STUDIES ON THE EFFECT OF ACTIVE TILLAGE TOOLS ON SOIL PROPERTIES

by

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(2017-18-011)

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KERALA, INDIA.

2019

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THESIS

Submitted in partial fulfillment of the requirement for the degree of

MASTER OF TECHNOLOGY

IN

AGRICULTURAL ENGINEERING

(Farm Power and Machinery)

Faculty of Agricultural Engineering and Technology

Kerala Agricultural University

DEPARTMENT OF FARM MACHINERY AND POWER ENGINEERING

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KERALA, INDIA.

2019

DECLARATION

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

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Certified that this thesis entitled **"STUDIES ON THE EFFECT OF ACTIVE TILLAGE TOOLS ON SOIL PROPERTIES"** is a record of research work done independently by Er. Amrutha K. under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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ACKNOWLEDGEMENT

Any accomplishment requires the efforts of many people and this work is no different. I feel great pleasure in expressing my deep sense of gratitude towards all those who have made it possible for me to complete this research with success.

First of all I would like to express my true and sincere gratitude to my chairman ***Er. Shivaji K. P.****, Assistant Professor, Department of FMPE, KCAET, Tavanur, for his dynamic and valuable guidance, care, patience and keen interest in this research work. He has been a strong and reassuring support to me throughout this work. I consider it as my greatest fortune to have him as the major advisor for my research work and my obligation to him lasts forever.*

I am indebted to ***Dr. Sathian K. K.****, Dean (Ag. Engg.), Professor and Head, Dept. of SWCE, KCAET, Tavanur and also my advisory committee member for the support and facilities offered while carrying out the research.*

I was fortunate to have ***Dr. Jayan P. R.****, Professor and Head, Dept. of FMPE, KCAET, Tavanur,* ***Dr. Shaji James P.****, Professor (FPM), ARS Mannuthy, and* ***Dr. Joby Bastian****, Professor (FPM), RARS, Kumarakom, also as members of my advisory committee. I express my sincere and well devoted thanks to for their valuable suggestions, helpful advice and encouragement during the course of research.*

I express my sincere thanks to ***Dr. Manoj Mathew****, Professor (FPM), Agricultural Engineering Centre, RRS, Moncompu for his valuable suggestions to carry out the field work and statistical analysis of the research outcomes and its interpretations.*

With a profound sense of gratefulness, I also acknowledge the invaluable and vital help given to me by my dear senior, ***Er. Younus A.****, Assistant Professor(C), Dept. of FMPE, KCAET.*

I also take this opportunity to express heartfelt thanks to ***FMPE Workshop team*** *in KCAET for their support and cooperation during the period of study and their technical help during the field studies. Special thanks to* ***Mr. Likesh****,* ***Mr. Shobith****,* ***Mr. Kiran****, and* ***Mr. Rishil****. The work would not have been completed successfully without their technical support.*

I remain indebted to ***Er. Rinju Lukose.****,* ***Er. Anjana S. R.****,and* ***Er. Amal Dev J.*** *- my classmates, and more than that, three very enterprising engineers, for their generous support to me. I also thank my batchmates –****Er. Arya K. T.****,* ***Er. Nandhu Lal A. M.****,* ***Er. Athira K.****,* ***Er. Nageshwar B.****,* ***Dr. Sarathjith M. C.****,* ***Er. Adarsh S. S.****,* ***Er. Prasang R. H.****,* ***Er. Anjali A. V.****, and* ***Er. Akila Shiney P.****,– and all my seniors especially* ***Er. Basavaraj P.****,* ***Er. Dipak S.****, and* ***Er. Sariga S.****, – and dear juniors* ***Ms. Midhula B. N.****,* ***Er. Panchamy Balan****, and* ***Er. Athira P.*** *for their encouragement, help and also for making the period of my study enjoyable.*

I express my thanks to all ***faculty members, technical, non-teaching and library staffs of KCAET****, for their ever willing help and co-operation. Also express my sincere thanks and gratitude to* ***Kerala Agricultural University*** *for providing this opportunity to do this research work.*

I am greatly indebted to my ***parents and dear one*** *for their love, blessings, and support which gave strength to complete the study.*

I have been fortunate to get a very encouraging response from all I have contacted in connection with my work, at various stages. It becomes difficult to pen down, as the list seems unending. However, I am forever thankful to each and every one, for their help rendered.

Last but not the least, I bow my heads before ***God Almighty*** *for the blessings bestowed upon me which made me to materialize this endeavor.*

Amrutha K.

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LIST OF SYMBOLS AND ABBREVIATIONS

%	: per cent
&	: and
AFC	: Actual Field Capacity
ANOVA	: Analysis of Variance
ASAE	: American Society of Agricultural Engineers
BD	: Bulk Density
CI	: Cone Index
cm	: Centimeter (s)
db	: Dry basis
DMRT	: Duncan's Multiple Range Test
DoF	: Degrees of Freedom
e.g.	: Example
et al.	: and others
etc.	: etcetera
FICCI	: Federation of Indian Chambers of Commerce & Industry
FMPE	: Farm Machinery and Power Engineering
Fig.	: Figure
g	: Gram (s)
GRA	: Grey Relational Analysis
GRG	: Grey Relational Grade
GST	: Grey System Theory

h	: Hour (s)
ha	: Hectare (s)
hp	: Horse power
IS	: Indian Standard
J	: Joule
KAU	: Kerala Agricultural University
KCAET	: Kelappaji College of Agricultural Engineering and Technology
kg	: Kilogram (s)
kg_f	: Kilogram force
km	: Kilometer (s)
kPa	: Kilopascal
kW	: Kilowatt
l	: Litre (s)
LSD	: Least Significant Differences
m	: Meter (s)
MB	: Mould Board
MC	: Moisture Content
MJ	: Mega Joule
min	: Minute (s)
mm	: Millimeter (s)
MMD	: Mean Mass Diameter
MPa	: Mega Pascal

MSS	: Mean Sum of Squares
MWD	: Mean Weight Diameter
N	: Newton (s)
No.	: Number
NS	: Non-significant
P value	: Probability value
PTO	: Power Take Off
Rs.	: Rupees
RNAM	: Regional Network of Agricultural Machinery
RPM	: Rotation Per Minute
s	: Second (s)
SD	: Standard Deviation
SI	: Soil Inversion
SS	: Sum of Squares
SPSS	: Statistical Package for the Social Sciences
TAR	: Total Accumulated Repair and maintenance cost
TFC	: Theoretical Field Capacity
TPI	: Tillage Performance Index

DEDICATED TO

MY

MENTOR

Introduction

CHAPTER I

INTRODUCTION

High population and low level of agricultural productivity are the major concerns of developing countries in comparison with developed nations. The low agricultural or land productivity may be attributed by insufficient power availability on farms and low level of farm mechanization. Farm mechanisation in India is still in its early stages as compared to the developed countries. Farm mechanisation is essential for sustaining agricultural growth, especially in the context of diminishing agricultural labour. The overall development of a country like India mainly depends on the agriculture, which in turn can be appraised by the level of mechanization. In India, growth of agricultural productivity is directly related to the mechanical power input in farming sector. Even with slow growth of mechanization, the total production of food grains in India increased from over 50 million tonnes in 1950-1951 to 272 million tonnes in 2016-2017. Food grain demand is expected to reach 355 million tonnes in 2030 as compared to 250 million tonnes in 2016. The adoption rates of farm equipment have been on a rise, which is clearly indicated by the rise in sales of tractors. Tractor sales increased from 0.35 million units in 2007 to 0.57 million units in 2016, witnessing a compound annual growth rate of 5.5 per cent during 2007-2016 (FICCI, 2017).

The extent of agricultural lands are decreasing and the population of small land holders are increasing due to the rapid increase in population and industrialization. In addition, the availability of manpower to perform various farm operations is reducing drastically. Hence, the need for farmers to introduce the cost-effective farm mechanization is becoming urgent scenario. Agricultural mechanization implies the application of machines to agricultural production, and this has been one of the outstanding developments in agriculture (Kepner *et al.,* 1978). Mechanization plays an important role in agriculture in order to overcome resource constraints for increased production, productivity and profitability through timeliness in operation. The higher performance of tractors compared to the existing draft animals lead to the high demand of tractors in the country.

However, large communities of small and marginal farmers are still not in a position to take full benefit of farm mechanization because of adverse economies of scale, particularly in operations like land preparation and harvesting (FICCI, 2017). Under these circumstances researchers had the challenge to introduce mechanized seedbed preparation suitable for different cropping pattern and save time, energy and cost.

Soil tillage is an important procedure in agricultural operations. For thousands of years of recorded history humankind has been tilling the soil in order to increase the production of food. Tillage, which may be defined as the mechanical manipulation or soil stirring actions exerted on soil to modify the soil condition for the purpose of nurturing crops, is one of the most critical operations in crop production. Soil tillage consists of breaking the compact surface of earth to a certain depth and to loosen the soil mass, so as to enable the roots of the crops to penetrate and spread into the soil, destroy weeds and enhance the circulation of water and air within the soil. Different designs and configurations of tillage tools and implements are used for achieving an acceptable tilth quality. About 20 per cent of energy expenditure in agriculture is used for field operations, with the major share expensed for tillage operations (Pal *et al.*, 2016). About 60 per cent of total energy required for preparing the soil is used for tillage and preparing a good seedbed (Reicosky and Allmaras, 2003).

Tillage literature categorizes tillage implements as hand operated, animal drawn or tractor drawn according to the source of power used. Tractor drawn implements may either of trailed, mounted or semi-mounted type according to the method of attachment to tractor. Tillage implements may also be classified as primary and secondary according to their impact on soil and seed bed preparation, and passive (drawn) and active (multi-powered) based on the power transmission to the soil working element. Active tillage implements can be either oscillating type, vibrating type or rotating type implements, the most common being rotary.

The primary and secondary tillage implements used in the country, except rotavator predominantly utilizes passive tillage elements. In implements with passive tillage elements, a draft force is applied to the tool, which causes the elements to move through the soil. The power required is developed by tractor engine and transmitted through soil-tire interface and drawbar. MB plough, disc plough, disc harrow etc. are coming under passive category. The poor efficiency of power transmission at the soil-tire interface reduces the tillage efficiencies. Also, as tractors require considerable weight to provide necessary traction, soil compaction may occur. Increased power is also required to overcome the wheel slip and rolling resistance of the tractor tires.

One method to bypass the inefficient soil-tire interface is through active or rotary powered tillage elements, which are tools that obtain their energy in more than one manner. In multi-powered or implements with active tools, a portion of the power is directly transmitted to the soil engaging elements through non-tractive means such as PTO. These machines generally till a greater volume of soil than is required in most field crop systems and therefore require considerable power per unit width. Only about 40 - 56 per cent of net engine power is available at the drawbar of a tractor when transmitting power through the soil-tyre interface, whereas it is about 80-85 per cent for PTO driven active tillage tools (Taylor and Burt, 1975).

Different arrangements and configurations of active tillage tools are deployed which includes longitudinal, vertical and transverse axis units (Kepner *et al*., 1978*)*. Rotary tillers with the soil working tool attached along a horizontal shaft rotating in a longitudinal axis, perpendicular to the direction of motion is the most common type among these and is conventionally known as rotavators. Vertical axis powered rotary tillage machines are termed as power harrows, which has vertical rotors across the width of the machine. Spading machines has a transverse, powered rotor with spades attached to arms mounted on it.

Farmers in the country were mainly depending on passive tillage elements for both primary as well as secondary tillage operations. The low power requirement and high efficiency of rotary tillage tools lead to the extensive use of rotavator in the country. By the advantage of rotary tillage tools, the primary and secondary tillage applications can be conjugated in one stage, especially in Kerala soils. Since the power is directly transmitted to the tillage blades, the power transmission efficiency in rotary implements is high. Presently there is no reference available for the selection of best machinery suitable to a particular location. Hence farmers and land owners mainly depend on the nearby available machinery for tillage. The common availability of rotavators in the country can clearly indicate the acceptance of rotary tillage tools among farmers. Recently power harrows and spading machines are also available in market and gaining the attention among farming community.

Manufactures and farmers claim different performance and tilth quality for these type of implements and it is generally accepted that vertical axis rotors gives a better tilth conditions than longitudinal and transverse axis rotors. In order to validate these three implements scientifically, researches are necessary for the assessment and comparison of the tilth conditions produced by these active tillage tools. As the performance of such implements is greatly influenced by soil type and properties, a generalized conclusion may not be drawn without analysing the soil properties and related machine parameters, to give proper recommendation for the use of these implements. Hence, this research programme intends to study the soil tilth condition produced by three different implements namely; rotavator, power harrow and spading machine in certain type of soil, so as to give proper recommendation for the use of these implements.

The study was taken up with the following objectives:

1. To study the soil physico-mechanical properties of longitudinal, vertical and transverse axis active tillage tools
2. To study the effect of operating parameters of active tillage tools on soil properties
3. To conduct a comparative assessment of cost and energy requirements of the active tillage tools.

Review of Literature

CHAPTER II

REVIEW OF LITERATURE

Soil tillage is the mechanical manipulation of soil in order to obtain good seedbed and tilth condition for cultivation. It is one of the major field operations in agriculture. Since the tilth condition obtained by various tillage implements are different with respect to the soil and machine parameters, there requires the need of assessment and comparison of different methods. Towards this end, a review of the process of soil tillage, purpose of tillage, the available machinery, different soil physical properties, and various tilth conditions obtained by different machines, is attempted in this chapter.

2.1 IMPORTANCE OF SOIL TILLAGE

Soil tillage was carried out in order to improve the productiveness of soil since tillage causes a breakdown of the large soil -particles into smaller ones, which results in increasing the surface from which plant roots obtain their food (Baver, 1956). Tilling the soil will help improve air, water and nutrient relationships for plant growth. The soil type had a very important effect on the tillage requirements (Browning, 1957). The primary purpose of tillage was to reduce aggregates or clod sizes. Aggregates should be small enough to prevent under drying of the soil to provide sufficient soil root contact and provide adequate aeration. Aggregation of the soil particles and arrangement of these aggregates within the soil had a large influence on consistency and moisture relationship in soil (Smith and Wischmeier, 1962). Tillage improves the physical condition of soil, and it resulted in better air-water temperature relationship and reduced root impedance. It also helps to cover plant residues, minimize erosion, control weeds, and to enable the accurate placement of seed and fertilizers (Kupiers, 1963). Hence soil tillage can defined as the mechanical manipulation of the soil and plays an important role in agricultural crop production. It develops soil structure for achieving desired seedbed. Tillage was mainly practiced for the purpose of loosening the soil prior to seedbed establishment, mixing surface residues deeper into the soil and to aid in weed control (Kepner *et al.*, 1978).

Tillage was as old as agriculture. Tillage requirements under specific soil, crop and climatic conditions were largely based on farmer's judgments or conventions. Inadequate land preparations often lead to poor tilth and thus poor crop stand and yield. The relationship between degree of tillage and tilth was highly subjective. Tilth had been viewed as a qualitative term describing the physical state of soil in terms of ease of tillage, seedbed preparation, seedling emergence and root growth (Brady, 1984).

Ahmad and Haffar (1993) opined that tillage was the most costly operation for a farmer. Amongst all the other agricultural operations like drilling, spraying, harvesting etc., tillage machinery need maximum amount of power for seedbed preparation. The main things involved in soil tillage include the physical properties of soil, power source and matching implement suitable to the power source.

Conventional tillage equipments for soil tillage include the plough, disc harrow and sweep cultivator. However, rotary tillage can also be used to prepare seedbed to the required quality. The rotavator became popular among farmers as it was efficient and provides good seedbed. Deep tillage had been considered indispensable for better yield, but many crops except the deep-rooted crops gave fairly good yields with 12-15 cm tillage depth. Rotavator also showed a good breakup of the soil by the rotavator; more than 45 per cent of clods being less than 10 mm in size (Prasad, 1995).

The primary tillage deals with the breaking up of clogged soil in the field and the mixing or inversion of the top layer. The plough was most frequently used for this purpose in past. But minimum tillage or zero tillage introduced as a part of reducing the negative economic and environmental impact of the tillage as well as to maximize the crop production involved the use of alternative machinery instead of the plough (Borin *et al.*, 1997). One of the alternatives was the development of spading machines.

As reported by Hermawan and Bomke (1997), seedbed preparation was crucial for crop establishment, crop growth and ultimately, yield. Typically the aims of tillage for seedbed were to incorporate crop residue, bury weeds and loosen soil to allow appropriate soil–seed contact, easy flow of nutrients, air and water and unimpeded root penetration and crop growth.

Muysen and Govers (2002) reported the soil displacement and tillage erosion during the secondary tillage operations in case of a rotary harrow and seeding equipment. Results showed that the soil displacements from such an implement are significant. Also they reported that tillage erosion can occur not only by primary tillage, but also secondary tillage contributed significantly to soil displacement and tillage erosion.

The main aim of researches on the effect of tillage on soil properties was natural resources preservation (Lal 2000; Sakin *et al*., 2011). Since crop growth and productivity were a reflection of soil quality, any degradation of the soil may adversely affect the stability of system (Van Dang 2007).

In the crop production, high yield and better quality of root can be achieved only from intensely tilled soil. The required level of tillage quality can be achieved only by using complex agricultural machinery with main tillage tool having a rotor, as in a rotary tiller (Bajkin *et al.,* 2010).

Seedbed preparation includes operation such as ploughing, disking, cultivating, harrowing etc. These operations gave better-pulverized soil leading to a friable and properly aerated soil that is ideal for better germination of seed. Many of the seedbed preparation implements such as M.B. plough, disc plough etc. were used for primary tillage and harrows and cultivators as secondary tillage tools. As farmers turn increasingly to multiple cropping systems in order to boost their incomes and meet increased demand for their produce, the time available for seedbed preparation had decreased considerably. This lead to the increase in use of powered implements (Dhakane *et al*., 2010).

Agricultural soil management practices can affect soil physical, chemical, and biological properties with consequences for the movement of water, nutrients, and pollutants in the vadose zone, and for plant growth. Alternative management practices such as conservation tillage or reduced tillage were encouraged to prevent environmental risks like soil erosion, flooding, and pesticide leaching in the groundwater. However, producers were reluctant to adopt these practices as their effects on soil and crop production were not yet well understood (Alletto *et al.*, 2011).

Tillage consumes a large part of the energy in mechanized agriculture. Tillage or soil preparation has been an integral part of traditional agricultural crop production practice. Tillage breaks the soil, enhances the release of soil nutrients for crop growth, destroys weeds and enhances the circulation of water and air within the soil (Kumar and Chopra, 2013).

Tillage operation expends more than half of the energy consumption of agricultural productions, this serves to keep production costs low. The purpose of tillage operation was to enhance the soil's tilth. Tilth is the physical condition of soil in relation to soil aggregate size. Proper sizes of soil aggregates results a good air to moisture ratio and consequently it gives a better yield. The most desirable tillage condition that the size of aggregate around a seedbed was changed according to requirement of seed. The creation of smaller aggregates caused energy losses due to unneeded tillage as well as extra tillage, in turn, increased the potential for soil compaction. On the other hand re-tillage operation would be required if the aggregates were larger. As a result, if the operator was informed about the sizes of aggregates during tillage, he could achieve desirable tillage quality by adjusting parameters such as tractor forward speed and tillage depth (Ajdadi *et al.*, 2016).

Buric *et al.* (2018) studied the effect of PTO driven tillage implements on soil particle transfer. They found that PTO driven implements displace the soil particles to a more distance compared to other conventional tillage implements.

2.2 IMPORTANT SOIL PROPERTIES

The soil physical and mechanical properties have significant influence on the performance and energy requirements of tillage tools. This is because these properties affect the soil strength, which has to be overcome by a tillage tool during a soil tillage operation (Gill and Vanden Berg, 1967). In this section, the pertinent soil physical and mechanical properties which affect the performance and energy requirements of tillage tools are discussed.

Camp and Gill (1969) and Smith (1964) observed that the soil bulk density was concurrently decreasing as the soil water content was increased. Thus, soil water content was a vital parameter in tillage since it influences many parameters that affect the energy requirements and performance of tillage tools.

Nichols and Heaves (1955) stated that optimum results with a particular tillage machine could be obtained only with a specific physical condition. Evaluating soil conditions could serve as guides to selection and design of tillage tools. They concluded that it was necessary to conduct tests of implements with physical measurements and studies of the soil in order to obtain reliable, consistent and understandable results with different tillage implements and soils.

It has been reported by Zoerb and Popoff (1967) that maximum tractive efficiency for a tractor-implement system was obtained when the wheel slip ranges in between 10 to 15 per cent. When the slip increased beyond 15 per cent, the fuel consumption was more which was wasted by unnecessary soil disturbance and the efficiency tends to decrease. Excessive slip also caused rapid wear to the tractor tyres. In their study, they mentioned the different methods of slip measurement. In the conventional method of drive wheel slip measurement, first the distance (B) for a given number of wheel revolutions in unloaded condition was recorded. Then the loaded distance (L) for the same number of revolutions was also recorded. Percentage slip was calculated as equal to 100 x (B-L)/B. In another method, as per the University of Nebraska official drawbar test, the total wheel revolutions to cover a fixed distance was counted under loaded condition(R) and under no load conditions (r) was counted and percentage slip was calculated as equal to [100×(R-r)/R].

Gill and Vandenberg (1967) stated that the soil physical, mechanical and soil dynamic properties had significant influence on the performance and energy requirement of the tillage tools. The properties like soil water content, bulk density, texture, temperature, and pore space affect the soil strength and mechanical behavior.

Soil bulk density varies with structural conditions of soil, especially with respect to the soil compaction. Compaction caused increase in bulk density (Chancellor, 1977). Bulk densities were found decreased with different tillage systems and combination tillage (Srivastava *et al.*, 2000; Bhattacharyya *et al.*, 2006). An ideal soil should contain about 50 per cent solid particles and 50 per cent pore space (Pikul and Aase, 1999) with bulk density of 1.3 g cm^{-3}. A bulk density greater than 1.2 g cm^{-3} in clayey soil, 1.6 g cm^{-3} in loam soil and 1.8 g cm^{-3} in sandy loam soil may adversely affect the paddy root growth (Kar *et al*., 1976). Grossman and Berdanier (1982) proposed bulk densities of 1.47 g cm^{-3} for clayey soil and 1.85 g cm^{-3} for sandy soil as root limiting bulk densities for most of the crops in temperate region.

Ehlers *et al*. (1983) studied the effect of penetration resistance, soil water content and bulk density in a tilled and an untilled soil. The bulk density and penetration resistance were found higher in the top layer of the untilled soil compared with the tilled soil. In the tilled soil, at a depth of more than 25 cm, the bulk density increased sharply due to the presence of traffic pan, whereas in untilled soil, bulk density remained constant. The same happened in the case of penetration resistance also.

Chaudhary *et al.* (1985) reported that loosening of soil by tillage decreased the soil bulk density and soil strength. However, the decrease in bulk density was only of the order of 0.1 g cm^{-3} as compared to a 10 - fold decrease in soil strength. They concluded that bulk density was only related to the total porosity of the soil, while soil strength was a composite property related to many other factors.

The soil moisture content of agricultural soils was commonly expressed as the ratio of mass of water contained in the mass of dry material (dry-basis soil water content). There were many methods for determining the soil water content (Erbach, 1987), but the usual and accurate way involves the placing of a weighed soil sample in a ventilated oven at a temperature between 100 °C and 110 °C until the sample mass becomes constant (Gardner, 1986).

Salokhe *et al.* (1994) conducted trial with a PTO powered disc tiller to see the effect of tilling on physical properties of clay soil at different forward speeds. The effect of disc tilling were assessed in term of bulk density, total porosity, cone index, clod size distribution and soil inversion during first and second passes and the same was compared with unpowered mode. The study revealed that the bulk density and cone index reduced and the total porosity content of clods of less than 15 mm diameter and soil inversion which increased with an increase in number of passes and forward speed. At any given pass and forward speed, there was reduction in bulk density as well as cone index. The effect of soil physical properties was found more for powered disc than unpowered mode of disc.

The intensity of soil breaking and tillage quality were depended on the conventional rotary tiller construction and its working parameters. One way to optimize rotary tiller working parameters was to define the mean diameter of the soil clods (Kosutic *et al.,* 1997).

Buschiazzo *et al.* (1998) found that soil physical properties were extremely vital to plant growth and the physical properties were changed due to different soil tillage treatments and it could influence the yield level of grown crops. Aggregate size, moisture content, penetration resistance, and bulk density were the important soil physical properties which affect the quality of tilth.

Taniguchi *et al.* (1999) reported that the changes in soil physical properties were not only because of constructional properties of soil tillage implements, but also because of their operational variables, such as operating speed. An increase in tillage operating speed resulted in more soil pulverization.

Thampatpong (1999) conducted a study in clay soil bin to find the optimum parameters for rotary tiller design. He measured moisture content, dry bulk density, power requirement, and clod size. The power required to cut and throw the soil was affected by the rotor speed, the forward travel speed and the tilling depth. The power requirement increased with increase in the rotor speed, forward speed and the tilling depth. These parameters were also found affected the soil breakage. When the tilling depth and the forward speed were high and the rotor speed was low, bigger clods size was found. The smaller clods size was occurred when the tilling depth and forward speed were low and the rotor speed was high. The optimum parameter for the design of rotary tiller were found to be 18 cm depth of the tilling, forward speed of 0.35 ms^{-1} and rotor speed of 165 to 220 rpm which will take power requirement of 2.70 to 3.50 kW. At this condition of rotary tiller working, the clod size developed will be the one recommended for soybean cultivation.

Loghavi and Benham (1999) illustrated the effects of soil moisture content and three levels of ploughing depth on soil pulverization in a clay loam soil by a 3 - bottom disc plough. A rotary sieve was used inorder to make a quantitative index to express the degree of soil pulverization. The results showed that soil moisture content significantly effect on mean weight diameter, whereas the effect of ploughing depth on MWD was not significant. The decreasing trend of MWD with soil moisture content persisted to the highest moisture level studied (16 - 18 per cent), in which the average clod MWD (33.8 mm) was about 72 per cent smaller than those formed at 10 - 12 per cent moisture content.

Salokhe and Ramalingam (2002) conducted experiments to investigate the effects of direction of rotation of a rotary tiller on soil properties. Tests were conducted at different tractor speeds. Bulk density, moisture content, puddling index, shear strength and cone index values were measured and found they were not significant. The strength of soil reduced after every pass of rotary tiller. The tractor forward speed also affected the cone penetration level. When forward speed increases, the soil clods formed were larger and pulverization was less.

This resulted in decrease in cone penetration. Moisture content of tilled soil increased after every pass as the soil become very loose whereas the value of bulk density found reduced after every pass.

Agodzo and Adama (2004) studied the relation between bulk density, cone index and water content in different type of soils. Water content affected the level of compaction of soil, which was indicated by its bulk density. The cone index of soil represent the degree of its strength and had been affected by its water content and bulk density. The dry bulk density increased linearly with soil strength in all type of soils.

Soil bulk density was defined as weight of wet soil per cubic centimetre and is calculated as per the IS: 2720 (Part XXIX) – 1975 (Reaffirmed 2005).

As reported by Zadeh (2006), the amount of energy consumed during a tillage operation depend on three categories of parameters like soil parameters, tool parameters and operating parameters. The primary interest in tillage operations was the application of mechanical forces by machines to change the soil condition for agricultural production purposes (Schafer and Johnson, 1982). Depth of cut, width of cut, tool shape, tool arrangement, and travel speed were the main factors that may affect draft and the energy utilization efficiency for a specific soil condition. The effects of these parameters vary with different types of implements and with different soil conditions. Factors such as soil texture, soil moisture content, soil compaction, tool geometry, tool operating depth, and tool forward speed mainly affect the energy requirement of a tillage operation. Soil physical and mechanical properties and soil dynamics properties have significant influences on the amount of energy requirement of a tillage operation.

Fernandes *et al.* (2007) informed that slip influences fuel consumption negatively; however it was required to increase the tractive efficiency and drawbar power. Hence an optimum range of slip was required for efficient tractor operation. Selection of radial tyres as against bias ply tyres, increase of number of tyres, monitoring of tyre wear, correct gear and engine speed etc. can reduce slip. They determined from their study that for a tractor with rated power of 89.7 kW, when slip was 18 per cent, there was a variation in fuel consumption of 5.36 *l* h^{-1}, which was about 23 per cent of the annual average fuel consumption value. Hence by reducing slip, the fuel consumption could be reduced. The efficient operation of tractor can be reached through three basic factors such as maximizing the fuel efficiency of the engine and mechanical efficiency of the drive train, maximizing tractive advantage of the traction devices, and selecting an optimum travel speed for a given tractor-implement system.

Fashola *et al.* (2007) examined the performance and evaluation of a 10 kW two wheel tractor (power tiller) and determined the cost of using power tiller. The main parameters assessed during the field test were average speed of operation, average wheel slip, average draught of implement and fuel consumption. Field efficiencies were also determined. Assessment of soil parameters before and after the operation showed that the power tiller with the attached tillage tool had improved the soil structure. The cost of operation over five years of usage was determined.

The bulk density of the soil determines the potential for roots to grow, as well as the capacity of the plants to explore the surrounding soil, and consequently absorb more nutrients which are necessary for plant growth and health. According to Singh *et al.* (2009), soil bulk density varied from 1.05 to 1.52 g cm^{-3} for no-tillage and 1.08 to 1.72 g cm^{-3} for conventional tillage. Overall bulk density in silty clay loam soil was significantly less than loam, sandy clay loam, and clay loam soils.

According to Olatunji and Davies (2009) the soil moisture content, bulk density, soil texture and soil strength contribute to tillage energy requirement. Operations that involve machinery traffic and soil engaging tools, such as tillage and planting, on agricultural soil was considered tractable if it can develop adequate resistance to minimize tyre slip and soil damage and can as well produce good soil tilth without the formation of clods.

