PERFORMANCE EVALUATION OF HORIZONTAL AND VERTICAL ROTAVATORS

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JUNAGADH – 362 001

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DEDICATION

This research project report is dedicated to the Almighty God and my beloved parents.

- Nelson

Abstract

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PERFORMANCE EVALUATION OF HORIZONTAL AND VERTICAL ROTAVATORS

ABSTRACT

Key words: horizontal rotavator, vertical rotavator, soil physical properties, machine performance

In tillage, rotavator blades may be rotated on vertical-axis or horizontal-axis rotor shafts. Little is known and shown about the vertical axis rotavators and thereby very little documentation is available on the performance of the vertical rotavator and or very few studies have been conducted on comparative performance of vertical rotavators with horizontal rotavators. Vertical and horizontal axis rotavators were tested in two different fields having 11.78 % and 10.51 % moisture contents. Their performance results were analyzed in terms of tilling quality of soil and machine performance. The effects of two operating parameters namely tilling depth and operating speed on soil physical properties like soil mean weight diameter, soil penetration resistance, bulk density and soil disturbed area were evaluated. Machine performance parameters like fuel consumption, energy requirement, field efficiency and operating cost were also determined.

Better performance in terms of tilling quality of soil was obtained by using vertical axis rotavator at field no.1 with soil moisture content 11.78 %. The average values of soil mean weight diameter, cone index, bulk density and the percentage of soil disturbed area were found to be 4.00 and 4.72 mm; 53.00 and 56.20 kPa; 1.18 and 1.22 g/cm^3 and 94.43 and 91.19 % by using vertical and horizontal axis rotavator, respectively. The average values of fuel consumption, energy requirement, field efficiency and operating cost were found to be 15.60 and 13.20 l/ha; 958.23 and 816.47 MJ/ha; 87.61 and 86.11 % and Rs 1900 and 1500 per ha for vertical and horizontal axis rotavators, respectively. Vertical rotavator was found better based on quality of work, while from economic point of view, the horizontal rotavator was found better. The optimum tilling depth and operating speed were found to be 10 cm and 2.71 km/h respectively for both the rotavators.

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CERTIFICATE-I

This is to certify that the thesis/project work report entitled **"PERFORMANCE EVALUATION OF HORIZONTAL AND VERTICAL ROTAVATORS"** submitted by **Mr. NELSON RICHARD** (Reg. No. J4-01244-2013) in partial fulfilment of the requirements for the award of the degree of **Master of Technology (Agricultural Engineering)** in the subject of **FARM MACHINERY AND POWER ENGINEERING** to the Junagadh Agricultural University is a record of bonafide research work carried out by him under my guidance and supervision and the thesis has not previously formed the basis for the award of any degree, diploma or other similar title. The candidate had fulfilled all prescribe requirements. The assistance and help received during the course of investigation have been fully acknowledged. He has successfully completed the comprehensive/preliminary examination held on **April 10, 2015** as required under the regulation for post-graduate studies. He has submitted kachha bound thesis on **May 29, 2015.**

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CERTIFICATE-II

Date: 25 /06/2015

This is to certify that the thesis/project work report entitled **"PERFORMANCE EVALUATION OF HORIZONTAL AND VERTICAL ROTAVATORS"** submitted by **Mr. NELSON RICHARD** (Reg. No. J4-01244-2013) to Junagadh Agricultural University, Junagadh in partial fulfilment of the requirements for award of the degree of **MASTER OF TECHNOLOGY** in the subject of **FARM MACHINERY AND POWER ENGINEERING** after recommendation by the external examiners were defended by the candidate before the following members of the examination committee. The performance of the candidate in the oral examination was satisfactory. We, therefore, forward with recommendation.

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Place: Junagadh

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(Nelson Richard)

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LIST OF ABBREVIATIONS

Agril.	:	Agricultural
AMA	:	Agricultural Mechanization in Asia, Africa and Latin America
ASAE	:	American Society of Agricultural Engineers
Avg.	:	Average
B. Tech	:	Bachelor of Technology
CAET	:	College of Agricultural Engineering and Technology
Dept.	:	Department
Engg.	:	Engineering
Er.	:	Engineer
etc	:	And so on
et al.	:	And others
Fig.	:	Figure
FMP	:	Farm Machinery and Power
HR	:	Horizontal Rotavator
i.e.	:	Id est and that is
Int.	:	International
ICAR	:	Indian Council of Agricultural Research
JAU	:	Junagadh Agricultural University
J.	:	Journal
Max.	:	Maximum
Min.	:	Minimum
M. Tech.	:	Master of Technology
No.	:	Number
Pub.	:	Publication
FRBD	:	Factorial Randomized Block Design
Reg. No.	:	Registration number
REE	:	Renewable Energy Engineering
Res.	:	Research
R1	:	Horizontal Rotavator
R2	:	Vertical Rotavator
Tech.	:	Technology

Trans.	:	Transactions
viz.	:	Namely
VR	:	Vertical Rotavator

LIST OF NOMENCLATURE

Ah	:	Ampere hour
Amp	:	Ampere
cm	:	Centimeter
cc	:	Cubic Centimeter
cm^3	:	Cubic Centimetres
db	:	Dry basis
dsm^{-1}	:	Decisiemens per metre
ed.	:	Edition
g	:	Gram
g/cc	:	Gram per cubic centimetre
h	:	Hour
ha	:	Hectare
hp	:	Horse power
kW	:	Kilowatt
kPa	:	Kilo Pascal
kg/cm^2	:	Kilogram per square centimetre
kg/m^3	:	Kilogram per cubic meter
km	:	Kilometre
km/h	:	Kilometre per hour
l	:	Litre
m	:	Meter
$Mgha^{-1}$	:	Mega gram per hectare
Mgm^{-3}	:	Mega gram per cubic meter
min	:	Minute
MJ	:	Mega Joule
MPa	:	Mega pascal
m/s	:	Meter per second
mm	:	Millimetre
s	:	Second
sq.	:	Square
Sr.	:	Serial

°	:	Degree
₹	:	Rupees
%	:	Per cent
+	:	Plus
θ	:	Theta

Introduction

CHAPTER I

INTRODUCTION

Farm mechanization has been helpful to bring about a significant improvement in agricultural productivity. Thus, there is strong need for mechanization of agricultural operations. The factors that justify the strengthening of farm mechanization in the country can be numerous. The timeliness of operations has assumed greater significant in obtaining optimal yields from different crops, which has been possible by way of mechanization. A delay beyond sowing period leads to decrease in the yield. This apply to all crops and for other farm operations like tillage, irrigation, harvesting, threshing and marketing, which need to be performed at appropriate time, otherwise the yield and farm income is affected adversely.

Tillage is the most important unit operation in agriculture. It is done mainly to loosen the upper layer of soil, to mix the soil with fertilizer and to remove weeds. As a result of this processing the water-air, thermal and nutrient regimes of the soil are improved in the interest of the growth and development of crops.

The most widespread method of tilling land is ploughing with mouldboard ploughs. In the process of ploughing, the soil layer is subjected to various deformations and is turned to the bottom of the groove. However, by the use of moldboard ploughs the upper layer of the soil is not always loosened to the desired extent, nor is the proper mixing of the different layers achieved. Hence, additional operations such as discing, cultivation and harrowing, etc., are carried out to improve on the ploughing.

1.1 Traditional Tillage Practices

Traditionally draught animals (oxen and bull buffaloes) have been used for seedbed preparation. With increased cropping intensity, farmers have supplemented animate power with tractors and power tillers. Farm power ensures timeliness operations, besides reducing drudgery. Available farm power and energy use per hectare are the indicators of modernization of agriculture. In developing countries some farm operations have been partially mechanized and rest of the operations are still done by the draught animals. The land preparation aspect of crop is energy intensive operation due to the presence of heavy soils and tendency to develop cracks. At present, because of lack of knowledge, experience and facility, farmers are stuck to the tractor operated / bullock operated MB ploughs and blade harrows for land preparation.

1.2 Rotary Tillers

The rotary tiller has been a device that inspired both enthusiasm and controversy since its original development. The first machine was introduced into the United States by a Swiss Manufacturer in 1930s. Shortly after this, several American companies started manufacturing rotary tillers; the greatest growth was after World War II.

In tillage, rotavator blades may be rotated on vertical-axis or horizontal-axis rotor shafts. The resulting texture of rotavators tilled-soil is a function of the soil condition, blade kinematics and soil flow dynamics (Kinzel *et al.*, 1981). The soil flow dynamics depends on whether the rotor axis of the rotavator is horizontal or vertical; and on the direction of the rotation of the blades. For the horizontal rotor axis, the blades may be rotated in the down-cut or up-cut direction; while for the vertical axis, the direction of rotation may be clockwise or anti-clockwise. In general, rotavators work on horizontal axis rotor; and seldom on a vertical or series of vertical axis rotors (Bukhari *et al.*, 1996).

The thrust force generated by the rotavator blades can be used as a traction aid and contributes significantly to the reduction of rolling resistance of the tractor. Reduced draught of the rotavators results in less wheel slip at the tractor tyre-soil interface, thus improving field productivity and efficiency. It allows the use of lighter tractors, thus reducing the soil compaction levels and the purchase price of tractors required to operate the tillers.

Rotavator mixes and pulverizes the tilled soil well; resulting in a good clod size distribution. The number of tillage passes required to achieve an acceptable tilth quality, using rotavator is also significantly reduced (Destan and Houmy, 1990) in comparison to the series of operations that would result in the same tilth quality with the use of passive tools.

According to Manian and Kathirvel (2001), the view of excessive energy consumption by rotavators only holds when the energy consumption of the rotavator is compared to the energy consumed by individual passive tillage tools, without considering the quality of the resultant tilth and the number of tillage operations required under conventional tillage. When the total energy demand for producing an acceptable tilth is considered, the series of passive tillage operations needed to realize the same tilth consumes more specific energy than the rotavators (Manian and Kathirvel, 2001; Prasad, 1996). The series of tillage operations for passive tools also require more time and additional resources, thus increasing the production costs of the crops.

1.3 Justification

Looking to the present practice of seed bed preparation among the farmers and implements used to perform different operations, there is need to study the best alternative, either operation wise or equipment wise, by which we can reduce the cost of operation and improve the efficiency of the system.

Recent changes in economic and regulatory situations on the agricultural market and with respect to the environment compel farmers to review their tillage systems and to implement new techniques of soil cultivation. Work rate and the energy consumption are the basic measures of machine performance. Quality must be also considered, because it describes the ability to manage the system without wasted product. To complete any of the tasks in given time, timeliness is crucial in agriculture which is sensitive to season and bad weather. There is a diverse range of implements available to achieve today's demands in soil cultivation.

From the profitable farming perspective, the rotavator hold immense potential for reducing the cost of production of crops especially if methods for reducing its perceived excessive power requirements in tillage can be found. One way of doing this is to carry out studies that would establish the effects of the rotavator design and operating parameters and soil conditions on its performance. Practically, this can be accomplished by studying different types of rotavators and their effect on soil physical properties.

In tillage, the performance of tools is determined by their specific draft, energy requirements, and the quality of work (Srivastava *et al.*, 1993). There is no precise definition of the quality of work, it is generally evaluated by clod size, the evenness of operative depth and percentage of plant residual covered after a tillage operation. Though numerous attempts have been made to quantify the performance of rotavators, little is known about how the rotavator design parameters and soil conditions influence the energy required and quality of work due to the experience or experimental nature of the studies on performance (Marenya *et al.*, 2003).

Some research has been done on comparison between rotavator and conventional ploughs. Soil texture after tillage with rotavator depends on soil conditions, blade kinematic and dynamic current of soil. Dynamic current of soil depends on rotor axle direction and blades could be in down-cut or up-cut direction; while in vertical axle, the rotation direction could be clockwise or counter clockwise. Horizontal axis tillers are more conventional among all tillers. Very few research documentation are available on the comparisons between horizontal and vertical axis rotavators.

In spite of more popularity of horizontal axis rotavators, vertical rotavators are also being manufactured. Numerous attempts have been made to quantify the performance of horizontal axis rotavators, while little is known and shown about the vertical axis rotavators and thereby very little documentation is available on the performance of the vertical rotavator and or very few (one or two) studies have been conducted on comparative performance of vertical rotavators with horizontal rotavators.

In this research, performance of rotavator with horizontal rotary axis and vertical rotary axis was evaluated and compared based on soil mean weight diameter, cone index, bulk density, cross-sectional area disturbed and energy consumption at different operating parameters.

1.4 Objectives

i. To determine the effect of speed and depth of horizontal axis rotavator on soil physical properties.
ii. To determine the effect of speed and depth of vertical axis rotavator on soil physical properties.
iii. To compare the performance and economy of both the horizontal and vertical axis rotavators.

Review of Literature

CHAPTER II

REVIEW OF LITERATURE

The past work done by the several scientists and engineers related to tillage, soil physical properties and different rotavators was reviewed and presented as follows.

2.1 Tillage

Raney and Zingg (1957) stated that tillage plays an important role in controlling weeds and managing crop residues, but the primary purpose of tillage is to change the soil structure.

Gill and McCreery, (1960); Gill and Vandenberg, (1967); McKyes, (1985); Boydas and Turgut, (2007) concluded that, to assure normal plant growth, the soil must be prepared in such conditions that roots can have enough air, water, and nutrients.

Lyles and Woodruff (1962) studied the effect of moisture content at the time of tillage on cloddiness for wind erosion control on a silt clay loam soil. They stated that soil moisture content at tillage affected the size distribution of the aggregates produced, and aggregates formed at low moisture content were 3 to 4 times more resistant to crushing than those formed at higher moisture content.

Kepner *et al.*, (1978) reported that tillage equipment should be capable to prepare a suitable seedbed with minimum expense. According to the previous researches, about 60 % of total energy required for preparing the soil is used for tillage and preparing a good seedbed (Jacobs and Harrol, 1983). Therefore it is very important to know which parameters can reduce the cost of tillage and traffic in fields.

Ojeniyi and Dexter (1979) indicated that at optimum water content tillage produces a maximum number of small soil particles and a minimum number of large voids. Russell (1961) states researchers generally accept that a soil particle size range of 1 to 5 mm is required for seedbeds.

Douglas and Mckyes (1983) reported that most tillage experiment inconsistencies were due to the complexity of the changes in soil properties caused by tillage. Chang and Lindwall (1990) indicated from a literature review that soil property changes due to tillage are related to several things. Those things include soil type, type of tillage equipment, tillage depth, soil conditions such as moisture content at the time of tillage and climatic conditions. Bauer and Kucera (1978) concluded inconsistencies in relative grain yield differences among tillage treatments over a period of years were, in part, associated with inconsistent differences in soil properties produced by given tillage treatments from one year to another. Inconsistencies were concluded to be likely associated with the presence of soil water at the time of tillage and climatic conditions - primary water supply, water distribution and temperature.

Gan *et al*., (1992) reported that plants that emerged early contributed more to crop yield than those that emerged later. Thus, desirable crop yields were achieved by providing seeds with an environment that encouraged early germination and emergence.

Çarman (1997) observed that different methods produced different yields, which appeared to relate to the soil conditions produced by tillage.

Mohanty and Painuli (2004) reported that tillage practices affected mechanical characteristics of seedbed considerably and thus crop emergence.

Patil *et al*., (2009) stated that land development, tillage and seedbed preparation together accounted for a major share of power utilization in the crop cycle. The implements used for seedbed preparation needs to be evaluated for maximum field capacity with reduced cost of operation.

2.2 Soil Physical Properties

Important soil physical properties resulting from tillage operation are discussed here.

2.2.1 Bulk density

Carter *et al*., (1965) found that seed cotton yield decreased linearly from 3.6 to 1.45 Mg ha^{-1} as soil strength increased from 0.3 to 4 MPa.

Gill and Vanden Berg (1968) reported that soil physical properties included the soil water content (or moisture content), bulk density, texture, temperature, colour, and pore (void/ porosity) space. The soil moisture content, bulk density and soil texture affected mechanical behaviour and strength of a soil.

Bauder *et al*., (1981) observed that bulk density was lower in the plots prepared by moldboard plow than those prepared by chisel plow and spring disk, and those with no tillage in the 0-10 cm layer.

One soil physical property that is nearly always altered by tillage operations is bulk density (Cassel, 1982). This has often been used as one measure of the effects of tillage practices. Density is a temporary condition that changes with time and rainfall. In field studies, density measurements exhibit both spatial and temporal variability (Cassel, 1982). The spatial variability results from vertical and lateral changes in soil properties such as texture, structure, and organic matter content and from the effects of past soil management practices. The temporal variability occurs after a tillage system is applied. To account for positional effects of tillage, bulk density as a function of both depth and position may be studied (Van Diepen, 1980). Position is defined as the perpendicular or normal distance from the crop row (Hageman and Shrader, 1979). Data from two dates may demonstrate the temporal changes (Tiarks *et al*., 1974). Therefore, extreme caution must be exercised when analyzing bulk density data collected on different dates. Temporal variation in bulk density of freshly tilled, non trafficked soil occurs due to shrinking and swelling of the soil (Berndt and Coughlan, 1976).

The range in density required for optimum plant growth was unknown for most soils. Density lower than optimum reduces water holding capacity, and higher bulk density leads to poor aeration which may limit root extension (Cassel, 1982). Tillage generally tends to decrease the density and increase the total porosity of the surface soil (Croney and Coleman, 1954). At the same time, the soil just below the plowed or tilled layer may become more dense due to the stresses applied to that layer by tillage machinery. The pore space geometry produced in the surface soil is usually very unstable and changes of the pore geometry with time are common (Klute, 1982). Statistically significant differences in density changes by tillage have been recorded but the effects of this density change on plant growth and/or yields were not well understood (Flocker *et al.*, 1960; Singh *et al.*, 1971).

Hillel (1982) reported that Bulk density was nearly always altered by tillage operations. An ideal soil contains about 50% solid particles and 50% pore space by volume.

Results of tillage and no-tillage treatments on bulk density were not consistent and at times are contradictory, as reported by Hill and Cruse (1985). Some researchers have observed significant differences in soil bulk density under conventional and conservation tillage treatments (Dickey *et al.*, 1983; Mulvaney and Paul, 1984; Unger and Stewart, 1988), whereas other researchers (Blevins *et al.*, 1977; Tollner *et al.*, 1984; Shear and Moschler, 1969) found non significant differences.

Core sampling has long been used for measuring soil bulk density (Voorhees and Lindstorm, 1984). Undisturbed core samples have been used successfully for the determination of bulk density of undisturbed soil or soil which has settled to a firm condition (Buchele, 1961). But, difficulties arise in determining the bulk density of freshly disturbed soil. Published bulk density values from tillage studies, based upon soil core samples, range from <1.0 to >1.7 Mgm^{-3}. Significant differences in bulk density among tillage treatments as small as 0.07 Mgm^{-3} have been reported (Cassel, 1982).

Glinski and Lipiec, (1990) concluded in order to efficiently handle the demand in agricultural food production; soil physical properties must be managed adequately. The main aspect of soil physics for plant productivity is to preserve suitable proportions between solid, liquid, and gaseous phases. Soil physical properties are extremely vital to plant growth. The influence of tillage implements on soil physical properties was significant (Boydas and Turgut, 2007). Buschiazzo *et al.*, (1998) determined that the soil physical properties, affected by soil tillage treatments, could influence the yield level of grown crops. Aggregate size, moisture content, penetration resistance, and bulk density are important soil physical properties. Singh *et al.*, (1992) reported that the bulk density of a typical mineral soil was about 1.3 Mgm^{-3}.

Husnjak *et al.*, (2002) reported that among the soil physical properties strong reciprocal dependence was found between crop yield and soil bulk density, and strong direct dependence between crop yield and total porosity.

