONS FOR FUTURE WORK

Based upon the findings of the present study, the following suggestions are given for future work:

1. A hydraulic mounted soil sensor for the cone index measurement can be used for further studies.
2. Core cutter for sub soil bulk density measurement (below 20cm) can be designed which could penetrate the deeper depths of soil.

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