Reshad and Loghavi (2009) investigated the effect of soil moisture content in primary tillage and travel speed during disking operation on the performance of an offset disk harrow in a silty clay loam soil. The performance parameters evaluated were: drawbar power requirement, tractor drive wheel slip and degree of soil pulverization. Results indicated that, drive wheel slip was highly influenced by travel speed, clod sizes and as well by their interactions. Soil moisture content was found an important factor affecting the size and hardness of soil clods made by ploughing operation.

Experiments were conducted by Gilandeh *et al*. (2009) to find the effect of tillage methods on soil fragmentation in loamy-clay soils. MB Plough, disc harrow, de-compactor and its combinations were used for the study. The soil samples were taken from the entire depth after tillage and analysed through standard test sieves. They also measured the soil bulk density and moisture content. Results showed that tillage treatments had significant effect on soil crumbling. They also reported that the optimum soil size for a good seed bed for seed germination was in the order of 0.5 to 8 mm aggregates. A large fraction of small aggregates (less than 1 mm) was not desirable because of increased risk of wind and water erosion. Furthermore a large fraction of aggregates greater than 8 mm was also not desirable because of a reduction in the soil-root contact area and a higher impedance to root penetration.

Sahay *et al*. (2009) had done the performance evaluation of a power tiller operated oscillatory tillage tool. In the field evaluation, they measured volume of soil handled per unit time, working depth, fuel consumption, mean weight diameter, soil inversion, and tillage performance index.

Ahmadi and Mollazade (2009) carried out a study to investigate the effect of ploughing depth and moisture content on reduced secondary tillage in silty clay loam and loam soil. MB plough and disc harrow were used for primary and secondary tillage respectively. Based on this research, it was found that, in the silty clay loam soil, mean clod weight diameter of soil was minimum with 15 - 18 per cent of soil moisture content regardless of ploughing depth, and it was maximum with 10 - 13 per cent of soil moisture content. In the loam soil, mean clod weight diameter was minimum at 18 - 20 per cent of soil moisture content for

15 - 20 cm ploughing depth and maximum at 13 - 18 per cent of soil moisture content for 25 - 30 cm ploughing depth. The soil clod diameter increased according to the depth of ploughing. Results showed that, if primary tillage was performed in the optimal soil moisture content, we will have suitable seedbed with minimum secondary tillage operation. This can help to reduce the costs of secondary tillage operations.

Al-Suhaibani and Ghaly (2010) investigated the effect of ploughing depth and forward speed on the performance of a medium size chisel plough operating in a sandy soil and observed that ploughing depth and forward speeds affect the average fuel consumption for different kinds of farm tractors operating in the same zone.

Nalavade *et al*. (2010) found that driving tillage disc by an external power source had significant effect on soil volume handling and consequently on forces acting on the disc. Free rolling disc was unable to displace the soil smoothly since it accumulate of soil volume in front disc, which significantly affected both soil failure pattern and pulverization of soil. This resulted in higher values of soil reactions on the disc. Conversely, powered disc provided smooth displacement of soil volume to the side and also it maintained uniform soil failure pattern throughout working length. Hence this showed lower values of the soil reactions acting on the disc. Also, it improved pulverization of the soil. They concluded that powered disc is advantageous over free rolling tillage disc in terms of draft reduction, energy utilization and, easy soil volume handling and its displacement to the side.

Shinde *et al*. (2011) analysed the tillage tool geometry on soil properties. The experiments were conducted in sandy loam soil with different forward speeds and operating depths. They measured physical properties such as soil texture, moisture, and cone index. They found that tool shape, operating speed and depth of cut had significant effect on the physical properties of soil. Furrow parameters such as furrow bottom, soil throw, soil disturbance in vicinity of tool in relation to speed and depth of operation were affected by tool parameters like shape and size.

Kumar *et al*. (2012) studied soil cone index in relation to soil texture, moisture content, soil depth and bulk density for no tillage and conventional tillage. It was found that the value of cone index decreased with increase in clay fraction, and increased with increase in sand and silt fractions of soil. Similarly, higher bulk density and greater soil depth resulted in higher cone index value, while higher moisture content reduced the cone index. The cone index also varied with other factors like the time of tillage, cropping system and climate.

Nkakini and Manuel (2014) reported the effect of soil moisture and tillage speed on disc ploughing in sandy loam soil. They measured soil moisture, soil strength, width and depth of tillage and forward speed. Soil strength properties were found decreased with increase in soil moisture content and tillage speeds.

Mandal *et al*. (2015) claimed that a rotary tiller is a specialized tillage machine designed for land preparation by breaking soil using a series of suitable rotating blades. It was desirable to have a granular soil structure in order to allow rapid infiltration and well retention of rainfall, for providing adequate air capacity within the soil and for minimizing root penetration resistance. The rotary tiller is a simple structure with high efficiency hence it had been highly used in agricultural applications nowadays. By taking rotary tillage, the primary and secondary tillage operations could be conjugated in one stage. Since the power was directly transmitted to the tillage blades, they had higher power transmission efficiency. The working widths of available rotavators were in the size of 1.20 to 1.80 m and they were suitable for tractors having 45 hp and above. The quality of work when using a rotavator not only depended on the design parameters, but also rotor speed, forward speed and soil conditions.

Kripanarayan (2015) evaluated the performance of a newly developed disc type vertical tillage implement. The performance was observed in terms of soil mean mass diameter, draft, fuel consumption, wheel slip and field capacity.

Villamil *et al*. (2015) investigated the effect of tillage on soil properties. They measured soil bulk density, penetration resistance and soil inversion and found that different tillage treatments significantly affect the soil properties.

Ranjbarian *et al*. (2015) analysed the performance of tractor and tillage implements in clay soil. They measured the fuel consumption, rear forward velocity, tillage depth engine speed and other parameters such as wheel slippage and tractor efficiency. The implements include MB plough disc plough and chisel plough and were operated at four different forward velocities. Analysis of resulted data concluded that increase in forward velocity resulted in increase of wheel slip and energy efficiency. Furthermore, fuel consumption decreased by increase of velocity from 1.5 km h^{-1} to 3 km h^{-1} but increased by increase of velocity from 3 km h^{-1} to 4 km h^{-1}. Forward velocity, implement type and interaction of them were effective on fuel consumption, wheel slippage, traction efficiency and overall energy efficiency.

In order to increase productivity in mechanized agriculture, need to improve on the efficiency of tillage operations became obvious. These effects can only be realized through the use of appropriate models that include all important compounding variables such as tractive force, wheel slip, moisture content, cone index, and tractor operational speeds (Nkakini, 2015).

Patel (2015) developed a tractor drawn multipurpose tillage implement. It was tested in field condition. He measured field efficiency, fuel consumption, mean mass diameter and cost of operation of the developed implement and the result was compared with that of other conventional tillage implements.

Tayel *et al.* (2015) studied the effect of ploughing conditions on fuel consumption and wheel slippage of tractor in sandy loam soil. They claimed that in every tillage operation, three main factors such as operator, tillage tool and soil should be considered for the achievement of desired results. The wheel slippage in tractors during field operation was one of the main efficiency factor affecting fuel consumption. The soil moisture content at ploughing, soil texture and soil strength contribute to tillage energy requirement. Increasing the ploughing depth and traction power caused both the wheel slip and fuel consumption to increase. Decreasing soil moisture content resulted in decrease of both wheel slippage and fuel consumption. Increasing the soil moisture content and tillage depth increased wheel slippage and fuel consumption due to decreased the tractive efficiency. A very efficient way of saving fuel was to choose the time which will avail good soil conditions: soil moisture content 8.60 per cent at ploughing, 10 cm ploughing depth and 1.79 km h^{-1}, tractor speed during tillage operation.

Shinde *et al.* (2016) evaluated the performance of rotavator in terms of width and depth of cut, speed of operation, fuel consumption, theoretical and effective field capacity. Also soil parameters like soil moisture content, type of soil, bulk density etc. were studied. The performance of rotavator was evaluated for medium black and trash soil. The cost of operation for the uncultivated and cultivated land were found separately and reported that the field efficiency for cultivated land was more compared to other.

Pal *et al.* (2016) mentioned the effect of various parameters on the performance of rotary tiller under actual field condition. Three forward speeds of tractor were used to examine the influence of forward speed, depth of cut at different moisture content fields. The dependent parameters like draft, fuel consumption, power consumption, field efficiency and residue incorporation by rotavator were studied. Results indicated that as the forward speed and depth of cut increased, the draft, fuel consumption, and power consumption also increased.

Dhiman (2016) studied the performance evaluation of a spading machine. The study involved two soil types, two forward speeds and three levels of depth of cut as independent parameters. Their effects were studied on dependent parameters like soil bulk density, PTO torque, cone index and pulverization index. Bulk density was found to be significantly higher in sandy loam soil but PTO torque was lower in sandy loam soil. Both the bulk density and PTO torque increased with depth of cut and forward speed. Soil strength was lower for sandy loam soil and both soil strength and mean clod diameter increased with increase in forward speed and depth of cut. The best operating parameters for the machine were found to be lower forward speed and lowest depth of cut in sandy loam soil.

Kankal *et al*. (2016) made an attempt to evaluate the performance of rotavator in dry land and wet land condition. From the study it was observed that the wetland operation required one or two passes to get desirable puddling index. The depth of puddle and puddling index were recorded as 19.68 - 20.25 cm and 78.84 - 80.63 per cent, respectively. The rate of work in dry land operation of rotavator while working in medium black soil was found in range of 0.33 - 0.35 ha $h^{-1}$with an operating depth ranging 9.85 - 10.21cm. The field efficiency of rotavator was recorded as 77.18 - 80.60 per cent.

Figueiredo *et al.* (2017) studied the effects of tillage operations on soil physical properties. They evaluated soil water content, porosity and penetration resistance while operating different tillage operations in the field.

Neudert and Smuty (2017) reported the impact of various soil tillage methods on soil physical properties. They stated that different soil tillage technologies had a different effect on the physical state of soil. They measured tillage depth, penetrometer resistance, soil moisture and dry bulk density. The quality of tilled soil was indicated by the bulk density value and the value was found in the range of 1.2 – 1.5 g cm^{-3}. Hula and Prochazkova (2008) described as an optimum bulk density in the range of 1.2 - 1.5 $t.m^{-3}$, which are values they have found in their experiment.

Xue *et al.* (2018) investigated soil physical properties response to tillage practices such as no tillage, ploughing and subsoiling. They stated that soil physical properties were the indicator of soil quality which directly affected the soil turnover and crop yield in drylands. They measured soil bulk density, moisture content and porosity before and after tillage. The bulk density after ploughing was found to be lowest than others.

Maharajan *et al.* (2018) tried to simulate the impact of tillage implements on soil physical and nutrient properties. They assessed soil bulk density, changes in soil porosity, soil aggregates, and redistribution of weeds after tillage while working with a plough, harrow and cultivator. Tillage reduced the bulk density of top soil or tilled layer. Breaking up of soil crusts resulted in increased porosity and infiltration. The long term tillage does not affect the average value of bulk density. The effect of tillage on aggregate size varied with the type of soil, soil texture and tillage tool used.

Dixit *et al*. (2018) evaluated three tillage practices such as conventional tillage, minimum tillage and zero tillage on clay loam soil. They measured bulk density, moisture content, depth of penetration and crop productivity.

Singh *et al*. (2018) attempted to relate the influence of tillage depth and tractor speed on the performance of primary tillage tools. The measurements of fuel consumption, depth of operation, field efficiency were noted. They found that increase in tractor speed would increase the fuel consumption in all implements. The overall efficiency increased with increase in tillage width.

2.3 COMPARISON STUDIES OF DIFFERENT IMPLEMENTS

The size and stability of soil aggregates can be indicators of the effects of tillage system and crop on soil. Well aggregated soils provide better moisture retention, adequate aeration, easy penetration for the roots, and good permeability. The size of aggregates and aggregation state were greatly affected by tillage implements and practices. Hughes and Baker (1977) compared traditional plough, rotary cultivation, and no tillage in a silt loam soil. They found that the rotary cultivation treatment resulted in the greatest proportion of soil in the smaller aggregate size fraction.

Bukhari *et al.* (1988) evaluated the performance of mould board, disc plough and cultivator. The draft requirement, travel reduction, speed operation, depth of cut, field capacity, soil disturbance and soil inversion were measured as the performance parameters. They concluded that the total draft of all three implement was nearly the same. The travel reduction was highest for the disc plough and lowest for the cultivator. The cultivator ploughed more area than mould board and disc plough. The soil volume disturbed by the mould board was about 29 per cent more than the disc plough and cultivator.

Rizvi *et al.* (1990) conducted trials on four tillage methods using field cultivator, rotavator, disc plough and mould board plough to study the changes in bulk density, penetration resistance, moisture content, surface roughness and wheat yield. Soil bulk density and penetration resistance were found significantly affected by different tillage methods. Surface roughness coefficient and water retention data were found higher after the mould board operation than rotavator. Grain yield were observed higher in mould board field than the cultivator. Statistical analysis revealed no significant effect on yield due to cultivation methods.

Singh and Panesar (1991) studied several combinations of tillage machines. Clod size distribution, crop yield, total energy, time and cost of seedbed preparation were studied for all machine systems. The combination of disc harrow, cultivator and planker gave minimum clod size. Combination of two operations of disc harrow, four of field cultivator with pulverizing roller and three of planker were optimum from net energy and economic returns point of view.

Berntsen and Berre (1993) conducted field experiments over a period of 6 years to study the effects of secondary tillage implements on soil fragmentation. Seedbed preparation was carried out on four different sites with soil having different clay contents. Three implement groups (drags and harrows; twin rotor; gyro and rota spikes) were used for the seedbed preparation. The results showed that there was no difference in fragmentation between harrows and rotary fragmentation implements. For the loosened soil state, there was no significant difference between the three implement groups. However rotary implements seemed to be more effective in the conversion of energy to fragmentation.

Comia *et al.* (1994) evaluated soil and crop responses to different tillage systems. MB plough, cultivator and power harrow were used for the purpose. They found that a reduced number of tractor passes were achieved by using the PTO driven harrow resulted in significantly lower bulk density and penetration resistance, while still providing an adequate seed bed. The characteristics of the seedbed were similar in the different tillage systems, despite differences in the number of passes with harrows. They also stated that a PTO driven harrow appears to be a viable alternative to conventional seedbed preparation.

Prasad (1996) compared the performance of a tractor operated rotavator with that of conventional tillage equipment for seedbed preparation. The treatments were sweep cultivator × 2 + disc harrow × 1(T1); M.B. ploughing ×1+ disc harrow ×2 (T2); rotavator × 1 (T3) and rotavator × 2 (T4). It was observed that the soil bulk density after tillage in T3 and T4 were significantly lower than in T1 and T2. The rotavator had significant effect on pulverization. The clod mean weight diameter in T3 and T4 was significantly smaller than T1 and T2. The yield of crop cultivated in the field was observed not affected by tillage treatment. The specific energy in preparing the seedbed was found low in one pass of rotavator (T3) as compared to T1 and T2, and consumed less time compared to others. The quality of seedbed, in terms of bulk density and MMD, prepared with single operation of rotavator was found to be better that obtained by other equipment.

Carman (1997) conducted field experiments in clay soil to determine effect of different tillage systems on soil properties and crop yield. There were 4 tillage treatments such as mould board ploughing, disc harrowing, rotary tillage and stubble cultivator. There were significant effects of the four tillage treatments on moisture content, bulk density, aggregate mean weight diameter, penetration resistance, and surface roughness. The smallest mean weight diameters and surface roughness were created by rotary tillage. Also it had the lower bulk density. Penetration resistance was observed decreasing depending on the tillage depth. The crop emergence was also varied according to tillage treatment. The greatest emergence rate and yield of wheat crop were obtained with stubble cultivator followed by disc harrowing.

According to Belel and Dahab (1997), the effectiveness of any tillage practice was evaluated depending on the change it brings about in soil physical properties, rather than depending on crop yield. Economic considerations were added to tillage evaluation parameters especially field capacity and energy utilization efficiency particularly when comparing two or more implements. Implement type, tillage depth and speed affect the seedbed properties as well as the tractor's driving wheel slippage, fuel consumption, and field capacity and efficiency.

Olsen and Borresen (1997) suggested change in tillage from mould board ploughing to reduced tillage with a rotavator to reduce the problems of soil erosion. The soil with reduced tillage had a nearly uniform density profile. The big pores in the surface layer collapse due to traffic and in the underground, the macroporosity was higher on rotavated soil than ploughed. Thus ploughing increases compaction compared to rotavation on the bottom of the plough layer.

Singh & Singh (1998) concluded that rotavator requires the minimum time for the operation. Since 90 percent of the required power passed through the PTO, the powered rotary implement had potential for reducing the energy loss through wheel slippage during the tillage. At the same time, it provided increased soil pulverization and mulch incorporation in comparison to conventional tillage implements. The use of powered rotary system, compared to conventional tillage systems could save an enormous amount of energy and labour. The use of rotavator was limited due to high cost and frequent replacement of its tynes due to wear.

Singh *et al*. (2002) made comparative field evaluation of powered harrow, disc harrow, rotavator and disc harrow combined with clod crusher for seedbed preparation after paddy were conducted. Results indicated that in order to get almost same level of tilth, the time required for rotavator was minimum followed by powered harrow, disc harrow and disc harrow + clod crusher combination. Fuel consumption was observed to be the minimum for powered harrow. The use of different combination of implements for seedbed preparation had no effect on wheat yield. The combination of powered harrow and disc harrow + clod crusher were better as compared to rotavator, disc harrow and clod crusher combination with respect to net returns.

Bapuso (2003) has done a field testing of three tractor-implement systems viz. rotavator, cultivator and disc plough in sandy loam soil at different load settings (engine rpm). He measured moisture content, bulk density, depth of operation. The gear selection was based on getting recommended speed of operation. An auxiliary fuel tank was made for measuring the fuel consumption. Soil pulverization was found by sieve analysis of tilled soil. The results showed that mean clod diameter increased with increase in engine rpm for all the implements except rotavator, which showed decreasing trend with increasing engine rpm. Energy requirement and field efficiency increased with increase in engine rpm for all the implements where as fuel efficiency decreased with the load.

Potekar and Tekale (2004) had done a comparative performance of rotavator and other tractor drawn implements. They measured pulverization index, performance index and energy requirement for seed bed preparation with available implements (MB Plough, disc Harrow, cultivator and rotavator). Different combinations of tillage system selected for study were ploughing, ploughing + cultivating, ploughing + disc harrowing, ploughing + rotavating, single operation of rotavator and double operation of rotavator. From the study it was observed that the combination of ploughing + rotavating gave the highest performance index of 85.06 per cent , pulverization index of 3.28 cm and energy consumption 2302 MJ ha^{-1} followed by rotavator operation observed performance index 76.03, pulverization index 3.98 cm and energy consumption 1462 MJ ha^{-1}. By considering these parameters, the combination of double rotavator operations was found to be most suitable combination of tillage system for seed bed preparation compared to others. They concluded that rotavator can be effectively used either single or in combination in the fields where shallow seedbed was needed in multiple cropping system. Rotavator tillage system consumed less energy and at the same time, pulverization index obtained was minimum. This resulted in fine seedbed with less effort and within short time as compared to other tillage systems.

Pezzi (2005) evaluated the performance of a plough, spading machine and rotary plough at two forward speeds and two soil depths, 0.3 and 0.4 m. Tests were done in silty – clay soil. Forward speed, wheel slip, fuel consumption, energy at PTO and drawbar were measured. Clodiness of the tilted soil was also compared. The spading machine was found to perform better under all the parameters tested. The results of the two PTO powered implements showed slighted advantages in terms of hourly capacity. The degree of soil pulverization was better. Economic evaluation showed lower unit costs (17 - 28 per cent), for the spading machines.

Boydas and Turgut (2007) claimed that different tillage implements and operational variables may affect soil physical properties. They conducted an experiment with different primary tillage implements and operating speeds and their influence on physical properties of loamy soil. The compared tillage implements were: Mouldboard plough, slatted mouldboard plough, disk plough, chisel plough and primary tillage + rotary harrow systems (mounted at the back of this primary tillage. The operating speeds selected were 1.25, 1.5, and 1.75 m s^{-1}. Effects of the tillage treatments on mean weight diameter (MWD), moisture content, penetration resistance, and bulk density were determined. Analysis of variance was used to evaluate the significance of each treatment in a randomized complete block design with 3 replications. Comparison of means was performed with Duncan's multiple range test. It was found that tillage implements had a significant effect on soil physical properties. As the operating speed increased, the MWD values decreased. With the effect of rotary harrow, MWD decreased and also it conserved soil moisture at the highest level. The best and optimum soil physical properties were found with the operating speed of 1.5 m s^{-1}.

Makki and Mohamed (2008) tested a chisel plough, disk plough and a ridger to evaluate their effect on selected soil physical properties along with their performance. Analysis of variance at 5 per cent significance level was used for the comparison. They found implement type had a consistent significant effect on soil moisture content, whereas bulk density showed inconsistent response. Chisel plough recorded the highest moisture content values as compared to the ridger and disk plough. The chisel plough had the highest power requirement and fuel consumption. The ridger had the lowest power requirement and fuel consumption, but has the highest field capacity and efficiency.

Ahmad *et al*. (2010) conducted field experiment to evaluate the effects of various tillage depths on soil properties and wheat yield. Different implements such as rotavator, modified rotavator, spade cultivator, chisel plough and combination of chisel and rotavator used for the tillage treatments. The data were analysed using analysis of variance. The results showed that these tillage implements had significant effect on soil properties and yield of crop. All the tillage implements showed nearly same bulk density on top layer but large variation was noted at greater depth. Penetration resistance at top layer (0-10 cm) was minimum 0.31 MPa with chisel plough + rotavator and maximum 2.46 MPa at depth of 20 - 30 cm with rotavator. The spade cultivator produced nearly the same resistance for the whole depth of 0 - 30 cm varying from 1.16 to 1.23 MPa. The minimum bulk density of 1.23g cm^{-3} at a depth of 20 - 30 cm was noted with spade cultivator and a maximum of 1.99 g cm^{-3} with rotavator. The results generally showed that tillage depth effectively altered soil moisture content, soil penetration resistance, soil bulk density and crop yield.

Rashidi and Keshavarzpour (2011) conducted field experiments to investigate the effect of different tillage methods on some physical and mechanical properties of soil. The measured properties were moisture content, bulk density and penetration resistance. Tillage treatments were mouldboard plough followed by two passes of disk harrow as conventional tillage, two passes of disk harrow as reduced tillage, one pass of disk harrow as minimum tillage and no-tillage. The statistical analysis of data was done using Randomized Complete Block Design. Duncan’s Multiple Range Test at 5 per cent probability was also performed to compare the means of different treatments by using the computer software SPSS 12.0 (Version, 2003). The statistical results of the study indicated that tillage method significantly affected physical and mechanical properties of soil. The highest moisture content (20.6 per cent) and the lowest bulk density (1.34 g cm^{-3}) and penetration resistance (487 kPa) were observed in case of conventional tillage treatment; while 3 the lowest moisture content (17.6 per cent) and the highest bulk density (1.44 g cm^{-3}) and penetration resistance (1087 kPa) were noted in case of no-tillage treatment. Also a loose and fine soil structure was observed in conventional tillage. Therefore, conventional tillage method was found to be more appropriate and profitable tillage method in enhancing selected physical and mechanical properties of soil in the arid lands of Iran.

A field study was conducted by Aikins and Afuakwa (2012) for duration of two years under rainfed conditions on sandy loam soil in order to compare the effect of different tillage practices on some selected soil physical properties under Asontem cowpea variety. The experiment was arranged in a randomized complete block design with three replications. The tillage treatments consisted of disc ploughing only, disc ploughing followed by disc harrowing, disc harrowing only and no tillage. Statistical data analysis was performed using the Balanced Analysis of Variance model in MINITAB Statistical Software Release 15 (MINITAB Inc., 2007). The data compared on treatment basis using the least significant difference test at $p < 0.05$. The disc ploughing followed by disc harrowing treatment gave the most favourable soil conditions such as lowest soil penetration resistance, lowest dry bulk density, highest soil moisture content, and highest total porosity compared with the other treatments. The no tillage plots produced the most unfavourable soil conditions like highest soil penetration resistance, highest dry bulk density, lowest soil moisture content, and lowest total porosity. Therefore the best tillage practice identified for Asontem cowpea production was disc ploughing followed by disc harrowing under the soil and weather conditions of the experiment.

Azadbakht *et al.* (2014) evaluated and compared the performance of rotavator with horizontal and vertical rotary axis. The mean weight diameter, cross sectional area disturbed, and cone index of soil were investigated. Factorial experiments based on a randomized complete block with 27 treatments, at three different velocities and three different depths with three replications were used. They found that the soil disturbed decreased with increase in velocity. Also soil resistance in vertical axis rotavator was less than horizontal axis rotavator and soil disturbed in vertical axis rotavator was much more than horizontal one. Thus, regardless of other factors and according to the results, use of rotavator with vertical blades was more appropriate than rotavator with horizontal blades.

Catania *et al*. (2014) compared the effects of three machines, chisel plough, roto-tilling machine and spading machine on soil penetration resistance in shallow tillage (0 - 15 cm). No tillage was also included. The penetration resistance values were found to be lower in case of tillage using spading machine throughout the tillage profile than roto-tilling machine, chisel plough and no tillage, and it did not exceed 2 MPa in the whole depth of tillage.

Amin *et al.* (2014) conducted field experiments to study the effect of different tillage practices on physical properties of a silty clay loam soil under irrigated agriculture. The time period of study was two years. Five tillage treatments consisted of tine cultivator twice, chisel plough, mouldboard plough, disk plough and tine cultivator once, each followed by a rotavator except the first treatment. Physical properties such as soil moisture content, bulk density and soil penetration resistances were recorded. The statistical analysis of data were done using analysis of variance technique for randomized complete block design and the means were compared using LSD test at 0.05 level of probability. The results showed that tillage practices had significant effect on soil moisture content, soil penetration resistance and bulk density at all operating soil depths. The highest soil moisture content and lowest bulk density or soil penetration resistance were recorded for soil tilled with chisel plough or mouldboard plough. Soil physical conditions were generally improved with time as moisture conservation in soil increased while soil bulk density and soil penetration resistance decreased at both soil depths in second year as compared to first year of study. These results suggested that deep tillage practices such as chisel plough, mouldboard plough performed better than shallow tillage practices like tine cultivator, and hence was recommended to improve soil moisture conservation and reduce both soil bulk density and penetration resistance under semi-arid environment.

A comparison between traditional ploughing and a spading was performed at different travelling and rotor speeds in order to evaluate both technical and agronomic parameters such as working time, power required, fuel consumption, pulling force, efficiency of crop residues incorporation, etc. The ploughing showed an effective tillage capacity 51 per cent higher than the faster spading. On the contrary, the spading machine required minimum pulling force, making operation possible even in critical conditions such as on wet soil. The spading machine showed clear advantages under the agronomic point of view: it does not create the typical compact layer at the bottom of the working depth, which reduces the root penetration and does not allow the capillary circulation of the solution into the soil. In any case, the spading machine better managed the crop residues, because they were mixed along the completely tilled layer. Considering the environmental and economic sustainability of the soil tillage, the fuel consumption was one of the parameters with a high impact. The hourly consumption of the plough was found 28 per cent higher than that of the spading machine. Considering the consumption per surface unit, the plough highlighted a value which was lower than those of the spading machine, in all working conditions investigated. Also single pass of spading machine was sufficient to create optimal conditions for seeding, while ploughing needs a secondary tillage such as harrowing in order to make a good seeding condition (Giordano *et al*., 2015).

Taiwo and Sekyere (2015) made a slippage study of tractor during the operation of a 2 bottom disc plough and 3 bottom disc plough, when mounted with a tandem disc harrow. A two-way analysis of variance was carried out on the data. Thereafter, the Least Significant Differences between the means were computed at 5 per cent level of significance and used to make paired comparisons between the treatment means. It was found that the use of 2-bottom disc plough resulted in higher wheel slippage for primary tillage and subsequent secondary tillage.

Makange and Tiwari (2015) tested vertical and horizontal axis rotavators in the field at two different moisture contents. The effects of operational parameters such as tilling depth and operational speed on soil physical properties were evaluated. The analysis was statistically done using two-way analysis of variance (ANOVA) for completely randomized design, in Microsoft Excel (2007) by ANOVA procedure. The comparison of treatment means were done using F-test at $p = 0.01$ and 0.05 level of significance. The results indicated that the operating speeds had found significant effect on MWD but vertical axis had not much effect MWD when speed changes. This means the mean weight diameters resulting from the analysis of soil after using vertical axis rotavator were not statistically different. However, in the same operating speed vertical axis rotavator pulverize soil more than horizontal one. Also in the same depth of cut, vertical axis rotavator pulverized soil more than horizontal one. The cone index measured after tillage operation using horizontal and vertical axis rotavators were statistically different. In the same depth of cut vertical axis rotavator resulted less penetration resistance and bulk density than horizontal one. The same happened in same speed condition also. Bulk density was found increasing with increase in speed in case of both rotavators. The optimum tilling depth and operating speed were found to be 10 cm and 2.71 km h^{-1} respectively for both the rotavators for getting better performance. Based on tilling quality of soil, vertical rotavator was found better while economic point of view, horizontal rotavator performed better.

Uma *et al.* (2016) conducted a comparative analysis of secondary tillage tools. They measured soil bulk density, moisture content, soil pulverization, depth of operation, energy requirement, field capacity, and performance index (field efficiency) while using different implements on same soil type.