2.2.2 Penetration resistance

Another important parameter usually reported in tillage research was the measurement of soil strength. Lindstrom *et al.*, (1984) reported consistently greater penetration resistance of soils under conservation tillage than soils under conventional tillage. Rizvi *et al.*, (1987) reported no difference of penetration resistance in no-tillage and chiseled treatments, but their penetrometer readings showed increasing values during the later part of the corn growing season compared to the resistance values just after tillage. They also reported significantly higher penetration resistance with depth under both tillage practices. Mazurak and Pohlman,(1968) observed that soil strength had minimal effect on root elongation unless the cone index value exceeds 400 kPa. Soil strength was shown to increase with increasing bulk density and decreasing soil matric potential, but not independently (Hill, 1990).

Values of penetration resistance at in situ field capacity, as measured by the cone penetrometer and reported as the cone index, range from zero in a subsoil slit to values >900 kPa in a tillage-induced pan (Cassel, 1982) . The Cone Index was defined by ASAE standard S313.2 (ASAE, 1990) as the force required to push a metal cone of specified geometry into the soil, divided by the base area of the cone. For proper interpretation of penetration resistance data, related soil physical properties data must be made available (Cassel, 1982). Hence, whenever penetration resistance measurements are taken, it is also necessary to collect soil water content and bulk density data. Penetration resistance generally increases with both bulk density and matric potential (Singh and Ghildyal, 1977). Other factors affecting penetration resistance are texture, structure, and particle surface roughness (Cruse *et al.*, 1980). It is important to select an appropriate time to measure penetration resistance.

Chancellor (1976) recommended that penetration resistance measurements be taken when the soil is at in situ field capacity. The shape of the tip (cone-shaped vs blunt), cone angle, cone diameter, and penetration rate are factors which affect measured values (Jezequel, 1969; Gooderham, 1976; Freitag, 1967; Bowen, 1976). Penetration resistance also may vary both spatially and temporally (Cassel, 1982).

Sial (1987) reviewed literature concerning the relative sensitivity of cone resistance and bulk density methods of measuring tillage responses in soils. He discussed Ronai's 1982 claim that bulk density was a more appropriate parameter to characterize soil compaction than penetration resistance. However, Voorhees et al. (1978) compared these techniques in a five year study and found that bulk density increased by 20% or less while the corresponding increases of penetration resistance were up to 400%, indicating a higher sensitivity of cone index measurements. Similarly, Carter and Tavernetti (1968) considered the use of cone penetrometer resistance superior to bulk density measurements.

Singh *et al.*, (1992) concluded that penetration resistance is a measure of soil strength and an indicator of how easily roots can penetrate into soil, and thus a measure of plant growth and crop yield.

Soil moisture is an important factor affecting soil cone index (CI) (Yasin *et al.*, 1993; Franzen et al., 1994). Typically drier soil has higher CI values (Tekeste *et al.*, 2008; Francis *et al.*, 1987). Busscher *et al.*, (1997) found an inverse linear relationship between CI and moisture content, while Ohu *et al.*, (1988) found an exponential relationship between CI and moisture content for loam and clay soils. Soil CI is also related to soil bulk density and soil textual parameters. Ayers and Perumpral (1982) reported a direct relationship between CI and bulk density.

CI has been used as an important indicator for soil compaction (Bédard *et al.*, 1997; Tessier *et al.*, 1997), crop root development (Materechera and Mloza-Banda, 1997; Chen *et al.*, 2005), soil water infiltration (Busscher *et al.*, 2006; Botta et al., 2006), draft of tillage tools (Manuwa and Ademosun, 2007) and the performance of tractors (Mari *et al.*, 2006).

Soil CI varies within the soil depth profile. Lower soil CI values are associated with a tilled layer near the soil surface, while higher CI values are associated with a compact soil layer below the tilled layer (Chen and Tessier, 1997; Doan *et al.*, 2005). Yasin *et al.*, (1993) found a cubic relationship between CI and depth.

2.2.3 Soil mean weight diameter

A major reason for tillage is to create soil physical conditions that are conducive to good seed germination (Gupta and Larson, 1982). Generally, this means desirable temperatures and favorable water and aeration conditions in the seed zone for a given plant species. Soil physical conditions, in turn, affect microbial activity, root growth, and other biological processes in the soil. During tillage, a part of the soil is broken into various size clods by the implements; depending upon the soil type, water content at the time of tillage, and stresses exerted by the tillage implements and equipment, soils are affected differently by the breakup processes. Allmaras *et al.*, (1965) showed that the geometric mean diameter of aggregates in the row zone varies with the type of tillage and the type of soil. The degree of soil breakup that is optimum for plant growth depends upon the seed size, the crop type, and the soil and weather conditions (Gupta and Larson, 1982). Larson and Swan (1970) suggested an average aggregate diameter of 6 mm in the row zone of wet soils for corn. They indicated that with most planters, this would produce good packing over the seed at water content favorable for germination. For dry soil, they suggested use of furrow openers to place the seed in moist soil and a bed of 2 to 6 mm aggregates at the soil surface to slow evaporation. Russell (1973) and Dexter (1988) have shown that the optimum seedbed is composed of aggregates with a size range between 1 and 5 mm diameter in the vicinity of the seed.

Tillage machine features such as size, shape, sharpness, and speed of operation do affect clod size. However, the resulting clod size is determined to a far greater extent by the soil type and condition at the time the tillage operation is performed. Ploughing when the soil is too wet, "near field capacity", or when it is too dry, "below the wilting point", usually produces large clods. This same operation when the soil is midway between field capacity and the wilting point will frequently produce a finely pulverized soil consisting of small clods (Lovely, 1967).

Clod size is more a function of soil conditions than machine features. However, tillage tools such as ploughs and subsoilers tend to create rougher soil surfaces than tools like harrows or powered rotary tillers (Lovely, 1967).

Cole (1939) studied changes in the size distribution of aggregates after tillage operations and found ploughing caused a decrease in clod size unless performed at excessive moisture contents. Lyles and Woodruff (1962) studied the effect of moisture and tillage on soil clod size. They found that type of implement had a decided influence on the size and stability of clods formed. The resulting differences caused by changes in tillage implements persisted longer than those due to variable moisture content. A mouldboard plough produced more large clods and fewer fine particles, than the one way disk or the sub-surface sweep.

Yassen *et al*., (1992) reported that with low soil moisture content the cohesion force between particles of soil is very strong and a lot of energy is needed during tillage. The plowing depth is a very important and effective parameter. Increasing the ploughing depth raise the clod mean weight diameter (MWD).

2.3 Operating Parameters

Operating parameters are discussed in this section.

2.3.1 Tilling depth

Dalin and Pavlov (1950) reported that depth of tillage, as similar to other tillage methods, has considerable influence on the power requirements and performance of rotary blades. The average depth of tillage is governed by the depth of effective tillage, the bit length, the peripheral and forward velocities, and the lateral spacing of the blades.

Mursch (1961) found the rotary power requirement increased with increasing tillage depth.

Matsuo (1963) developed theoretical and experimental data comparing forward, down cut, and reverse, up-cut tiller operation using a Japanese style blade having rotor radius of 220 mm. The experiments were conducted over a depth range of 20 to 150 mm and a range of rotational velocity of 50 to 350 rev / min. It was found that the power requirements were less for reverse rotation, given the same pitch of cut, and that the reduction in power become larger as the soil strength became smaller.

Tsuchiya (1965) found that the rotary power input, at a constant rotor speed, increased more rapidly with increases in forward velocity at deeper than at shallow depths of operation.

Gosh (1967); Hendrick and Gill (1971) and Shibusawa (1993) concluded that as with any other tillage tool, the depth of operation has considerable influence on the power requirements and performance of rotary tillers. The rotary tiller is unique in that during its operation the actual depth of tillage for each blade varies through-out the rotational path of the tool. Thus the average depth of tillage will be governed by factors other than the ratio of rotor radius and depth. An increase in the depth of operation of a rotary tiller, other conditions being constant, increases the power requirement. While power input increases with depth, the specific power requirement (power per unit volume of soil tilled) decreases.

Matyashine (1968) reported that at shallow tilling depths (cutting depth less than rotor radius), forward rotation required 10 to 15% less energy than reverse rotation. When tilling depth (cutting depth greater than rotor depth), reverse rotation reduced the energy requirement by 20 to 30 %.

Depth of tillage is an important factor in the dissemblance, the mixing of soil and cutting of roots. The depth of operation has considerable effect on the power requirement and performance of rotary tillers because the actual depth of tillage for each blade during its operation varies throughout the rotational path of the blade (Hendrick and Gill, 1971, and Gill and Hendrick, 1976).

Power requirement increased as depth of tillage increased for direction of rotation, peripheral velocity and bit length (Hendrick and Gill, 1971).

Niyamapa *et al.*, (1994) determined the design parameters of rotary cultivators, namely, the depth of tillage, the rotor and forward speed influence on the power requirement to cut and throw the soil clods under soil bin laboratory study and recommended clod size development for soybean cultivation.

Collins and Fowler (1996) reported that shallow seed placement (less than 25 mm) is recommended for most crops that are directly seeded. However, the depth of the crop roots should determine plowing depths, while the availability of time and implement width will determine the speed required to finish the work on time (Mustafa and Turgut, 2007). The results obtained from this study indicated that the ploughing depth has more effect on the tractor fuel consumption than the ploughing speed. Therefore, the depth of plowing should be determined based on the root length of crop. Increasing the ploughing speed will improve the quality of the seedbed and will not increase the fuels consumption proportionally.

Kosutic *et al.*, (1996) increasing the depth of tillage by 40%, it decreased the energy requirement per unit volume of tilled soil by 19.3%.

Tsuchiya (1965) investigated the rotary power requirement increase with increasing tillage depth. It was concluded that increasing the tillage depth increases the total power requirement, but decreases the specific power requirement.

Saraswat (1987) reported that with an increase in the cutting depth from 50 to 75 mm, the specific energy requirements of the "Pick"-shaped rotary blades decreased, at the rotation speeds of 150 to 300 rpm.

Yusuph (2001) reported that the rotary tillage influenced soil bulk density, strength of tilled soil, mean mass diameter of clods, aggregation of particles <2 μm, particle size density and porosity. Generally, soil bulk density, soil strength, and particle size density increased with increase in depth from 0-2.5 cm depth to 10.0-12.5 cm depth beyond of which there was decrease. Aggregation of particles increased in soil moisture from 11%, w/w at 0- 2.5 cm depth to 37%, w/w at 12.5-15.0 cm depth. The greatest bulk densities of 1.495 g cm^{-3} and 1.432 g cm^{-3} occurred at 10.0-12.5 cm depth on tilled and untilled plots respectively. It is possible to achieve a considerable reduction in the bulk density with one passage of rotary tiller.

2.3.2 Operating speed

The tilling power requirement increased with increasing forward velocity while the specific energy decreased (Dalin and Pavlov, 1950). According to Furlong (1956), varied velocity ratio by increasing forward velocity while maintaining a constant value of ω . Three rotary velocities were used in reverse as well as in forward directions. It was observed that as tilling pitch increased, draft power also increased for each set of rotor speeds.

Butterworth (1972) designed "C" and "L" – shaped blades for deep and shallow tillage for tillers with a rotor speed of about of 180 rpm, forward speed of 2.01 km /h and a bit length of 100 mm appeared optimum for power and cultural optimization.

Singh (1979) concluded that at a constant rotational velocity, the input power requirement of rotary blade has been increased with an increase in forward velocity at deeper than at shallow depth of operation.

Walton and Warboys (1986) conducted experiments to determine the factors affecting the power requirements of the way double digger including the variation of the rotor speed between 94 and 242 rev/min and forward speed between 1.8 and 5.1 km/h. There have been used 16 and 24 straight –shank tynes and 12 pick type tynes. The experiments showed that there was an increase in take off power with an increase in either rotor or forward speed. Draft power increased with forward speed, the total power requirements increased with both an increase in forward and rotor speed. However, the total specific energy requirements increased with an increase in rotor speed but fell with an increase in forward speed. The straight –shank tynes used up to 50% more power tynes.

Niyamapa *et al.*, (1994) determined the optimum parameters for the design of a rotary cultivator in a laboratory study in a soil bin with clay soil at a moisture content of 23.26% (dry basis) and a dry bulk density of 1.29 g / cm ^{2}. Experiments were conducted at working depths of 12 and 18 cm, rotor speeds of 140, 160, 180, 200, and 220 rpm and forward speeds of 0.16, 0.23, 0.35, 0.64, and 1.25 m/s. The width of cut was 55 cm. From the speed and rotor torque data, power consumption was calculated. The power requirement for cutting and throwing the soil increased with an increase in rotor speed, forward speed, and tilling depth at a given width of tiller. These three parameters also affected the soil breakage. Larger clod sizes were found when tillage depth and forward speed were high and the rotor speed was low. Smaller clod sizes were found when tillage depth and forward speed were low and the rotor speed was high. The optimum parameters for the design of a rotary cultivator were found to be a tillage depth of 18 cm at a forward speed of 0.35 m/s and rotor speed range of 165 - 220 rpm.

2.4 Rotary Tillers

Hendrick (1980) built and tested a single rotor powered active tillage machine. He compared the power requirements of a similar passive chisel shank with that of the powered rotor operating at the same depth in three different soil types. The powered rotor disturbed a larger volume of soil and broke the soil more finely than a passive chisel shank. It was also noticed that the forward rotating powered rotor provided its own thrust through the soils and returned a proportion of its power demand to the system as negative thrust. If the negative draft force was utilized, the specific energy requirements for the powered rotor would have been 51% less than that for the passive chisel.

Godwin *et al.,* (1984) reported that the use of rotary cultivators in primary tillage in fieldwork was somewhat limited mainly because of the high power requirements and excessive soil pulverization. Rotary tiller is a power intensive process. Results indicated that the power consumed by a rotary tiller was greater than that by ploughs. However, the rotary soil tillers were better for loosening soil clods and weed infested soils so that power consumption during subsequent soil working was reduced.

Godwin *et al.,* (1984) stated that rotary tillers, which may be used as the powered rotating mechanism in Asia and Europe, are popular for rice cultivation. The rotary tiller, which produces a finely harrowed seedbed, was better than the use of ploughs or disk harrows. After seedbed preparation, the field has to be peddled with sufficient water. The soil conditions have to be kept flat having uniform soft tilled soil. Tillage by rotary tiller, therefore, helps to accomplish many operations with one or two passes.

Kosutic *et al.,* (1994) reported that one rotary tillage operation may be equivalent to several conventional tillage operations as far as the quality of the seedbed is concerned. Rotary tillers can replace the plough, disk and harrow. A negative draft produced by the rotary action results in a lower power requirement, and less soil compaction. The total power requirement for rotary tillers is generally higher than for conventional ploughs. In maize and spring barley production systems in combination with a chisel plough, rotary tillers have been found to have high energy requirements, but rotary tilling is more effective in saving labour compared to conventional tillage systems. To increase crop intensity, rotary tillers are more suitable for tillage operations close to the main crops for a complete mixing of residues into the soil and faster decomposition.

Mansouri *et al.*, (2002) designed and developed rotary tiller implement for a two-wheeled tractor. The tiller was designed based on some measurements and data collected by the manufacturers. The machinery specifications were: machinery width- 80 cm, forward velocity- 30 cm/s, maximum working depth- 15 cm and rotational speed- 200 rpm.

Jeevarathinam and Velmurugan (2012) reported that rotary tiller is a tillage machine designed for preparing land suitable for sowing seeds (without overturning of the soil), for eradicating weeds, mixing manure or fertilizer into soil, to break up and renovate pastures for crushing clods etc. It offered an advantage of rapid seedbed preparation and reduced draft compared to conventional tillage. It saved 30-35 % of time and 20-25 % in the cost of operation as compared to tillage by cultivator. It gave higher quality of work (25-30 %) than tillage by cultivator. The Rotavator is the most efficient means of transmitting engine power directly to the soil with no wheel slip and a major reduction in transmission power loss.

2.5 Horizontal Rotavator

Kovachev *et al.*, (1972) stated that winter wheat grown after maize or wheat on plots given Gramaxone [paraquat] for weed control and cultivated with the British Howard Rotaseeder (which combines simultaneous seedbed preparation and seed drilling) gave grain yields similar to, or higher than, those obtained on plots disked, or ploughed with a conventional plough, followed by additional cultivation before sowing.

Hughes and Baker (1977) compared traditional plough, rotary tillage, and notillage in a silt loam soil. They found that the rotary tillage resulted in the greatest proportion of soil in the smaller aggregate size fraction at all sampling dates.

Harral (1986) assessed the effects of 4 operating parameters. Forward speed, rotor speed, rotor depth and number of rotor blades were varied in field tests at 7 different sites. Linkage forces, depth wheel load, PTO torque and axial force, and strain histories from 4 gauges on the hull were recorded in some or all of the tests. Force records were analyzed for simple statistics and strain records were analysed according to BS 5400 for fatigue damage. An increase in forward speed at low rotor speeds reduced PTO power, but increased PTO power at high rotor speeds. An increase in rotor speed always increased PTO power and linkage forces, and reduced hull fatigue life. An increase in rotor depth increased PTO power. An increase in the number of rotor blades reduced PTO power and increased hull fatique life.

Salokhe *et al.*, (1993) reported that the rotavator will produce a perfect seedbed in fewer passes. It is the ideal implement for cash crop farmers who need to bury and incorporate crop residues quickly, between crops. Tillage tools direct energy into the soil to cause some desired effect such as cutting, breaking, inversion, or movement of soil. Soil is transferred from an initial condition to a different condition by this process. It was observed that 'C'-shaped blades consumed less power than 'L' and 'C-L' blade attachments at any forward speed and pass. The 'L' blade attachment required 33%, 24% and 14%, while the 'C-L' blade attachment required 14%, 12% and 4% higher power than the 'C' blade attachment during the pass 1 at 1.0, 1.5 and 2.0 km/h forward speeds, respectively. The power consumed decreased at higher passes. For the 'C' blade, the per cent reduction in bulk density and the puddling index was higher compared to the per cent reduction in bulk density and puddling index obtained with 'L' and 'C-L' blade rotavators. In general, the 'C' blade performed better than the other two types investigated in this study.

Singh *et al.*, (1998) reported that rotavator required the minimum time for the operation and transferring the tractor power through PTO is more efficient than through traction wheels for a traction dependent implement. Since 90 percent of the required power passes through the PTO, the powered rotary implement has potential for reducing the energy loss through wheel slippage during the tillage. At the same time it provides increased soil pulverization and mulch incorporation in comparison to conventional implements. The use of powered rotary system, compared to conventional tillage systems can save an enormous amount of energy and labour. The use of rotavator is limited due to high cost and frequent replacement of its tynes due to wear.

Saxena (2009) observed that during operation, the blades of rotavator were subjected to fatigue and abrasive wear. As a result theses blades required frequent replacement, which add to equipment running cost as well as down time. The purpose of this study was to undertake metallurgical up-gradation on rotavator blades to enhance its service life. Four grades of spring steels (two Boron based and two Boron free) were selected for the study. The quenching and tempering on all grades and additional austempering on two grades of Boron steels were imparted. All six treatments were compared for abrasive wear with two popular brands of rotavator blades. The wear analysis of six treatments was carried out in three stages, firstly in laboratory scale by using DUCOM make dry sand abrasion test ring (ASTM G 65), secondly in a specially designed rotary soil bin and finally in the field trial. The study revealed an identical wear ranking order of treatments in all three stages. The 50B50 (Boron steel) quenched and tempered steel ranked top as far as mass wear was concerned. But the higher cost of boron steels in Indian market put this to second place and the SAE-6150 has been found to be the best suitable steel considering benefit cost ratio.