Dabhi *et al.* (2016) evaluated comparative performance of mini tractor drawn tillage implements for seed bed preparation under sandy loam condition. Cultivator, MB Plough and rotavator were used for the seedbed preparation. The main parameters evaluated were wheel slip, speed of operation, soil volume disturbed, bulk density, fuel consumption, field efficiency and soil pulverization.

Single pass of rotavator was found economical with respect to operational cost and also it performed satisfactory for good seed bed compared to other implements in terms of field efficiency and soil pulverization.

Fanigliulo *et al*. (2016) conducted experiments to evaluate the work quality and energy requirements of tillage implements, spading machine, furrow plough and conservation tillage implements such as rotary harrow, subsoiler, disc harrow, and combined cultivator for medium deep tillage in silty clay soil. Forward speed, wheel slip, fuel consumption and energy demands were measured. Also evaluated the cloddiness and roughness of tilled soil and biomass coverage index. Since the data did not follow normal distribution, a Shapiro-Wilk normality test was performed on the data and the likelihood of statistically significant differences among implements, in terms of dynamic-energetic parameters and working quality indices, was assessed by a non-parametric test. P - value of less than 0.05 was considered for significance in the tests. The statistical procedures were computed with the software R (R Core Team, 2013). The conservation tillage implements gave the best results in fuel consumption and energy requirements respect to the conventional implements, with energy savings up to 86 per cent in the case of disk harrow. The rotary harrow showed intermediate values and the best soil refinement.

Sukcharoenvipharat *et al.* (2017) conducted a study to compare the tilling performances of a rotary tiller and a power harrow. The results showed that both the rotary tiller and the power harrow had negative slip, indicated that they generated force to push a tractor. The rotary tiller created negative vertical force to lift up the tractor whereas opposite result was found when using the power harrow. Statistical analysis indicated that in case of rotavator, forward speed did not affect the working depth, drawbar pull, vertical force, torque and soil clod diameter meanwhile it significantly affected the PTO power to working depth and the PTO power to area. The power harrow created higher positive vertical force as forward speed increased. Also forward speed significantly affected drawbar pull, vertical force, torque of harrow, PTO power and PTO speed but not the working depth, soil clod diameter and slip. But forward speed of power harrow had no significant effect on the PTO power to working depth and PTO power to working area. Since working depths were different, vertical forces, torques and PTO powers for two equipment types were significantly different. However, no significant differences were found for the forward speeds, slips, drawbar pulls and drawbar powers. Comparative analysis showed that two equipment types had significant difference in PTO power to working depth, drawbar power to working depth, PTO power to working area, drawbar power to working area and soil pulverization.

Kumar *et al*. (2017) conducted an experiment to evaluate the performance of different sized tractor-rotavator combination in order to suggest the farmers in selecting suitable tractor for cost effective operation. Majority of farmers were not conscious to select correct power source and corresponding implements to meet their requirement to perform various farm operations hence they used traditional as well developed implements for seedbed preparation and other farm operations irrespective to the quality of work and cost of operation. Effective use of proper implement helps to improve moisture retention capacity and quality of soil thus enhance the crop yield. Here they used power tiller (13 hp), mini tractor 1 (12 hp), mini tractor 2 (15 hp) and medium size tractor (35 hp) in order to make seedbed under identical operating conditions using rotavator as matching implement. The parameters evaluated were travel reduction (wheel slippage), draft, speed of operation, drawbar power, volume of soil disturbed, fuel consumption, field efficiency and soil pulverization. Results indicated that mini tractor (Yuvraj 215) of 15 hp performed better from the standpoint of operational efficiency and economy in the region of Gujarath.

Singh (2017) evaluated the field performance of tractor drawn tillage implements. The field trials for two bottom mouldboard (60 cm), two bottom disk plough (70 cm) and seven tines spring loaded cultivator (165 cm) were carried out. The spring tine cultivator recorded the highest effective field capacity, lowest fuel consumption and minimum power requirement whereas the mouldboard plough recorded the highest draft force and fuel consumption while the disk plough recorded the highest field efficiency and lowest delay time.

A field performance analysis was conducted by Yadav *et al.* (2017) with the use of rotavator and other passive tillage implements like MB plough, cultivator and disc harrow. The performance was found considerably varied according to the type of soil, moisture content, crop residues and travelling speed. The tests were conducted as per the RNAM test code. They calculated depth of penetration, area covered in unit time, mean weight diameter of soil, field capacity, fuel consumption, field efficiency, cost of operation and energy requirement for seedbed preparation using various implements and its combinations. They concluded that double operation of rotavator will give best results for seed bed in sandy loam soil.

Jebur and Alsayyah (2017) made a study on the effect of soil moisture content and the speed of the tractor on some tractor performance indicators and some of soil physical characteristics in silt clay loam soil. They used sweep plough, MB plough and chisel plough as machinery unit in the study and selected five levels of speed for each. Slippage percentage, Pull force, Effective field capacity, soil moisture level and soil bulk density were measured in the experiment. They found that increasing tractor speed led to increase in wheel slippage and soil bulk density. The moisture content had also significant effect on slippage.

Agbede and Adekiya (2018) compared five tillage methods with reference to their effect on soil physical and chemical properties. Data were subjected to analysis of variance using the Genstat statistical package (GENSTAT, 2005) to determine the effects of treatments on soil physical and chemical properties. The standard error of difference between means was used to compare the treatment means. The statistical significance was referred as $p = 0.05$. They found that ploughing plus twice harrowing resulted in higher soil bulk density compared to the tillage methods such as zero tillage, manual ridging, manual mounding and ploughing plus harrowing.

Maheshwari and Singh (2018) reported that one rotavator operation is equivalent to several other conventional tillage operations when the quality of seedbed was concerned. The negative draft produced by the rotary action makes less power for the tillage compared to other ploughs and harrows. Since the tractor engine power was directly applied to the soil through PTO rather than tyre tractive force, there happens less wheel slippage, low soil compaction. They evaluated rotavator in comparison with disc harrow and cultivator. The quality of seed bed was assessed by taking bulk density and mean mass diameter of clods. They found that there was a considerable reduction of bulk density of seedbed with rotavator operation while compared to other implements. The same happened in case of mean mass diameter also. Hence the rotavator had improved soil tilth. Cultivator and disc harrow needs more number of passes in order to achieve the same tilth condition as that of one pass of rotavator. Also in rotavator, the control of soil clod size was possible by adjusting rotor speed and forward travelling speed. The rotavator gave greater advantage in use both in terms of fuel consumption and time of operation over other implements. Eventhough the hourly cost of operation of rotavator was high compared to the others due to high initial cost, the cost of operation in terms of area basis was found to be minimum for single rotavation since others were involved a number of times.

Lathifmanesh *et al.* (2018) studied the integrative impact of rotational tillage. They had taken no tillage and subsoiling with rotary tillage for the study. Penetration resistance, bulk density and moisture content were measured during the operation. The differences among the treatments were tested by data analysis using analysis of variance; and the treatment means were compared with the least significant difference test at $P < 0.05$. Comparison of treatments showed that the use of sub-soiling with rotary tillage during the wheat season significantly decreased soil penetration resistance and bulk density, but enhanced maximum water holding capacity.

2.4 GREY RELATIONAL ANALYSIS

The grey system theory was one of the developed multiple attribute decision-making technique. In a complex multivariate system, many factors simultaneously influence the system to determine its state of development. We need to know the combination effect of these factors on the system. It can be achieved by Grey Relational Analysis.

In 1982, Professor Deng Julong, a Chinese scholar, initiated the grey system theory (GST) under the assumption that circumstantial information obtained by decision makers or researchers may be partially unknown, uncertain or incomplete. Grey Relational Analysis is a simple and accurate method of selecting factors for problems with unique characteristics. It is an effective tool to make system analysis, modelling, forecasting, and clustering (Tsai and Chang, 2003).

Salleuddin *et al.* (2008) conducted a study to utilize the Grey Relational Analysis to establish a ranking scheme called grey relational grade (GRG) that rank the order of grey relationship among dependent and independent factors. This scheme helped to select significant factors in multivariate series, where the GRG was rearranged according to the order of their magnitude.

Materials and Methods

CHAPTER III

MATERIALS AND METHODS

This chapter explains the methodology adopted for the performance comparison of selected active tillage tools on the basis of soil, machine and economical parameters. The methods followed to quantify and study the soil parameters related to tillage, machine parameters, performance parameters related with implement and tractor system, cost and data analysis are also explained.

3.1 SELECTION OF EXPERIMENTAL PROGRAMME

3.1.1 Selection of tool

This research work focuses on study of the effect of active tillage tools on soil properties. Three tillage implements namely; rotavator, power harrow and spading machine having active tillage elements were selected for this study. The specifications of the implements and prime mover used were given in Appendix I.

3.1.2 Selection of research locations

Three locations in Malappuram district were selected for the field testing and assessment of soil properties using the selected implements. The locations were Mangattoor (10° 49′ 06″ N and 75° 59′ 18″ E), Instructional Farm, KCAET Tavanur(10° 51′ 25″ N and 75° 59′ 13″ E), and Tavanur(10° 50′ 20″ N and 75° 59′ 23″ E). The locations were renamed as Field F1, Field F2 and Field F3 respectively.

Generally tillage machineries give best performance result in rectangular fields. Rectangular sections of the location were selected as the experimental plot. All the locations selected were fallow paddy fields after harvest. The plot does not have any previous tillage treatment after the last crop harvested. The size of each field where the implements were operated is given in Table 3.1

Table 3.1 Size of experimental plot

Field	Size of plot in meters (Length × Width)		
	Rotavator	Power harrow	Spading machine
F1	132 × 52	108 × 47	99 × 46
F2	124 × 43	118 × 62	103 × 52
F3	117 × 39	101 × 54	111 × 39

3.1.3 Field operational pattern

Field capacity and field efficiency of an implement is affected by field operational pattern which is closely related to the shape and size of the field, the type and size of implement. By selecting appropriate field operational pattern, it is possible to reduce the non-working or unproductive time. Here, throughout the experiment, overlapping alteration pattern is followed.

3.1.4 Preliminary soil studies

In the preliminary studies, soil samples were collected from the respective research locations in order to determine various soil properties. Five set of readings were recorded from each test plot regarding soil resistance and bulk density and mean value is taken as observation. Five samples of soil were collected from each of the three research plot and were used to analyse the soil type and moisture content.

Soil physical properties such as soil texture, bulk density and moisture content were assessed at soil mechanics laboratory, KCAET Tavanur using standard instruments and techniques.

3.1.5 Experimental Design

The experiment was completely randomized block design with three fields (Field F1, Field F2 and Field F3), three implements (Rotavator, Power Harrow and Spading Machine) and three engine speeds (E1 = 1200, E2 = 1600 and E3 =

2000 RPM). Each implement was operated in three fields and the various soil properties and machine parameters were recorded.

3.2 DETERMINATION OF SOIL PROPERTIES

The soil condition was assessed by assessment of soil properties like moisture content, soil texture, bulk density, soil penetration resistance, soil inversion and soil pulverization. These soil data were recorded from five randomly selected different locations for each plot and calculations were made using standard procedures as explained in following sub sections.

3.2.1 Soil moisture Content

Moisture content of the soil was computed on dry weight basis. It is the amount of water present in the soil. It can be calculated by drying the soil in an air oven at 105 °C for 24 hours, and the moisture content was expressed as a percentage of the mass of dry soil. Five soil samples from different location of the same test plot was collected from each test plots and these were oven dried at 105 °C for 24 hours untill they attained constant weight. The moisture content (dry basis) was calculated using the following formula:

$$W = \frac{M_W}{M_S} \times 100 \qquad (3.1)$$

where,

W = moisture content (dry basis), per cent

M_W = mass of water, g

M_S = mass of dry soil, g

3.2.2 Particle Size Distribution (Soil Texture)

Soil texture is an inherent property of the soil. Soils occurring in nature are composed of different percentage of sand, silt and clay size particles. Soil classification of composite soils exclusively based on the particle size distribution is known as textural classification. The textural class of the soil is determined, based on the relative proportion of size of soil separates, using the soil textural triangle. The particle size distribution analysis helps to determine the proportions (by mass), of the different sizes of particles quantitatively, present in a soil thus defining the soil texture. The best known textural classification is the triangular classification of US Public Roads Administration. In order to get the particle size, the soil sample to be analysed was dried under shade. Then it is passed through 2mm, 0.2 mm, 0.002 mm sieves. According to the percentage of soil particle, the texture was found from the textural triangle (Fig. 3.1).

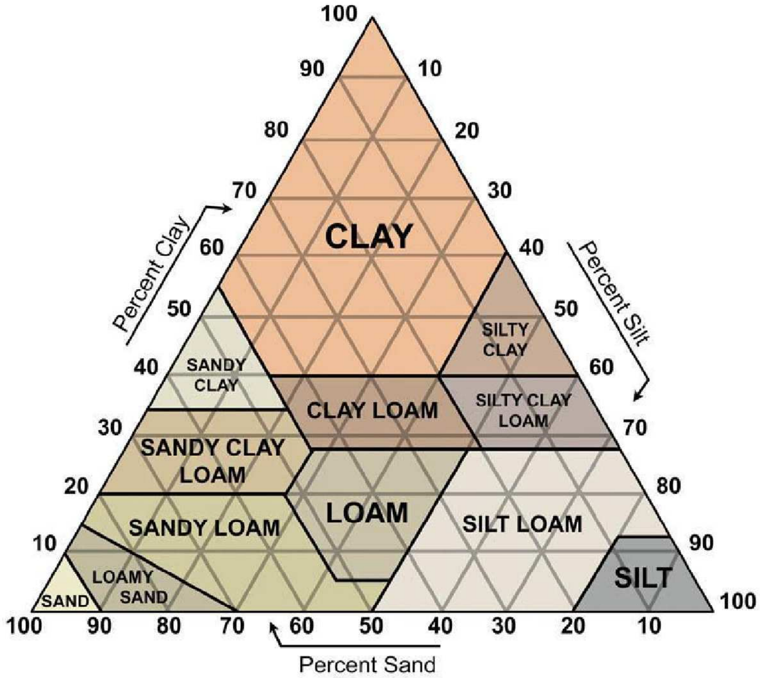

Fig. 3.1 Textural triangle for determination of particle size

3.2.3 Bulk Density

The bulk density of soil is an indicator of soil compaction. It is the weight of soil divided by its total volume. Higher bulk densities tend to restrict plant root growth. For the analysis, the bulk density is measured in dry basis, the dry weight of soil in unit volume of core cutter. The apparatus used for measuring bulk density consisted of a hollow cylindrical steel core cutter, a dolly which fit on top of the core cutter, a rammer with a MS foot and a solid MS staff. Bulk density was measured as per IS: 2720 (Part XXIX), 1975. The inner volume of the core was calculated and weight of the empty core was noted. The cutter was placed over the soil, the dolly placed exactly above on it and the core cutter was vertically rammed down to the soil using the rammer. The core was then dug out from the soil using a spade or knife, without rocking it and allows some soil to project from the lower end of the core cutter. Then the excess soil protruding out from the ends of core was trimmed off. The weight of the core cutter with soil was recorded. Then a representative sample of soil is taken from this and it was oven dried in order to find its moisture content and dry density.

The bulk density (γ_b), which the wet soil weight per cubic centimetre, was calculated as

$$\gamma_b = \frac{W_s - W_c}{V_c} \tag{3.2}$$

where,

W_s = weight of soil and core cutter, g

W_c = weight of empty core, g

V_c = volume of the core, cm^3

The dry bulk density (γ_d) is calculated as follows:

$$\gamma_d = \frac{100\ \gamma_b}{100 + W} \tag{3.3}$$

where,

γ_b = wet bulk density, g cm^{-3}

W = moisture content (dry basis), per cent

Bulk density values were determined for five soil samples each, collected from different locations of the same plot which is selected randomly, and the mean value was taken.

Fig. 3.2 Determination of soil bulk density by core cutter method

3.2.4 Soil Penetration Resistance (Cone index)

Soil penetration resistance is an indicator of compaction of the soil. Cone penetrometer is used to measure the cone index of soil. The cone index, an index of soil strength, is defined as the force per unit base area, expressed in kg cm^{-2} or MPa, required to push the penetrometer through a specified soil depth (ASABE, 2011a, b). It measures the force required to insert a cone into the soil. The cone penetration resistance over a depth range has been termed as cone index (ASAE, 1999). The cone penetrometer, with a standard SS cone of 30° cone angle and a base area of 6.45 cm^2 was used for the study. In order to use cone penetrometer, proving ring was attached with dial gauge and handle to the rod. It is necessary to adjust the zero of the dial gauge and calibrate the proving ring. To take measurement of soil strength profile the penetrometer was held vertically over the soil surface where the reading is to be taken. It was gently pushed into the soil at a penetration speed of about one cm s^{-1}. The deflection values were recorded against each depth of penetration, up to a maximum depth possible, using the base of cone as reference point. The initial reading was taken when the base of the cone was level with the soil surface. The subsequent readings were observed at incremental depths of 25 mm.

The cone index (CI), in kg cm^{-2}, was calculated using the following equation (Tada, 1987)

$$CI = \frac{(F + W)}{A} \tag{3.4}$$

where,

F = applied force, kg_f

W = weight of the cone penetrometer, kg_f

A = base area of the cone, cm^2

Fig. 3.3 Measurement of penetration resistance using cone penetrometer

3.2.5 Soil inversion

The soil inversion refers to how much amount of furrow slice is inverted. Inversion characteristics can be measured by the weed count method. A square frame of 100 cm × 100 cm is used for this. The ring is placed in the test plot. The number of weeds / stubbles present inside the ring before and after the tillage operation was counted. This is done randomly in five locations of each test plot. The soil inversion in percentage basis is expressed as:

$$\text{Soil inversion} = \frac{W_B - W_A}{W_B} \times 100 \qquad (3.5)$$

where

W_B = Number of weeds present per unit area before the operation

W_A = Number of weeds present per unit area after the operation

Fig. 3.4 Determination of soil inversion

3.2.6 Soil pulverization

Soil pulverization indicates the general fragmentation of soil mass resulting from the action of tillage forces. It is the process of breaking the soil into small aggregates resulting from the action of tillage forces. The mean mass diameter (MMD) of these soil aggregates is considered as the index of soil pulverization and it was evaluated by using a set of standard test sieves using RNAM test code. The soil samples were collected from an area of 15 cm × 15 cm and to the depth of operation of the implement, randomly from three different places of the same test plot. Soil sample was passed through a set of different size mesh sieves. The sieve analysis of the soil samples was done in soil mechanics laboratory, KCAET

Tavanur, for the calculation of mean mass diameter of the soil. For the study of clod size distribution, a set of 6 sieves, arranged in descending order viz; 11.2, 8.0, 5.6, 4.75, 4.0, 2.8, 2.0 mm and pan (IS: 460 - 1962) was used. Mechanical sieve shaker is used and is operated for 20 minute and soil collected over each sieve was weighed. The mean soil clod diameter was calculated. Smaller the mean mass diameter, higher the index of pulverization, thus, better the level of pulverization.

Table 3.2 Sieve sizes and diameter of soil

Size of aperture (mm)	Dia. of soil passing the upper sieve and retained on the next small aperture sieve (mm)	Representative dia. of soil (mm)	Weight of soil (Kg)
2	< 2	1	A
2.8	2 - 2.8	2.4	B
4.0	2.8 - 4.0	3.4	C
5.6	4.0 - 5.6	4.8	D
8.0	5.6 - 8.0	6.8	E
11.2	8.0 - 11.2	9.6	F

$$MMD = \left(\frac{1}{W}\right)(A + 2.4B + 3.4C + 4.8D + 6.8E + 9.6F + XS) \quad (3.6)$$

where,

MMD = Mean mass diameter

s = Mean of measured dia. of soil clods retained on the largest aperture sieve

W = Total mass of soil = A + B + C + D + E + F

A = Soil mass which having pass through 2.0 mm sieve

B = Soil mass which having retained between 2.0 - 2.8 mm sieve

C = Soil mass which having retained between 2.8 - 4.0 mm sieve

D = Soil mass which having retained between 4.0 - 5.6 mm sieve

E = Soil mass which having retained between 5.6 - 8.0 mm sieve

F = Soil mass which having retained between 8.0 - 11.2 mm sieve

X = Soil mass which having retained in 11.2 mm sieve

Fig. 3.5 Determination of MMD using sieve analysis

3.3 DETERMINATION OF PERFORMANCE EVALUATION PARAMETERS

3.3.1 Speed of Operation

The speed of operation was measured by marking a specified distance, 20 m, in the field by fixing two poles and observing the actual time taken to cover this distance with the help of a stop watch. The easy visible point of the machine was selected for measuring the time. The speed in km h^{-1} was from an average of five readings.

$$S = \frac{D}{t} \times \frac{18}{5} \qquad (3.7)$$

where,

S = Speed in km h^{-1}

D = distance travelled, m (20 m)

t = time taken, s

3.3.2 Width of cut

The width of cut is the measured composite width in the direction perpendicular to the direction of travel. The width of cut was measured at five equidistant places in the direction of travel for obtaining the average working width.

3.3.3 Depth of cut

Depth of cut of an implement is the vertical distance between furrow sole and ground level. In order to obtain accuracy, the depth was measured at five random places and its average was taken.

3.3.4 Fuel Consumption

Fuel consumed by the tractor during tillage operations was measured using the fuel consumption measuring setup which is fixed on the tractor. The setup consist of a graduated cylindrical jar of 2 litre capacity as auxiliary fuel tank, a supply pipe connected in between on-off valve of fuel tank and fuel pump and an overflow pipe connected in between fuel injectors and fuel tank to allow fuel overflow back into the graduated cylinder. The graduated cylinder was filled to its full capacity before and after operation. The fuel consumed during each operation, time of operation and area covered were noted to arrive at the fuel consumption in litre per hour as well as litre per hectare.

Fig. 3.6 Fuel consumption measuring setup

3.3.5 Wheel Slip

The distance travelled by the tractor in a given number of rotations of the drive wheel decreases when the wheel slips, that is number of revolutions increases. Tractor drive wheel normally slip in all field operations (Mehta *et al.,* 2005). In order to calculate the wheel slip, a fixed distance is marked on the field and a visible mark was made on the periphery of the drive wheel at a point. The number of revolutions of the tractor drive wheel taken to cover this distance is counted and recorded under load and no load conditions. The wheel slip was calculated as follows:

$$\text{Wheel slip (percentage)} = \frac{N - N_0}{N} \times 100 \tag{3.8}$$

where,

N_0 = number of rotations of the drive wheel at no load condition

N = number of rotations of the drive wheel at load condition

The readings were noted from all the test plots and an average of five readings were taken to calculate the wheel slip.

3.3.6 Energy requirement

Energy requirement for a given tractor-implement system was calculated from the fuel consumed in a given time. Considering calorific value of diesel fuel as 45.5 MJ kg^{-1} and specific gravity of 0.832, energy requirement was calculated as:

$$E = F \times 45.5 \times 0.832 \qquad (3.9)$$

where,

E = energy requirement, MJ ha^{-1}

F = fuel consumed per unit time, *l* ha^{-1}

3.3.7 Theoretical field capacity (TFC)

It is the rate of field coverage of the implement, based on its 100 per cent of the time at the rated speed and covering 100 per cent of its rated width. It was calculated as:

$$TFC = \frac{W \times S}{10} \qquad (3.10)$$

where,

TFC = theoretical field capacity, ha h^{-1}

W = width of implement, m

S = speed of operation, km h^{-1}.

3.3.8 Actual field capacity (AFC)

It is defined as the actual area covered by the implement, based on its time consumed for real work and that lost for other activities such as turning, adjustments etc. It was calculated as:

$$AFC = \frac{A}{T_t} \qquad (3.11)$$

where,

AFC = Actual field capacity, ha h^{-1};

A = Actual area covered, ha

T_t = total time required, h.

3.3.9 Field efficiency (FE)

It gives an indication of time lost in the field and the failure to utilize the working width of the implement. It is expressed in percentage and was calculated as:

$$FE = \frac{EFC}{TFC} \times 100 \quad (3.12)$$

3.4 TILLAGE PERFORMANCE INDEX

Comparison of tillage performance was done by tillage performance index (TPI) (Sahay *et al.*, 2009; Prem *et al.,* 2017). It is expressed as proportional to the volume of soil tilled in unit time (V_s) and the percentage soil inversion (S_i); and inversely proportional to the mean weight diameter of soil clods (D_{MW}), and fuel consumption (F_e).

$$TPI = K \times \frac{V_S \times S_i}{D_{MW} \times F_e} \quad (3.13)$$

TPI = tillage performance index

V_S = volume of soil tilled in unit time, m^3 h^{-1}

S_i = soil inversion, percentage

D_{MW} = mean weight diameter of soil clods, mm

F_e = fuel consumption, MJ ha^{-1}

K = constant

While comparing the TPI of machine with different settings, the proportionality constant K can be taken as unity.

$$F_e = \frac{F_C \times C_V \times 0.832}{EFC} \quad (3.14)$$

$$V_S = EFC \times d \times 10000 \quad (3.15)$$

d = depth of operation, m

F_C = Fuel consumption, l h^{-1}

EFC = Effective field capacity, ha h^{-1}

C_V = Calorific value of fuel, MJ kg^{-1} = 45.5 MJ kg^{-1}

Specific gravity of diesel fuel = 0.832

3.5 ECONOMICS OF OPERATION

In order to evaluate the effectiveness of the treatments and to ascertain the most remunerative treatment, the cost incurred for the seed bed preparation under each treatment (Rs ha^{-1}) were computed as per IS 9164:1979.

The cost of using farm machinery consists of expenses for ownership and operation, and overhead charges. Generally the cost analysis is divided under two heads. Ownership costs which are independent of use and are often called as fixed costs. Costs for operation vary directly with use and are referred to as variable costs.

3.5.1 Fixed cost

a. *Depreciation*

This cost reflects the reduction in value of a machine with use and time. The following formula was used as per straight-line method.

$$D = \frac{P - S}{L} \quad (3.16)$$

where,

D = Depreciation cost, average per year

P = Purchase price of machine

S = Salvage value of machine, 5 per cent of purchase price

L = useful life of machines in years.

Depreciation cost per hour can be calculated by dividing D by the number of expected working hours (H) in a year.

The useful life of tractor is 10 years with 1000 expected working hours per year. In case of tillage implements like rotavator, the expected life is 8 years with 300 working hours per year.

b. ***Interest on investment***

Annual charge of interest was calculated on the basis of actual rate of interest payable. If this information is not available, 12 per cent of average purchase price should be taken. Average purchase price was calculated as:

$$A = \frac{(P + S)}{2} \qquad (3.17)$$

Where,

A = Average purchase price

P = Purchase price of machine

S = Salvage value of the machine

c. ***Housing***

Housing cost was calculated on the basis of the prevailing rates of the locality. The housing cost should be calculated on the basis of 1.5 per cent of the average purchase price (A) of the machine.

d. ***Insurance and Taxes***

Insurance and annual tax charge was taken on the basis of the actual payment but roughly speaking, it may be taken on the basis of 2 per cent of the average purchase price (A) of the machine.

3.5.2Operating (variable) cost

a. *Fuel cost*

Fuel cost was calculated on the basis of fuel consumption in the tractor. Fuel consumption of a machine depends on the size of power unit and operating conditions.

b. *Oil*

Charges for oil were calculated on the actual consumption in while the machine is working. In case of the consumption data is not available, it was taken as 2.5 to 3 per cent of the fuel consumption on volume basis.

c. *Repair and maintenance*

Repair and maintenance expenditures were necessary to keep a machine operable due to wear, part failures, accidents etc. Normal wear deterioration is directly related to use, and repair costs are assumed to be typical variable costs. Maintenance costs, primarily those related to lubrication, are directly related to use also.

The total accumulated repair and maintenance costs (TAR) at any point in a machine's life can be estimated as per IS 9164:1979 (4.3.1) and the repair cost was 3.2 – 14.5 per cent of the purchased price for tractors and for the implement was 6 – 14.2 per cent of the purchased price.

d. *Wages and Labour charges*

In performing a custom work, the cost of at least one operator has to be included. Wages were calculated on the basis of actual wages of the workers. Average cost per hour may be computed by dividing the total cost by the number of hours the operator has performed the work. This cost will be higher than the average per hour work on the farm because part of the time will be used for travelling, interruptions and moving machines from one place to another, and this was not paid directly by the customers.

3.6 STATISTICAL ANALYSIS

The statistical analysis of the data obtained by the experiments was done using two-way analysis of variance (ANOVA) for the completely randomized block design. The software used for the statistical computations was RStudio (base and agricola packages). Comparisons among treatment means, when significant, were done using Duncan's Multiple Range Test (DMRT) at 5 per cent significance level.

3.7 GREY RELATIONAL ANALYSIS

It is a statistical tool used for the optimization of parameters considering multiple performance characteristics. The approach is based on the level of similarity and variability among the factors for establishing their relation. The process parameters which are closely correlated with the performance parameters are firstly finding out and the normalized experimental results of the performance parameters are then introduced to calculate the coefficient and grades according to GRA. Optimized process parameters simultaneously leading to the optimum value of process parameters will then be verified through a confirmation experiment. The details of the procedures are explained in the following sub sections.

a. Data pre-processing

The data pre-processing was usually required when the ranges and units in one process parameter data sequence differ from the others. Data pre-processing was also necessary when the sequence scatter range is too large, or when the directions of the target in the sequence are different. Therefore it is a process of changing the original sequence to a comparable sequence. For this purpose, the experimental results are normalized in the range between zero and one. There are various methodologies of data pre-processing available for the GRA depending on the characteristics of data sequence. The procedure for data normalization is given below.

- Identification of the performance characteristics and process parameters to be evaluated.
- Determination of the number of levels for the process parameters and appropriate orthogonal array and assigning the process parameters to array.
- Conducting the experiments based on the arrangement of the array and normalization of the experimental results of process parameters
- Performing the grey relational analysis and calculation of grey relational coefficient.
- Calculating the grey relational grade by averaging the grey relational coefficients.
- Selecting the optimal levels of process parameters.

The data normalization will give the dominant response in performance which decides the optimization of performance under consideration. For the "larger-the-better" characteristic, the original sequence can be normalized as follows:

$$x_i^*(k) = \frac{x_i(k) - \min x_i(k)}{\max x_i(k) - \min x_i(k)} \quad (3.18)$$

If the expectancy is "smaller-the-better", then it can be normalized as:

$$x_i^*(k) = \frac{\max x_i(k) - x_i(k)}{\max x_i(k) - \min x_i(k)} \quad (3.19)$$

where,

$x_i^*(k)$ = sequence after the data pre-processing.

$x_i(k)$ = original sequence.

i = 1,2,............,m

k = 1,2,............,n

m = number of experimental data items

n = number of parameters

The deviation sequence ($\Delta_{0i}(k)$) of the reference sequence $x_0^*(k)$ and the comparative sequence $x_i^*(k)$ is computed as

$$\Delta_{0i}(k) = | x_0^*(k) - x_i^*(k) | \tag{3.20}$$

The minimum value of $\Delta_{0i}(k)$ is Δ_{min} and maximum value of $\Delta_{0i}(k)$ is Δ_{max}, and their values will be zero and one respectively in an analysis.

b. Computation of Grey Relational Coefficient and the Grey Relational Grade

The grey relational coefficient ξ_i (k) can be calculated using the pre-processed sequence. It expresses the relationship between the normalized reference series and normalized comparative series. The grey relational coefficient can be calculated as follows:

$$\xi_i (k) = \frac{\Delta_{\min} + \zeta\Delta_{\max}}{\Delta_{0i}(k) + \zeta\Delta_{\max}} \tag{3.21}$$

where,

$\Delta_{0i}(k)$ is the deviation sequence of the reference sequence $x_0^*(k)$

$x_i^*(k)$ is the comparative sequence

ζ is the distinguishing or identification coefficient. If all the parameters are given equal preference, then the value of ζ is taken as 0.5.

The overall evaluation of the multiple performance characteristics is based on the grey relational grade. It is the numerical measure degree of influence that the comparability sequence can exert over reference sequence. Grey relational grade is calculated by averaging the grey relational coefficient corresponding to each performance characteristic. The value will always between zero and one. Grey relational grade (γ_i) is computed using the formula:

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n} \xi_i(k) \tag{3.22}$$

Where γ_i is the grey relational grade for the i^{th} experiment and n is the number of performance characteristics. The higher grey relational grade represents that the corresponding experimental result is closer to the ideally normalized value. Thus, larger grey relational grade is desired for optimum performance.

Fig.3.7 Rotavator operation

Fig. 3.8 Power harrow operation

Fig. 3.9 Spading machine operation

Results and Discussion

CHAPTER IV

RESULTS AND DISCUSSION

This study primarily focuses on the comparative assessment of physico-mechanical properties of soil by the operations of longitudinal, vertical and transverse axis active tillage tools and effect of their operating parameters on soil properties. This chapter describes the results of the experiments conducted with selected active tillage implements for studying their effect on various soil properties and tilth condition. It includes soil properties of the selected research locations, various performance parameters, variation of soil properties with respect to experimental conditions and their effect on tillage.

4.1 VARIATIONS IN SOIL PROPERTIES

4.1.1 Initial soil properties

The initial soil properties such as bulk density and moisture content of the upper layer were measured. The particle size analysis was also carried out as described in section 3.2.2 and the sand, silt and clay fractions were determined. These were plotted on the USDA soil texture triangle to obtain the soil type. The data are given in Appendix II. The values of different initial soil properties are presented in Table 4.1.

Table 4.1 Initial soil properties in test fields

Field	MC	BD	Particle size distribution (per cent)			Soil type
	per cent	g cm^{-3}	Sand	Silt	Clay	
F1	2.08	1.68	62.88	25.26	11.86	Sandy loam
F2	16.89	1.76	60.92	24.87	14.21	Sandy loam
F3	11.58	1.73	61.28	24.52	14.20	Sandy loam

4.1.2 Bulk density

Bulk density is a soil physical property, which can be considered as the major factor influencing quality of tilth. Tillage operations are aimed in reducing the bulk density and in general, tillage operations reduce bulk density as tillage increases the pore space in soil. As discussed under section 3.1.1, three active tillage implements were operated in three different fields with different operating conditions for studying the variations in soil properties. The dry bulk densities of soil before and after the operations were estimated using the procedure explained in section 3.2.3. It was observed that the reduction in the bulk density was in the range of 9.09 to 32.77 per cent in a single pass operation of these implements.

The bulk density of soil before operation in the three field namely F1, F2, F3 were 1.68, 1.76 and 1.73 g cm^{-3} respectively. The maximum percentage of reduction in bulk density was observed in field F2 with power harrow operation. The minimum percentage of reduction in bulk density was observed while working with rotavator in field F2. The final bulk density of tilled soil was in the range of 1.6 to 1.13 g cm^{-3} which is found similar as the optimum bulk density described by Hula and Prochazkova (2008) and the same results was obtained in the experiment by Neudert and Smuty (2017).

The change in bulk density by the use of different implements and the effect of operating parameters on bulk density are discussed in following sub sections.

4.1.2.1 *Rotavator*

The change in bulk density as percentage of initial value was analysed to the study the effect of engine speed on bulk density. It was observed that the percentage change in bulk density was increased with the increase in engine speed in fields F1 and F2, whereas in field F3 the trend shown was reverse. Percentage change in bulk densities in different fields at different engine speeds are depicted in Fig 4.1. The reduction in bulk densities obtained in the different fields is presented in Table 4.2 and Fig 4.2.

Table 4.2 Variation of bulk density by rotavator operation

Engine rpm	E1			E2		E3	
Field	Bulk density						
	Before ($g\ cm^{-3}$)	After ($g\ cm^{-3}$)	Change (%)	After ($g\ cm^{-3}$)	Change (%)	After ($g\ cm^{-3}$)	Change (%)
F1	1.68	1.45	13.76	1.24	25.95	1.13	32.77
F2	1.76	1.6	9.09	1.54	12.50	1.50	14.77
F3	1.73	1.37	20.81	1.47	15.03	1.53	11.56

The minimum bulk density after tillage operation was observed in field F1, 1.13 $g\ cm^{-3}$ and this field also recorded the maximum change in bulk density, 32.77 per cent. The maximum value of bulk density after rotavator operation, 1.6 $g\ cm^{-3}$ was noted at field F2 with engine speed E1 with change of 9.09 per cent, which is the lowest percentage change among the experiment.

The data obtained from the experiment was statistically analysed to study the variations within the field, between the fields and effect of engine speed. Bulk densities estimated from five different randomly selected points in each field was used for the analysis. The analysis of variance for percentage change in bulk density is shown in Table 4.3.

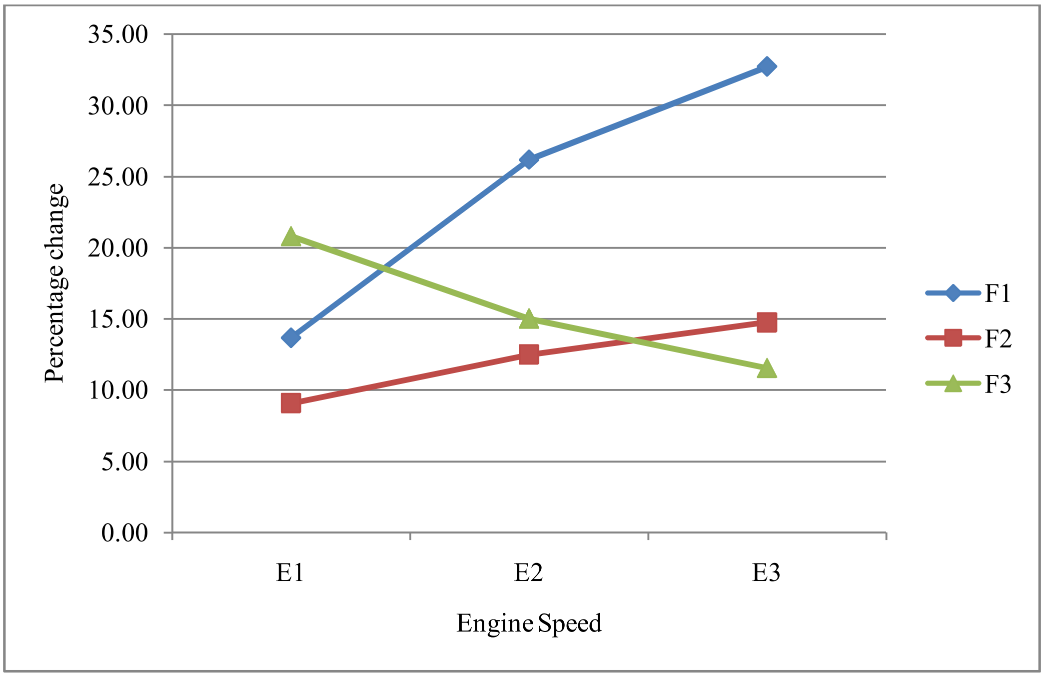

Fig. 4.1 Percentage change in bulk density in rotavator operation

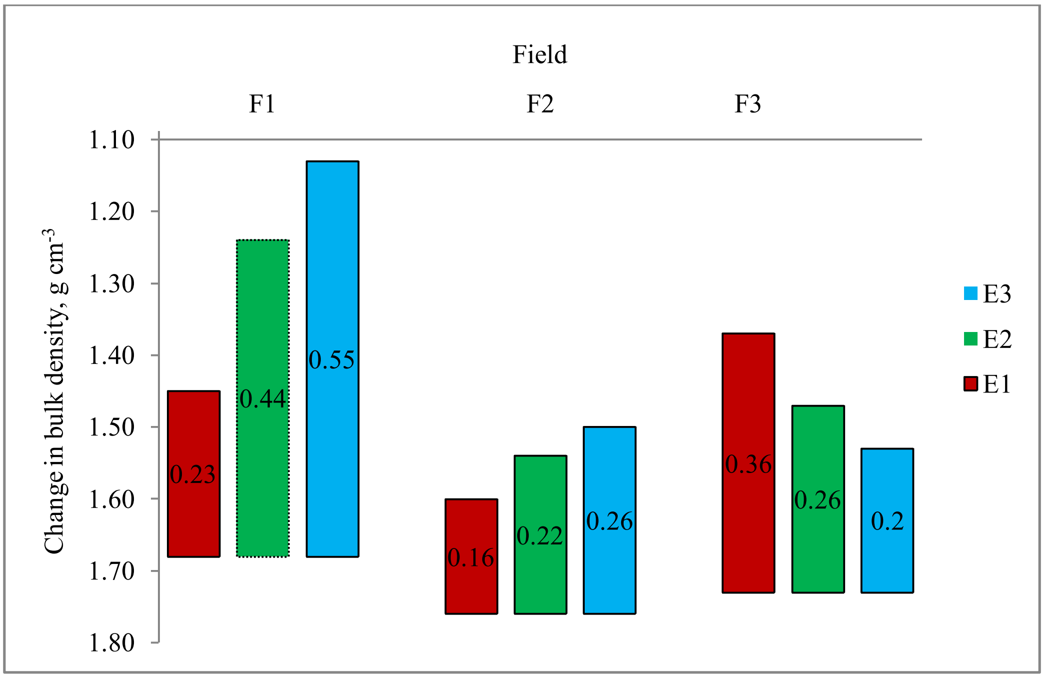

Fig. 4.2 Reduction in bulk density with respect to rotavator operation

Table 4.3 Analysis of variance for change in bulk density in rotavator operation

Source of variation	DoF	SS	MS	F-value	Significance level
Within field	4	15	3.70	0.11	0.98^{NS}
Between field	2	1151	575.60	16.72	7.31e-06 **
Engine Speed	2	206	103.00	2.99	0.06^{NS}
Residuals	36	1239	34.40		
Total	44	2611			

**Significant at 1 per cent level   NS: Non-significant

The analysis of variance table indicated that the variation within the field is non-significant, which shows that the change of bulk density within a field is uniform. Similarly the effect of engine speed also is non-significant, thus the engine speed does not significantly influence the change in bulk density.

The field conditions significantly affect the percentage change in bulk density from which it can be concluded that field conditions and initial bulk density influence the has a major effect on the quantum change in bulk density. Moisture content and vegetative matter on the soil can be considered as two major factors which defines the field conditions. The moisture content in the different fields were analysed and it was found that it significantly varied with respect to fields. The corresponding table for analysis of variance is provided as Table V(i) in Appendix V. This indicates that water content may be one of the major factor which influence the quantum of change in bulk density (Agodzo and Adama, 2004). The analysis of variance for vegetative matter present on the field prior to tillage is provided as Table V(ii) in Appendix V which indicates that this may be another important field condition which influences the quantum of change in bulk density.

4.1.2.2 *Power Harrow*

The operation of power harrow in different fields at various engine speeds gave similar trend as rotavator. The field operation at various engine speeds decreased the soil bulk density in the range of 1.46 to 1.18 g cm^{-3}. The change in bulk density as percentage of initial value was analysed to the study the effect of engine speed on bulk density. The value was increased with the increase in engine speed in fields F1 and F2, whereas in field F3 the change decreased. Percentage change in bulk densities in different fields at different engine speeds are shown in Fig. 4.3. The variation of bulk density with fields in different engine speeds is given in Table 4.4 and reduction is shown in Fig. 4.4.

Table 4.4 Variation of bulk density by power harrow operation

Engine rpm		E1		E2		E3	
Field	Bulk density						
	Before (g cm^{-3})	After (g cm^{-3})	Change (%)	After (g cm^{-3})	Change (%)	After (g cm^{-3})	Change (%)
F1	1.68	1.43	14.94	1.27	24.31	1.19	29.22
F2	1.76	1.46	17.05	1.24	29.55	1.18	32.95
F3	1.73	1.41	18.50	1.42	17.92	1.45	16.18

The low bulk density value of 1.18 g cm^{-3} was observed in field F2 with engine speed E3 with highest percentage change of 32.95 per cent. The higher bulk density was noted as 1.46 g cm^{-3} in field F2 with engine speed E1 with a change of 17.05 per cent. The lowest change in bulk density was recorded in field F3 was 16.18 per cent, with engine speed E3 and the bulk density value observed there is 1.45 g cm^{-3}.

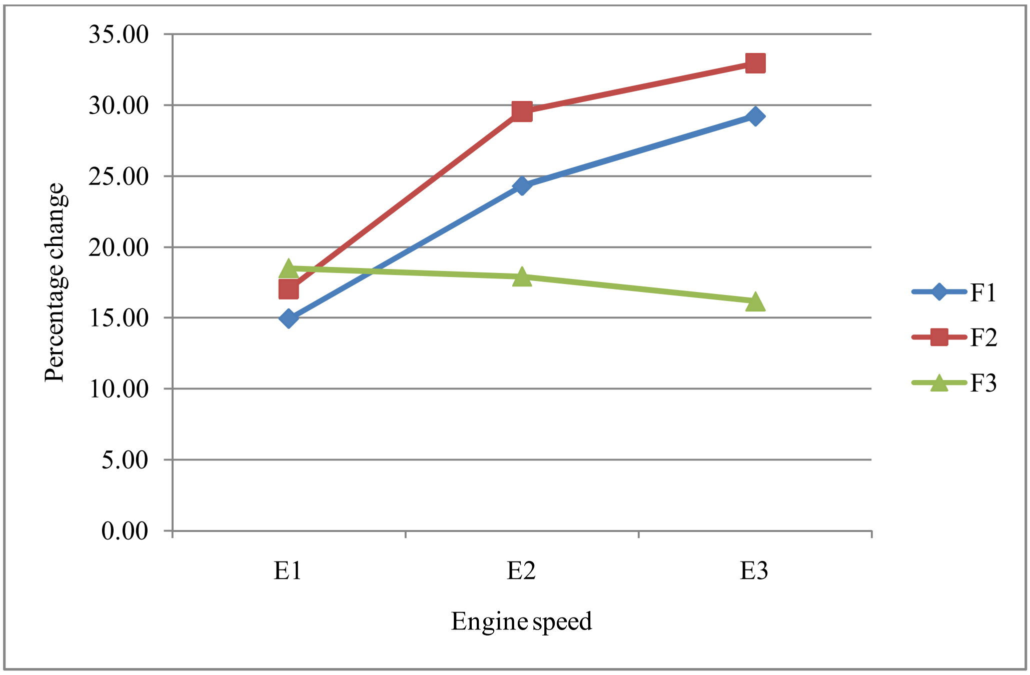

Fig. 4.3 Percentage change in bulk densities in power harrow operation

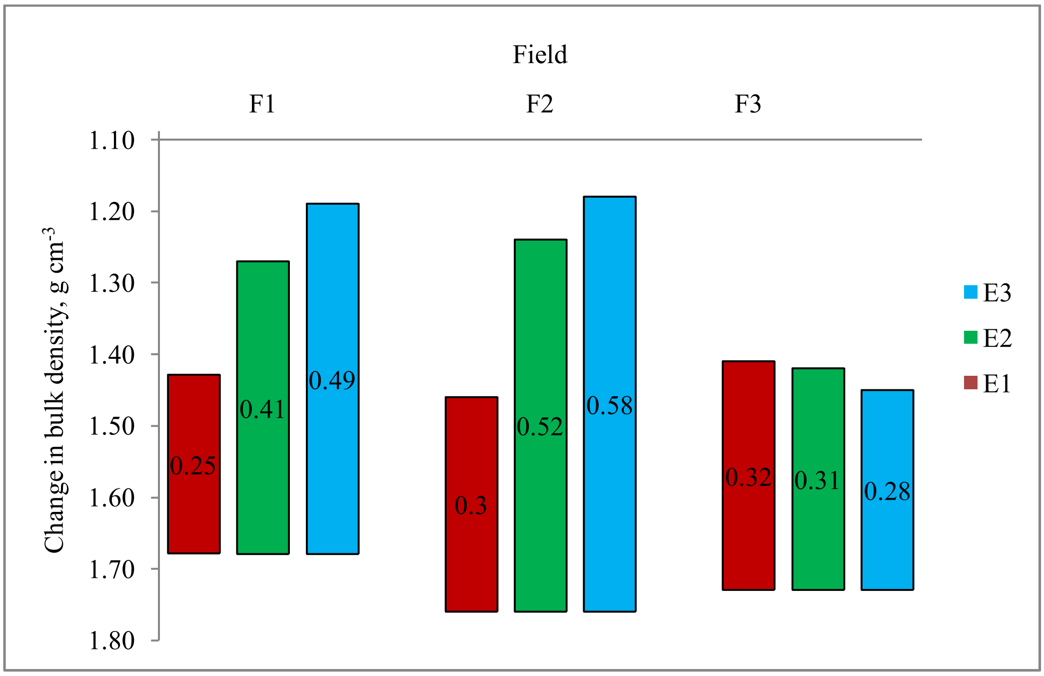

Fig. 4.4 Reduction in bulk density with respect to power harrow operation

The statistical analysis of data obtained from the experiment was done in order to study the variations within the field, between the fields and effect of engine speed. Bulk densities estimated from five different randomly selected points in each field was used for the analysis of variation within the field. The analysis of variance for percentage change in bulk density is shown in Table 4.5.

From analysis of variance table it was observed that the variation within the field is not significant and this indicates that the change of bulk density within a field is uniform. The effect of engine speed is found significant, thus the engine speed influence the change in bulk density. Similarly the field conditions also have significant effect on the percentage change in bulk density. Hence it was assessed that field conditions, initial bulk density and engine speed have influence the change in bulk density. Makange and Tiwari (2015), in their research works also had concluded that while using rotary harrow, the engine speed has significant influence on bulk density. The moisture content in the different fields and vegetative matter present on the field prior to tillage were analysed and it was found that they significantly varied with respect to fields. The corresponding table for analysis of variance is provided as Table V(i) and Table V(ii) in Appendix V. This indicated that moisture content and vegetative matter may be major factors for change in bulk density with respect to field conditions (Ahmadi and Mollazade, 2009).

Table 4.5 Analysis of variance for change in bulk density in power harrow operation

Source of variation	DoF	SS	MS	F-value	Significance level
Within field	4	9.50	2.40	0.14	0.96^{NS}
Between field	2	601.80	300.90	17.98	3.85e-06 **
Engine Speed	2	693.30	346.70	20.72	1.03e-06 **
Residuals	36	602.50	16.70		
Total	44	1907.10			

**Significant at 1 per cent level NS: Non-significant

Duncan's multiple range test (DMRT) was used for comparing the change in bulk density at various engine speeds. The result of the test is presented in Table 4.6.

Table 4.6 DMRT for change in bulk density with respect to engine speed in power harrow operation

Engine Speed	Change in bulk density (per cent)
E3	26.03[a]
E2	23.92[a]
E1	16.85[b]

The results of DMRT indicated that engine speed E1 produced the lowest change in bulk density and this was significantly less compared to other two engine speeds. The change in bulk density obtained at engine speeds E2 and E3 are almost similar. Hence it may be concluded that operations of power harrow at higher engine speeds (E2, E3) gave maximum change in bulk density.

4.1.2.2 *Spading machine*

The change in bulk density as percentage of initial value was used in the case of spading machine also for studying the effect of engine speed. It was observed that the percentage change in bulk density was first decreased with the increase in engine speed, and then increased when engine speed further increased in fields F1 and F2, whereas in field F3 the trend shown was reverse. Percentage change in bulk densities in different fields at different engine speeds are depicted in Fig. 4.5. Variation of bulk densities with different engine speeds at various fields are presented in Table 4.7 and reduction in bulk density was shown in Fig. 4.6.

Table 4.7 Variation of bulk density by spading machine operation

Engine rpm	E1			E2		E3	
Field	Bulk density						
	Before (g cm^{-3})	After (g cm^{-3})	Change (%)	After (g cm^{-3})	Change (%)	After (g cm^{-3})	Change (%)
F1	1.68	1.28	23.87	1.23	27.00	1.45	13.56
F2	1.76	1.43	18.75	1.46	17.05	1.31	25.57
F3	1.73	1.25	27.75	1.49	13.87	1.36	21.39

The highest change of bulk density value 27.75 per cent was observed at engine speed E1 in field F3, with a bulk density of 1.25 g cm^{-3}. Lowest change was 13.56 per cent with a bulk density value of 1.45 g cm^{-3} obtained at engine speed E3 in field F1. The maximum value of bulk density after the operation of spading machine was 1.49 g cm^{-3} and was noted at field F3, and the minimum value of bulk density 1.23 g cm^{-3} was observed at field F1 with engine speed E2 with percentage change of 13.87 and 27.00 per cent respectively.

The data obtained from the experiment was analysed statistically and the results are presented in the Table 4.8.

Table 4.8 Analysis of variance for change in bulk density in spading machine operation

Source of variation	DoF	SS	MS	F-value	Significance level
Within field	4	23.30	5.83	0.17	0.95^{NS}
Between field	2	6.60	3.31	0.10	0.91^{NS}
Engine Speed	2	145.70	72.83	2.16	0.13^{NS}
Residuals	36	1216.70	33.80		
Total	44	1392.30			

NS: Non-significant

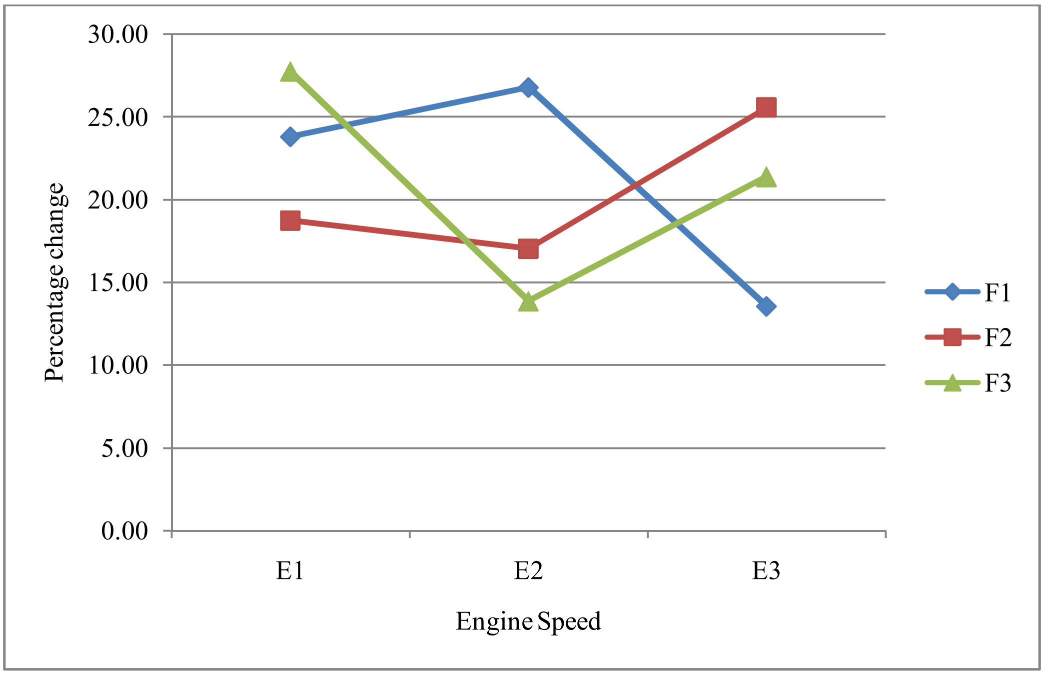

Fig. 4.5 Percentage change in bulk density in spading machine operation

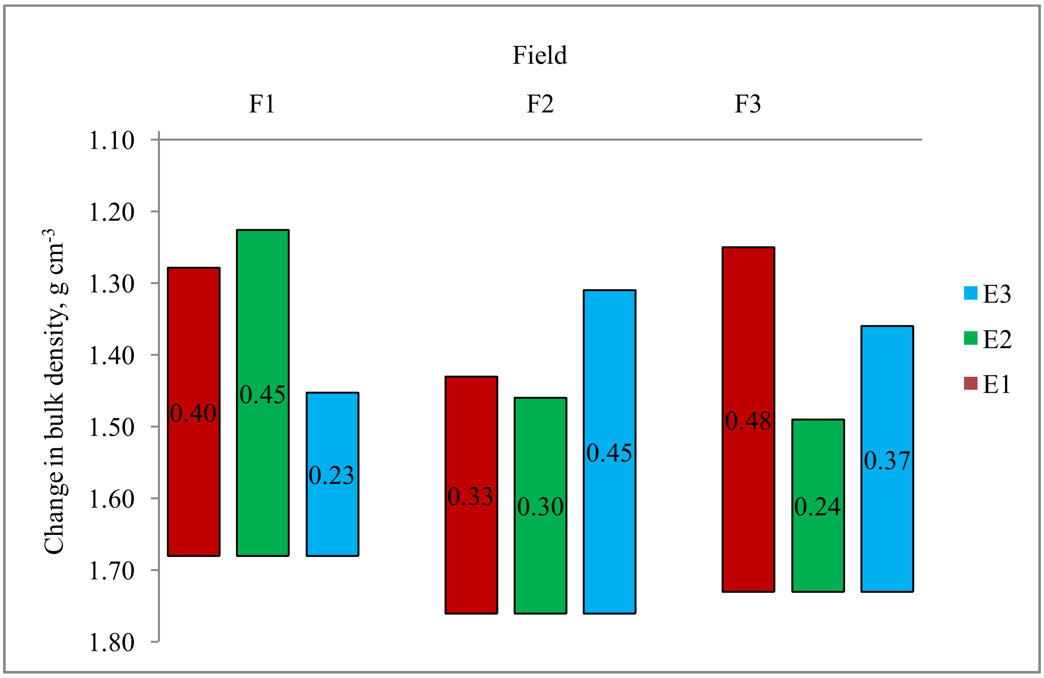

Fig. 4.6 Reduction in bulk density with spading machine operation

From analysis of variance table (Table 4.8), it was observed that the variation within the field is not significant and this indicates that the change of bulk density within a field is almost uniform. Similarly the effect of engine speed and between fields was found also not significant, thus it was concluded that field conditions, initial bulk density and engine speed have not influence the change in bulk density significantly. The change in engine speed does not make much change in forward speed of spading machine while comparing to other two implements in the experimental condition. This may be the reason for the insignificance of engine speed.

4.1.2.4 *Comparison of change in bulk density*

The comparative assessment of change in bulk density obtained by three active tillage implements was done by analysing the data obtained from experiment statistically. The results are presented in Table 4.9.

The analysis of variance table indicated that the variation of change in bulk density with different engine speeds and between the implements were significant. The change with respect to field conditions were found significant in the case of rotavator and power harrow and are already discussed in preceding sections. Although the engine speed has not significantly influenced the change in bulk density in the case of rotavator and spading machine operation, it had influenced significantly during operation of power harrow. This was also discussed in the previous section.

Table 4.9 Analysis of Variance for change in bulk density with respect to implements

Source of variation	DoF	SS	MS	F-value	Significance level
Fields	2	514	256.99	6.46	0.002**
Engine Speed	2	309	154.28	3.88	0.023*
Implements	2	576	287.88	7.24	0.001**
Residuals	128	5088	39.75		
Total	134	6487			

*Significant at 5 per cent level **Significant at 1 per cent level

It was observed that the type of implement used for operation has significant effect on percentage change in bulk density. The data is statistically compared using Duncan's multiple range test (DMRT) to find the influence of given active tillage implements and engine speed on amount of change in bulk density. The result obtained by DMRT is presented in Table 4.10 and Table 4.11.