Libin *et al.*, (2010) concluded that in comparison to passive tools, the rotavator has a superior soil mixing and pulverization capability.

Mahal *et al.*, (2012) stated that tillage is an operation performed to obtain a desirable soil structure for a seedbed or root bed. A granular structure is desirable to allow rapid infiltration and good retention of rainfall and to minimize resistance to root penetration. Rotavator (also called as rotary tiller) is a tractor operated cultivating implement that breaks or works the soil with the help of rotating blades. The use of rotavator is increasing due to its versatility in doing a good quality tillage job with minimum number of passes. The rotavator do simultaneous ploughing and harrowing in dry and optimum soil moisture in single operation.

2.6 Vertical Rotavator

Guglev (2009) conducted research on a vertical rotary two-knife soil tillage unit to elaborate on a time- and angle-defining method at the crossing of the vertical knives' trajectories in the forming of the soil chip. The coordinates of the vertical knives' trajectories cross points were calculated to define the initial and the final cutting points of the soil chip. The time needed for cutting the soil chip was determined depending on the constructive parameters and the operating mode of the performing unit. The coefficient of using the time spent on soil chip cutting and the coefficient of using the working width of the vertical rotary soil tillage unit were determined as well.

Shinde (2011) stated that rotary tiller is a tillage machine designed for preparing land suitable for sowing seeds (without overturning of the soil), for eradicating weeds, mixing manure or fertilizer into soil, to break up and renovate pastures for crushing clods etc. It offers an advantage of rapid seedbed preparation and reduced draft compared to conventional tillage. It saved 30-35 % of time and 20-25 % in the cost of operation as compared to tillage by cultivator. It gave higher quality of work (25-30 %) than tillage by cultivator. The Rotavator is the most efficient means of transmitting engine power directly to the soil with no wheel slip and a major reduction in transmission power loss.

Azadbakht (2014) evaluated and compared vertical axis and horizontal axis rotavators and found vertical rotavator gave better quality of soil than horizontal rotavator. Result showed that maximum MWD in 6.1 km/h and 15cm of depth were

55.6 and 52.5mm for horizontal axis rotavator, respectively. The minimum MWD in 2.2 km/h and 5cm of depth for vertical axis rotavator were 34.9 and 35.1mm, respectively. The values of cone index 1861.1 and 2339.5 kPa for vertical axis rotavator and horizontal axis rotavator were obtained, respectively, also the values of cross-sectional area disturbed 687 and 497.2 cm^2 for vertical axis rotavator and horizontal axis rotavator were obtained, respectively.

2.7 Economic Analyses

Possible savings depend on how much cultivation and, therefore, machinery use can be reduced. It is evident that every extra pass on the field means additional costs. Nix (1987) suggested the following areas of possible savings on machinery costs:

- have less capacity- with the same labour, tractors, etc. increase the tillage area or with less labour, tractors and machinery to farm the same area.
- later replacement- keeping machinery longer.
- more careful maintenance- reduce repairs and prolong productive life cycle of machinery.
- more careful consideration of whether to have your own machine or use the contractors.

Forristal (1995) reported that to assure high efficiency, the full potential of each machine needs to be exploited. On smaller farms, which are usually over-mechanised, because the utilisation of the machines is low, the use of a contractor is a cost-effective option. A contracting service can reduce the number of operations and machines. Medium-sized farms can use contractors for a particular operation. In peak periods, short-term hire may also be attractive. On large farms mechanisation strategy needs to be carefully selected to allow optimizing of costs and minimizing labour and machine requirements.

Markham and Chapman (1998) in their earlier study showed that machinery costs can represent substantial part of the total costs of agricultural businesses. It is obvious that an attempt to minimize costs of farm production must be focused on possible savings in machinery fleet. Many tillage systems and machinery are available

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on the market and it is advantageous for the farmer to have the information about comparable systems. To investigate the optimum tillage system, alternative implements need to be compared. The economic comparison of the tillage systems tested during the field and soil bin experiments was conducted.

Witney (1988) reported that, the machine fixed costs include the interest on capital, which is invested in the machine. If the capital is borrowed, an expected inflation is included in the interest rates. A charge is made even if the capital is already owned, because money could be earned from an alternative investment. The costs when owned capital is invested are called opportunity cost of capital. Interest charges can be calculated as an equal yearly charge through the life of the machine. The real cost of borrowing can be reduced by both inflation and tax allowances.

Hunt (2001) and Witney (1988) reported that, machinery shelter increases resale value, as earlier surveys showed. Especially complex machinery, such as combine harvesters, is stored under a roof for at least part of the year. The shelter can be a roofed construction with open sides or enclosed building including workshop facilities. Depending on the type of the shelter, the annual storage costs are equal to 0.5% to 1% of the machine purchase price.

Vozka (2007) stated that every business is focused on creating a profit. The same applies in the field of agriculture, where the aim is to get the greatest output at a minimum cost. A significant part of the total production costs represents the cost of owning and operating machinery. The actual costs of a machine are not known, until the machine is sold or scrapped. However, reasonable assumptions can be made about the 'life' and final value of the machine based upon historic depreciation data. The costs of operation can be estimated, when an accurate record of the costs of the machine is maintained. For systematic machine management, cost analysis and careful planning are crucial. According to Landers, (2000), the main reasons for monitoring costs are:

- good farm management is based on knowledge of the input costs of labour and machinery
- knowing current machinery costs enables to consider an alternative to ownership, as least costly method of obtaining farm machinery can be found

- new production techniques can be considered
- future changes in the farm business and fiscal policy

It was also observed that machinery costs are one of the key components distinguishing tillage systems. Those techniques which are less energy and time demanding can be advantageous to the farmers. More advanced, more efficient and thereby more expensive machines are being developed, but the yield targets also continue to increase. This and other factors in today's agriculture, as higher prices for parts and energy together with decreasing product prices put more pressure on machine management to adopt smart policy of owning and using farm machinery. It is, therefore, important to fully exploit expensive high-output machinery as well as to monitor their costs to improve their performance.

2.8 Energy Requirement

The world has been facing a crisis in the field of energy in the last decades. The crisis is as serious as many analysts believe that the origin of many conflicts in the world reflects the crisis in the field of energy and resources of energy. In agriculture, although new machinery systems have facilitated production, they have increased the demand for energy. Tillage as one preliminary and basic step for any agricultural production demands huge amount of energy.

Cooper and Gill (1966) illustrated that energy consumed in a tillage operation was a function of both initial and final conditions of soil. This obviously includes soil physical properties such as soil moisture content, soil bulk density as well as soil texture.

Gill and Vanden Berg (1968) reported two additional factors including tool shape and manner of tool movement as affecting factors on energy requirement of a tillage tool. The report refers to the tool affecting factors such as tool speed, tool operating depth, tool shape, and tool rake angle.

Panwar and Siemens (1972) reported that in a tillage operation, energy can be expressed in terms of energy per unit area or per volume of disturbed soil. For a tillage operation, the report of energy requirement should include the depth of operation as well.

Potekar and Tekale (2004) tested rotavator of 102 cm width in the barred field. In that trial rotavator was operated on barren land. In 26.116 minutes 0.1008 ha area was covered. Operating speed of the implement was 4.0 km/hr. The fuel consumption rate was 15.7 l/ha and 3.72 l/h. Average depth and width of cut was 11.08 cm and 102 cm, respectively. Actual and theoretical field capacities measured were 0.2405 ha/hr and 0.408 ha/hr, respectively. Field performance index and pulverization index were 58.97% and 4.75 cm, respectively. Energy requirement for this trial was 985.00MJ/ha.

Zahed (2006) summarized that energy requirement of tillage implements has received much attention from researchers through numerous studies carried out in last decades. Despite this attention, a lack of knowledge of agricultural soil mechanics from one side and limitations in developing real tests and collecting experimental data at desirable conditions from the other side have slowed down any new development in this area. One area in tillage energy studies that has too much room to improve yet is the area of extending the knowledge on different energy consuming components in a tillage operation. This improvement would help to optimize energy requirement through optimizing the influencing parameters on those energy components.

Wang ZhiShan *et al.*, (2010) tested the actual power consumption of the rotary tillage and stubble-mulch knife roller in mid-season rice straw field by using magnetic torque sensor based on the principle of phase difference. The results of field testing showed that the tillage depth of the machine and the rotate speed of axis greatly influenced the power consumption.

The above reviews suggest that the energy requirement and quality of work of rotavator is affected by many factors including the soil physical parameters, soil strength, depth of tillage, forward velocity and the blade configuration and arrangement. The soil physical properties which include soil moisture content, bulk density and soil strength have a marked influence on the energy requirement and the quality of work of rotavator. Increasing the depth of tillage increases the energy requirement of rotavator. Increasing the depth of operation shows a slight trend to increase clod size. Increasing forward speed results in an increase in the energy requirement, but a reduction in specific energy requirement and increase in the clod size of tilth soil. Arrangement of blades and number of blades as presented in horizontal and vertical rotavators will affect the energy requirement and ratio of soil breaking. The number of tillage passes required to achieve an acceptable tilth quality using rotavators, is also significant reduces in comparison to the series of operations that would result in the same tilth quality with the use of passive tools. During rotavator tillage operations various factors affect its energy requirement and quality of work. To evaluate the performance of rotavators the effect of machine paramaters and operating parameters on quality of soil and energy requirement must be studied. Though numerous attempts have been made to quantify the performance of horizontal rotavators, but little was shown about vertical rotavators. In this research the same factors will be used to evaluate the performance of the horizontal and vertical rotavators.

Materials & Methods

CHAPTER III

MATERIALS AND METHODS

This chapter deals with the procedure followed and materials used to achieve the objectives of the selected research problem. Horizontal and vertical rotavators were evaluated and their performance was compared. The observations were taken for soil mean weight diameter, penetration resistance, bulk density, soil disturbance area, energy requirement, field efficiency and operating cost.

3.1 Location of Experiment

Field experiments were conducted in the farm of the College of Agricultural Engineering and Technology, Junagadh Agricultural University, Junagadh. Some laboratory experiments were conducted in the departments of Farm Machinery and Power and in the Processing & Food Engineering, CAET, JAU, Junagadh.

3.2 Year of Experiment

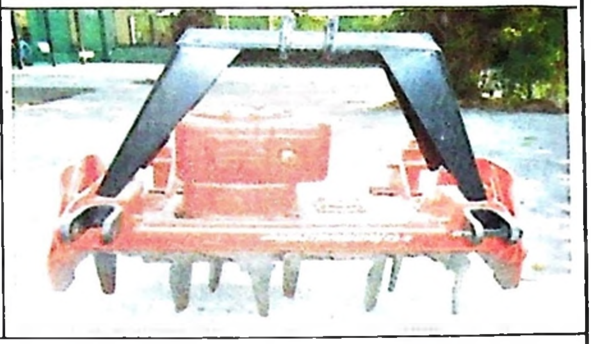
Experiments were conducted during the academic year 2014-2015.

3.3 Details of the Tested Rotavators

Horizontal axis and vertical axis rotavators were selected for the study. The details of the horizontal and vertical rotavators are shown in Table 3.1.

Table 3.1 Details of the rotavators

A. Figure of the rotavator

Horizontal rotavator	**Vertical rotavator**
	

B. Specifications

Particulars	**Horizontal rotavator**	**Vertical rotavator**
Total width of rotavator (mm)	1410	1050
Height of rotavator (mm)	1000	1220
Length of rotavator (mm)	6800	1040
Working width (mm)	1160	1000
Power of tractor used (hp)	55	55
Number of flanges	6	4
Number of blades	30	8
Types of blades	L-shaped	Straight knife type
Thickness of blade (mm)	5	12
Cutting width of the blade (mm)	120	40
PTO speed (rpm)	540	540
Rotor speed (rpm)	290	290
Type of linkage system	3 point linkage	3 point linkage
Type of transmission system	Gear drive and chain	Gear drive
Type of the gear system	Bevel pinion type	Bevel pinion type
Total weight (N)	4060 (406 kg)	4600 (460 kg)

3.4 Working Principle of Horizontal and Vertical Axis Rotavators

The rotating blades on the main shaft of a rotary tiller cut the soil when moving rotatory and translatory motions. The blades cause cycloidal because of the forward travel and they cut wedge shaped slices from the soil surface. After cutting the slices, vertical rotavator throw them against the side plates of the rotavator while for the case of horizontal rotavator slices are thrown against the back shield of the rotavator which cause further crumbling. The working principle of both horizontal and vertical rotavators is shows in Figure 3.1.

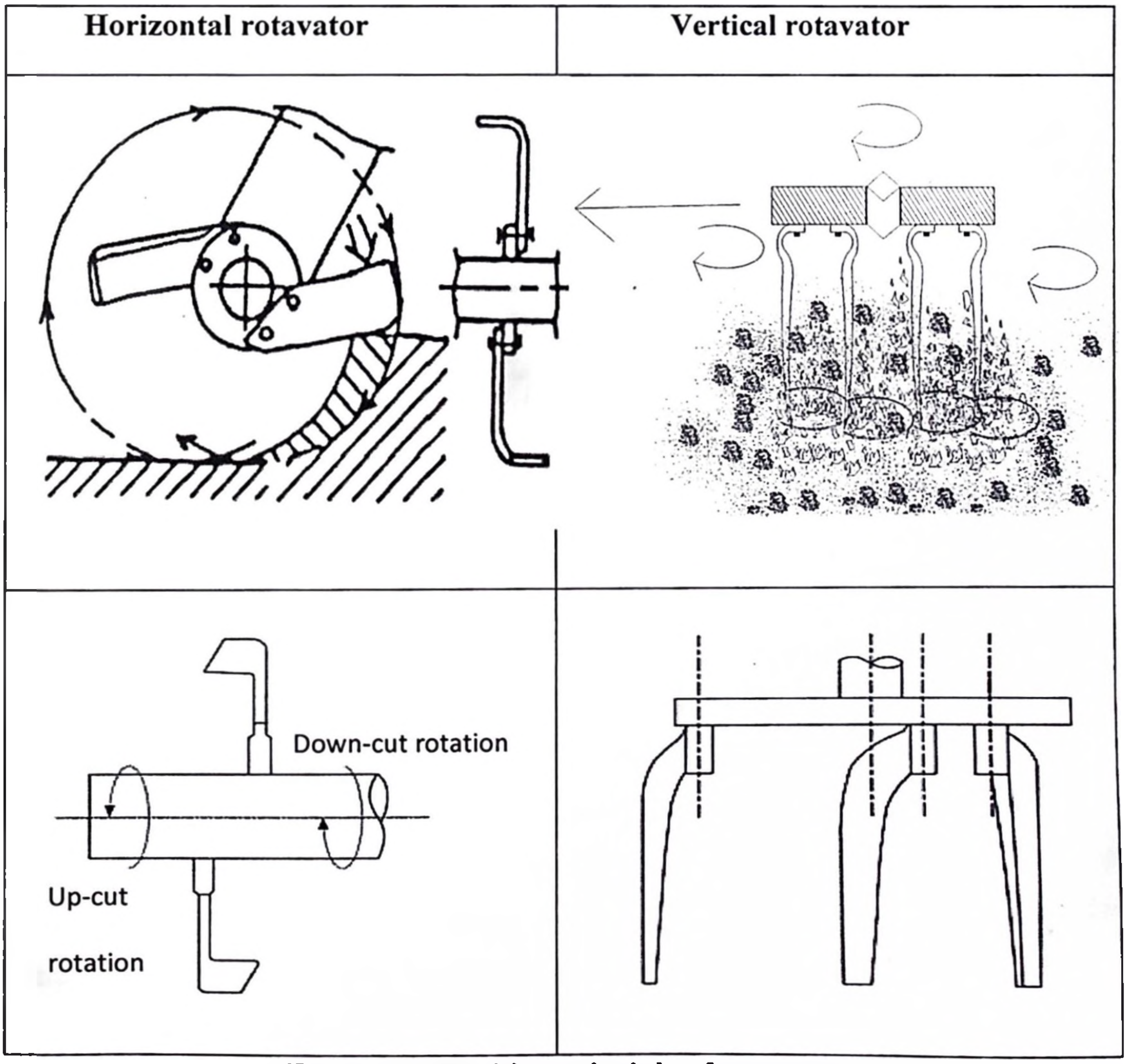


Figure 3.1 Working principle of rotavator

Horizontal axis rotavator

Blades are attached on flanges along a horizontal shaft that are perpendicular to the direction of motion.

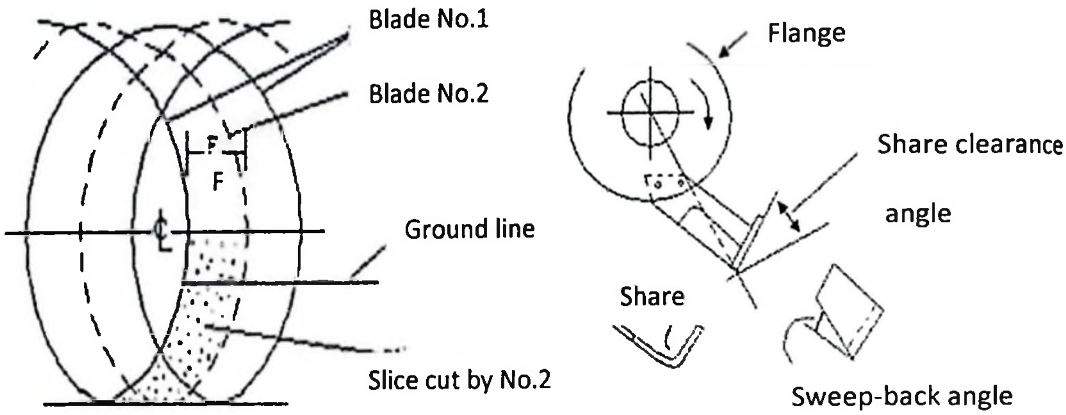


Figure 3.2 Path of cutting edge of horizontal rotavator in relation to forward travel

In horizontal rotavator, rotar rotates in the same direction as the tractor wheels. Each blade cuts a segment of soil as it moves forward and towards the rear. Most rotary tillers make 2 or 3 cuts per revolution along any one longitudinal line. Bite length 'F' as shown in Figure 3.2 is defined as amount of forward travel per cut and it can be increased by reducing rotor speed or by increasing forward speed. Slice thickness varies during the cut and also the force. High peak torques developed during each cut requires staggering of blade in different courses, with equal angular displacements between them. So no two blades strike the soil at same time. Blades experience an upward component of force 'V' and a forward component 'L'. Relative magnitudes of these forces are influenced by depth, rotor dia, bite length, soil type and condition, type of blade, share (Blade, c clearance angle). Upward component reduces the amount of implement gravitational force that must be supported by gage wheels or tractor. Under some conditions it causes rotor to walk out of ground. Forward component results in negative draft and negative specific energy requirement for traction, both increasing in magnitude and bite length. Forward thrust from negative draft is troublesome to tractor stability and design.

Rotavator assembly consists of number of parts with specific functions. Independent Top Mast is used to transmit power from tractor P.T.O. to input rotavator shaft. A gear box with bevel gears, main shaft, pinion shaft, heavy duty roller bearings make a unit which reduces standard P.T.O. rpm (540 rpm to 290 rpm). It enables the rotor shaft to rotate in the direction of travel. This helps in throwing the material behind the rotavator, which facilities in preventing the clogging of rotavator. A chain and gear cover part flange is a supporting element on which chain and gears are mounted. There are different shapes of blades; however, L shaped is most common. The material composition of tine is generally carbon, manganese, and silicon. By adjusting the position of rear cover; the degree of pulverization of soil is controlled. If the cover is kept wide open, the clods are thrown away from the rotor. The closed position of cover facilities the clods to get further pulverized by the action of rotating blades and fine tilth obtained. Adjustable depth skids are used to control depth.