Table 4.10 DMRT for change in bulk density with respect to implements

Implements	**Change in bulk density (per cent)**
Power harrow	22.26[a]
Spading machine	20.95[a]
Rotavator	17.38[b]

It can be observed from the table that the field operation with power harrow and spading machine gave similar results on change in bulk density with an average change of 22.26 per cent and 20.94 per cent respectively. The quantum of change in bulk density achieved by power harrow and spading machine was significantly higher than those obtained by using rotavator. This indicates, for obtaining higher change in bulk density, power harrow or spading machine can be used.

Table 4.11 DMRT for change in bulk density with respect to engine speed

Engine Speed	**Change in bulk density ($g\ cm^{-3}$)**
E3	21.96[a]
E2	20.35[ab]
E1	18.27[b]

The analysis of variance table also had indicated that the engine speed significantly effects percentage change in bulk density. From the previous sections, it was found that only in the case of power harrow, engine speed influences change in bulk density significantly. For both rotavator and spading machine this effect was not significant. So this significance in case of engine speed may attribute to power harrow. Further the DMRT table (Table 4.11) for comparison of mean values also indicates that the non-significance between pairs.

4.1.3 Soil pulverization (Mean mass diameter)

Mean Mass Diameter (MMD) of soil clods, which represents the index of soil pulverization is important soil property analysed to study tilth quality while considering tillage studies. The mean diameter of soil clods effects the root penetration and soil aeration. In general, tillage operations reduce MMD as tillage breaks and pulverize the soil clods. As discussed under section 3.1.1, three active tillage implements were operated in three different fields with different operating conditions for studying the variations in soil properties. The MMD of soil clods after each tillage treatment were estimated using the procedure explained in section 3.2.6, using standard test sieves.

The least MMD was observed in field F3 with rotavator operation and the value was 1.59 mm. The highest value was observed as 5.06 mm while working with spading machine in field F1. The optimum soil size for a good seed bed for seed germination was in the order of 0.5 to 8 mm aggregates (Braunack and Dexter, 1989). The variation in MMD by the use of different implements and the effect of operating parameters on MMD are discussed in following sub sections.

4.1.3.1 *Rotavator*

The MMD of soil tilled by rotavator as a part of present study varied from 1.59 to 4.65 mm. The average MMD along with standard deviation (SD) is presented in Table 4.12. Fig. 4.7 shows variation of MMD with respect to engine speed in different speeds.

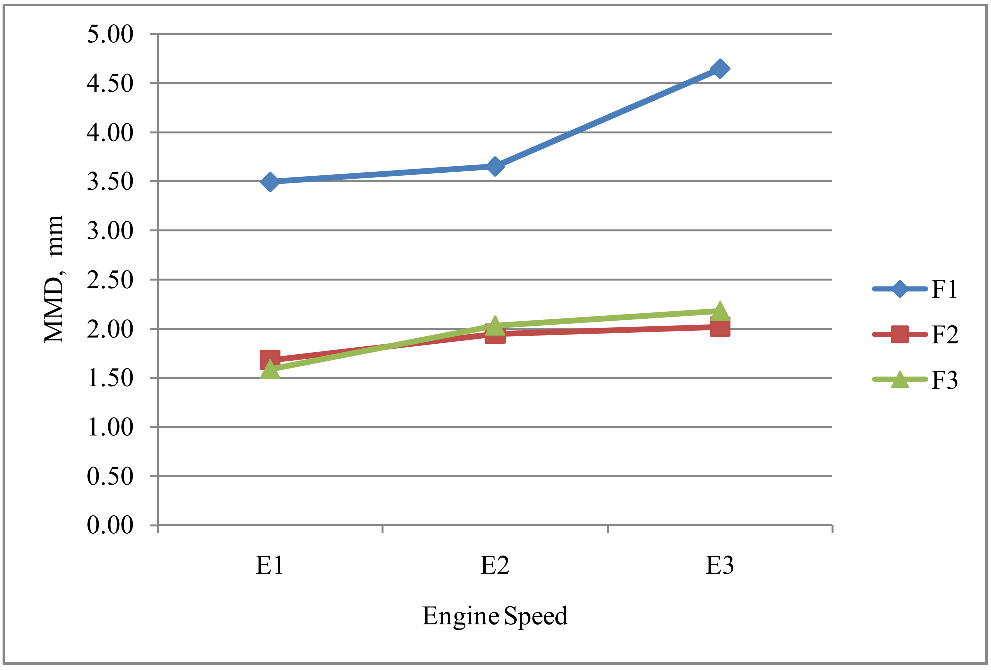

Fig 4.7 Variation of MMD during rotavator operation

Table 4.12 Variation of MMD by rotavator operation

Field	**Mean Mass Diameter (mm)**					
	E1		E2		E3	
	Mean	SD	Mean	SD	Mean	SD
F1	3.50	0.70	3.65	0.31	4.65	0.35
F2	1.68	0.46	1.95	0.68	2.02	0.33
F3	1.59	0.44	2.03	0.23	2.18	0.48

It was observed that the average value of MMD increased with increase in engine speed in all the three fields. The similar results were observed by Thampatpong (1999). The increase in MMD with respect to engine speed may be due to the change in kinematic index which in turn affects bite length of rotavator. Engine speeds E1 and E2 gave similar bite length (4.19 cm, 4.15 cm) whereas for E3, it was on a higher side (4.37 cm). The MMD also indicated similar trend with

E3 having higher MMD. The MMD obtained at engine speeds E1 and E2 were not significantly different. The lowest MMD was found in field F3.

The variations of MMD within the field, between the fields and effect of engine speed on MMD was analysed statistically through Analysis of variance. The results are presented in Table 4.13.

Table 4.13 Analysis of variance for MMD in rotavator operation

Source of variation	DoF	SS	MS	F-value	Significance level
Within field	4	0.41	0.10	0.41	0.800^{NS}
Between field	2	40.97	20.48	82.20	3.790e-14 **
Engine Speed	2	3.64	1.82	7.30	0.002 **
Residuals	36	8.97	0.25		
Total	44	53.99			

**Significant at 1 per cent level NS: Non-significant

The results indicated that the soil pulverization within field was uniform since variation within the field is not significant. The engine speed was found significantly influencing the MMD. Similarly, the different field conditions also had significant effect on the MMD from which it can be concluded that the initial field conditions and engine speed influence the breaking of soil clods. Similar findings were obtained for Makange and Tiwari (2015) in their research work.

Moisture content and vegetative matter on the soil can be considered as two major factors which defines the field conditions. The moisture content in different fields were significantly varied with respect to fields. The corresponding table for analysis of variance is provided as Table V(i) in Appendix V. This indicates that water content may be one of the major factor which influence the MMD (Tayel *et al.,* 2015). The analysis of variance for vegetative matter present on the field prior to tillage is provided as table V(ii) in Appendix V which indicates that this may be another important field condition which influences the variation in MMD.

The change of engine speed with respect to MMD in rotavator operation was compared by using Duncan's multiple range test (DMRT). The result is presented in Table 4.14.

Table 4.14 DMRT for variation of MMD with respect to engine speed in rotavator operation

Engine Speed	MMD (mm)
E3	2.95[a]
E2	2.54[b]
E1	2.26[b]

The results concluded that the field operation with rotavator at engine speed E1 and E2 result in similar changes on MMD and the value is lower than that from engine speed E3. The field operation with rotavator at engine speed E1 or E2 was recommended for getting fine soil tilth.

4.1.3.2 *Power harrow*

The operation of power harrow showed the same trend in result as that of rotavator in variation of MMD. An increasing trend of MMD was found with increase in engine speed in all the fields examined. The reason may be similar to rotavator operation. The change in kinematic index and corresponding locii of cutting path of power harrow blades at different engine speeds may be the primary factor for the increase in value of MMD. Lower value of MMD obtained at engine speed E1 compared to E2 and E3. Lowest value of MMD, 1.74 mm and highest value 2.92 mm was observed in field F3 with engine speed E1 and E3 respectively. The variations of MMD in different fields with various engine speeds are expressed in Fig. 4.8. The variation of MMD with engine speed was expressed in Table 4.15.

Table 4.15 Variation of MMD with respect to power harrow operation

Field	Mean Mass Diameter (mm)					
	E1		E2		E3	
	Mean	SD	Mean	SD	Mean	SD
F1	2.06	0.35	2.32	0.33	2.88	0.40
F2	1.98	0.30	2.43	0.40	2.62	0.54
F3	1.74	0.30	2.46	0.65	2.92	0.40

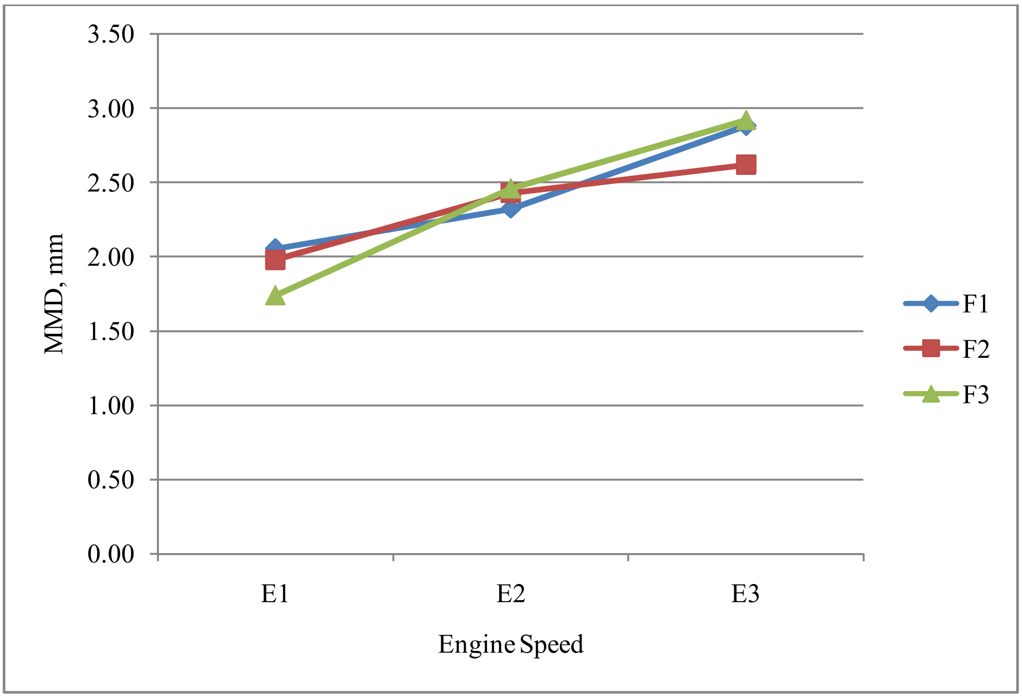

Fig. 4.8 Variation of MMD during power harrow operation.

The result obtained from the experiment is analysed statistically to study the variation of MMD values within the field, between the fields and the effect on engine speed. The MMD values of soil sample collected from randomly selected five points in each field was used for the analysis. The analysis of variance table was shown in Table 4.16

Table 4.16 Analysis of variance for MMD in power harrow operation

Source of variation	DoF	SS	MS	F-value	Significance level
Within field	4	0.32	0.08	0.44	0.78[NS]
Between field	2	0.04	0.02	0.12	0.89[NS]
Engine Speed	2	5.86	2.93	15.77	1.21e-05 **
Residuals	36	6.69	0.19		
Total	44	12.91			

**Significant at 1 per cent level   NS: Non-significant

The analysis of variance table pointed that there was no significant difference for MMD within a field hence the soil pulverization within a field was uniform. The results also revealed that the initial field conditions have no significant effect on MMD. The engine speed has significant influence on MMD of soil clods from which it can be concluded that while operating power harrow in different field condition, change in engine speed affects the change in MMD value.

The data were compared using Duncan's multiple range test (DMRT) in order to find the variation of engine speed on MMD in power harrow operation. The result obtained was given in Table 4.17.

Table 4.17 DMRT for variation of MMD with respect to engine speed in power harrow operation

Engine Speed	MMD (mm)
E3	2.81[a]
E2	2.41[b]
E1	1.93[c]

From the table, it was observed that the field operation with power harrow results in least MMD or higher pulverization at engine speed E1. Higher MMD is observed at engine speed E3.

4.1.3.3 *Spading machine*

The variation of MMD in different fields and engine speeds are given in Fig. 4.9.

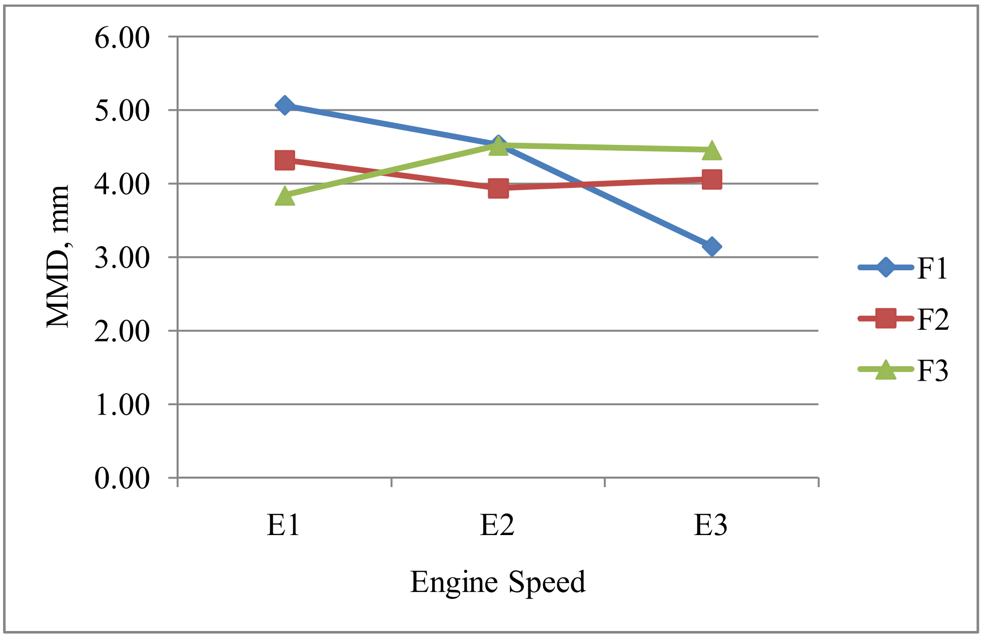

Fig. 4.9 Variation of MMD during spading machine operation

The values of MMD with engine speed was expressed in Table 4.18.

Table 4.18 Variation of MMD with respect to spading machine operation

Field	Mean Mass Diameter (mm)					
	E1		E2		E3	
	Mean	SD	Mean	SD	Mean	SD
F1	5.06	0.30	4.53	0.41	3.14	0.43
F2	4.32	0.56	3.94	0.62	4.06	0.67
F3	3.84	0.70	4.52	0.59	4.46	0.46

The low MMD value of 3.14 was observed at engine speed E3 and Maximum MMD was obtained for the speed E1 in field F1.

The data were statistically analysed to study the variations of MMD within field, between the fields and the effect of engine speed. Soil samples are collected from five random locations of each field in order to find the MMD and were used for the analysis. The ANOVA table was shown in Table 4.19.

Table 4.19 Analysis of variance for MMD in spading machine operation

Source of variation	DoF	SS	MS	F - value	Significance level
Within field	4	0.55	0.14	0.26	0.90[NS]
Between field	2	0.24	0.12	0.23	0.80[NS]
Engine Speed	2	2.36	1.18	2.21	0.12[NS]
Residuals	36	19.22	0.53		
Total	44	22.37			

NS: Non-significant

The ANOVA table was analysed and it was observed that the variation of MMD within the field is also not significant. Similarly either the initial field conditions or engine speed has no significant effect on value of MMD, thus it can be concluded that while working spading machine, MMD values are not influenced by engine speed and initial field conditions.. The working of spading machine at various engine speeds in different fields had made changes in MMD values, which is not significant.

4.1.3.4 *Variation of MMD with respect to different implements*

The MMD values obtained by operation of the three active tillage implements in different fields with various engine speeds was statistically analysed using analysis of variance. The result obtained from the analysis is given in Table 4.20.

Table 4.20 Analysis of variance for variation of MMD values with respect to implements

Source of variation	DoF	SS	MS	F-value	Significance level
Fields	2	15.45	7.72	13.93	3.35e-06 **
Engine Speed	2	2.88	1.44	2.60	0.08^{NS}
Implements	2	90.57	45.29	81.70	< 2e-16 **
Residuals	128	70.95	0.55		
Total	134	179.85			

**Significant at 1 per cent level NS: Non-significant

The analysis of variance table for change in MMD is shown in Table 4.20. It was observed that MMD does not vary with engine speed. The type of implement used for operation has significant effect on MMD. Similarly there is significant difference between MMD values obtained from different fields.

Duncan's multiple range test (DMRT) was used to compare the change of MMD with respect to different implements and the result obtained is presented in Table 4.21.

Table 4.21 DMRT for variation of MMD with respect to implements

Implements	MMD (mm)
Spading Machine	4.21^{a}
Rotavator	2.58^{b}
Power Harrow	2.38^{b}

It may be concluded that the field operation with rotavator and power harrow have similar results on MMD with an average change of 2.58 and 2.38 mm respectively. Hence it can be concluded that rotavator and power harrow can be used for getting finer soil tilth than spading machine.

4.1.4 Soil inversion

Tillage operations are aimed in inverting the soil by burying the vegetative residuals if any and improve the tilth condition. Soil inversion is a property that which indicates how much percentage of soil is inverted or dislocated during a tillage operation. The soil inversion is quantified as the percentage of the vegetative matter buried. It is accomplished by counting the number of vegetative matter remains in topsoil before and after tillage. Maximum soil inversion is expected in a good quality tilth. As discussed under section 3.1.1, three active tillage implements such as rotavator, power harrow and spading machine were operated in three different fields with different operating conditions to study the variations in soil properties. The soil inversion was estimated using the procedure explained in section 3.2.5. It was observed that the soil inversion was in the range of 79.63 to 94.87 per cent in a single pass operation of these implements in fields were this study was conducted.

The maximum percentage soil inversion was observed in field F1 with operation of spading machine. The minimum soil inverted in field F3 also with operation of spading machine. The amount of soil inversion by the use of different implements and the effect of operating parameters on soil inversion are discussed in following sub sections.

4.1.4.1 *Rotavator*

Soil inversions obtained by rotavator in different fields at different engine speeds are presented in Fig. 4.10 and Table 4.22. The graph indicates that the soil inversion decreased with increase in engine speed, irrespective of field. This decrease in soil inversion with respect to engine speed may be due to the change in kinematic index of rotavator which in turn affects bite length of rotavator.

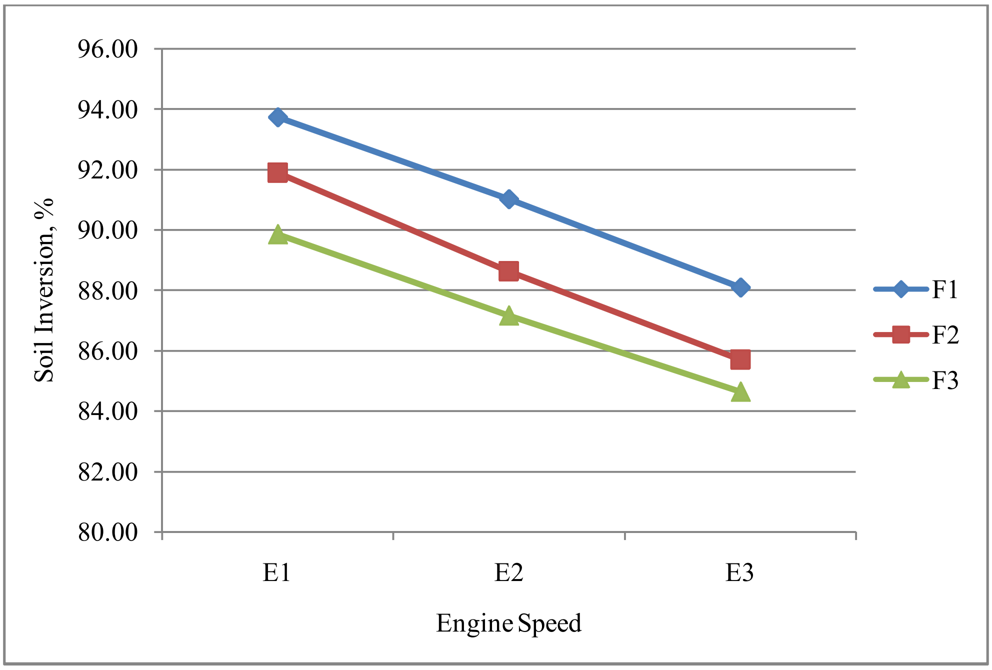

Fig. 4.10 Variation of soil inversion with rotavator operation

Table 4.22 Variation in soil inversion with respect to rotavator operation

Field	Soil Inversion (per cent)		
	E1	**E2**	**E3**
F1	93.75	91.03	88.10
F2	91.89	88.64	85.71
F3	89.86	87.18	84.66

The maximum percentage soil inversion was obtained at low engine speed E1 and the highest value 93.75 per cent was observed in field F1. The minimum value was for engine speed E3 and the lowest soil inversion observed was 84.66 per cent in field F3.

The analysis of variance of soil inversion with respect to fields and engine speeds is given as Table 4.23.

Table 4.23 Analysis of variance for variation of soil inversion by rotavator operation.

Source of variation	DoF	SS	MS	F-value	Significance level
Within field	4	46.10	11.52	0.651	0.630^{NS}
Between fields	2	105.40	52.69	2.977	0.064^{NS}
Engine Speed	2	241.80	120.88	6.829	0.003**
Residuals	36	637.20	17.70		
Total	44	1030.50	150.10		

**Significant at 1 per cent level NS: Non-significant

The variation of soil inversion within the field found insignificant which indicates that the soil was uniformly inverted throughout a single field. Similarly the field conditions also is not significant, thus the initial field condition does not influence the amount of soil inverted. The engine speed has found significant effect on the soil inversion from which it can be concluded that the major factor which influence soil inversion is the engine speed.

The data was compared using Duncan's multiple range test (DMRT) to find the influence of engine speed on soil inversion in rotavator operation. The result obtained is presented in Table 4.24.

Table 4.24 DMRT for variation in soil inversion with respect to engine speed by rotavator operation

Engine Speed	Soil Inversion (per cent)
E1	91.83^{a}
E2	88.95^{ab}
E3	86.16^{b}

The analysis indicates that there is significant difference in soil inversion obtained at engine speeds E1 and E3. The soil inversion obtained at engine speed E2 was found similar to those obtained in engine speed E1 or E3. Hence for getting the maximum soil inversion, the engine speed E1 can be recommended.

4.1.4.2 ***Power harrow***

The operation of power harrow resulted in a reverse pattern of results when compared to that of rotavator. The value of percentage soil inversion was analysed to study the effect of engine speed on amount of soil inversion. The value of percentage soil inversion was found increased with increase in engine speed in all the fields evaluated. The percentage soil inversion in different fields at different engine speeds are expressed in Fig. 4.11.

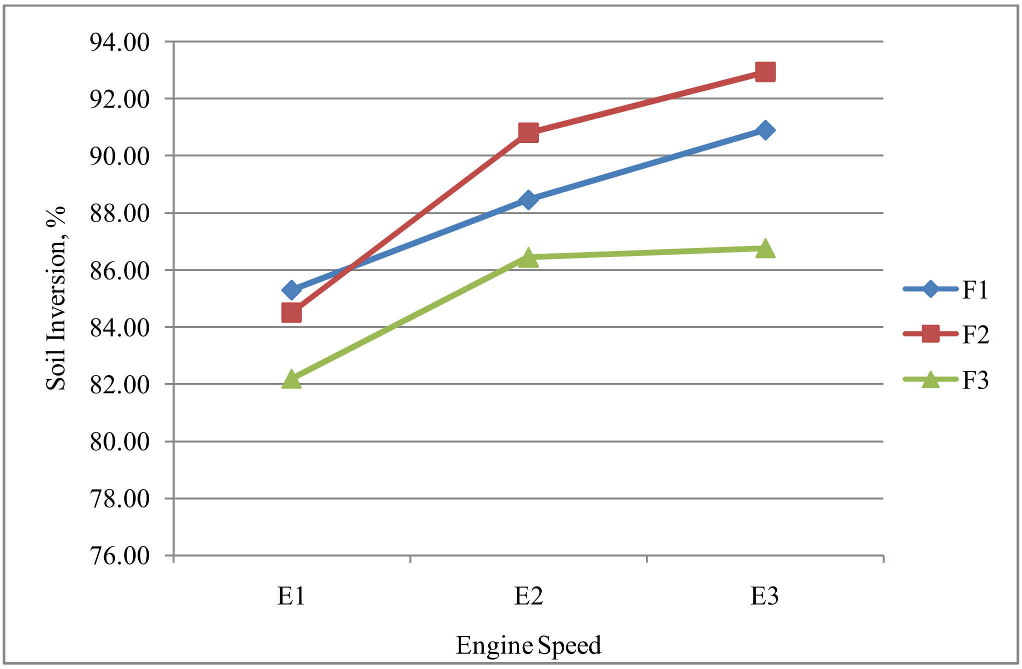

Fig. 4.11 Variation of soil inversion by power harrow operation

The value of soil inversion obtained in the different fields is presented in Table 4.25.

The higher amount of soil inversion has observed in engine speed E3 and the maximum value was 92.94 per cent, in field F2. Lower value of soil inversion obtained as 82.19 per cent in field F1 with engine speed E1.

Table 4.25 Variation in soil inversion with respect to power harrow operation

Field	Soil Inversion (per cent)		
	E1	**E2**	**E3**
F1	85.29	88.46	90.91
F2	84.51	90.80	92.94
F3	82.19	86.44	86.76

The data were statistically analysed to study the variations of soil inversion within the field, between the fields and the effect of engine speed. The soil inversion calculated from five different randomly selected plots in each field was used for the analysis. The ANOVA table for the amount of percentage soil inversion is shown in Table 4.26.

Table 4.26 Analysis of variance for variations in soil inversion by power harrow operation

Source of variation	DoF	SS	MS	F-value	Significance level
Within field	4	282.20	70.55	2.47	0.06^{NS}
Between field	2	146.60	73.32	2.56	0.09^{NS}
Engine Speed	2	310.50	155.26	5.43	0.01 **
Residuals	36	1029.20	28.59		
Total	44	1768.50			

**Significant at 1 per cent level NS: Non-significant

The analysis of variance table indicates that the variation within the field is not significant and thus indicates the soil was uniformly inverted within a field. Similarly there is no significant difference between the fields and we can say that initial field condition does not influence the soil inversion. The engine speed has significantly affecting the amount of soil inversion from which it can be concluded that the change in engine speed will influence the percentage of soil inverted.

Duncan's multiple range test (DMRT) was used for comparing the data to find the soil inversion in power harrow operation. The result obtained is expressed in Table 4.27

Table 4.27 DMRT for variation in soil inversion with respect to engine speed in power harrow operation

Engine Speed	Soil Inversion
E3	90.21^{a}
E2	88.57^{a}
E1	84.00^{b}

The table was analysed and it was observed that the field operation with power harrow results in higher soil inversion at engine speed E3 and is also found statistically similar to speed E2, the soil inversion getting by engine speed E3 and E2 are found almost equal. It can be concluded that power harrow can be operated at engine speed E3 or E2 for getting maximum soil inversion than speed E1.

4.1.4.3 ***Spading machine***

The soil inversion calculated were analysed to study the effect of engine speed on soil inversion. The variation with respect to engine speed in different fields was presented in Fig. 4.12. .The mean value of percentage soil inversion obtained by operating the spading machine in different conditions were presented in Table 4.28

Table 4.28 Variation in soil inversion with respect to spading machine operation

Field	Soil Inversion (per cent)		
	E1	E2	E3
F1	85.19	94.87	87.50
F2	83.05	91.67	85.37
F3	79.63	81.25	80.37

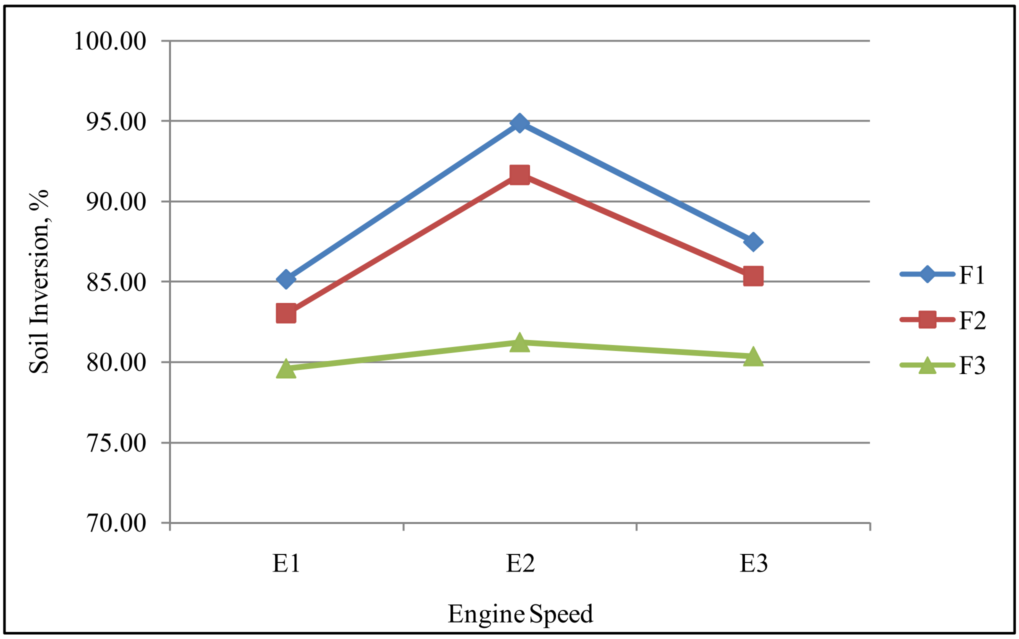

Fig. 4.12 Variation in soil inversion by spading machine operation

The data analysed and it was observed that higher soil inversion is obtaining in E2 and lower in E1. Highest soil inversion observed was 94.87 per cent in field F1 and lowest value was 79.63 per cent observed in field F3.

The statistical analysis of data was achieved by analysis of variance. The analysis of variance for the variation in soil inversion is presented in Table 4.29

Table 4.29 Analysis of variance for Soil inversion by spading machine operation

Source of variation	DoF	SS	MS	F-value	Significance level
Within field	4	119.10	29.79	0.891	0.479^{NS}
Between field	2	612.80	306.41	9.168	0.001**
Engine Speed	2	354.30	177.13	5.300	0.009 **
Residuals	36	1203.20	33.42		
Total	44	2289.40			

**Significant at 1 per cent level NS: Non-significant

The analysis of variance table was observed and the variation within the field was found not significant and this indicates that the change of soil inversion within a single field was uniform. Significant difference was observed between the fields, thus the field conditions influence the amount of soil inversion. The moisture content in the different fields were analysed and it was found significantly varied with respect to fields. The corresponding table for analysis of variance is provided as Table V(ii) in Appendix V. This indicated that moisture content of the fields may be major factors for change in soil inversion with respect to field conditions (Jebur and Alsayyah, 2017).

Similarly, the effect of engine speed also found significant so that it can be concluded that the engine speed has influence on percentage of soil inverted.

The data was compared statistically using Duncan's multiple range test (DMRT) in order to find the influence of engine speed on soil inversion in spading machine operation. The result obtained by DMRT is presented in Table 4.30.

Table 4.30 DMRT for variation in soil inversion with respect to engine speed in spading machine operation

Engine speed	Soil inversion (mm)
E2	89.26[a]
E3	84.41[b]
E1	82.62[b]

It can be concluded that the field operation with spading machine results in higher soil inversion at engine speed E2. The soil inversion observed at engine speed E3 is found similar to soil inversion at engine speed E1.

4.1.4.4 ***Variation of soil inversion with respect to different implements***

The percentage soil inversion obtained by operation of the three active tillage implements in different fields with various engine speeds was analysed statistically with the help of analysis of variance. The result obtained from the analysis is given in Table 4.31

Table 4.31 Analysis of variance for change in soil inversion with respect to implements

Source of variation	DoF	SS	MS	F-value	Significance level
Fields	2	669	334.30	10.10	8.42e-05 **
Engine Speeds	2	185	92.30	2.79	0.06[NS]
Implements	2	288	143.80	4.34	0.02*
Residuals	128	4235	33.10		
Total	134	5377			

*Significant at 5 per cent level **Significant at 1 per cent level NS: Non-significant

The ANOVA table for variations in soil inversion was observed and from the table it can be seen that soil inversion varies significantly with different field conditions. The significant change between fields during the operation of the implements is already discussed in preceding sections. Similarly it was observed that the type of implement used for operation has significant effect on soil inversion.

The variation of soil inversion with respect to different implements was compared using Duncan's multiple range test (DMRT) The result obtained by DMRT is presented in Table 4.32.

Table 4.32 DMRT for variation in soil inversion with respect to implements

Implements	Soil Inversion (per cent)
Rotavator	88.98[a]
Power Harrow	87.59[ab]
Spading Machine	85.43[b]

From the analysis it was observed that the field operation with rotavator and spading machine results in significantly different soil inversion. The soil inversion obtained by operation of power harrow was found similar to those obtained by rotavator and spading machine. Hence rotavator and power harrow can be recommended for getting more amount of soil inversion.

4.2 VARIATIONS IN PERFORMANCE EVALUATION PARAMETERS

4.2.1 Depth of operation

Tillage operations are carried out for moving up the lower soil layers up to a certain depth. Depth of operation determines the amount of soil tilled by a certain implement. It helps in aeration of soil and facilitates better crop growth. Each tillage implement is designed to have a specific operating depth. Normally the depth of operation of rotavator and power harrow was in the range of 10-20 cm. Spading machines are designed for getting higher operating depth in the range of 25 – 30 cm. Also the depth of operation of tillage implements may vary according to operating parameters. As discussed under section 3.1.1, three active tillage implements were operated in three different fields with different operating conditions for studying the variation in soil properties. Spading machine considerably results in higher depth of operation compared to other two implements. The operating depths of soil after the tillage operation of each implement were estimated using procedure explained in section 3.3.3. The average value of depth of operation and standard deviation obtained by each implement is given in Table 4.33.

Table 4.33 Depth of operation with respect to implements

Implement	**Depth of operation, cm**	
	Mean	SD
Rotavator	12.67	4.53
Power Harrow	10.99	2.67
Spading Machine	24.43	3.38

The maximum operating depth was obtained spading machine. However the minimum operating depth was observed while working with power harrow, rotavator also gives almost similar depth. Hence it can be concluded that spading machine can be used for getting higher depth of operation.

4.2.2 Fuel Consumption

Fuel consumption of a tillage operation is a machine parameter, which can be considered as one of the major indicator of cost of operation. The tillage operation aimed in development of good soil tilth with minimum cost, hence minimum fuel consumption. As discussed under section, 3.1.1, three active tillage implements such as rotavator, power harrow and spading machine were operated in three different fields with different operating conditions for studying the variations in soil properties with different parameters. The fuel consumed during each tillage operation was estimated using the procedure explained in section 3.3.4. It was observed that the amount of fuel consumed was in the range of 12.31 to 62.22 l ha^{-1} in a single pass operation of these implements.

The minimum fuel consumption was observed during the operation of rotavator in field F2. The maximum amount fuel is consumed for operation of spading machine in field F3. The variation of fuel consumption by the use of different implements and the effect of operating parameters on fuel consumption are discussed in the following subsections.

4.2.2.1 *Rotavator*

The operation of rotavator in different fields at various engine speeds consumed 12.31 to 22.89 litres of diesel fuel per hectare. The change in fuel consumption was analysed to study the effect of engine speed on fuel consumed. It was observed that the amount of fuel needed for operation of rotavator was increased with the engine speed in fields F2 and F3. Fig. 4.13 shows the change in fuel consumption in different fields at different engine speeds.

The amount of fuel consumed in each experiment in different fields was illustrated in Table 4.34.

Table 4.34 Fuel consumption by rotavator operation

Field	**Fuel Consumption (l ha^{-1})**		
	E1	E2	E3
F1	22.38	12.52	13.04
F2	12.31	13.25	14.76
F3	14.65	18.32	22.89

Minimum fuel consumption 12.31 l ha^{-1} was observed in field F2 with engine speed E1. The maximum fuel consumed during the operation in field F3, with engine speed E3 with a consumption of 22.89 litres per hectare.

The data was statistically analysed to study the variations due to engine speed and field condition. The result is presented in Table 4.35.

Table 4.35 Analysis of variance for fuel consumption in rotavator operation

Source of variation	**DoF**	**SS**	**MS**	**F-value**	**Significance level**
Between fields	2	40.27	20.14	0.89	0.48^{NS}
Engine Speed	2	8.13	4.07	0.18	0.84^{NS}
Residuals	4	90.66	22.67		
Total	8	139.06			

NS: Non-significant

From the ANOVA table it was observed that the variation of fuel consumption between the fields is not significant. Similarly the effect of engine speed was also found not significant. Hence it can be concluded that the initial field conditions and engine speed does not influence the amount of fuel utilized for field operation.

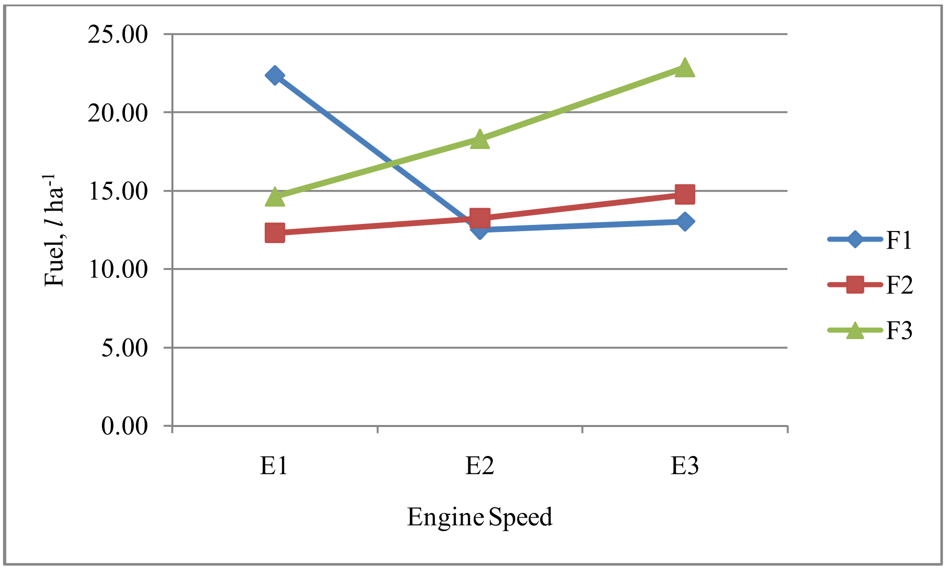

Fig. 4.13 Variation of fuel consumption in rotavator operation

4.2.2.2 *Power harrow*

The operation of power harrow in different fields at various engine speeds consumed 18.69 to 37.71 litres of diesel fuel per hectare. The change in fuel consumption was analysed to study the effect of engine speed on fuel consumed. It was observed that the amount of fuel utilized for power harrow was increased with the engine speed in fields F2 and F3. The change in fuel consumption in different fields at different engine speeds are depicted in Fig. 4.14.

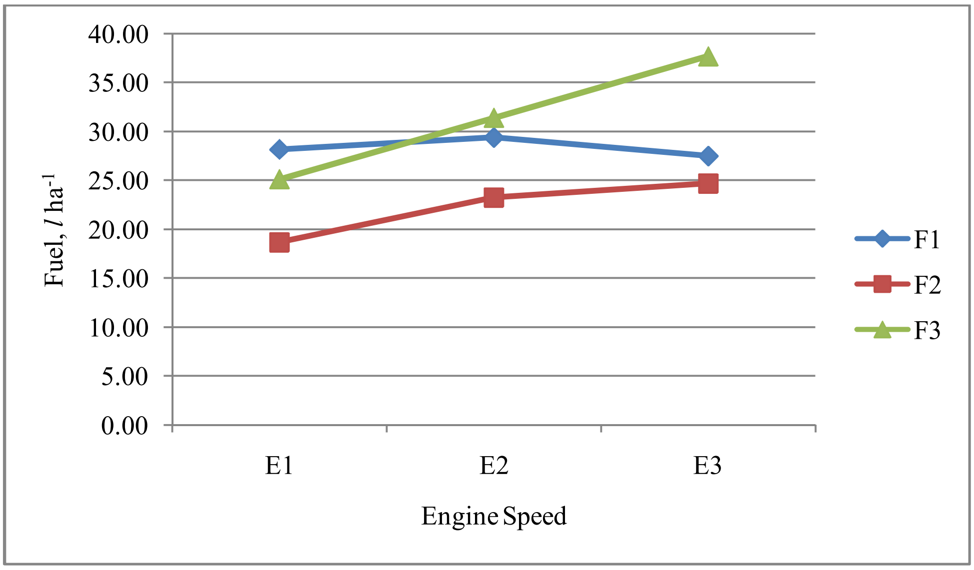

Fig. 4.14 Variation of fuel consumption in power harrow operation

The details of fuel utilized by power harrow operation in different fields at various engine speeds are showed in Table 4.36.

Table 4.36 Fuel consumption by power harrow operation

Field	**Fuel Consumption (*l* ha^{-1})**		
	E1	E2	E3
F1	28.20	29.40	27.53
F2	18.69	23.26	24.70
F3	25.14	31.42	37.71

The minimum fuel utilization of 18.69 *l* ha^{-1} was found in field F2 with engine speed E1. Maximum amount of fuel used for field F3 at engine speed E3 with a rate of 37.71 *l* ha^{-1}.

The variation of fuel consumption between the fields and the effect of engine speed was analysed using analysis of variance and is presented in Table 4.37.

Table 4.37 Analysis of variance for fuel consumption in power harrow operation

Source of variation	**DoF**	**SS**	**MS**	**F-value**	**Significance level**
Field	2	131.97	65.99	5.88	0.06^{NS}
Engine Speed	2	55.59	27.79	2.48	0.20^{NS}
Residuals	4	44.86	11.21		
Total	8	232.42			

NS: Non-significant

The results indicated that variation of fuel consumption between the fields is not significant. The effect of engine speed is also found significant effect on change in rate of fuel used. From the analysis it can be concluded that neither the initial field conditions nor the engine speed have influence on the amount of fuel utilized for field operation.

4.2.2.3 *Spading machine*

The operation of spading machine in different fields at various engine speeds consumed 18.78 to 62.22 litres of diesel fuel per hectare. The change in fuel consumption was analysed to study the effect of engine speed on fuel consumed. It was observed that the amount of fuel consumed per hectare was increased with the engine speed in fields F1 and F2. The change in fuel consumption in different fields at different engine speeds are expressed in Fig. 4.15.

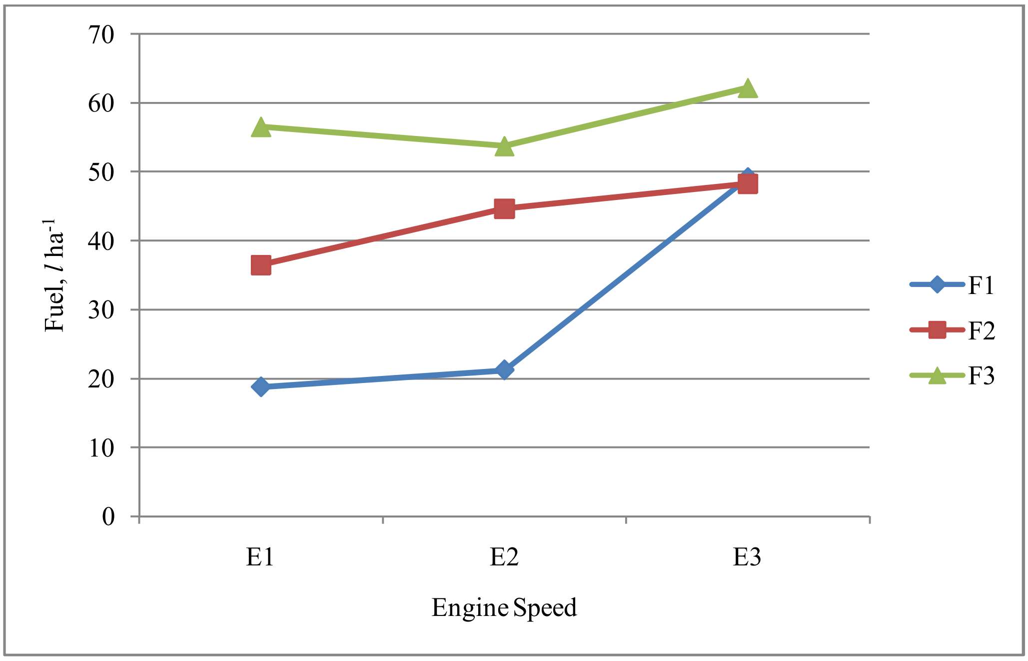

Fig. 4.15 Variation of fuel consumption in spading machine operation

The details of fuel consumed by spading machine operation per hectare in different fields at various engine speeds are showed in Table 4.38.

Table 4.38 Fuel consumption by spading machine operation

Field	**Fuel Consumption (l ha^{-1})**		
	E1	E2	E3
F1	18.78	21.23	49.13
F2	36.46	44.61	48.25
F3	56.56	53.73	62.22

The minimum fuel utilization of 18.78 l ha^{-1} was found in field F1 with engine speed E1. Maximum amount of fuel used in field F3 at engine speed E3 with a rate of 62.22 l ha^{-1}.

The data obtained from the experiment is analysed statistically to study the variation between the fields and the effect of engine speed on operation of spading machine. The analysis of variance for variation in fuel consumption rate is presented in Table 4.39.

Table 4.39 Analysis of variance for fuel consumption in spading machine operation

Source of variation	**DoF**	**SS**	**MS**	**F-value**	**Significance level**
Fields	2	1159.10	579.60	9.66	0.30 *
Engine Speed	2	438.60	219.30	3.65	0.12^{NS}
Residuals	4	240.10	60.00		
Total	8	1837.8			

*Significant at 5 per cent level NS: Non-significant

It was observed that that the effect of engine speed on fuel consumption was not significant, thus the engine speed does not influence the amount of fuel utilized for field operation. The fuel consumption in different fields was found significantly different, so that it can be concluded that the initial field condition has influence in the amount of fuel consumed per hectare during operation of spading machine. Moisture content and vegetative matter on the soil can be considered as two major factors which defines the field conditions. The moisture content in the different fields were analysed and it was found that it significantly varied with respect to fields. The corresponding table for analysis of variance is provided as Table V(i) in Appendix V. This indicates that water content may be one of the major factor which influence the change in fuel consumption (Tayel *et al., 2015*). The analysis of variance for vegetative matter present on the field prior to tillage is provided as table V(ii) in Appendix V which indicates that this may be another important field condition which influences the change in fuel consumption.

4.2.2.4 *Variation of fuel consumption with respect to different implements*

The rate of fuel utilized by operation of the three active tillage implements in different fields with various engine speeds was analysed statistically to study the variations between the fields, effect engine speed and type of implement. The analysis of variance was and the result obtained from the analysis is given in Table 4.40.

Table 4.40 Analysis of variance for change in fuel consumption with respect to implements

Source of variation	DoF	SS	MS	F-value	Significance level
Fields	2	657	328.60	5.15	0.02 *
Engine speed	2	276	138.20	2.17	0.14^{NS}
Implements	2	3419	1709.70	26.81	2.19e-06 **
Residuals	20	1276	63.80		
Total	26	5628			

*Significant at 5 per cent level **Significant at 1 per cent level NS: Non-significant

The ANOVA table for variations in rate of fuel consumed was observed and from the table it can be seen that the fuel consumption of selected active tillage implements change with initial field conditions since significant difference is found between fields. The fuel consumption doesn't have significant change with engine speeds. The effect of fields and engine speed is already discussed in previous sections. Similarly it was observed that the type of implement used for operation has significant effect on fuel consumption.

The variation of amount of fuel consumed between different implements was statistically compared using Duncan's multiple range test (DMRT). The result obtained by DMRT is presented in Table 4.41

Table 4.41 DMRT for variation of fuel consumption with respect to implements

Implements	**Fuel Consumption, *l* ha^{-1}**
Spading Machine	43.44[a]
Power Harrow	27.34[b]
Rotavator	16.01[c]

From the DMRT it can be concluded that field operation with rotavator consume the least amount of fuel per hectare. Hence rotavator can be recommended in terms of amount of fuel needed for field operation.

The average fuel consumption per unit time and unit area for different implements are given in Table 4.42

Table 4.42 Fuel consumption with respect to implements

Implement	**Fuel Consumption, *l* ha^{-1}**	**Fuel Consumption, *l* h^{-1}**
Rotavator	16.01	5.00
Power Harrow	27.34	4.87
Spading Machine	43.44	3.16

4.2.3 Speed of operation and Field capacity

4.2.3.1 *Speed of operation*

All the experiments were done in low first gear condition by keeping the engine throttle lever at 1200 (E1), 1600 (E2) and 2000 RPM (E3). While operating spading machine, creeper gear was used. The forward speed was measured at each time in different experiments as per section 3.3.1. The average value actual forward speed of different implements at various engine speeds are shown in Table 4.43.

Table 4.43 Forward speed of implements

Implement	**Forward Speed (km h^{-1})**		
	E1	E2	E3
Rotavator	1.36	1.79	2.36
Power Harrow	1.31	1.64	2.09
Spading Machine	0.46	0.56	0.70

Higher forward speed was observed in operation with rotavator. Since all the experiments with spading machine were done in creeper gear condition, its forward speed is much lower than that of rotavator and power harrow.

4.2.3.2 *Theoretical field capacity*

Theoretical field capacity (TFC) is calculated on the basis of forward speed and width of operation. The working width of rotavator, power harrow and spading machine were 2.4, 1.4, and 1.6 meters respectively.

The average theoretical field capacity of the implements were calculated and is shown in Table 4.44.

Table 4.44 Theoretical field capacity of implements

Implement	Theoretical field capacity (ha h^{-1})		
	E1	E2	E3
Rotavator	0.33	0.43	0.57
Power Harrow	0.18	0.23	0.29
Spading Machine	0.08	0.09	0.11

Maximum TFC was observed at rotavator operation and minimum for spading machine. The higher value of rotavator is due to its high value of forward speed and larger width of operation compared to power harrow and spading machine. Lower value of field capacity for spading machine is due to the lower forward speed compared to others.

4.2.3.3 ***Actual field capacity***

Actual field capacity (AFC) of implements is found on the basis of actual area covered in a unit time period. The actual field capacity values of different implements at various engine speeds are presented in Table 4.45.

Table 4.45 Actual field capacity of implements

Implement	Actual field capacity (ha h^{-1})		
	E1	E2	E3
Rotavator	0.25	0.35	0.45
Power Harrow	0.15	0.17	0.22
Spading Machine	0.07	0.08	0.10

The table indicated that the AFC also shown the similar trend of TFC. The higher AFC observed in rotavator operation due to the higher area coverage. The

AFC of spading machine was found lower because of the higher time it took to cover an area compared to rotavator and power harrow.

4.2.3.4 *Field efficiency*

The field efficiency of an implement is the ratio of AFC to TFC. The higher field efficiency indicates better performance. The field efficiency calculated for different implements are given in Table 4.46.

Table 4.46 Field efficiency of implements

Implement	**Field efficiency (per cent)**		
	E1	E2	E3
Rotavator	75.76	81.40	78.95
Power Harrow	83.33	73.91	75.86
Spading Machine	87.50	88.89	90.90

Higher field efficiency among the three implements was observed in spading machine, and highest at engine speed E3. The higher field efficiency for rotavator was obtained at engine speed E2 and for power harrow, it was observed at engine speed E1.

4.2.4 Wheelslip

The variation wheel slip of driving wheels of tractor operating with rotavator, power harrow and spading machine was found not related to engine speed, but changes with respect to field conditions. A specific trend cannot be recorded for the value of slip during the experiment. The percentage value of wheelslip in each field was shown in Table 4.47.

Table. 4.47 Variation of wheelslip in implements

Field	Rotavator	Power harrow	Spading machine
F1	-6.00 to 5.78	3.64 to 7.83	-21.14 to 3.64
F2	0.24 to 5.78	-6.00 to 5.78	-6.00 to 9.79
F3	-21.14 to -6.00	-6.00 to 5.78	-6 to 3.20

It was noticed that the percentage value of wheelslip varied from -21.14 to 5.78 per cent, -6 to 7.83 per cent and -21.14 to 9.79 per cent in operation with rotavator, power harrow and spading machine respectively. This behaviour may be due to the changes in field. The negative value of slip indicates the thrust force developed by the active tillage implements to push the tractor in the longitudinal direction (Sukcharoenvipharat *et al.*, 2017)

4.3 CONE INDEX

The strength of soil is expressed as penetration resistance which is indicated by cone index. Cone indices of soil after tilling with the selected implements were calculated. Cone index of soil in each field at different operating depths with the implements were compared and are expressed in Fig. 4.16, 4.17 and 4.18.

It was observed that the cone index increases with depth. In the same depth of cut, power harrow resulted less penetration resistance than rotavator. This result was agreed with those in the research work of Makange and Tiwari (2015). The spading machine was found the lowest cone index while compared to other implements. Maximum cone index (3.13 kg cm^{-2}) was observed in field F2 with operation of rotavator. The values of cone index recorded are given in Appendix IV.

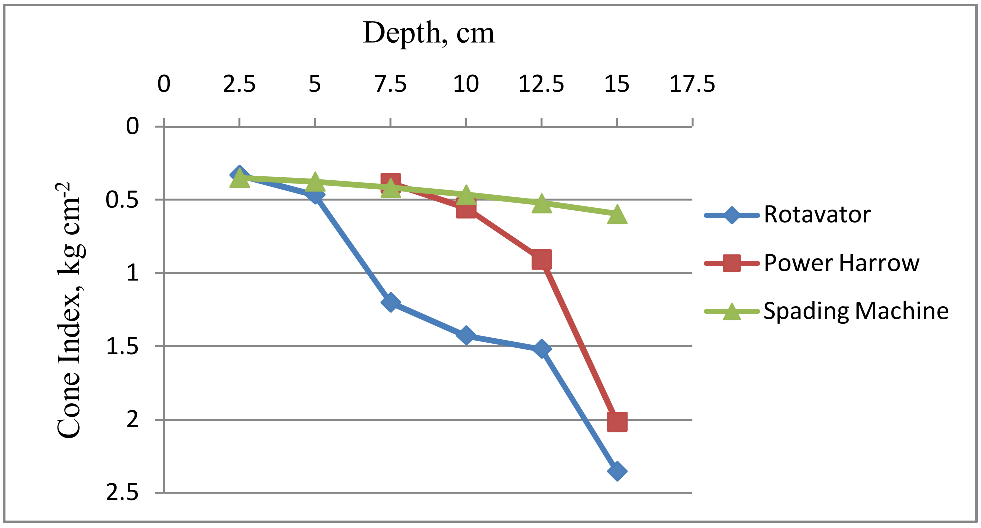

Fig. 4.16 Cone index at field F1

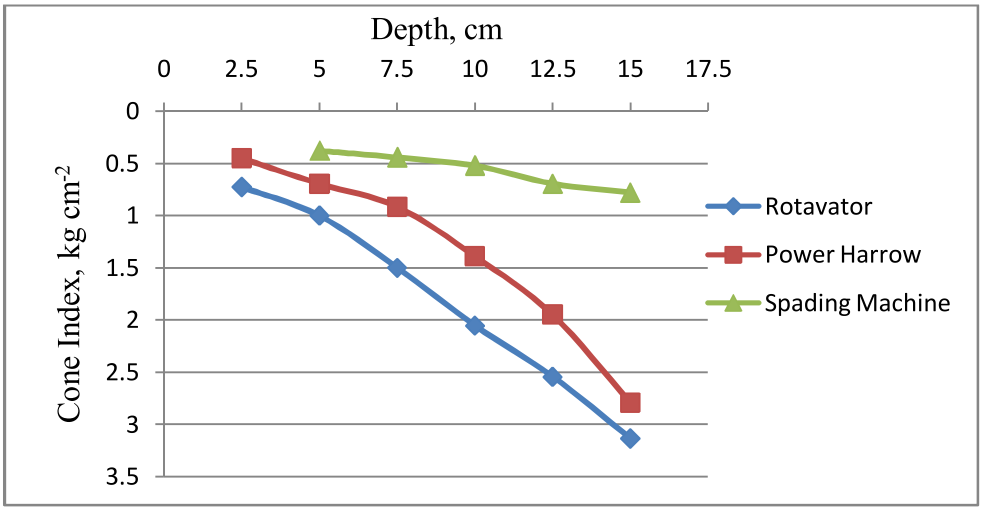

Fig. 4.17 Cone index at field F2

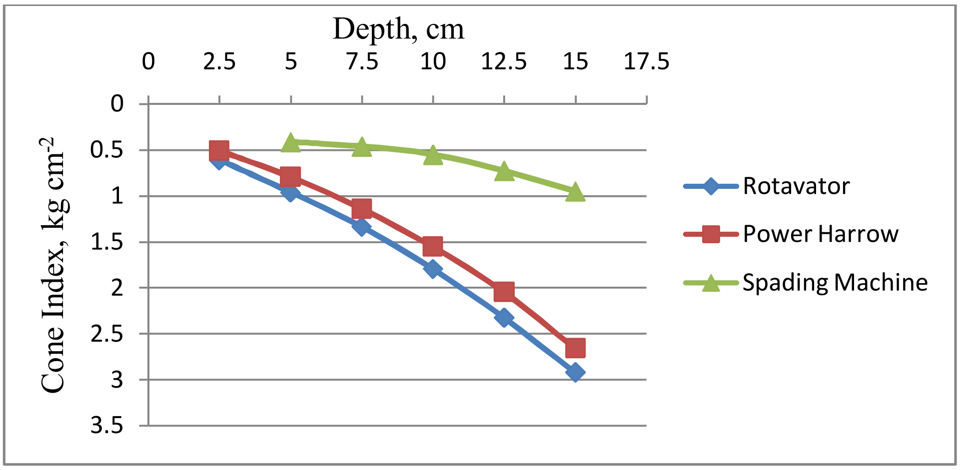

Fig. 4.18 Cone index at field F3

4.4 SOIL MOISTURE CONTENT

Tillage is expected to uniformly distribute the moisture content of soil layers in the operating depth. The moisture distribution depends on the amount of water present in the soil layers of each field and the operating depth of implement. Moisture content of the fields before and after tillage was found out using procedure explained in section 3.2.1.The variation of moisture content in different fields while operating with different implements was presented in Table 4.48.