Vertical axis rotavator

These machines have series of two tine vertical rotors across the width of machine.

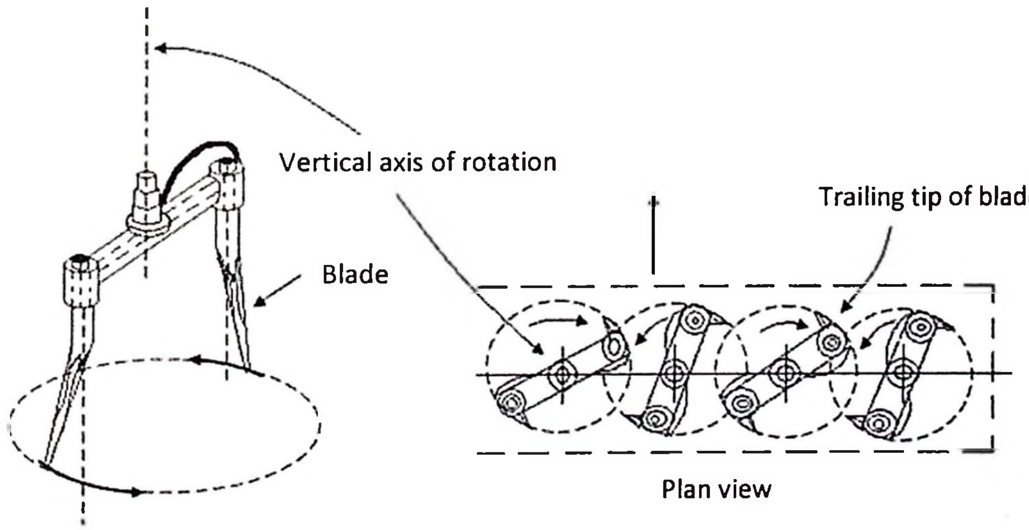


Figure 3.3 Vertical axis rotavator

The path of adjacent rotor overlaps as shown in Figure 3.3. Gear on upper ends of rotor shaft transmits power from one rotor to other and provide counter rotation of adjacent rotor. This rotavator is good for pulverization and secondary tillage however, it does not work well in loose surface trash, it works well in heavy soils and does not create hardpan at the soil bottom after tillage operation.

3.5 Research Plan

The following research plan was used to carry out the selected research project. The details of the selected independents and dependents parameters with their codes are shown in Table 3.2.

Table 3.2 Details of the research plan (FRBD)

A. Independent variables:		
i) Type of rotavator	2 levels	HR (Horizontal rotavator) VR (Vertical rotavator)
ii) Forward speed	3 levels	S_1 = 1.5 to 2 km/h S_2 = 2.5 to 3 km/h S_3 = 3.5 to 4.1 km/h
iii) Depth of operation	3 levels	D_1 = 6 to 8 cm (7 cm) D_2 = 9 to 11 cm (10 cm) D_3 = 12 to 14 cm (13 cm)
Replication	3	
Total no. of Experiment	2×3×3×3 = 54	

B. Dependent variable

a) Soil parameter

i) Soil mean weight diameter (mm)

ii) Penetration resistance (kPa)

iii) Bulk density (g/m^3)

iv) Soil disturbance area (cm^2)

b) Machine parameters

i) Energy requirement (MJ/ha)

ii) Field efficiency (%)

iii) Operating Cost

3.6 Details of Experimental Field

It deals with the arrangement of experimental field layout and test procedure used during experiment. Details of experimental fields are shown in Table 3.3.

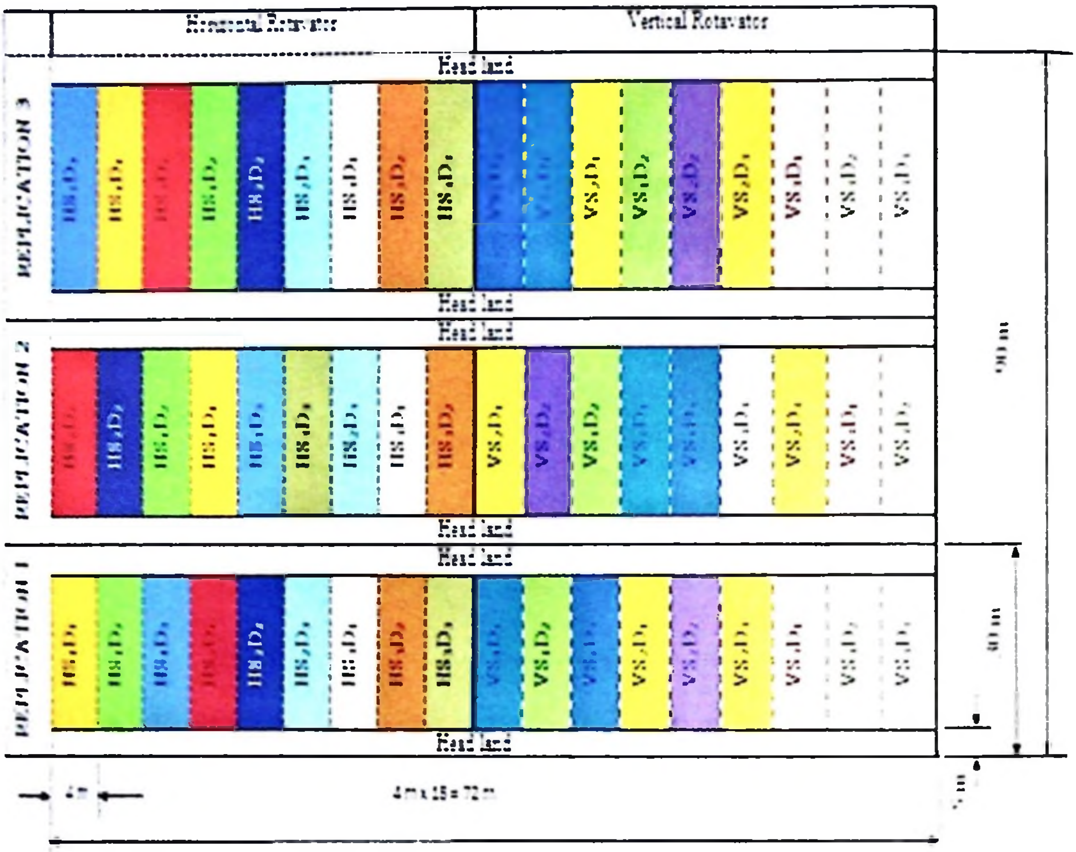
Table 3.3 Details of experimental fields

Sr. No.	Parameters	Details	
	Type of Experimental field	**Field no.1**	**Field no.2**
1	Location of experimental field	FMP- Farm	SWE – Farm
2	Type of soil	Medium black	Medium black
3	Moisture content	11.78%	10.51%
4	Total area of experimental field, m^2	6480	6480
5	No. of test plots	54	54
6	Length of each test plot, m	30	30
7	Width of each test plot, m	4	4
8	Area of each test plot, m^2	120	120
9	Shape of field/ plot	Rectangular shape	Rectangular shape

3.6.1 Field Layout

Two experimental fields each having area of 0.648 ha was selected in the farm of College of Agricultural Engineering and Technology, Junagadh Agricultural University, India. Each experimental field was divided into 54 plots. Area of each subplot was 4 × 30 m^2. Each plot was having head land for turning of tractor and pre setting of test machines. The field layout of test plots of one experimental field (FRBD) is shown in Table 3.4.

Table 3.4 Field Layout (FRBD)



3.7 Test Procedure

As such there was no standard test code for rotavator testing. all laboratory and field tests were carried out indirectly as per the recommendation of the Regional Network for Agricultural Machinery (RNAM. 1983); IS: 11531: 2001. Test Code for Puddler; IS: 4468-2001 (Part-1). Agricultural wheeled tractor- rear mounted three mounted three point linkage; IS: 4931-2006, Agricultural tractor-rear mounted power take off types 1. 2 and 3 and IS: 6690-2002, specification for blades for rotavator for power tillers.

The instruments and equipments used for the field test were two tractors, length measuring tape, horizontal axis rotavator, vertical axis rotavator, soil sample auger, cone penetrometer, Metallic core cylinder, stop watch, soil disturbance measuring device, etc. Before conducting the actual field test, first necessary settings and proper attachments were made and preliminary tests were conducted. Firstly, marking of the test field with white powder having 30 m length of land was done.

Also tractor drive wheel was marked with coloured tapes for easy counting of number of revolutions during slip measurement. The performance parameters like bulk density, soil pulverization, soil disturbance area, moisture content of the soil, depth and width of cut, fuel consumption, field capacity and slip were determined.

Plate 3.1 View of field before rotavator operation

Plate 3.2 Horizontal rotavator during field operation

Plate 3.3 Vertical rotavator in working condition

3.7.1 Moisture content of the soil

Moisture content of the soil was determined by oven dry method. Five samples were taken from the different locations of the test plots in different moisture boxes. These were kept in oven for 24 hours at the temperature of 105 °C. The mass of wet and dry samples were determined and average moisture content on dry basis calculated. Moisture content of soil was calculated by using following standard formula:

$$\text{Moisture Content (db)\%} = \left(\frac{\textbf{weight of wet soil} - \textbf{weight of dry soil}}{\textbf{weight of dry soil}}\right) \text{X } 100 \ldots\ldots\ldots (3.1)$$

3.7.2 Bulk density

Metallic core cylinder was used to take sample from the field. Sample was taken by 55 mm diameter and 95 mm long core sampler. The samples were weighed with an accuracy of 0.1 gram. The dry weight of the samples was calculated from the moisture content (d.b.). The ratio of the dry weight of the soil to the volume gave the bulk density. Bulk density of soil was calculated by using following standard formula:

$$\text{Bulk density of soil, (g/cc)} = W/V \qquad \text{....(3.2)}$$

Where,

W = Weight of dry mass of soil (g),

V = Volume of metallic core (cc)

Plate 3.4 Collection of soil sample for bulk density measurement before operation

3.7.3 Cone index

Cone index is an indication of soil hardness and is expressed as force per square cm required for penetrating a cone into the soil. This is called cone index. Cone index in the same soil varies with cone apex angle and area of cone bottom. Cone index was measured by using cone penetrometer up to a depth of 13 cm. The average reading was taken as cone index. The diameter and height of cone were measured and then surface area of cone was calculated by using the formula (ref):

$$\text{Surface area of cone, } A = \pi r l + \pi r^2 \qquad \text{.... (3.3)}$$

Where,

r = radius of cone; and

l = slant height of cone.

The calibration of penetrometer was carried out in laboratory before its actual use. This is important to demonstrate its linearity of response. The penetrometer, loads ranging from 0 N to 100 N, bench vise, flat plate and a notebook were used as instrumentation for calibration. The cone penetrometer was fixed on bench vise and loads applied on top of the instrument. The output deflections were recorded and tabulated in Table 3.5. A linear relationship was obtained as shown in Figure 3.4.

Table 3.5 Calibration of cone penetrometer

Load (N)	Dial Reading, Div (After increasing load)	Dial Reading, Div (After decreasing load)	Average Dial reading, Div
0	0	0	0
10	1.8	1.9	1.85
20	2.9	2.7	2.8
30	4.4	4.6	4.5
40	6.6	7	6.8
50	8.5	8.7	8.6
60	9.6	9.6	9.6
70	11.2	11.2	11.2
80	12.8	12.8	12.8
90	14.5	14.6	14.55
100	16.2	16.2	16.2

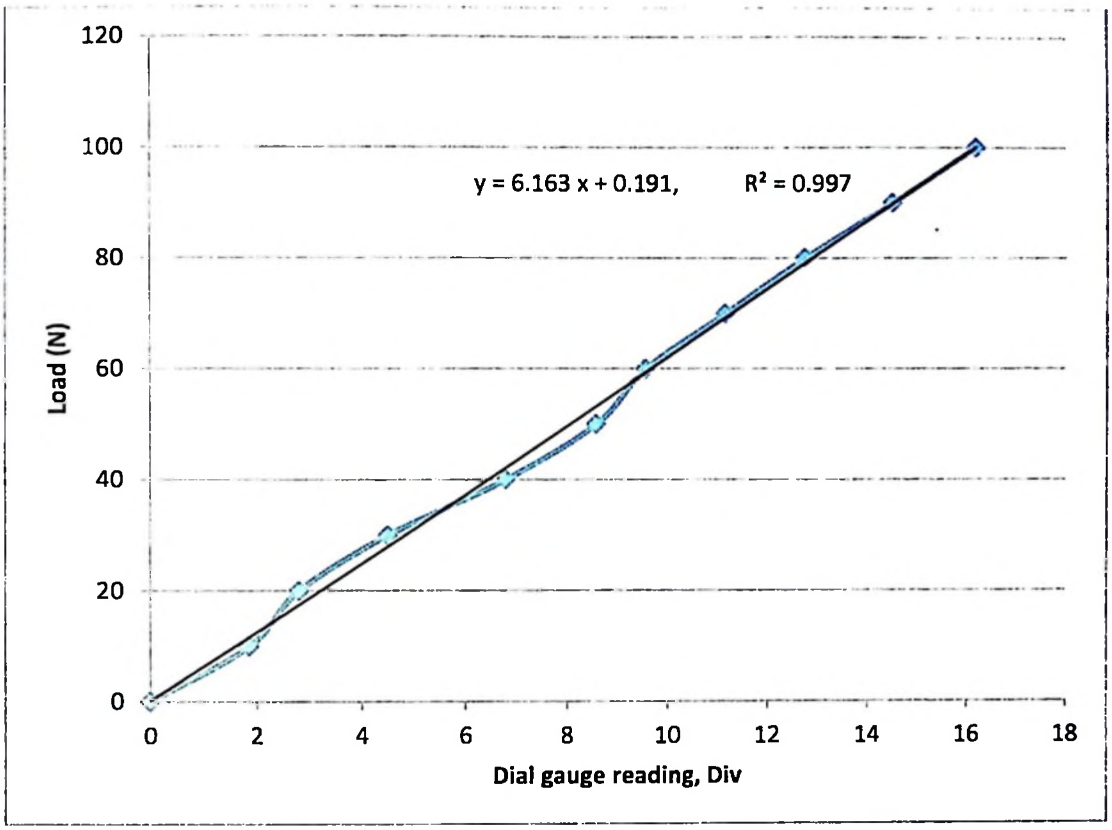


Figure 3.4 Calibration of a mechanical cone penetrometer (dial gauge type)

The radius and height of cone were measured and the surface area of cone was calculated by using the formula:

Radius of cone (r) = 1.5 cm

Slant height of cone (l) = 8 cm

Surface area of cone, $A = \pi r l + \pi r^2$

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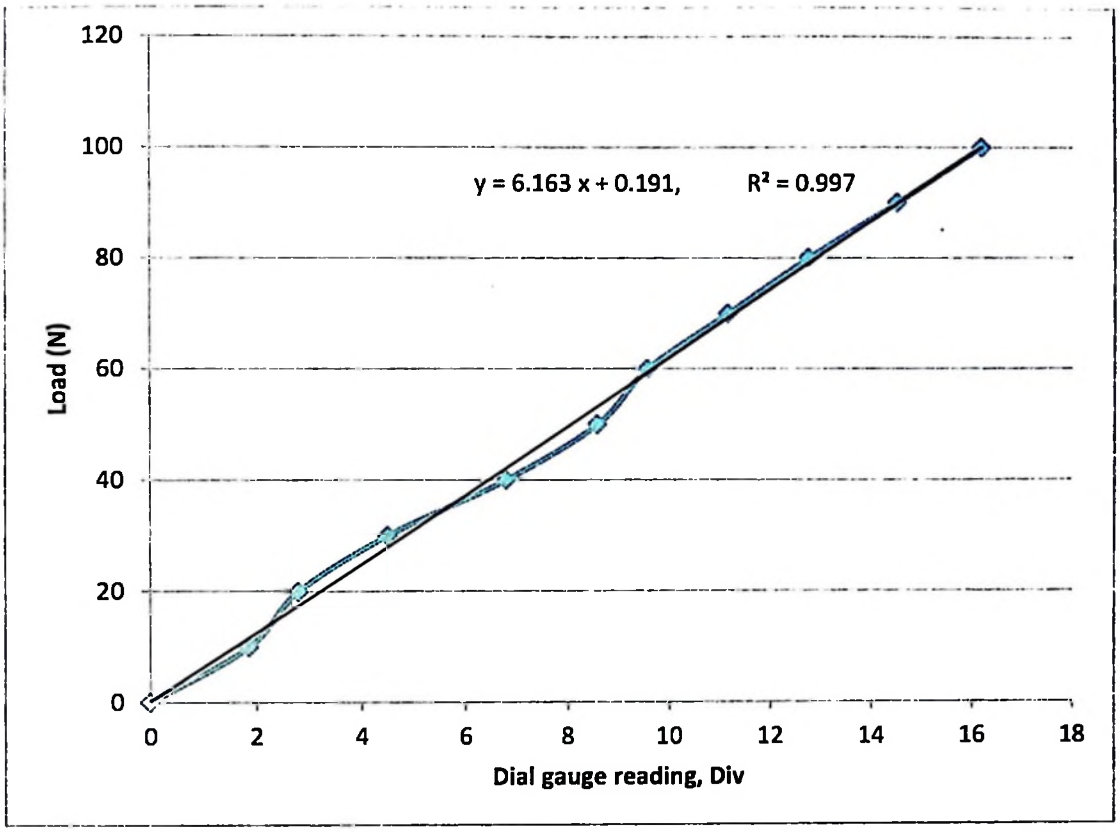
30	4.4	4.6	4.5
40	6.6	7	6.8
50	8.5	8.7	8.6
60	9.6	9.6	9.6
70	11.2	11.2	11.2
80	12.8	12.8	12.8
90	14.5	14.6	14.55
100	16.2	16.2	16.2



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Radius of cone (r) = 1.5 cm

Slant height of cone (l) = 8 cm

Surface area of cone, $A = \pi r l + \pi r^2$

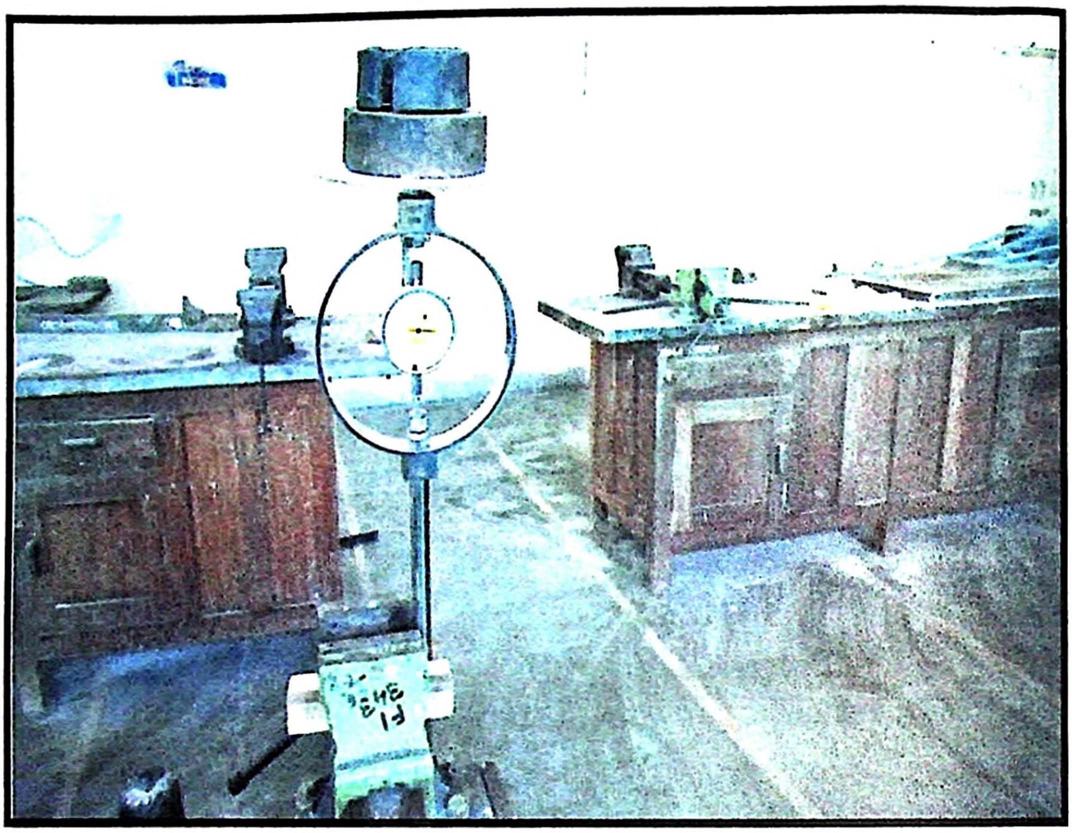

Plate 3.5 Calibration of cone penetrometer

3.7.4 Soil mean weight diameter

For determining the Soil Mean Weight Diameter (SMWD) soil sample was allowed to pass through a set of sieves. Weighed soil retained on the largest aperture sieve, passed through each sieve and retained on the next sieve and passed through the smallest aperture sieve. Soil Mean Weight Diameter was calculated as shown in Table 3.6. (Mehta *et al.*1995).