Table 4.48 Variation of soil moisture content with respect to implements

Field	Initial (% db)	Final (% db)		
		Rotavator	Power harrow	Spading machine
F1	2.08	6.23	3.50	11.02
F2	16.89	22.99	18.01	22.69
F3	11.58	20.95	13.38	25.78

It was observed that the moisture content on the top layer of soil tilled with rotavator and spading machine increased when compared to that of untilled soil. In the case of power harrow, comparatively lower changes are found in the top layer of tilled soil. These variations are depending on the amount of water which was present in the soil layers before the operation. The higher moisture available in the soil layers below topsoil was mixed thoroughly during tillage operation. The moisture content of the top layer of soil in was increased 1.36 to 3.00 times in rotavator as compared to initial moisture content of the untilled soil in respective fields. The moisture content was found 1.07 to 1.69 times increased in power harrow operation and 1.34 to 5.30 times in spading machine operation.

It was also analysed that there was no significant variation in change in moisture content between different fields. Also the moisture content within a field was found uniform in randomly selected areas of same field. The change was found between the implements.

The higher change during spading machine operation may due to the higher depth obtained while operating spading machine. The lower moisture content in the power harrow operation may be due to lower operating depth compared to the other two implements. Also the rotation of blades of power harrow is such that its rotation breaks the soil but not displace the soil layers much. This indicates that power harrow has the advantage of conserving soil moisture by not exposing the lower soil layer to the surface. This may be one of the reasons for the lower moisture change observed in power harrow. Similar results were found in the research by Chan *et al.* (1993).

4.5 COST OF OPERATION AND ENERGY REQUIREMENT

The tractor-implement combinations have different cost of operation depending on the purchase price of implement and fuel consumption. The cost per hectare including labour charges was found by calculating fixed cost and variable cost as per section 3.5 and energy requirement was calculated as per section 3.3.6 and the cost of tractor and implements are expressed in Appendix III. Table 4.49 shows the maximum average cost of operation of different implements per hectare.

Table 4.49 Cost of operation and energy requirement

Implement	**Operating cost (Rs ha^{-1})**	**Operating cost (Rs h^{-1})**	**Energy required (MJ ha^{-1})**
Rotavator	3300	1020	827.91
Power Harrow	4500	950	1029.68
Spading Machine	7900	870	1686.10

Rotavator shows the lower operating cost per hectare, even though the operating cost per hour was higher. This may due to higher width of operation and forward speed of rotavator compared to others. Since spading machine has the lowest speed, it has higher operating cost per hectare due to higher time needed for operation.

The energy requirement was found higher for spading machine and lower for rotavator. Spading machine requires double amount of energy compared to rotavator.

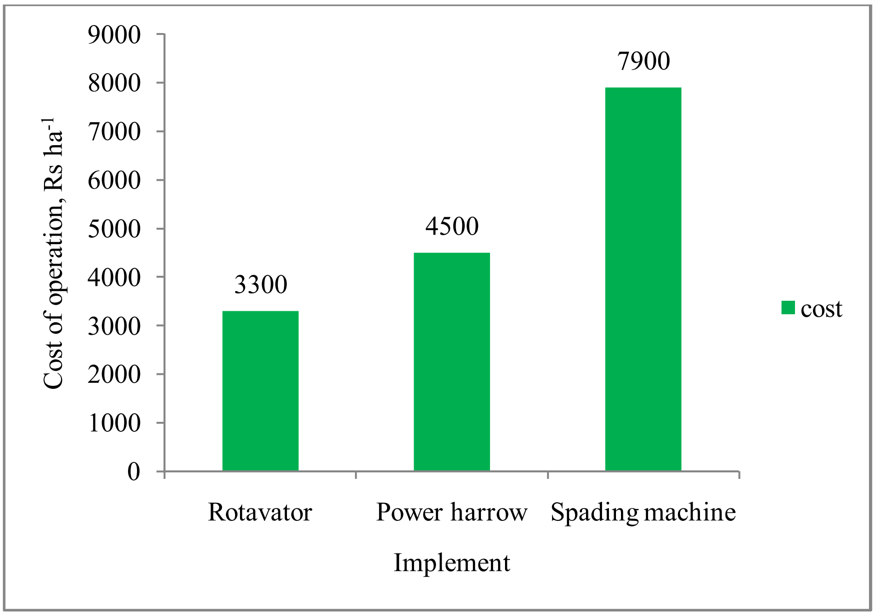

Fig. 4.19 Cost of operation of implements

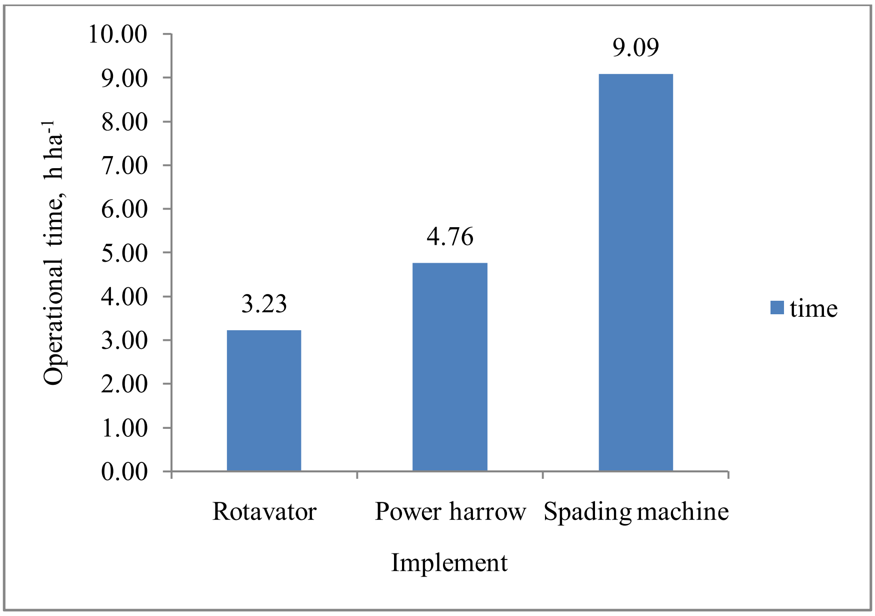

Fig. 4.20 Operational time of implements

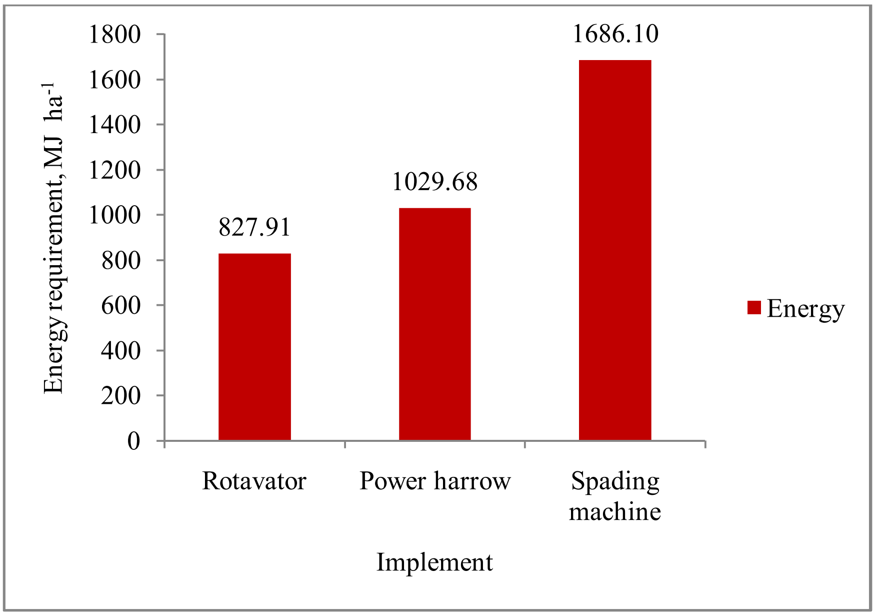

Fig. 4.21 Energy requirement of by implements

4.6 COMPARISON OF TILLAGE PERFORMANCE

The comparison of tillage performance was achieved in two methods such as selection of implement based on soil properties observed and by ranking with respect to Grey Relational Analysis (GRA) and Tillage Performance Index (TPI). The GRA ranks of different operations are given in Appendix VI.

4.4.1 Selection of implements based on soil properties

Based on the results obtained in the previous sections, an approach was done to select an appropriate machinery and engine speed based on better performance observed in each properties studied. The results are presented in Table 4.50.

The table indicates the results obtained regarding the selection of implement for getting a desired value for each soil property. From the table it can be observed that, for getting better performance on the basis of bulk density of soil, power harrow and spading machine can be recommended at engine speed either E2 or E3. Similarly for getting higher soil pulverization, rotavator or power harrow can be recommended. The higher soil inversion was getting by the usage of rotavator and power harrow either in engine speed E2 or E3. Rotavator can be recommended when selection was based on fuel consumed per hectare.

Table 4.50 selection of implements based on soil properties and engine speed

Properties	E1	E2	E3
Bulk Density		P S	P S
Mean Mass Diameter	R P	R	
Soil Inversion	R	P	P
Fuel Consumption	R	R	R

R – Rotavator, P – Power harrow, S – Spading machine

4.4.2 Selection of implements based on GRA and TPI

The performance of implements can be analysed based on the data obtained from the operation of different implements in each field to find which implement is better for each field in terms of performance economical and aspect. The ranking based on Grey Relational Analysis (GRA) and computation of Tillage Performance Index (TPI) was used for the purpose. The parameters considered were change in bulk density (percentage), soil inversion (percentage), actual field capacity (ha h^{-1}), depth of operation (cm), mean mass diameter (mm), fuel consumption (l ha^{-1}) and operating cost per hectare. The multivariate data were analysed and the respective ranks of each treatment was calculated for each field. The results are given in Table 4.51, Table 4.52 and Table 4.53.

Table 4.51 shows the ranks obtained by GRA and it can be observed that rotavator at engine speed E2 will give the better performance among the experiments in field F1 based on above mentioned parameters.

The value of tillage performance index for the respective operations in Field F1 was shown also in table. The higher TPI were observed in highest rank experiment. The lower values have almost similar value of TPI.

Table 4.51 TPI and ranking based on GRA for field F1

Implement	Engine Speed	GRA Rank	TPI
R	E2	1	28.50
R	E3	2	20.92
R	E1	3	3.96
S	E2	4	4.8
P	E3	5	6.32
P	E2	6	5.01
S	E1	7	3.06
P	E1	8	5.12
S	E3	9	3.43

Table 4.52 TPI and ranking based on GRA for field F2

Implement	Engine Speed	GRA Rank	TPI
R	E3	1	45.67
R	E1	2	31.29
R	E2	3	36.92
P	E3	4	8.62
P	E2	5	6.87
S	E3	6	3.34
P	E1	7	9.98
S	E2	8	2.62
S	E1	9	1.85

Table 4.52 indicates that highest rank based on GRA was for the operation of Rotavator at engine speed E3. Hence it can be concluded that the rotavator at engine speed E3 will give the better performance in field F2 based on above mentioned parameters. The value of tillage performance index also found higher for rotavator.

Table 4.53 TPI and ranking based on GRA for field F3

Implement	Engine Speed	GRA Rank	TPI
R	E1	1	28.19
R	E2	2	27.92
R	E3	3	24.83
P	E1	4	10.81
P	E2	5	6.29
S	E1	6	0.88
P	E3	7	5.18
S	E3	8	1.60
S	E2	9	1.42

The ranks obtained by GRA in field F3 was presented in Table 4.53 and it can be observed that better performance in field F3 was obtained by the operation of rotavator at engine speed E1. The higher TPI was also obtained for rotavator.

4.5 EFFECT OF MULTIPLE PASSES AND ITS COST ECONOMICS

The quality of tilth produced by different tillage implements vary according to their type and operating conditions. Majority of the tillage implements are operated for more than one pass in field for achieving the required quality of tilth. In order to obtain the tilth quality produced by one implement, another implement may have to be operated more than once. To study the effect of multiple passes of the same implement and to analyse cost economics for obtaining similar tilth quality by different implements, the three active tillage implements were operated in same field conditions and operating conditions. The prime mover was operated in L2 gear condition with 1800 engine rpm in all the experiments. The number of passes by each implement was selected by observing the visible similarity of the tilled soil. Rotavator and power harrow were used 2 times and spading machine 3 times in field. Soil properties such as Bulk density, Mean mass diameter and soil inversion were measured for each pass in order to assess the tilth quality (Maheswari and Singh, 2018). The results obtained are discussed in the following sections.

4.5.1 Bulk Density

Tillage operations will decrease the bulk density of the soil and multiple passes of the same implement should also give lower bulk density after each pass. The bulk density observed after each pass of the implements had indicated this trend, but quantum of change in bulk density varied with respect to implement and number of passes. The initial bulk density of the soil in the field where these operations were carried out was 1.69 g cm^{-3}. The final bulk density obtained after each operation and percentage change calculated for each operation are presented in Table 4.54.

Table 4.54 The change and final bulk density for different operations

Operation	Final bulk density (g cm^{-3})	Percentage change
Rotavator one pass (RT1)	1.39	17.75
Rotavator two pass (RT2)	0.85	38.85
Power Harrow one pass (PH1)	1.42	15.98
Power Harrow two pass (PH2)	0.81	42.25
Spading Machine one pass (SM1)	1.31	22.49
Spading Machine two pass (SM2)	1.17	10.68
Spading Machine three pass (SM3)	0.80	31.62

The maximum change in bulk density, 42.25 per cent was noticed for the second pass of power harrow. The percentage change in bulk density in the second pass was higher compared to the first pass for rotavator and power harrow, whereas this was lower in the case of spading machine. However the next pass of spading machine (SM3) gave a much higher change in bulk density with a final bulk density value of 0.80 g cm^{-3}.

The bulk density obtained after each operation and the change in bulk density were analysed statistically to study the significance of trend. The analysis of variance tables are given as Table 4.55 and Table 4.56.

Table 4.55 Analysis of variance for final bulk density after each operation

Source of variation	DoF	SS	MS	F-value	Significance level
Replications	4	0.02	0.007	1.80	0.16^{NS}
Operations	6	2.36	0.393	107.10	4.03e-16 **
Residuals	24	0.09	0.004		
Total	34	2.47			

**Significant at 1 per cent level   NS: Non-significant

Table 4.56 Analysis of variance for change in bulk density after each operation

Source of variation	DoF	SS	MS	F-value	Significance level
Replications	4	33	8.20	0.22	0.93^{NS}
Operations	6	4438	739.60	19.73	3.01e-08 **
Residuals	24	899	37.50		
Total	34	5370			

**Significant at 1 per cent level   NS: Non-significant

The analysis of variance table indicated that both the final bulk density values and percentage change in bulk density were significant over the operations. The Duncan's multiple range test (DMRT) was done for comparing both the final bulk density and percentage change in bulk density and the results are given in Table 4.57 and Table 4.58.

Table 4.57 DMRT for final bulk density with respect to operations

Operations	Bulk Density (g cm^{-3})
PH1	1.42^{a}
RT1	1.39^{a}
SM1	1.31^{b}
SM2	1.17^{c}
RT2	0.85^{d}
PH2	0.81^{d}
SM3	0.80^{d}

Table 4.58 DMRT for change in bulk density with respect to operations

Operations	Change (per cent)
PH2	42.25^{a}
RT2	38.85^{ab}
SM3	31.62^{b}
SM1	22.49^{c}
RT1	17.75^{cd}
PH1	15.98^{cd}
SM2	10.68^{d}

It was observed from Table 4.58 that the final results can be categorized into two groups. Field operation with single pass of power harrow and that of rotavator were coming under one category and have similar results with higher value of bulk density. Two pass operation of rotavator, two pass of power harrow and three pass operation of spading machine under second category which gave similar results for bulk density. Also that was the lowest bulk density recorded.

The percentage change in bulk density also had shown significance. While observing the Table 4.58 it can be seen that the highest change was during PH2 and RT2. Two categories of results can be interpreted from the Table. PH2 and RT2 and SM3 in one category having higher change in bulk density. Second category was RT1, PH1 and SM2 which also show the similar amount of change, but lower amount.

It can be interpreted from the above results that RT2, PH2 and SM3 have the similar trend in the case of bulk density, hence these operations are equivalent while taking bulk density into consideration.

4.5.2 Mean Mass Diameter

The variation of MMD had also indicated similar trend as that of bulk density. After each pass, the soil got finer. The mean mass diameter of soil particles after each operation was indicated in Table 4.59.

Table 4.59 Variation of MMD with respect to operations

Operations	MMD (mm)
Rotavator one pass (RT1)	1.59
Rotavator two pass (RT2)	1.38
Power Harrow one pass (PH1)	1.73
Power Harrow two pass (PH2)	1.39
Spading Machine one pass (SM1)	3.86
Spading Machine two pass (SM2)	2.53
Spading Machine three pass (SM3)	1.50

The MMD was decreased with number of pass of the implement. The value of MMD decreased by 13.21 per cent from RT1 to RT2 whereas the reduction was 19.65 per cent in the case of power harrow. The MMD after two pass operation was 1.59 mm and 1.73 mm for rotavator and power harrow respectively. The highest percentage of change was observed in spading machine. The MMD decreased by 34.46 per cent from one pass to two pass operation of spading machine. Again it decreased by 40.71 per cent from two pass to three pass operation. The final MMD observed after SM3 was 1.50 mm.

The data was statistically analysed to find the variation of MMD between the trials. Analysis of Variance was used and the results are presented in Table 4.60.

Table 4.60 Analysis of variance for change in MMD with respect to each operation

Source of variation	DoF	SS	MS	F-value	Significance level
Replications	4	0.53	0.13	1.39	0.27[NS]
Operations	6	24.91	4.15	43.34	1.02e-11 **
Residuals	24	2.30	0.09		
Total	34	27.74			

**Significant at 1 per cent level NS: Non-significant

The analysis indicated significant difference in MMD between operations. The MMD obtained at the end of each operation were compared using DMRT and the results are presented in Table 4.61.

Table 4.61 DMRT for change in MMD with respect to operations

Operations	MMD (mm)
SM1	3.86^{a}
SM2	2.53^{b}
PH1	1.73^{c}
RT1	1.59^{c}
SM3	1.50^{c}
PH2	1.39^{c}
RT2	1.38^{c}

The results indicated that SM1 and SM2 were not giving much soil pulverization compared to other operations and are also found significantly different. The operations such as PH1, PH2, RT1, RT2, and SM3 have similar MMD values. The single pass and second pass operations of rotavator and power harrow were found similar in terms of MMD. The spading machine should operate at least three passed to achieve similar MMD as that of rotavator or power harrow. Hence we can conclude that, one pass operation of rotavator or power harrow is enough to get the tilth quality on the basis of MMD only.

4.5.3 Soil Inversion

The soil inversion of the field was found increased with each pass of an implement. Highest soil inversion was observed during the operation of rotavator compared to other implements. The variation of percentage soil inversion with each trial is indicated in Table 4.62.

Table 4.62 Variation of soil inversion with respect to operations

Operations	Soil inversion (per cent)
Rotavator one pass (RT1)	95.63
Rotavator two pass (RT2)	95.74
Power Harrow one pass (PH1)	91.67
Power Harrow two pass (PH2)	94.83
Spading Machine one pass (SM1)	84.21
Spading Machine two pass (SM2)	89.64
Spading Machine three pass (SM3)	93.78

Lower soil inversion was found in SM1 and highest value in RT2. The values observed in RT1 and RT2 were almost similar. It was observed that the value of soil inversion increased by 3.45 per cent from PH1 to PH2.The soil inversion increased by 6.45 per cent from SM1 to SM2 and by 4.62 per cent from SM2 to SM3.

The statistical analysis of data were carried out using analysis of variance. Five replications of data were taken from the same field for the analysis. The ANOVA table is presented in Table 4.62.

Table 4.63 Analysis of variance for soil inversion after each operation

Source of variation	DoF	SS	MS	F-value	Significance level
Replications	4	3.60	0.90	0.38	0.82^{NS}
Operations	6	521.90	86.98	37.10	5.44e-11 **
Residuals	24	56.30	2.34		
Total	34	581.80			

**Significant at 1 per cent level NS: Non-significant

The result indicated that the change in percentage soil inversion between different operations was significant. The amount of soil inversion observed in each operation was compared using DMRT and the results are shown in Table 4.63.

Table 4.64 DMRT for comparison of soil inversion after operations

Operations	SI (per cent)
RT2	95.74[a]
RT1	95.63[a]
PH2	94.83[a]
SM3	93.78[a]
PH1	91.67[b]
SM2	89.64[c]
SM1	84.21[d]

The soil inversion observed during SM1 and SM2 were less and different. Soil inversion in RT1, RT2, PH2 and SM3 were found similar and higher compared to the rest. Soil inversion obtained by rotavator was same in one pass and two pass operation. Spading machine has to be operated three times to get the similar result. Hence we can recommend single pass operation of rotavator if we are interested in soil inversion only during tillage.

4.5.4 Similar quality of tilth

The comparison of quality of tilth obtained by different implements in different passes, and identification of the operations which gave similar tilth quality were done by analysing the results obtained by the DMRT. The comparison of means table for different operations were presented in Table 4.63.

Table 4.65 Comparison of means for different operations

Operations	BD	MMD	SI
RT1	1.39^{a}	1.59^{c}	95.63^{a}
RT2	**0.85^{d}**	**1.38^{c}**	**95.74^{a}**
PH1	1.42^{a}	1.73^{c}	91.67^{b}
PH2	**0.82^{d}**	**1.39^{c}**	**94.83^{a}**
SM1	1.31^{b}	3.86^{a}	84.21^{d}
SM2	1.17^{c}	2.53^{b}	89.64^{c}
SM3	**0.79^{d}**	**1.50^{c}**	**93.78^{a}**

It was observed from the table that, operations RT2, PH2 and SM3 had the same superscripts in all the columns, corresponding to the three soil property studied. This indicated that there is no significant difference in the final values of soil property obtained in these operations. Hence it can be interpreted that RT2, PH2 and SM3 gave similar quality of tilth in terms of bulk density, soil inversion and mean mass diameter.

With a view to ascertain the economics of using the above implements, the operating costs, time of operation and fuel energy required for the three operations were computed. The cost, time and energy expenditures for obtaining similar tilth quality in terms of BD, MMD and SI was estimated and is presented in Fig. 4.20 (a), (b) and (c).

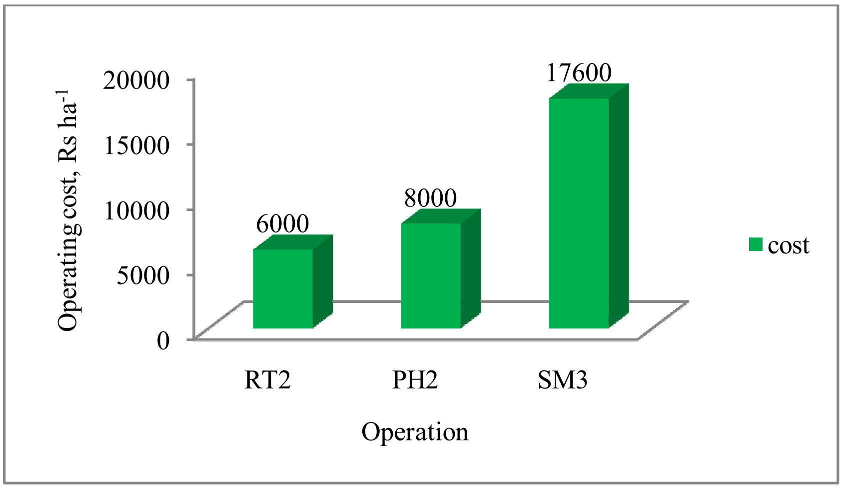

Fig. 4.22 Required cost for the operations

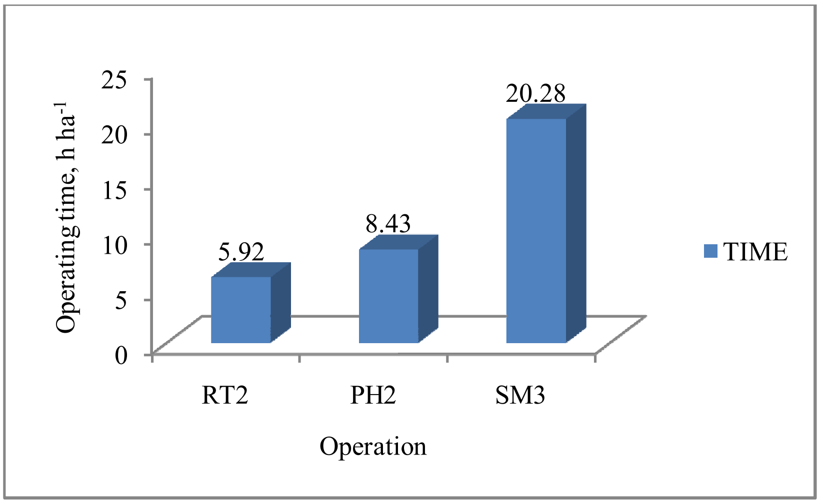

Fig. 4.23 Time taken for the operations

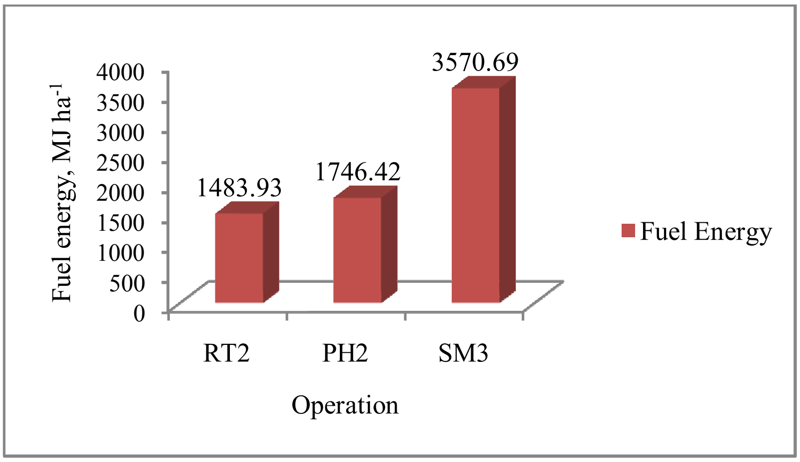

Fig. 4.24 Fuel energy required for operations

The operation with second pass of rotavator had shown lowest in terms of cost, time and fuel energy required for operations, while spading machine showed the highest among them. Rotavator took 5.92 hour to complete two pass operation in one hectare, with an average cost of Rs. 6000 and using 1483.93 MJ energy, while spading machine need 20.28 hours, Rs. 17600 and 3570.69 MJ to get the same tilth quality. The ratios of cost, time and energy requirement are respectively 1:1.33:2.93, 1:1.42:3.43 and 1:1.18:2.41 for rotavator, power harrow and spading machine. Hence based on economical aspect, rotavator can be recommended for achieving a particular tilth quality among the three operations.

The additional amount of energy cost expensed for power harrow was Rs.2000. That can be accounted to the advantage of power harrow that it will result in less soil compaction while compared to rotavator when used continuously for many years. It is due to the vertical rotation of blades. The spading machine costs almost three times the amount that of rotavator, also about 4 times more time and energy requirement to till a given soil. Even though the time and cost is higher for spading machine, it gives depth of operation of about two times higher than rotavator and power harrow. In tillage which needs higher depth in the range of 25 – 30 cm, we can recommend spading machine.

4.7 PERFORMANCE INDICATORS

GRA and TPI were used for studying the data obtained from the operations to find which operation is better among this in terms of performance aspect. The operations which are giving same tilth quality based on bulk density, MMD, soil inversion as obtained by previous sections were analysed. The Grey Relational Analysis was done by considering parameters such as final bulk density (g cm^{-3}), soil inversion (percentage), actual field capacity (ha h^{-1}), depth of operation (cm), mean mass diameter (mm), fuel consumption (l ha^{-1}) and operating cost per hectare. The multivariate data were analysed and the respective ranks of each operation was calculated. Also the tillage performance index of the operations was calculated. The results are given in Table 4.65.

Table 4.66 TPI and ranking based on GRA for operations having similar tilth quality

Operation	TPI	GRA Rank
RT2	28.65	1
PH2	16.30	2
SM3	8.91	3

Table shows the ranks obtained by GRA and it can be observed that two pass operation of rotavator have better performance among the operations based on above mentioned parameters. The value of tillage performance index for the respective operations was also shown also in Table. The higher TPI was observed for RT2 which is having first rank in GRA while lower TPI obtained in spading machine which is having least rank. The higher value of TPI for rotavator may be due to more volume of soil handled and lower fuel energy requirement. The spading machine has higher depth of operation while compared to others, even though it has lower GRA rank and TPI, also the cost and energy requirement is also higher for spading machine.