Table 3.6 Soil Mean Weight Diameter calculation method

Size of aperture (mm)	Diameter 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	11.2>		

(Source: Mehta *et al.* 1995)

$$SMWD = \frac{(A + 2.4B + 3.4C + 4.8D + 6.8E + XF)}{W} \quad \ldots..(3.4)$$

Where,

X = mean of measured dia. of soil clods retained on the largest aperture sieve,

SMWD = the mean weight diameter of soil, mm,

W = the total weight of the soil sample.

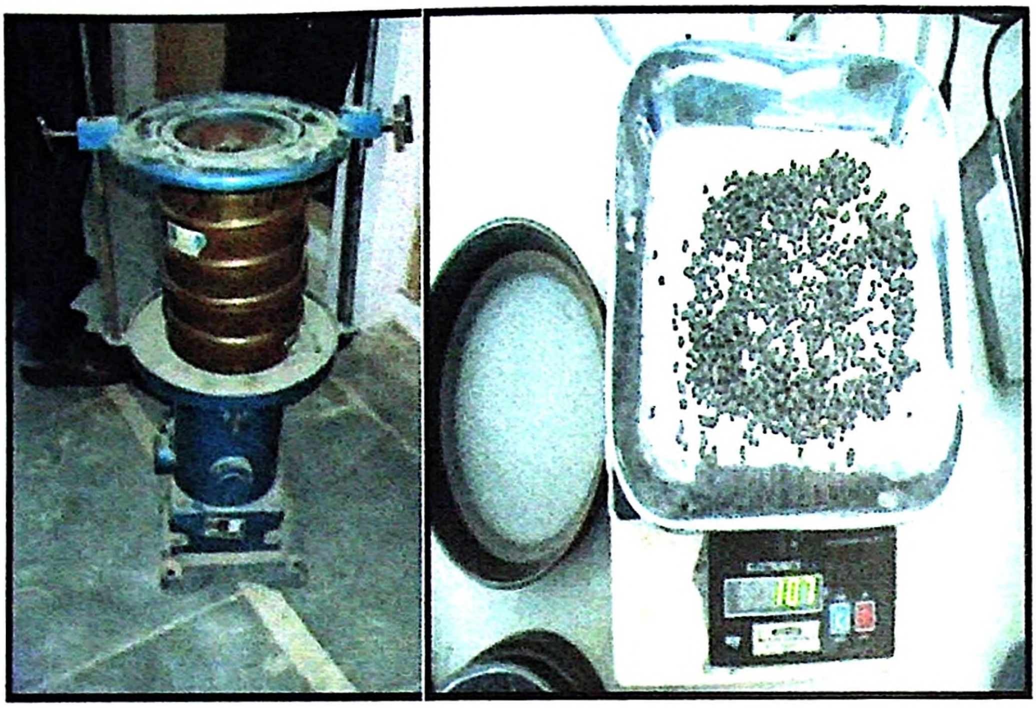

Plate 3.6 Measuring Soil Mean Weight Diameter

3.7.5 Soil disturbed area

Soil disturbance measuring device consists of number of graduated rods and one plate on which holes are drilled for inserting rods was used to measure the soil disturbed area after tillage operation. These rods were used to measure depth of tilled land for calculating soil disturbance at particular point. The device consisted of 11 graduated rods each of 1 cm diameter and 75 cm height, distance between graduated rods is 5cm. and having a plate of 60 cm in length (Khole, 2014). A complete soil profile meter is shown in Plate 3.7.

$$\text{Soil disturbance Area} = \left(\frac{1}{2} \times L_1 \times d_1\right) + \left(\frac{1}{2} \times (d_1 + d_2) \times L_2\right) + \left(\frac{1}{2} \times (d_2 + d_3) \times L_3\right) + \cdots + \left(\frac{1}{2} \times Ln \times dn\right) \quad ...(3.5)$$

Where,

L_1 to Ln = distance measured between bars

d_1 to dn = depth measured at a point

Due to different widths of horizontal and vertical axis rotavators, percentage of soil disturbed area was determined in order to compare that which implement disturbed soil more than the other. The percentage of soil disturbed area was calculated using the following formula,

$$\text{Percentage of soil disturbed area (\%)} = \frac{\text{Soil disturbance Area}}{\text{Cross section area of the implement}} \text{x}100 \ldots\ldots\ldots\ldots\ldots (3.6)$$

Plate 3.7 Measuring soil disturbed area by using soil profile meter

3.7.6 Depth and width of cut

The depth of cut was determined by measuring the distance between horizontal soil surfaces to the bottom of dug out furrow with the help of steel scale. Depth measurements were taken in different places of the field and the average depth was used as the depth of cut.

Tillage depth was regulated by side mounted skids. Skid is fixed in front part of the machine. In the rear part of the side plate there are some holes. To select the desired working depth the corresponding fastener is changed by simply using only one wrench. Plate 3.8 shows regulation of depth of cut by changing side mounted skids position.

Plate 3.8 Regulating depth of cut by changing side mounted skids position

The width of cut was determined by measuring the horizontal distance cut by blade with the help of measuring tape. Plate 3.9 showed the measuring of width of cut.

Plate 3.9 Measuring width and depth of cut

3.7.7 Wheel slip

Tractor drive wheels slip in all field operations. Percentage of wheel slip is also called travel reduction ratio. However, the traveled distance of tractor in a given number of revolutions increases in a few cases when the mounted implement pushes the tractor as in case of a rotavator. Thus the wheel slip is negative. The tractor drive wheel was marked with coloured tapes for counting the no. of revolutions and the distance traveled by the tractor moved forward measured, for 10 revolutions under no load (A) and on the same surface and with same number of revolution with loaded condition (B). The percentage slip was calculated using the following formula,

$$\text{Percentage wheel slip} = \frac{A - B}{A} \times 100 \qquad \ldots(3.7)$$

Table 3.7 Wheel slip determination at field no. 1

Speed (km/h)		1.50 (S1)			2.71 (S2)			4.10 (S3)		
Depth(cm)		7 cm	10 cm	13 cm	7 cm	10 cm	13 cm	7 cm	10 cm	13 cm
HR	A (m)	42.00	42.00	42.00	42.00	42.00	42.00	42.00	42.00	42.00
	B (m)	42.31	42.30	42.31	42.31	42.51	42.33	42.43	42.51	42.61
	Slip (%)	**-0.71**	**-0.71**	**-0.75**	**-0.75**	**-1.21**	**-0.79**	**-1.03**	**-1.21**	**-1.45**
VR	A (m)	42.00	42.00	42.00	42.00	42.00	42.00	42.00	42.00	42.00
	B (m)	42.37	42.39	42.33	42.32	42.56	42.42	42.53	42.56	42.68
	Slip (%)	**-0.88**	**-0.93**	**-0.78**	**-0.77**	**-1.33**	**-0.99**	**-1.27**	**-1.34**	**-1.62**

Table 3.8 Wheel slip determination at field no. 2

Speed (km/h)		1.50 (S1)			2.71 (S2)			4.10 (S3)		
Depth(cm)		7 cm	10 cm	13 cm	7 cm	10 cm	13 cm	7 cm	10 cm	13 cm
HR	A (m)	42.00	42.00	42.00	42.00	42.00	42.00	42.00	42.00	42.00
	B (m)	42.40	42.45	42.36	42.38	42.54	42.47	42.47	42.60	42.68
	Slip (%)	-0.95	-1.07	-0.86	-0.90	-1.29	-1.12	-1.12	-1.44	-1.63
VR	A (m)	42.00	42	42	42	42	42	42	42	42
	B (m)	42.46	42.49	42.37	42.48	42.60	42.54	42.59	42.65	42.70
	Slip (%)	-1.10	-1.16	-0.89	-1.14	-1.43	-1.28	-1.40	-1.55	-1.67

3.7.8 Field efficiency

Field efficiency is the ratio of effective field capacity to the theoretical field capacity expressed as percentage. The field efficiency of the rotavators was determined using following formula (Sahay, 2006).

$$\text{Field efficiency (\%)} = \frac{\text{Effective field capacity}}{\text{Theoretical field capacity}} \times 100 \quad \ldots..(3.8)$$

3.7.9 Theoretical field capacity

The theoretical field capacity is the rate of field coverage that was obtained when the rotavator operated continuously without interruption.

It was calculated by the formula,

$$\text{TFC} = \frac{W \times S}{10} \quad \ldots..(3.9)$$

Where,

TFC= Theoretical field capacity (ha/h)

W = Width of cut (m)

S = Forward speed (km/h)

3.7.10 Effective field capacity

This was the actual rate of field coverage based on field time. This was calculated by measuring area covered by rotavator and divide by time taken.

It was calculated by the formula,

$$EFC = \frac{W \times L}{T \times 10000} \qquad \ldots\ldots(3.10)$$

Where,

EFC= Effective field capacity (ha/h)

W= Width of cut (m)

L= Length of strip (m)

T=Time taken (h)

3.7.11 Forward speed

The distance covered divide by time spent to cover that distance gave forward speed of the machine.

As a general principle fine tilths are produced by a combination of slow tractor speeds, fast rotor speeds and a lowered trailing board. Conversely, coarse tilths are produced by fast tractor speeds, slow rotor speeds and a raised trailing board. Intermediate grades of tilth from coarse to fine can be obtained by varying the rotor speed, adjusting the height of the trailing board which by impact shatters the blade-cut "clods". Raised trailing boards also deposit weeds and trash on the surface to wither, whilst lowered trailing boards bury trash as well as having a levelling effect on the soil. Increasing or decreasing the tractor travel speed altered the size of blade-cut "clods". Higher travel speeds may also be used for shallow work on previously broken ground or scalping passes for weed control.

Table 3.9 Determination of field efficiency of the Rotavators

Treatment	Field 1 at 11.78 % MC						Field 2 at 10.51 % MC					
	Horizontal rotavator			Vertical rotavator			Horizontal rotavator			Vertical rotavator		
	TFC (ha/h)	EFC (ha/h)	FE (%)	TFC (ha/h)	EFC (ha/h)	FE (%)	TFC (ha/h)	EFC (ha/h)	FE (%)	TFC (ha/h)	EFC (ha/h)	FE (%)
S1D1	0.174	0.162	93.100	0.150	0.142	94.670	0.174	0.159	91.570	0.150	0.140	93.200
S1D2	0.174	0.163	93.870	0.150	0.143	95.110	0.174	0.158	90.800	0.150	0.140	93.560
S1D3	0.174	0.162	93.100	0.150	0.142	94.890	0.174	0.161	92.280	0.150	0.141	93.780
S2D1	0.314	0.274	87.370	0.271	0.239	88.070	0.314	0.262	83.450	0.271	0.231	85.360
S2D2	0.314	0.277	88.110	0.271	0.240	88.440	0.314	0.260	82.800	0.271	0.230	84.750
S2D3	0.314	0.276	88.000	0.271	0.240	88.680	0.314	0.257	81.950	0.271	0.231	85.360
S3D1	0.476	0.385	80.950	0.410	0.346	84.310	0.476	0.358	75.280	0.410	0.334	81.460
S3D2	0.476	0.388	81.580	0.410	0.337	82.110	0.476	0.351	73.740	0.410	0.329	80.330
S3D3	0.476	0.379	79.600	0.410	0.336	82.030	0.476	0.441	92.580	0.410	0.332	80.890

3.7.12 Fuel consumption

The fuel measuring device was used to measure the amount of fuel consumed during tillage operation. The device with graduated scales was filled up to the top. Tractor was kept on level land before use and the initial reading value was recorded. After operation the final reading was recorded. The difference between these two readings was taken as the amount of fuel consumed by the tractor. Amount of fuel obtained after the test divided by time gives fuel consumption for each test. Fuel consumption measuring device is shown in Plate 3.10.

Plate 3.10 Fuel consumption measuring device

3.7.13 Energy requirement

The total energy required for tillage operation was determined, which included machinery energy, diesel-oil energy and human energy.

The machinery energy (Tractor with implement) is obtained by multiplying actual operating hours of tractor per hectare (h/ha) by 13.06 MJ/h. Whereby, 13.06 MJ/h is the energy equivalence for machinery as shown in Table 3.10.

The diesel-oil energy is obtained by multiplying fuel consumption of tractor (l/ha) by 56.31 MJ/l. Whereby, 56.31 MJ/l is the energy equivalence for diesel per litre as shown in Table 3.10.

The human energy (as operator) is equal to actual man power per ha times 1.96 MJ/h. Whereby, 1.96 MJ/h is the energy equivalence for an adult man as shown in Table 3.10.

Therefore, total energy required during seedbed preparation is the sum of machinery, diesel-oil and human energy.

Table 3.10 Energy equivalents of inputs in seedbed preparation

Input	**Energy equivalent (MJ/unit)**	**Reference**
Human labour (h)	1.96	Sing et al. (2002).
Machinery (h)	13.06	Ozkan et al. (2004).
Diesel-oil (l)	56.31	Sing et al. (2002).

3.8 Operating Cost

The cost of operation of the machines in terms of Rupees per hectare and Rupees per hour was determined based on fixed cost and variable cost with the help of straight line method. The total cost of a machine depends on many factors (how many years it is used, what is the yearly usage) and these consist of two components: fixed and variable costs. Fixed costs are occurring regardless of the machine use and variable costs depending upon the use of the machine. This distinction is possible only if a machine is operating in average conditions. Fixed costs, as depreciation and loss in value, are also dependant on machine utilization, because heavy usage reduces its operational life span. Conversely, some maintenance and repairs would be needed, even if the machine is slightly used.

3.8.1 Fixed costs

Fixed costs of a machine include depreciation, costs of interest, taxes, insurance and shelter. Depreciation is usually the largest component of machine total costs. It measures the amount, by which the value of a machine decreases in time, whether it is used or not (Hunt, 2001).

There are several methods of calculating depreciation. The most common methods are straight line method, declining balance depreciation and decremental depreciation (Witney, 1988).

3.8.2 Variable costs

The variable costs of a machine as it name suggests vary with its use and they are expressed as costs per area worked or hour of operation. They are divided into maintenance and repair costs and costs of fuel and oil.

The fuel consumption is based on the fuel requirements per hectare or per hour. Oil consumption is defined as the volume of the oil replaced at the recommended change intervals (Witney, 1988).

Fixed and variable costs give the overall costs of operation of a machine. Labour charges must be added depending on labour requirements of particular operation. The average labour costs include National insurance contribution, employer's liability, overtime and benefits.

The straight line method assumes equal reduction in the value of machine every year. Use of tractor and rotavator was considered as 1100 and 700 h respectively. The following formulae were used for cost calculation of the machine.

a. Depreciation= $\frac{C-S}{L\times H}$ .... (3.11)

Where,

C = Purchase cost, ₹

S = Salvage value (10 % of initial cost), ₹

L = Life of machine, yr

H = Annual use, h

b. Interest = $(\frac{C+S}{2}) \times 0.12$ .... (3.12)

c. Taxes, housing, insurance = 2 % of initial investment .... (3.13)

d. Fuel cost= ₹ 60 per litre .... (3.14)

e. Lubrication cost = 25% of fuel cost .... (3.15)

f. Repair and maintenance cost= 5 % of initial investment .... (3.16)

3.9 Statistical Analysis

The field data were statistically analyzed, using two-way analysis of variance (ANOVA) for the factorial randomized complete design with three replicates. The software used was Microsoft Excel (2007) using ANOVA procedure. The ANOVA procedure was used to evaluate the significance of each parameter and the interactions between parameters on soil physical properties and energy consumption. Mean values at each treatment combination were statistically analyzed to determine soil response to the field operating parameters. Comparisons among treatment means, when significant, were conducted using F-test at $p = 0.01$ and 0.05 level.

Results & Discussion

CHAPTER IV

RESULTS AND DISCUSSION

This chapter deals with the results of the field observations of the horizontal and vertical axis rotavators and their comparative performance. Result data are given in Appendices I through IV. The analysis of variance tables obtained using MICROSOFT EXCEL programs are presented in the Appendices. Tables of means, summary of significance levels for F-tests, and the graphical presentations are included in the text for discussion.

Two rotavators namely horizontal axis and vertical axis were tested in two different fields. Their performance results were analysed in terms of qualitative soil parameters, economically and presented in the following manner:

- **Effect of Operating Parameters on Soil Physical Properties**
- **Effect of Operating Parameters on Machine Performance**
- **Comparative Performance of the Rotavators**

4.1 Effect of Operating Parameters on Soil Physical Properties

To evaluate the performance of the horizontal and vertical rotavators, their operating parameters like depth of tilling and speed of operation were varied and their effects on soil physical properties like bulk density, soil penetration resistance, soil mean weight diameter and soil disturbed area were determined, analysed statistically and presented graphically in the following manner:

- **Effect of depth on soil mean weight diameter**
- **Effect of depth on soil penetration resistance**
- **Effect of depth on bulk density**
- **Effect of depth on soil disturbed area**
- **Effect of forward speed on soil mean weight diameter**

- **Effect of forward speed on soil penetration resistance**
- **Effect of forward speed on bulk density**
- **Effect of forward speed on soil disturbed area**

4.1.1 Effect of depth on soil mean weight diameter

The main function of rotavator is tilling and pulverising the soil. The quality of pulverising is measured in terms of soil mean weight diameter (SMWD). The SMWD was determined by standard procedure (section 3.7.4). To determine the effect of depth on soil mean weight diameter the rotavators were operated at three different depths (7, 10, 13 cm). The results data and the analysis of variance (ANOVA) were given in the Appendix II. For statistical analysis the mean values of SMWD at the different depths were taken from Appendix II and summarized in Table 4.1. The effects of depth of horizontal and vertical rotavators on SMWD in the field no. 1 and 2 were graphically presented in the Figure 4.1.

Figure 4.1 (a) shows the effect of tilling depth of horizontal and vertical rotavator on SMWD in field no. 1. The figure shows that the value of SMWD of tilled soil increased with tilling depth for both the rotavators. The value of SMWD increased continuously in case of horizontal rotavator, while in case of vertical rotavator the value of SMWD was almost constant i.e. not increased much. The mean values of SMWDs were 4.17, 4.28, and 4.31 mm for horizontal rotavator and 3.86, 3.87, and 3.87 mm for vertical rotavator at the depth of 7, 10 and 13 cm respectively in the field no. 1.