4.7 SURFACE PROFILE

The soil surface profile observed after each operation are expressed in Fig. 4.21

RT1

RT2

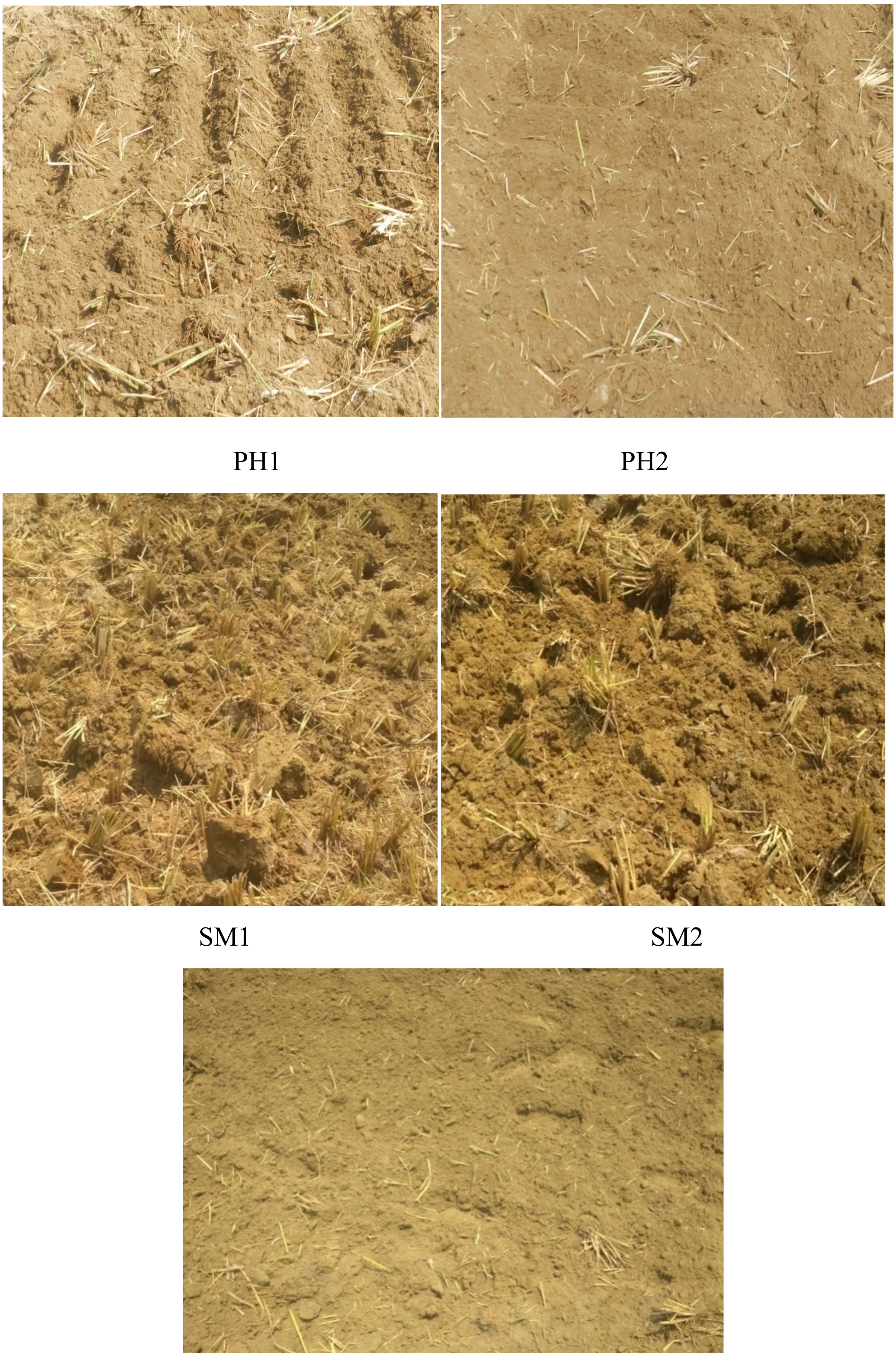

Fig. 4.25 Soil surface profile after each operation

Summary and Conclusion

CHAPTER V

SUMMARY AND CONCLUSION

Tillage operations are mostly carried out with tractor powered tillage implements. Passive tillage implements were mainly used in the country for this purpose. The low power requirement and high efficiency of rotary tillage tools lead to the extensive use of rotavator in the country. Also active tillage implements like power harrow and spading machine came into the farming community. The comparison of the tilth conditions produced by these three active tillage tools was necessary for giving a proper recommendation for the use of these implements.

The methodologies adopted for the study, experiments conducted, the major observations made and conclusions drawn from the various experiments are summarised in this chapter. Experiments were conducted in three different fields of Malappuram district, using three active tillage implements such as Rotavator, Power harrow and Spading machine. John Deere 5065 E was used as the prime mover for all the experiments. All the experiments were done in low first gear condition by keeping the engine throttle lever at 1200, 1600 and 2000 RPM. Spading machine was operated in creeper gear condition such that it gives lower speed compared to the other implements. The soil properties such as soil texture, bulk density, moisture content, mean mass diameter, soil inversion, and soil penetration resistance were measured from each plot using standard techniques as per RNAM test codes, and other machine parameters such as fuel consumption, wheelslip, speed and depth of operation were also recorded. Preliminary soil sampling and assessment of soil properties were also done. The cost of operation was found out adopting the procedure explained in IS 9164-1979. Total operational time and energy requirement for each tillage implement was computed in order to make a comparison on economic basis. Grey relational analysis and Tillage Performance Index were used as the indicators for tillage performance. The effects of multiple passes of implements were also studied for ascertaining the cost, energy and time expenditure by different implements to produce identical quality of tillage.

The soils at each experimental plot considered were sandy loam structure. The moisture content (db) of the fields F1, F2 and F3 were 2.08 per cent, 16.89 per cent and 11.58 per cent respectively. The results indicated that the suitability of implements for a particular field was different with respect to each soil property which is taken into consideration. The moisture content of top layer of soil increased with all the tillage operations, and the variation was with respect to the depth of operation. The cone index of soil also increased with operating depth.

The forward speed of rotavator, power harrow and spading machine were 1.36 to 2.36 km h^{-1}, 1.31 to 2.09 km h^{-1} and 0.46 to 0.70 km h^{-1} respectively. The lower speed for spading machine is due to operation in creeper gear condition.

The bulk density of soil decreased with the tillage operation. The change in bulk density was found varied with respect field conditions, engine speed and between implements. Higher change in bulk density was achieved by the usage of power harrow and spading machine and the optimum engine speed of power harrow operation was found either at 1600 or 2000 engine RPM.

MMD value of the soil was varied with respect to the field and implements used for the operation. It was found that rotavator and power harrow are suited for more pulverization, hence they are getting lower value of MMD. Better soil inversion is found by the tillage treatments. The soil inversion was changed with respect to the fields and type of implement used for tillage. It was observed that higher soil inversion was found in rotavator and power harrow when operated in engine speeds 1600 and 2000 RPM.

The operating depth of implements varied according to the design of implements. The higher operating depth was achieved by spading machine in the range of 24.43 ± 3.38 cm followed by rotavator which was in the range of 12.67 ± 4.53 cm. The lower depth of operation among the three is for power harrow, 10.99 ± 2.67 cm. The selection of implements can be done based on the requirements of operating depth.

The fuel consumption per hectare varies between the implements and field conditions. Rotavator consumed less fuel in the range of 16.01 *l* ha^{-1}, followed by power harrow 27.34 *l* ha^{-1}. Higher fuel consumption of 43.44 *l* $ha^{-1}$was observed in spading machine due to the lower forward speed obtained hence higher time needed to cover unit area. While considering fuel consumption per hour, a reverse trend was observed, higher fuel consumption for rotavator followed by power harrow and low amount fuel consumed by spading machine in unit time.

Theoretical field capacity and actual field capacity of rotavator was found higher in the range of 0.33 - 0.57 ha h^{-1} and 0.25 – 0.45 ha h^{-1} respectively. The actual field capacities of power harrow and spading machine were respectively 0.15 – 0.22 ha h^{-1} and 0.07 – 0.10 ha h^{-1}. The higher value for rotavator with respect to that of power harrow and spading machine was due to higher operating width, forward speed and lower operating time. The field efficiencies of rotavator, power harrow and spading machine were found as 75.76 – 81.40 per cent, 73.91 – 83.33 per cent and 87.5 – 90.90 per cent respectively. The wheelslip values are showing changes with respect to field conditions. Negative wheel slip accounts for the thrust force developed by the tillage implement which push the tractor in forward direction.

The cost of operation and energy requirement of the tillage implements showed that lower operating cost of Rs. 3300 per hectare was observed in operation of rotavator followed by power harrow, Rs. 4500 per hectare and higher operating cost was found in spading machine as Rs. 7900 per hectare, with the same trend in energy requirement 827.91, 1029.68 and 1686.1 MJ ha^{-1} respectively. The time consumed per hectare operation of respective implements were 3.03, 4.76 and 9.09 hours respectively.

The tilth produced by different experiments were analysed by computing the Tillage Performance Index (TPI). Higher TPI value of 28.19 to 45.67 was observed for rotavator, which was due to higher volume of soil tilled per unit time and lower fuel consumed per unit area. The TPI values observed for power harrow was less than 10.00 and that of spading machine was less than 5.00. Hence rotavator is found better based on TPI. Grey Relational Analysis (GRA) was also used to analyse the tilth quality based on certain properties. The higher GRA rank was also obtained for rotavator operation. The best engine speed was found was 1600 RPM in first field, 2000 RPM in second field and 1200 RPM in third field in both TPI and GRA based analysis.

The implements are operated multiple passes in same field in order to study the variations. Based on the soil properties considered such as bulk density, MMD and soil inversion, it was found that similar tilth quality can be achieved by two pass of rotavator, two pass of power harrow and three pass of spading machine. The operation of rotavator took 5.92 hours to complete two pass operation in one hectare, with a total cost of Rs.6000 and 1483.93 MJ energy, and was found economical on the basis of operating cost per hectare, fuel energy required and operating time. The ratios of cost, time and energy requirement are respectively 1:1.33:2.93, 1:1.42:3.43 and 1:1.18:2.41 for rotavator, power harrow and spading machine. The grey relational ranking and tillage performance index values also indicated the better performance of rotavator followed by power harrow and then spading machine. Even though power harrow is having more cost, time and energy requirement compared to rotavator, it can be recommended in order to reduce soil compaction, which will be more while using rotavator operation. Higher depth of operation was achieved using spading machine among the three, hence it can compensate for the higher operating cost, time and energy requirement of spading machine.

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CHAPTER VI

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Appendices

APPENDIX I

i. Specifications of implements and prime mover used in the study

A. Specifications of Prime mover

Prime mover	Tractor – 4WD
Make	John Deere
Model	5065 E
Chassis serial No	1PY5065EAFA018415
Engine serial No.	PY3029H042216
Engine	65 hp, 2400 RPM, DI
Gear box	9 forward + 3 reverse
Steering type	Power steering
PTO	Independent, 6 splines, Dual PTO
Maximum PTO power	41.5 kw/56.4 hp
Total weight (kg)	2540
Specific fuel consumption	285 g kWh^{-1}/209.6 g hph^{-1}

B. Specification of power harrow

Make	Delfino DL
Model	1500
Name	Power harrow
Manufacturer	MASCHIO
Working width (mm)	1500
Working depth (mm)	200
Tractor power	50 hp and above
Number of blades	12
Weight (kg)	516

C. Specification of rotavator

Model	Howard 7 feet
Name	Howard 48/7 feet rotavator
Type	Chain drive
Manufacturer	Farm implements(India) Pvt. Ltd. 13, Kumarappa str., Nungambakkam Chennai-600034, Tamil Nadu
Dimensions (mm)	2340 × 1030 × 1000
Working width (mm)	2400
Tractor power	40 hp and above
Number of blades	48
Length of blade (mm)	250
Serial number	R11-129139

D. Specification of spading machine

Model	SPD1606
Name	Spading machine
Type	Tractor PTO operated
Manufacturer	Gomadhi engineering service Chinnegoundanvalasu Tirupur Dist., Tamil Nadu
Dimensions (mm)	1615 × 1320 × 1150
Working width (mm)	1600
Tractor power	45 hp and above with creeper gear
Number of blades	6
Working depth (mm)	250 - 300
Weight (kg)	510

APPENDIX II

i. Particle size distribution of the soils at the experimental fields

Field	Replication	Particle Fractions (per cent)			Total (per cent)
		Sand	Silt	Clay	
F1	R1	61.96	25.67	12.37	100
	R2	63.24	25.53	11.23	100
	R3	62.67	25.21	12.12	100
	R4	63.29	24.91	11.8	100
	R5	63.24	24.98	11.78	100
	Mean	**62.88**	**25.26**	**11.86**	**100**
F2	R1	61.23	25.11	13.66	100
	R2	60.89	24.72	14.39	100
	R3	61.17	24.51	14.32	100
	R4	60.47	25.94	13.59	100
	R5	60.84	24.07	15.09	100
	Mean	**60.92**	**24.87**	**14.21**	**100**
F3	R1	60.94	25.16	13.9	100
	R2	61.39	24.99	13.62	100
	R3	61.08	24.41	14.51	100
	R4	61.73	23.98	14.29	100
	R5	61.26	24.06	14.68	100
	Mean	**61.28**	**24.52**	**14.2**	**100**

APPENDIX III

i. Cost of operation of tractor per our

TRACTOR-John Deere 5065E		Operation with rotavator	Operation with power harrow	Operation with spading machine
Purchase price (Rs.)		900000.00	900000.00	900000.00
Salvage value (Rs.)		45000.00	45000.00	45000.00
Average purchase price (Rs.)		472500.00	472500.00	472500.00
Useful life of equipment (years)		10.00	10.00	10.00
Average annual use (h)		1000.00	1000.00	1000.00
Interest rate (percentage)		12.00	12.00	12.00
Fuel consumption (l h^{-1})		6.78	5.71	4.90
oil consumption (l h^{-1})		0.20	0.17	0.15
Cost of fuel per litre (Rs.)		70.00	70.00	70.00
Cost of oil per litre (Rs.)		200.00	200.00	200.00
Cost of labour per day of 8 hours (Rs.)		1000.00	1000.00	1000.00
(i). FIXED COST PER YEAR (Rs.)				
a	Depreciation (Rs.)	85500.00	85500.00	85500.00
b	Interest (Rs.)	56700.00	56700.00	56700.00
c	Housing (Rs.)	7087.50	7087.50	7087.50
d	Insurance and Taxes (Rs.)	9450.00	9450.00	9450.00
Total fixed cost per year (Rs.)		158737.50	158737.50	158737.50
Total fixed cost per hour (Rs.)		158.74	158.74	158.74
(ii). OPERATING COST				
a	Repair and maintenance cost (Rs.)	120600.00	120600.00	120600.00
	Repair and maintenance cost per hour (Rs.)	120.60	120.60	120.60
b	Fuel cost (Rs.) per hour	474.60	399.91	342.93
c	oil cost (Rs.) per hour	40.68	34.28	29.39
d	Labour cost per hour (Rs.)	125.00	125.00	125.00
Total operating cost per hour (Rs.)		760.88	679.79	617.92
Total cost of operation (i + ii) of tractor per hour (Rs.)		**919.62**	**838.53**	**776.66**

ii. Cost of operation per hour for implements

Implement	Rotavator	Power harrow	Spading machine
Purchase price (Rs.)	150000.00	180000.00	160000.00
Salvage value (Rs.)	7500.00	9000.00	8000.00
Average purchase price (Rs.)	78750.00	94500.00	84000.00
Life of equipment (years)	8.00	8.00	8.00
Average annual use (h)	300.00	300.00	300.00
Interest rate (percentage)	12.00	12.00	12.00
(i). FIXED COST PER YEAR (Rs.)			
a) Depreciation (Rs.)	17812.50	21375.00	19000.00
b) Interest (Rs.)	9450.00	11340.00	10080.00
c) Housing (Rs.)	1181.25	1417.50	1260.00
Total fixed cost per year (Rs.)	10631.25	12757.50	11340.00
Total fixed cost per hour (Rs.)	35.44	42.53	37.80
(ii). OPERATIONAL COST			
a) Repair and maintenance cost (Rs.)	19950.00	23940.00	21280.00
Repair and maintenance cost per hour (Rs.)	66.50	79.80	70.93
Total operating cost per hour (Rs.)	66.50	79.80	70.93
Total cost of operation (i + ii)of implement per hour (Rs.)	**101.94**	**122.33**	**108.73**

iii. Average operating cost over years from purchase of machine

Year	Variation of repair and maintenance percentage over years		Total cost of tractor-implement combination per hour (Rs.)		
	Tractor	Implement	Rotavator	Power harrow	Spading machine
1	3.2	6	900	825	760
2	5.8	8.8	930	870	795
3	7.5	14.2	975	915	840
4	8.8	7.4	950	890	815
5	9.7	12.3	985	920	845
6	11.2	12.9	1000	940	855
7	12.4	13.8	1015	950	860
8	13.4	13.3	1020	950	870

APPENDIX IV

i. Cone index values obtained from different fields with various implements

Depth (cm)	Cone index (kg cm^{-2})								
	F1			F2			F3		
	R	P	S	R	P	S	R	P	S
2.50	0.33	0	0.35	0.73	0.45	0	0.61	0.51	0
5.00	0.47	0	0.37	1.00	0.70	0.38	0.96	0.79	0.41
7.50	1.20	0.38	0.42	1.50	0.92	0.44	1.33	1.14	0.46
10.00	1.43	0.55	0.46	2.05	1.39	0.52	1.79	1.55	0.55
12.50	1.52	0.91	0.52	2.54	1.95	0.70	2.32	2.04	0.73
15.00	2.36	2.02	0.60	3.13	2.79	0.78	2.92	2.66	0.95

R – Rotavator, P – Power harrow, S – Spading machine

APPENDIX V

V(i) ANOVA for variation of moisture content of fields before tillage

Source of variation	DoF	SS	MS	F-value	Significance level
Fields	2	5067	2533.70	402e+30	< 2e-16 **
Residuals	132	0	0		
Total	134	5067			

**Significant at 1 per cent level

V(ii) ANOVA for variation of number of vegetative matter present in fields before tillage

Source of variation	DoF	SS	MS	F-value	Significance level
Fields	2	23168	11584	392.50	< 2e-16 **
Residuals	132	3896	30		
Total	134	27064			

**Significant at 1 per cent level

APPENDIX VI

i. Grey relational analysis for experiments in Field F1

I	E	GREY RELATIONAL COEFFICIENT							GRG	Rank
		D	BD	SI	Area	MMD	Fuel	Cost		
R	E1	0.33	0.38	0.87	0.51	0.48	0.71	1.00	0.61	3
R	E2	0.36	0.63	0.67	1.00	0.67	0.99	1.00	0.76	1
R	E3	0.41	0.98	0.53	0.99	0.36	0.97	1.00	0.75	2
P	E1	0.36	0.40	0.45	0.42	0.79	0.61	0.33	0.48	8
P	E2	0.37	0.58	0.55	0.42	0.70	0.59	0.33	0.51	6
P	E3	0.38	0.76	0.80	0.47	0.57	0.62	0.33	0.56	5
S	E1	0.51	0.57	0.44	0.35	0.33	0.79	0.37	0.48	7
S	E2	0.68	0.67	1.00	0.36	0.37	0.74	0.37	0.60	4
S	E3	0.72	0.38	0.51	0.37	0.53	0.40	0.37	0.47	9

ii. Grey relational analysis for experiments in Field F2

I	E	GREY RELATIONAL COEFFICIENT							GRG	Rank
		D	BD	SI	Area	MMD	Fuel	Cost		
R	E1	0.40	0.33	0.72	0.49	0.95	1.00	1.00	0.70	2
R	E2	0.41	0.37	0.55	0.66	0.83	0.96	1.00	0.68	3
R	E3	0.44	0.40	0.46	0.92	0.80	0.91	1.00	0.70	1
P	E1	0.40	0.43	0.43	0.40	0.82	0.80	0.33	0.52	7
P	E2	0.38	0.78	0.66	0.42	0.67	0.70	0.33	0.56	5
P	E3	0.39	1.00	0.66	0.47	0.63	0.67	0.33	0.59	4
S	E1	0.62	0.46	0.40	0.35	0.39	0.51	0.37	0.44	9
S	E2	0.75	0.43	0.71	0.35	0.42	0.44	0.37	0.50	8
S	E3	1.00	0.62	0.45	0.37	0.41	0.41	0.37	0.52	6

iii. Grey relational analysis for experiments in Field F3

I	E	GREY RELATIONAL COEFFICIENT							GRG	Rank
		D	BD	SI	Area	MMD	Fuel	Cost		
R	E1	0.45	0.50	0.61	0.44	1.00	0.91	1.00	0.70	1
R	E2	0.52	0.40	0.50	0.50	0.80	0.81	1.00	0.65	2
R	E3	0.55	0.36	0.43	0.55	0.75	0.70	1.00	0.62	3
P	E1	0.47	0.45	0.38	0.40	0.92	0.66	0.33	0.52	4
P	E2	0.42	0.44	0.48	0.42	0.67	0.57	0.33	0.48	5
P	E3	0.41	0.42	0.49	0.46	0.57	0.50	0.33	0.45	7
S	E1	0.72	0.70	0.34	0.33	0.44	0.36	0.37	0.46	6
S	E2	0.69	0.38	0.36	0.35	0.37	0.38	0.37	0.41	9
S	E3	0.76	0.51	0.33	0.36	0.38	0.33	0.37	0.43	8

iv. Grey relational analysis for multiple passes operation

Operation	GREY RELATIONAL COEFFICIENT							GRG	Rank
	BD	SI	MMD	Area	Fuel	Depth	Cost		
PH1	0.33	0.59	0.78	0.46	0.88	0.33	0.86	0.60	5
PH2	0.96	0.86	0.99	0.56	0.60	0.48	0.60	0.72	3
RT1	0.34	0.98	0.86	0.71	1.00	0.36	1.00	0.75	2
RT2	0.85	1.00	1.00	1.00	0.67	0.51	0.73	0.82	1
SM1	0.38	0.33	0.33	0.33	0.62	0.72	0.61	0.48	7
SM2	0.46	0.49	0.52	0.38	0.41	0.90	0.41	0.51	6
SM3	1.00	0.75	0.91	0.44	0.33	1.00	0.33	0.68	4

BD – Bulk density

SI – Soil Inversion

R – Rotavator

P – Power harrow

S – Spading machine

E – Engine speed

I – Implement

RT1 - Rotavator one pass

RT2 - Rotavator two pass

PH1 - Power Harrow one pass

PH2 - Power Harrow two pass

SM1 - Spading Machine one pass

SM2 - Spading Machine two pass

SM3 - Spading Machine three pass

GRG – Grey Relational Grade

D – Operating depth

STUDIES ON THE EFFECT OF ACTIVE TILLAGE TOOLS ON SOIL PROPERTIES

by

AMRUTHA K.

(2017-18-011)

ABSTRACT OF THESIS

Submitted in partial fulfillment of the requirement for the degree of

MASTER OF TECHNOLOGY

IN

AGRICULTURAL ENGINEERING

(Farm Power and Machinery)

Faculty of Agricultural Engineering and Technology

Kerala Agricultural University

DEPARTMENT OF FARM MACHINERY AND POWER ENGINEERING

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2019

ABSTRACT

Three active tillage implements; rotavator, power harrow and spading machine were tested in three fields at various engine speeds in order to study the tilth produced by these implements. It was observed that the suitability of an implement was changed according to the soil properties considered. Power harrow and spading machine can be recommended for getting lower bulk density, whereas rotavator and power harrow were suitable for higher soil pulverization and soil inversion. The deeper operating depth can be achieved by the usage of spading machine. Rotavator consumed less fuel and lower operating cost per unit area.

The soil tilths obtained by these implements were compared using value of tillage performance index and ranking by grey relational analysis. In both the cases rotavator was found to be better compared to others. The cost of operation, energy requirements and time of operation of the tillage implements showed that lower values of Rs. 3300, 827.91 MJ and 3.03 hours per hectare were observed in operation of rotavator followed by power harrow, Rs. 4500, 1029.68 MJ and 4.76 hours, and higher values of Rs. 7900, 1686.10 MJ, 9.09 hours were found in spading machine respectively.

The implements were operated in multiple passes on the same field to study the variations in tillage quality. Two pass of rotavator, two pass of power harrow and three pass operation of spading machine were found to be similar based on the soil properties. The respective ratios of cost, energy and time expenditure were obtained as 1 : 1.33 : 2.93, 1 : 1.42 : 3.43 and 1 : 1.18 : 2.41 for rotavator, power harrow and spading machine. While considering in the point of view of grey relational ranking and tillage performance index, rotavator operation was found best. The cost and energy analysis of the operations also have computed. It also indicated rotavator has the best results. The spading machine can be used for fields which need higher operating depth, even though it's operating cost and time of operation were higher.

സംഗ്രഹം

ട്രാക്ടറിൽ ഘടിപ്പിച്ച് നിലം ഉഴുതുമറിയ്ക്കുവാൻ ഉപയോഗിക്കുന്ന, ട്രാക്ടർ പി.ടി.ഒ. ശക്തിയാൽ പ്രവർത്തിക്കുന്ന കൊഴുക്കളുള്ള ഉഴവുപകരണങ്ങൾ മണ്ണിന്റെ ഘടനയിൽ വരുത്തുന്ന മാറ്റങ്ങളെക്കുറിച്ചുള്ള താരതമ്യ പഠനത്തിനായി റോട്ടവേറ്റർ, പവർ ഹാരോ, സ്പേഡിങ് മെഷീൻ എന്നിവ വിവിധ എൻജിൻ വേഗതകളിൽ വ്യത്യസ്ഥ വയലുകളിൽ പ്രവർത്തിപ്പിച്ചു. ഓരോ സ്ഥലത്തേയും മണ്ണിന്റെ സ്വഭാവമനുസരിച്ചും, ആവശ്യമായ അവസ്ഥ / ഘടന അനുസരിച്ചും ഉപകരണങ്ങളുടെ അനുയോജ്യത മാറുന്നതായി കണ്ടെത്തി. മണ്ണിൻറെ സാന്ദ്രതയിൽ ഉയർന്ന മാറ്റം (കുറഞ്ഞ സാന്ദ്രത) ലഭിക്കുന്നതിന് പവർ ഹാരോയും സ്പേഡിങ് മെഷീനും ശുപാർശ്ശ ചെയ്യാവുന്നതാണ്. അതേസമയം ഉയർന്ന രീതിയിൽ മണ്ണ് മറിച്ചിടാനും പൊടിയ്ക്കാനും റോട്ടവേറ്ററും പവർ ഹാരോയും അനുയോജ്യമാണ്. സ്പേഡിങ് മെഷീൻ ഉപയോഗിച്ചാൽ ആഴത്തിൽ (30 സെ. മി.) മണ്ണ് ഇളക്കാൻ സാധിക്കും. വിസ്തീർണാടിസ്ഥാനത്തിൽ ഇന്ധന ഉപഭോഗവും പ്രവർത്തനചിലവും കുറവ് റോട്ടവേറ്ററിനാണ്.

ഉഴവളവ് സൂചികയും (ടില്ലേജ് പെർഫോമൻസ് ഇൻഡെക്സ്) ഗ്രേ റിലേഷണൽ റാങ്കിങ്ങും ഉപയോഗിച്ച് ഈ ഉപകരണങ്ങൾ മണ്ണിൽ വരുത്തിയ മാറ്റങ്ങളെ (ടിൽത്ത് ഗുണങ്ങളെ) താരതമ്യം ചെയ്തു. രണ്ട് രീതികളിലും റോട്ടവേറ്റർ മികച്ചതായി കണ്ടെത്തി. റോട്ടവേറ്റർ ഉപയോഗിക്കുമ്പോൾ ഒരു ഹെക്ടർ സ്ഥലം

ഉഴുതുമറിയ്ക്കാൻ 3.03 മണിക്കൂർ സമയവും, പ്രവർത്തന ചിലവായി 3300 രൂപയും, 827.91 മെഗാജൂൾ ഇന്ധനോർജ്ജവും ആവശ്യമായി വന്നു. അതേസമയം പവർ ഹാരോയും സ്പേഡിങ് മെഷീനും ഉപയോഗിക്കുമ്പോൾ ഇവ യഥാക്രമം 4.76 മണിക്കൂർ, 4500 രൂപ, 1029.68 മെഗാജൂൾ; 9.09 മണിക്കൂർ, 7900 രൂപ, 1686.10 മെഗാജൂൾ എന്നിങ്ങനെയാണ്.

വ്യത്യസ്ഥ ഉപകരണങ്ങളാൽ സമാനരീതിയിൽ മണ്ണിന്റെ ഘടന ലഭിക്കുവാൻ ഒരേ സ്ഥലത്ത് ഓരോ ഉപകരണവും ഒന്നിലേറെ തവണ ഉപയോഗിക്കേണ്ടി വരുന്നു. റോട്ടവേറ്ററും പവർ ഹാരോയും രണ്ട് തവണ ഉപയോഗിക്കുമ്പോഴും സ്പേഡിങ് മെഷീൻ മൂന്ന് തവണ ഉപയോഗിക്കുമ്പോഴും മണ്ണിന് സമാന ഘടന ലഭിക്കുന്നതായി കണ്ടെത്തി. പ്രവർത്തനചിലവ്, ഇന്ധനോർജ്ജം, പ്രവർത്തനസമയം എന്നിവ റോട്ടവേറ്റർ, പവർ ഹാരോ, സ്പേഡിങ് മെഷീൻ എന്നീ ഉപകരണങ്ങൾക്ക് യഥാക്രമം 1:1.33:2.93, 1:1.42:3.43, 1:1.18:2.41 അനുപാതത്തിൽ ലഭിച്ചു. സമാന ഫലങ്ങൾ തരുന്ന ഈ പ്രവർത്തനങ്ങളുടെ ചിലവും സമയവും ഊർജ്ജവിശകലനവും നടത്തി, റോട്ടവേറ്റർ മികച്ചതായി കണ്ടെത്തി. ഉഴവളവ് സൂചികയുടേയും ഗ്രേ റിലേഷണൽ റാങ്കിങ്ങിന്റെയും അടിസ്ഥാനത്തിലും റോട്ടവേറ്ററിന്റെ പ്രവർത്തനം മറ്റുള്ളവയെ അപേക്ഷിച്ച് മികച്ചതായി കണ്ടെത്തി. പ്രവർത്തന ചിലവും സമയവും കൂടുതൽ ആണെങ്കിലും ആഴത്തിലുള്ള ഉഴുതുമറിയ്ക്കൽ ആവശ്യമുള്ള സ്ഥലങ്ങളിൽ സ്പേഡിങ് മെഷീൻ നിർദ്ദേശിക്കാവുന്നതാണ്.