The results of F-tests are shown in Table 4.1 (a) for field no. 1. The tilling depths have significant effect on SMWD resulted from horizontal rotavators at each depth. But vertical axis rotavator on different depth levels have no effect on SMWD. This means the mean weight diameters resulting from the analysis of soil aggregate sizes obtained after using vertical axis rotavator were not statistically different. However, in the same depth of cut, vertical axis rotavator pulverized soil more than the horizontal rotavator. Maximum SMWD (4.31 mm) was observed at 13 cm depth by horizontal axis rotavator. Minimum SMWD (3.86 mm) was observed at 7 cm depth with vertical axis rotavator.

Table 4.1 Comparison tests of different levels of depth and type of rotavators on SMWD (mm)

	(a) Field no. 1		(b) Field no. 2	
Depth (cm)	Horizontal rotavator	Vertical rotavator	Horizontal rotavator	Vertical rotavator
7	4.17**	3.86 ns	4.61**	4.39 ns
10	4.28**	3.87 ns	4.69**	4.40 ns
13	4.31**	3.87 ns	4.72**	4.40 ns

** -Significant at 1 % level

ns – Non significant.

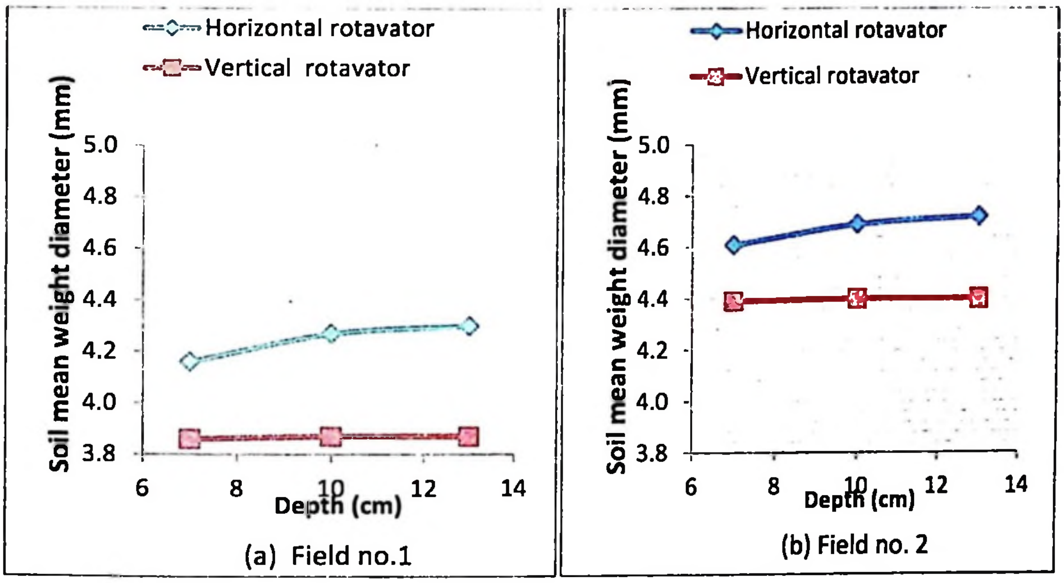

Figure 4.1 Effect of depth on soil mean weight diameter

Figure 4.1 (b) shows the effect of tilling depth of horizontal and vertical rotavator on SMWD in field no. 2. The figure shows that the value of SMWD of tilled soil increased with tilling depth for both the rotavators. The value of SMWD increased continuously in case of horizontal rotavator, while in case of vertical rotavator the value of SMWD was almost constant i.e. not increased much. The mean values of SMWDs were 4.61, 4.69 and 4.72 mm for horizontal rotavator and 4.39, 4.40, and 4.40 mm for vertical rotavator at the depth of 7, 10 and 13 cm respectively in the field no. 2.

The results of F-tests are shown in Table 4.1(b). The tilling depths have significant effect on SMWD resulted from horizontal rotavators at each depth. But vertical axis rotavator on different depth levels have no effect on SMWD. This means the mean weight diameters resulting from the analysis of soil aggregate sizes obtained after using vertical axis rotavator were not statistically different. However, in the same depth of cut, vertical axis rotavator pulverized soil more than horizontal one. Maximum SMWD (4.72 mm) was observed at 13 cm depth by horizontal axis rotavator. Minimum SMWD (4.39 mm) was observed at 7 cm depth with vertical axis rotavator.

The same trend was seen in the experiment conducted at field no. 1 and field no. 2. However, the SMWDs obtained at field no. 1 were smaller than compared to the field no. 2. This might be due to the optimum moisture content at field no. 1 which resulted in better soil pulverisation. Results show that changing of depth of cut has much effect on horizontal axis rotavator than on vertical one. Overall, the sizes of soil mean weight diameters obtained by horizontal axis rotavator were larger than obtained by vertical rotavator. The level of pulverisation was affected by different tilling depths and this result was also supported by the study of Azadbakht, 2014.

4.1.2 Effect of depth on soil penetration resistance

Cone index is an indication of soil hardness and was determined by standard procedure (section 3.7.3). The level of soil penetration resistance is affected by different tilling depths (Azadbakht, 2014). Therefore, to determine the effect of depth on cone index the selected rotavators were operated at three different depths (7, 10, 13 cm) and their results data and the analysis of variance (ANOVA) were given in the Appendix II. For statistical analysis the mean values of cone index at different depths were taken from Appendix II and summarized in Table 4.2. The effects of depth of horizontal and vertical rotavators on cone index in the field no. 1 and 2 were graphically presented in the Figure 4.2.

Figure 4.2 (a) shows the effect of tilling depth of horizontal and vertical rotavator on cone index in field no. 1. The figure shows that the value of cone index of tilled soil increased with tilling depth for both the rotavators. The mean values of cone index were 44.90, 54.05 and 58.55 kPa for horizontal rotavator and 44.59, 50.90 and 54.05 kPa for vertical rotavator at the depth of 7, 10 and 13 cm respectively in the field no. 1.

The results of F-tests are shown in Table 4.2 (a). The tilling depths have significant effect on cone index resulted from both horizontal rotavator and vertical rotavator at each depth. This means the cone index measured after tillage operation using horizontal and vertical axis rotavators were statistically different. However, in the same depth of cut vertical axis rotavator resulted less penetration resistance than horizontal one. Maximum cone index (58.55 kPa) was observed at 13 cm depth by horizontal axis rotavator. Minimum cone index (44.59 kPa) was observed at 7 cm depth with vertical axis rotavator.

Table 4.2 Comparison tests of different levels of depth and type of rotavator on cone index (kPa)

	(a) Field no. 1		(b) Field no. 2	
Depth (cm)	**Horizontal rotavator**	**Vertical rotavator**	**Horizontal rotavator**	**Vertical rotavator**
7	44.90**	44.59**	54.50**	50.00**
10	54.05**	50.90**	60.81**	57.65**
13	58.55**	54.05**	64.41**	60.81**

** -Significant at 1 % level

ns – Non significant.

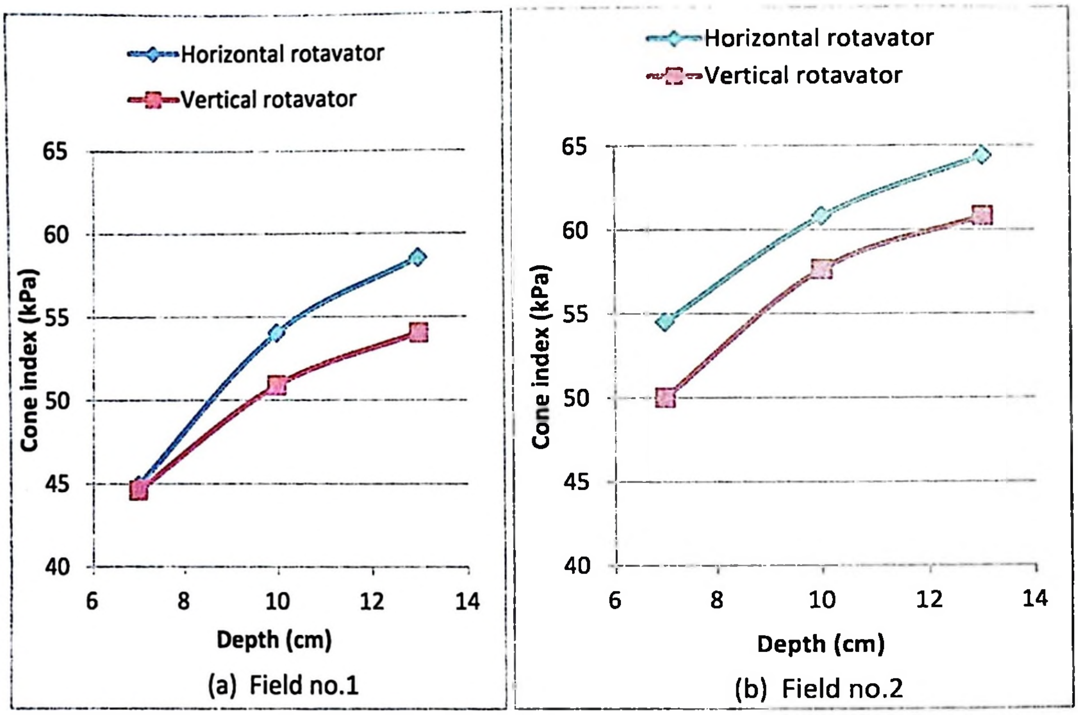

Figure 4.2 Effect of depth on cone index

Figure 4.2 (b) shows the effect of tilling depth of horizontal and vertical rotavator on cone index in field no. 2. The figure shows that the value of cone index of tilled soil using rotavator increased with tilling depth for both the rotavators. Rotavators interacted more volume of soil with comparatively less in time, resulted the level of pulverization was comparatively low with increasing depth. The mean values of cone index were 54.50, 60.81 and 64.41 kPa for horizontal rotavator and 50.00, 57.65 and 60.81 kPa for vertical rotavator at the depth of 7, 10 and 13 cm respectively in the field no. 2.

The results of F-tests for field no. 2 are shown in Table 4.2 (b). The tilling depths have significant effect on cone index resulted from both horizontal rotavator and vertical rotavator at each depth. This means the cone index measured after tillage operation using horizontal and vertical axis rotavators were statistically different. However, in the same depth of cut vertical axis rotavator results in less soil penetration resistance than horizontal one. Maximum cone index (64.41 kPa) was observed at 13 cm depth by horizontal axis rotavator. Minimum cone index (50.00 kPa) was observed at 7 cm depth with vertical axis rotavator.

Results showed that the value of cone index decreased with the increase of moisture content (Figure 4.2). It means the dry soil results in higher cone index, which is in the agreement with the findings from other researchers (Ayers and Perumpral, 1982; Busscher et al., 1997; Earl, 1996; Mapfumo and Chanasyk, 1998).

4.1.3 Effect of depth on bulk density

Bulk density is an indication of sticky soil particles and was determined by standard procedure (section 3.7.2). Therefore, to determine the effect of depth on bulk density the selected rotavators were operated at three different depths (7, 10, 13 cm) and their results data and the analysis of variance (ANOVA) were given in the Appendix II. For statistical analysis the mean values of cone index at different depths were taken from Appendix II and summarized in Table 4.3. The effects of depth of horizontal and vertical rotavators on bulk density in the field no. 1 and 2 were graphically presented in the Figure 4.3.

Figure 4.3 (a) shows the effect of tilling depth of horizontal and vertical axis rotavator on bulk density in field no. 1. The figure shows that the value of bulk density of tilled soil increased with tilling depth for both the rotavators. The mean values of bulk density were 1.12, 1.17, and 1.33 g/cm^3 for horizontal rotavator and 1.10, 1.15 and 1.20 g/cm^3 for vertical rotavator at the depth of 7, 10 and 13 cm respectively in the field no. 1.

The results of F-tests are shown in Table 4.3 (a). The tilling depths have significant effect on bulk density resulted from both horizontal rotavator and vertical rotavator at each depth. This means the bulk density measured after tillage operation using horizontal and vertical axis rotavators were statistically different. However, in the same depth of cut vertical axis rotavator resulted less bulk density than horizontal one. Maximum bulk density (1.33 g/cm^3) was observed at 13 cm depth by horizontal axis rotavator. Minimum bulk density (1.10 g/cm^3) was observed at 7 cm depth with vertical axis rotavator.

Table 4.3 Comparison tests of different levels of depth and type of rotavator on bulk density (g/cm^3)

	(a) Field no. 1		(b) Field no. 2	
Depth (cm)	**Horizontal rotavator**	**Vertical rotavator**	**Horizontal rotavator**	**Vertical rotavator**
7	1.12**	1.10**	1.20**	1.19**
10	1.17**	1.15**	1.25**	1.23**
13	1.33**	1.20**	1.35**	1.29**

** -Significant at 1 % level

ns – Non significant.

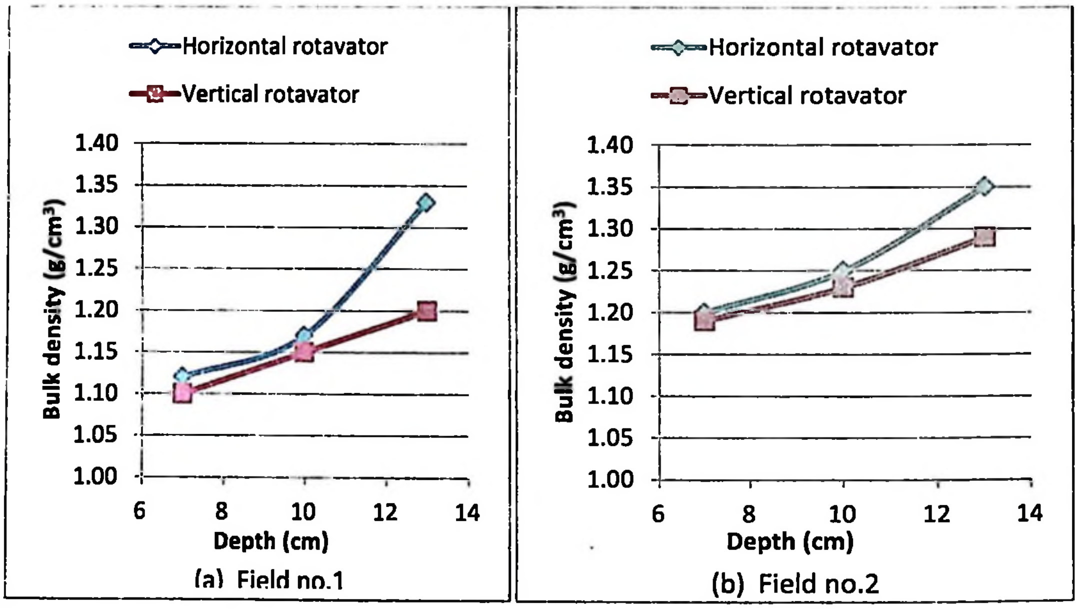

Figure 4.3 Effect of depth on bulk density

Figure 4.3 (b) shows the effect of tilling depth of horizontal and vertical rotavator on bulk density in field no. 2. The figure shows that the value of bulk density of tilled soil increased with tilling depth for both the rotavators. Rotavators interacted more volume of soil with comparatively less in time, resulted the level of pulverization was comparatively low with increasing depth. The mean values of bulk density were 1.20, 1.25, and 1.35 g/cm^3 for horizontal rotavator and 1.19, 1.23, and

1.29 g/cm^3 for vertical rotavator at the depth of 7, 10 and 13 cm respectively in the field no. 2.

The results of F-tests are shown in Table 4.3 (b). The tilling depths have significant effect on bulk density resulted from both horizontal rotavator and vertical rotavator at each depth. This means the bulk density measured after tillage operation using horizontal and vertical axis rotavators were statistically different. The level of soil looseness is affected by different tilling depths as reported by Azadbakht, 2014. However, in the same depth of cut vertical axis rotavator resulted less bulk density than horizontal. Maximum bulk density (1.35 g/cm^3) was observed at 13 cm depth by horizontal axis rotavator. Minimum bulk density (1.19 g/cm^3) was observed at 7 cm depth with vertical axis rotavator. The overall measurement shows that at high moisture content bulk density was less in comparison to the low moisture content field.

4.1.4 Effect of depth on soil disturbance

Soil disturbed area is an indication of how much soil was tilled by the tillage implements and was determined by standard procedure (section 3.7.5). The percentage of soil disturbed is affected by different tilling depths. Therefore, to determine the effect of depth on disturbed area the selected rotavators were operated at three different depths (7, 10, 13 cm) and their results data and the analysis of variance (ANOVA) were given in the Appendix II. For statistical analysis the mean values of percentage of soil disturbed area at different depths were taken from Appendix II and summarized in Table 4.3. The effects of depth of horizontal and vertical rotavators on percentage of soil disturbed area in the field no. 1 and 2 were graphically presented in the Figure 4.4.

Figure 4.4 (a) shows the effect of tilling depth of horizontal and vertical rotavator on percentage of soil disturbed area in field no. 1. The figure shows that the value of percentage of soil disturbed area of tilled soil increased with tilling depth for both the rotavators. The mean values of percentage of soil disturbed area were 88.04, 89.84 and 91.32 % for horizontal rotavator and 92.22, 94.36 and 94.43 % for vertical rotavator at the depth of 7, 10 and 13 cm respectively in the field no. 1.

The results of F-tests are shown in Table 4.4 (a). The tilling depths have significant effect on percentage of soil disturbed area resulted from both horizontal rotavator and vertical rotavator at each depth. This means the percentage of soil disturbed area measured after tillage operation using horizontal and vertical axis rotavators were statistically different. However, in the same depth of cut vertical axis rotavator disturbed the soil at higher percentage than horizontal. Maximum percentage of soil disturbed area (94.43 %) was observed at 13 cm depth by vertical axis rotavator. Minimum percentage of soil disturbed area (88.04 %) was observed at 7 cm depth with horizontal axis rotavator.

Table 4.4 Comparison tests of different levels of depth and type of rotavator on percentage of soil disturbed area (%)

	(a) Field no. 1		(b) Field no. 2	
Depth (cm)	Horizontal rotavator	Vertical rotavator	Horizontal rotavator	Vertical rotavator
7	88.04**	92.22**	85.40**	91.98**
10	89.84**	94.36**	88.00**	93.81**
13	91.32**	94.43**	91.19**	93.89**

** -Significant at 1 % level

ns – Non significant.

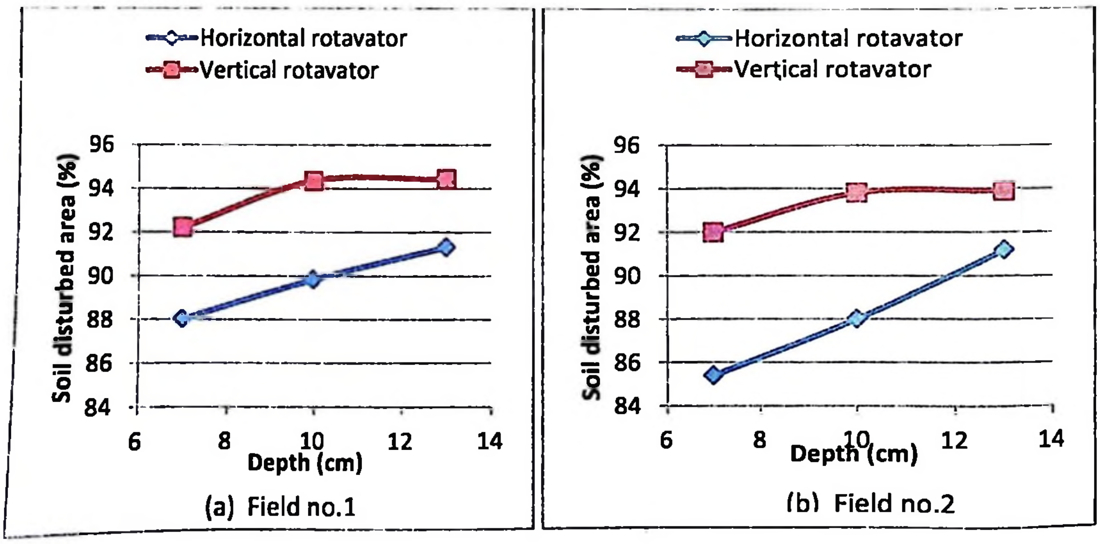

Figure 4.4 Effect of depth on percentage of soil disturbed area

Figure 4.4 (b) shows the effect of tilling depth of horizontal and vertical rotavator on percentage of soil disturbed area in field no. 2. The figure shows that the value of percentage of soil disturbed area of tilled soil increased with tilling depth and then decreased for both the rotavators. The mean values of percentage of soil disturbed area were 85.40, 88.00 and 91.19 % for horizontal rotavator and 91.98, 93.81 and 93.89% for vertical rotavator at the depth of 7, 10 and 13 cm respectively in the field no. 1.

The results of F-tests are shown in Table 4.4 (b). The tilling depths have significant effect on percentage of soil disturbed area resulted from both horizontal rotavator and vertical rotavator at each depth. This means the percentage of soil disturbed area measured after tillage operation using horizontal and vertical axis rotavators were statistically different. However, in the same depth of cut vertical axis rotavator resulted higher percentage of soil disturbed area than horizontal one. Maximum percentage of soil disturbed area (93.89 %) was observed at 13 cm depth by vertical axis rotavator. Minimum percentage of soil disturbed area (85.40 %) was observed at 7 cm depth with horizontal axis rotavator.

4.1.5 Effect of forward speed on soil mean weight diameter

To determine the effect of speed on soil mean weight diameter the selected rotavators were operated at three different speeds (1.5, 2.71, 4.10 km/h) and their results data and the analysis of variance (ANOVA) are given in the Appendix II. For statistical analysis the mean values of SMWD at different speeds are taken from Appendix II and summarized in Table 4.5. The effects of speed of horizontal and vertical rotavators on SMWD in the field no. 1 and 2 were graphically presented in the Figure 4.5.

Figure 4.5 (a) shows the effect of operating speed of horizontal and vertical rotavator on SMWD in field no. 1. The figure shows that the value of SMWD of tilled soil increased with operating speed for both the rotavators. The value of SMWD increased continuously in case of horizontal rotavator, while in case of vertical rotavator the value of SMWD was almost constant, not increased much. The mean values of SMWDs were 4.27, 4.29 and 4.37 mm for horizontal rotavator and 3.87, 3.87, and 3.87 mm for vertical rotavator at the speeds of 1.5, 2.71 and 4.10 km/h respectively in the field no. 1.

The results of F-tests are shown in Table 4.5 (a). The operating speeds have significant effect on SMWD resulted from horizontal rotavators at each speed. But vertical axis rotavator on different speed levels have no much effect on SMWD. This means the mean weight diameters resulting from the analysis of soil aggregate sizes obtained after using vertical axis rotavator were not statistically different. However, in the same operating speed vertical axis rotavator pulverize soil more than horizontal one. Maximum SMWD (4.37 mm) was observed at 4.10 km/h speed by horizontal axis rotavator. Minimum SMWD (3.87 mm) was observed at 1.5 km/h speed with vertical axis rotavator.

Table 4.5 Comparison tests of different levels of speed and type of rotavator on SMWD (mm)

	(b) Field no. 1		(b) Field no. 2	
Speed (km/h)	Horizontal rotavator	Vertical rotavator	Horizontal rotavator	Vertical rotavator
1.50	4.27**	3.87 ns	4.68**	4.39 ns.
2.71	4.29**	3.87 ns	4.70**	4.39 ns
4.10	4.37**	3.87 ns	4.77**	4.40 ns

** -Significant at 1 % level

ns – Non significant.

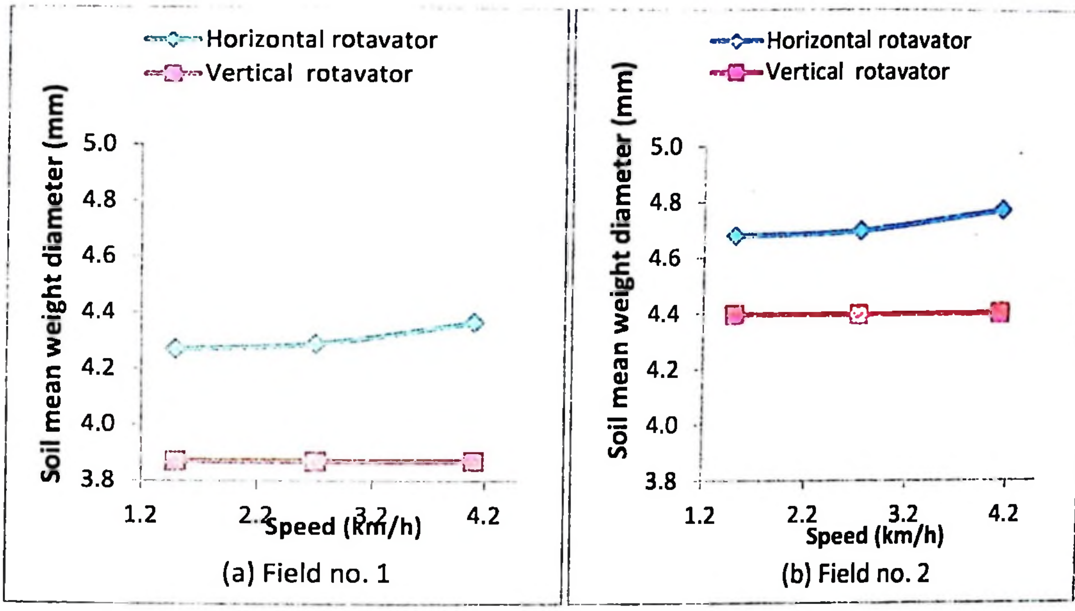

Figure 4.5 Effect of speed on soil mean weight diameter

Figure 4.5 (b) shows the effect of operating speed of horizontal and vertical rotavator on SMWD in field no. 2. The figure shows that the value of SMWD of tilled soil increased with operating speed for both the rotavators. The value of SMWD increased continuously in case of horizontal rotavator, while in case of vertical rotavator the value of SMWD was almost constant, not increased much. The mean values of SMWDs were 4.68, 4.70, and 4.77 mm for horizontal rotavator and 4.39, 4.39 and 4.40 mm for vertical rotavator at the speeds of 1.5, 2.71 and 4.10 km/h respectively in the field no. 2.

The results of F-tests are shown in Table 4.5 (b). The operating speeds have significant effect on SMWD resulted from horizontal rotavators at each speed. But vertical axis rotavator on different speed levels have no effect on SMWD. This means the mean weight diameters resulting from the analysis of soil aggregate sizes obtained after using vertical axis rotavator are not statistically different. However, in the same operating speed vertical axis rotavator pulverize soil more than horizontal one. Maximum SMWD (4.77 mm) was observed at 4.10 km/h speed by horizontal axis rotavator. Minimum SMWD (4.39 mm) was observed at 1.5 km/h speed with vertical axis rotavator.

The same trend was seen in experiment conducted at field no. 1 and field no. 2. However, the SMWDs at field no. 1 were small compared to the one obtained in field no. 2. This was due to the optimum moisture content at field no. 1 which resulted in better soil pulverisation. Results show that changing of operating speed has much effect on horizontal axis rotavator than on vertical one. Overall, the speed of only horizontal axis rotavator affected on SMWD.

4.1.6 Effect of forward speed on soil penetration resistance

To determine the effect of speed on cone index the selected rotavators were operated at three different speeds (1.5, 2.71, 4.1 km/h) and their results data and the analysis of variance (ANOVA) are given in the Appendix II. For statistical analysis the mean values of cone index at different speeds are taken from Appendix II and summarized in Table 4.6. The effects of speed of horizontal and vertical rotavators on cone index in the field no. 1 and 2 are graphically presented in the Figure 4.6.

Figure 4.6 (a) shows the effect of operating speed of horizontal and vertical rotavator on cone index in field no. 1. The figure shows that the value of cone index of tilled soil increases with operating speed for both the rotavators. Rotavators interacted more volume of soil with comparatively less in time, resulted the level of pulverization was comparatively low with increasing forward speed. The mean values of cone index were 43.55, 55.40 and 58.55 kPa for horizontal rotavator and 41.89, 52.25 and 55.40 kPa for vertical rotavator at the speed of 1.5, 2.71 and 4.10 km/h respectively in the field no. 1.

The results of F-tests are shown in Table 4.6 (a). The operating speeds have significant effect on cone index resulted from both horizontal rotavator and vertical rotavator at each speed. This means the cone index measured after tillage operation using horizontal and vertical axis rotavators are statistically different. However, in the same operating speed vertical axis rotavator resulted less soil penetration resistance than horizontal one. Maximum cone index (58.55 kPa) was observed at 4.1 km/h speed by horizontal axis rotavator. Minimum cone index (41.89 kPa) was observed at 1.5 km/h speed with vertical axis rotavator.

Table 4.6 Comparison tests of different levels of speed and type of rotavator on cone index (kPa)

Speed (km/h)	(a) Field no. 1		(b) Field no. 2	
	Horizontal rotavator	Vertical rotavator	Horizontal rotavator	Vertical rotavator
1.50	43.55**	41.89**	51.80**	48.65**
2.71	55.40**	52.25**	62.61**	57.65**
4.10	58.55**	55.40**	65.31**	62.16**

** -Significant at 1 % level

ns – Non significant.

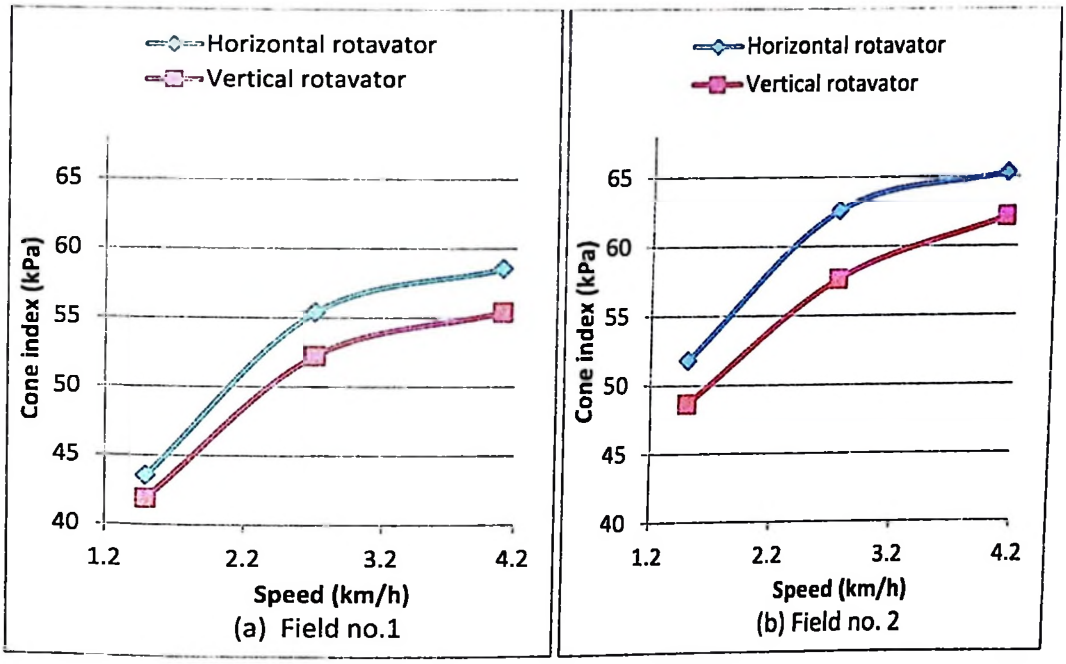

Figure 4.6 Effect of speed on cone index

Figure 4.6 (b) shows the effect of operating speed of horizontal and vertical rotavator on cone index in field no. 2. The figure shows that the value of cone index of tilled soil increased with operating speed for both the rotavators. The mean values of cone index were 51.23, 62.61 and 65.31 kPa for horizontal rotavator and 48.65, 57.65 and 62.16 kPa for vertical rotavator at the speed of 1.5, 2.71 and 4.10 km/h respectively in the field no. 2.

The results of F-tests are shown in Table 4.6 (b). The operating speeds have significant effect on cone index resulted from both horizontal rotavator and vertical rotavator at each speed. This means the cone index measured after tillage operation using horizontal and vertical axis rotavators were statistically different. However, in the same operating speed vertical axis rotavator resulted to less soil penetration resistance more than horizontal one. Maximum cone index (65.31 kPa) was observed at 4.1 km/h speed by horizontal axis rotavator. Minimum cone index (48.65 kPa) was observed at 1.5 km/h speed with vertical axis rotavator.

The same trend was seen in experiment conducted at field no. 1 and field no. 2. However, the cone indexes at field no. 1 were small compared to the one obtained in field no. 2. This was due to the optimum moisture content at field no. 1 which resulted in less soil penetration resistance. As an overall average among the treatments, horizontal axis rotavator had larger cone index values than vertical axis rotavator.

4.1.7 Effect of forward speed on bulk density

Three different forward speeds viz. 1.50, 2.71 and 4.10 km/h caused different results in soil bulk density as the depth of operation was kept constant. As the forward speed increased bulk density increased respectively. Therefore, to determine the effect of speed on bulk density the selected rotavators were operated at the three different speeds and their results data and the analysis of variance (ANOVA) were given in the Appendix II. For statistical analysis the mean values of cone index at different depths were taken from Appendix II and summarized in Table 4.7. The effects of depth of horizontal and vertical rotavators on bulk density in the field no. 1 and 2 were graphically presented in the Figure 4.7.

Figure 4.7 (a) shows the effect of operating speed of horizontal and vertical rotavator on bulk density in field no. 1. The figure shows that the value of bulk density of tilled soil increased with operating speed for both the rotavators. Rotavators interacted more volume of soil with comparatively less in time, resulted the level of pulverization was comparatively low with increasing forward speed. The mean values of bulk density were 1.14, 1.17 and 1.27 g/cm^3 for horizontal rotavator and 1.11, 1.13 and 1.16 g/cm^3 for vertical rotavator at the depth of 1.50, 2.71 and 4.10 km/h respectively in the field no. 1.

The results of F-tests are shown in Table 4.7 (a). The operating speeds have significant effect on bulk density resulted from both horizontal rotavator and vertical rotavator at each speed. This means the bulk density measured after tillage operation using horizontal and vertical axis rotavators were statistically different. However, in the same operating speed vertical axis rotavator resulted less bulk density than horizontal one. Maximum bulk density (1.27 g/cm^3) was observed at 4.10 km/h depth by horizontal axis rotavator. Minimum bulk density (1.11 g/cm^3) was observed at 1.50 km/h depth with vertical axis rotavator.

Table 4.7 Comparison tests of different levels of speed and type of rotavator on bulk density (g/cm^3)

	(a) Field no. 1		(b) Field no. 2	
Speed (km/h)	**Horizontal rotavator**	**Vertical rotavator**	**Horizontal rotavator**	**Vertical rotavator**
1.50	1.14**	1.11**	1.18**	1.16**
2.71	1.17**	1.13**	1.27**	1.26**
4.10	1.27**	1.16**	1.36**	1.29**

** -Significant at 1 % level

ns – Non significant.

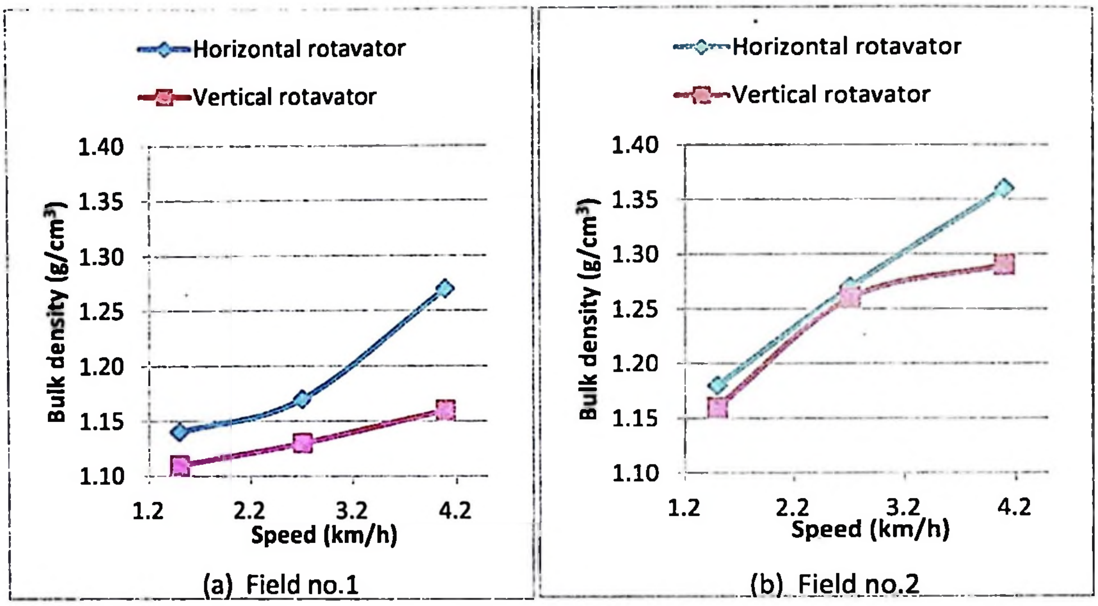

Figure 4.7 Effect of speed on bulk density

Figure 4.7 (b) shows the effect of operating speed of horizontal and vertical rotavator on bulk density in field no. 2. The figure shows that the value of bulk density of tilled soil increased with operating speed for both the rotavators. The mean values of bulk density were 1.18, 1.27 and 1.36 g/cm^3 for horizontal rotavator and 1.16, 1.26 and 1.29 g/cm^3 for vertical rotavator at the depth of 1.5, 2.71 and 4.1 km/h respectively in the field no. 2.

The results of F-tests are shown in Table 4.7 (b). The operating speeds have significant effect on bulk density resulted from both horizontal rotavator and vertical rotavator at each speed. This means the bulk density measured after tillage operation using horizontal and vertical axis rotavators were statistically different. However, in the same operating speed vertical axis rotavator resulted less bulk density than horizontal one. Maximum bulk density (1.36 g/cm^3) was observed at 4.10 km/h depth by horizontal axis rotavator. Minimum bulk density (1.16 g/cm^3) was observed at 1.50 km/h depth with vertical axis rotavator.

4.1.8 Effect of forward speed on soil disturbed area

Soil disturbed area is an indication of how much soil was tilled by the tillage implements and was determined by standard procedure (section 3.7.5). The percentage of soil disturbed is affected by different operating speeds. Therefore, to determine the effect of speed on disturbed area the selected rotavators were operated at three different speeds (1.50, 2.71 and 4.10 km/h) and their results data and the analysis of variance (ANOVA) were given in the Appendix II. For statistical analysis the mean values of percentage of soil disturbed area at different speeds were taken from Appendix II and summarized in Table 4.8. The effects of speed of horizontal and vertical rotavators on percentage of soil disturbed area in the field no. 1 and 2 were graphically presented in the Figure 4.8.

Figure 4.8 (a) shows the effect of operating speed of horizontal and vertical rotavator on percentage of soil disturbed area in field no. 1. The figure shows that the value of percentage of soil disturbed area of tilled soil decreased with operating speed for both the rotavators. The mean values of percentage of soil disturbed area were 91.98, 89.79 and 87.43 % for horizontal rotavator and 94.94, 93.78 and 92.30 % for vertical rotavator at the speed of 1.50, 2.71 and 4.10 km/h respectively in the field no. 1.

The results of F-tests are shown in Table 4.8 (a). The operating speeds have significant effect on percentage of soil disturbed area resulted from both horizontal rotavator and vertical rotavator at each speed. This means the percentage of soil disturbed area measured after tillage operation using horizontal and vertical axis rotavators were statistically different. However, in the same speed of cut vertical axis rotavator resulted higher percentage of soil disturbed area than horizontal one. Maximum percentage of soil disturbed area (94.94 %) was observed at 1.50 km/h speed by vertical axis rotavator. Minimum percentage of soil disturbed area (87.43 %) was observed at 4.10 km/h speed with horizontal axis rotavator.

Table 4.8 Comparison tests of different levels of speed and type of rotavator on percentage soil disturbed area (%)

	(a) Field no. 1		(b) Field no. 2	
Speed (km/h)	Horizontal rotavator	Vertical rotavator	Horizontal rotavator	Vertical rotavator
1.50	91.98**	94.94**	89.77**	94.36**
2.71	89.79**	93.78**	86.99**	93.38**
4.10	87.43**	92.3**	84.81**	91.94**

** -Significant at 1 % level

ns – Non significant.

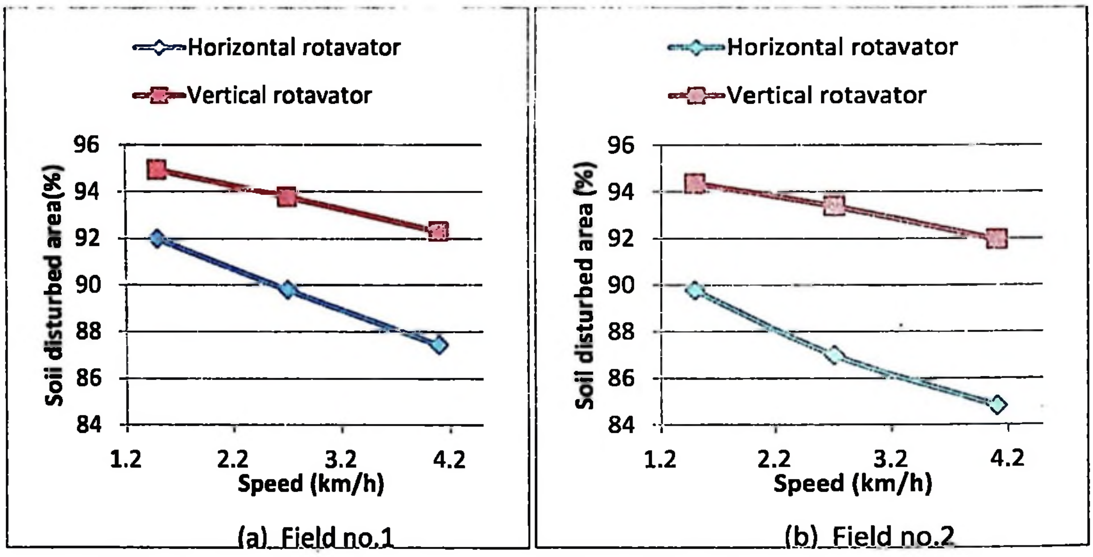

Figure 4.8 Effect of speed on percentage soil disturbed area

Figure 4.8 (b) shows the effect of operating speed of horizontal and vertical rotavator on percentage of soil disturbed area in field no. 2. The figure shows that the value of percentage of soil disturbed area of tilled soil decreased with operating speed for both the rotavators. The mean values of percentage of soil disturbed area were 89.77, 86.99 and 84.81 % for horizontal rotavator and 94.36, 93.38 and 91.94 % for vertical rotavator at the speed of 1.5, 2.71 and 4.10 km/h respectively in the field no. 2.

The results of F-tests are shown in Table 4.8 (b). The operating speeds have significant effect on percentage of soil disturbed area resulted from both horizontal rotavator and vertical rotavator at each speed. This means the percentage of soil disturbed area measured after tillage operation using horizontal and vertical axis rotavators were statistically different. However, in the same speed of cut vertical axis rotavator resulted higher percentage of soil disturbed area than horizontal one. Maximum percentage of soil disturbed area (94.36 %) was observed at 1.5 km/h speed by vertical axis rotavator. Minimum percentage of soil disturbed area (84.81 %) was observed at 4.1 km/h speed with horizontal axis rotavator.

4.2 Effect of Operating Parameters on Machine Performance

To evaluate the performance of both the selected horizontal and vertical rotavators, two main operating parameters like depth of tilling and speed of operation were selected and their effects on machine parameters like fuel consumption, energy requirement, field efficiency and operating cost were determined, analysed statistically and presented graphically in the following manner:

- **Effect of depth on fuel consumption**
- **Effect of depth on energy consumption**
- **Effect of depth on field efficiency**
- **Effect of depth on operating cost**
- **Effect of forward speed on fuel consumption**
- **Effect of forward speed on energy consumption**
- **Effect of forward speed on field efficiency**
- **Effect of forward speed on operating cost**

4.2.1 Effect of depth on fuel consumption

To determine the effect of tilling depth of rotavators on fuel consumption, selected rotavators were operated at different depths and consumed fuel was measured by standard procedure (Section 3.7.12). The horizontal and the vertical rotavators were operated at three different depths (7, 10, 13 cm) and the observations for the consumed amount of fuel were taken. The detailed results /data and the analysis of variance (ANOVA) were given in the Appendix II. For the statistical analysis only the mean values of fuel consumption at the three different depths were taken from Appendix II and summarized in Table 4.9 which was further graphically presented in the Figure 4.9(a) and 4.9(b) for the field no. 1 and 2 respectively.

Figure 4.9 (a) shows the effect of tilling depth of horizontal and vertical rotavator on fuel consumption in field no. 1. The figure shows that the value of fuel consumption of tractor increased continuously with tilling depth for both the rotavators. Vertical rotavator consumed more fuel as compared to horizontal rotavator. The mean values of fuel consumption were 10.69, 11.97 and 15.62 l/ha for horizontal rotavator and 12.73, 14.22 and 18.46 l/ha for vertical rotavator at the depth of 7, 10 and 13 cm respectively in the field no. 1.

The fuel consumption increased by 11.97 % (1.28 l/ha) when tillage depth of horizontal rotavator increased from 7 to 10 cm while it increased by 30.5 % (3.65 l/ha) when tillage depth increased from 10 to 13 cm. The fuel consumption value increased by 11.7 % (1.49 l/ha) when tillage depth of vertical rotavator increased from 7 to 10 cm while it increased by 29.8 % (4.24 l/ha) when tillage depth increased from 10 to 13 cm. The fuel consumption increased about three times more even increasing the tilling depth only by 3 cm from 10 cm for both the rotavators. Fuel consumption is not only affected by type of rotavator but also by different tillage depth. The fuel consumption increased sharply after increasing tilling depth above 10 cm.

To determine the significant effect of tillage depth and type of rotavator on the fuel consumption, F-tests were done and the results of the F-tests were shown in Table 4.9 (a). From the table it can be seen that the tilling depths have significant effect on fuel consumption and that too at each depth and with the rotavator type. It is also clear from the table that the vertical axis rotavator consumed comparatively more fuel even at the same depth of tilling than the horizontal one. Maximum fuel consumption (18.46 l/ha) was observed at 13 cm depth by vertical axis rotavator. Minimum fuel consumption (10.69 l/ha) was observed at 7 cm depth with horizontal axis rotavator.

Table 4.9 Comparison tests of different levels of depth and type of rotavators on fuel consumption (l/ha)

	(a) Field no. 1		(b) Field no. 2	
Depth (cm)	Horizontal rotavator	Vertical rotavator	Horizontal rotavator	Vertical rotavator
7	10.69**	12.73**	11.39**	13.88**
10	11.97**	14.22**	13.43**	15.12**
13	15.62**	18.46**	16.61**	19.34**

** -Significant at 1 % level

ns – Non significant.

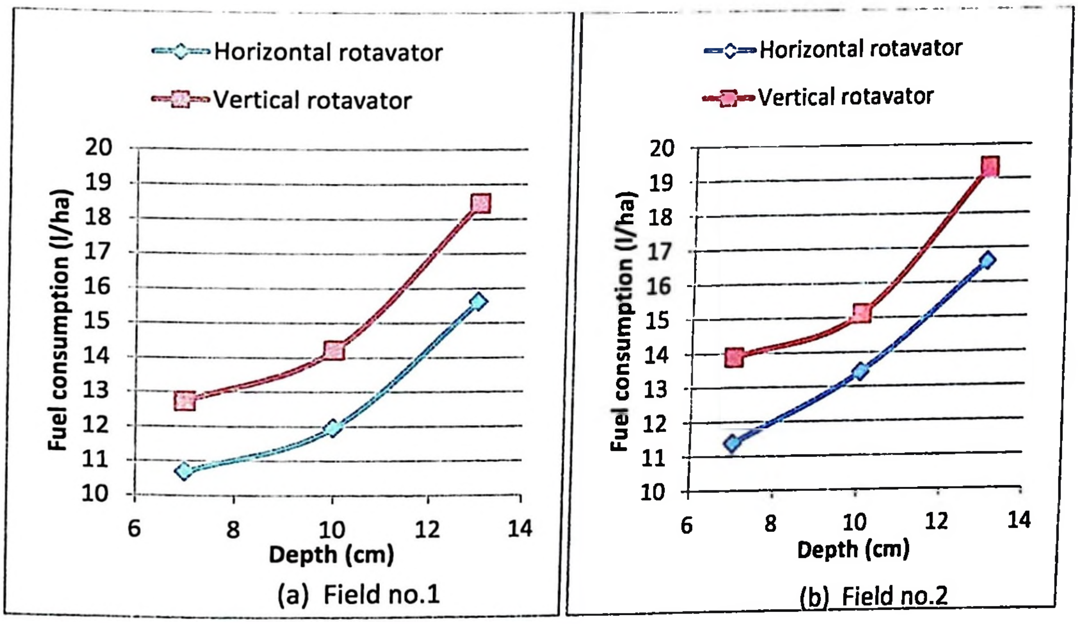

Figure 4.9 Effect of depth on fuel consumption

Figure 4.9 (b) shows the effect of tilling depth of horizontal and vertical rotavator on fuel consumption in field no. 2. The figure shows that the value of fuel consumption of tractor increased continuously with tilling depth for both the rotavators. The mean values of fuel consumption were 11.39, 13.43 and 16.61 l/ha for horizontal rotavator and 13.88, 15.12 and 19.34 l/ha for vertical rotavator at the depth of 7, 10 and 13 cm respectively in the field no. 2.

The fuel consumption value increased by 17.91 % (2.04 l/ha) when tillage depth of horizontal rotavator increased from 7 to 10 cm while it increased by 23.68 % (3.18 l/ha) when tillage depth increases from 10 to 13 cm. The fuel consumption value increased by 8.93 % (1.24 l/ha) when tillage depth of vertical rotavator increased from 7 to 10 cm while it increased by 27.91 % (4.22 l/ha) when tillage depth increased from 10 to 13 cm. The fuel consumption increased about three times more even increasing the tilling depth by only 3 cm from 10 cm for both the rotavators. Fuel consumption is significantly affected with tillage depth as well as type of rotovator.

To determine the significant effect of tillage depth and type of rotavator on the fuel consumption, F-tests were done and the results of the F-tests were shown in Table 4.9 (b). From the table it can be seen that the tilling depths have significant effect on fuel consumption and that too at each depth and with the rotavator type. It is also clear from the table that the vertical axis rotavator consumed comparatively more fuel even at the same depth of tilling than horizontal one. Maximum fuel consumption (19.34 l/ha) was observed at 13 cm depth by vertical axis rotavator. Minimum fuel consumption (11.39 l/ha) was observed at 7 cm depth with horizontal axis rotavator.

From the above Figure 4.9 it can be concluded that fuel consumption increased with the tilling depth. The vertical rotavator consumed comparatively more fuel than the horizontal rotavator even at the same depth. Another important point was also observed that the fuel consumption increased at a higher rate when the depth of tilling increased from 10 cm to 13 cm depth with both the rotavators. The same trend was obtained in both the experimental fields (Field no. 1 & 2). However, the fuel consumption at field no. 1 was overall less as comparative to in the field no. 2. This might be due to the difference in field moisture content and other physical parameters. Economical fuel consumption of point of view rotavator should be operated up to the depth of 10 cm. The same trend was obtained by Srisvastava, 1993 and McLaughlin, 1993.

4.2.2 Effect of depth on energy requirement

Energy requirement was determined by standard procedure (section 3.7.13). The amount of energy required in tillage operation is affected by different tilling depths. Therefore, two selected rotavators one horizontal and another vertical were operated at three different depths (7, 10, 13 cm) and the observations for the consumed amount of energy were calculated. The detailed results /data and the analysis of variance (ANOVA) were given in the Appendix II. For statistical analysis only the mean values of energy requirement at different depths were taken from Appendix II and summarized in Table 4.10 which was graphically presented in the Figure 4.10(a) and 4.10(b). Both the figures showed the effects of depth of horizontal and vertical rotavators on energy requirement in the field no. 1 and 2.

Figure 4.10 (a) shows the effect of tilling depth of horizontal and vertical rotavator on energy requirement in field no. 1. The figure shows that the value of energy requirement during tillage operation increased continuously with tilling depth for both the rotavators. The mean values of energy requirement were 664.13, 735.72 and 941.63 MJ/ha for horizontal rotavator and 794.48, 874.60 and 1166.79 MJ/ha for vertical rotavator at the depth of 7, 10 and 13 cm respectively in the field no. 1.

The energy requirement increased by 10.78 % (71.59 MJ/ha) when tillage depth of horizontal rotavator increased from 7 to 10 cm while it increased by 27.99 % (205.91 MJ/ha) when tillage depth increases from 10 to 13 cm. The energy requirement value increased by 10.8 % (80.12 MJ/ha) when tillage depth of vertical rotavator increased from 7 to 10 cm while it increased by 33.41 % (292.19 MJ/ha) when tillage depth increased from 10 to 13 cm. The energy requirement increased about three times more even increasing the tilling depth only by 3 cm from 10 cm for both the rotavators. Energy requirement is affected by tillage depth as well as with type of rotovator.

To determine the significant effect of tillage depth and type of rotavator on the energy requirement, F-tests were done and the results of the F-tests were shown in Table 4.10 (a). From the table it can be seen that the tilling depths have significant effect on energy requirement and that too at each depth and with the rotavator type. It is also clear from the Table that the vertical axis rotavator consumed comparatively more energy even at the same depth of tilling than horizontal one. Maximum energy requirement (1166.79 MJ/ha) was observed at 13 cm depth by vertical axis rotavator. Minimum energy requirement (664.13 MJ/ha) was observed at 7 cm depth with horizontal axis rotavator.

Table 4.10 Comparison tests of different levels of depth and type of rotavators on energy requirement (MJ/ha)

	(a) Field no. 1		(b) Field no. 2	
Depth (cm)	Horizontal rotavator	Vertical rotavator	Horizontal rotavator	Vertical rotavator
7	664.13**	794.48**	706.01**	826.52**
10	735.72**	874.6**	854.1**	925.63**
13	941.63**	1166.79**	997.24**	1161.37**

** -Significant at 1 % level

ns – Non significant.

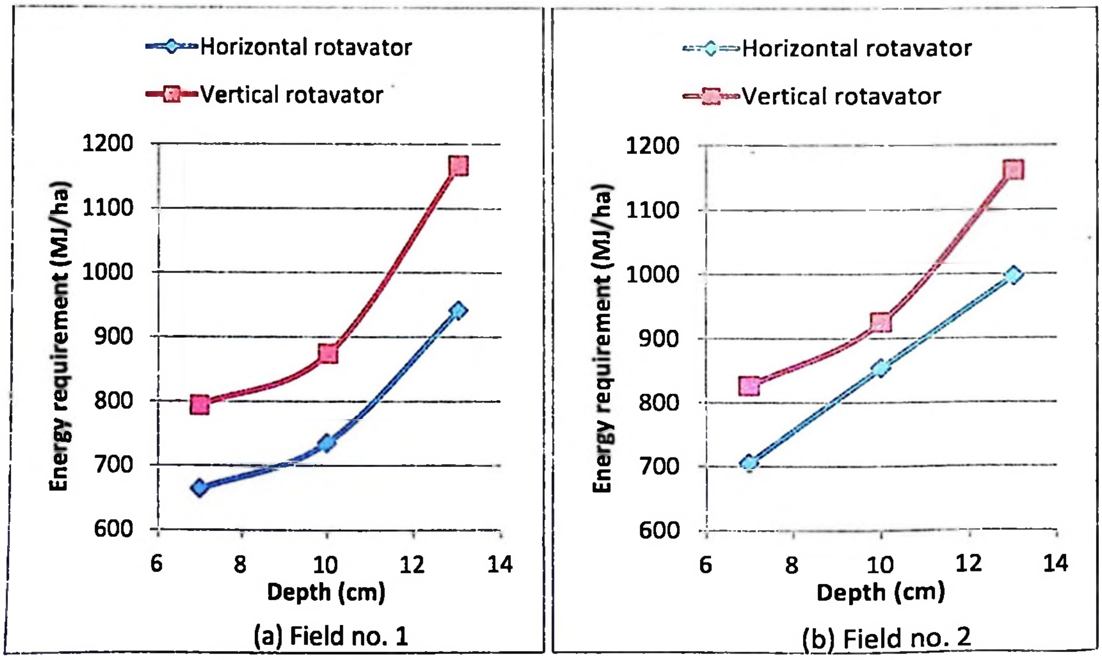

Figure 4.10 Effect of depth on energy requirement

Figure 4.10 (b) shows the effect of tilling depth of horizontal and vertical rotavator on energy requirement in field no. 1. The figure shows that the value of energy requirement during tillage operation increased continuously with tilling depth for both the rotavators. The mean values of energy requirement were 706.01, 854.1 and 997.24 MJ/ha for horizontal rotavator and 826.52, 925.63 and 1161.37 MJ/ha for vertical rotavator at the depth of 7, 10 and 13 cm respectively in the field no. 1.

The energy requirement increased by 20.98 % (148.09 MJ/ha) when tillage depth of horizontal rotavator increased from 7 to 10 cm while it increased by 16.76 % (143.14 MJ/ha) when tillage depth increases from 10 to 13 cm. The energy requirement value increased by 11.99 % (99.11 MJ/ha) when tillage depth of vertical rotavator increased from 7 to 10 cm while it increased by 25.47 % (235.74 MJ/ha) when tillage depth increased from 10 to 13 cm. The energy requirement increased about three times more even increasing the tilling depth only by 3 cm from 10 cm for both the rotavators. Energy requirement is affected by tillage depth as well as with type of rotovator.

To determine the significant effect of tillage depth and type of rotavator on the energy requirement, F-tests were done and the results of the F-tests were shown in Table 4.10 (b). From the table it can be seen that the tilling depths have significant effect on energy requirement and that too at each depth and with the rotavator type. It is also clear from the table that the vertical axis rotavator consumed comparatively more energy even at the same depth of tilling than horizontal one. Maximum energy requirement (1161.37 MJ/ha) was observed at 13 cm depth by vertical axis rotavator. Minimum energy requirement (706.01 MJ/ha) was observed at 7 cm depth with horizontal axis rotavator.

4.2.3 Effect of depth on field efficiency

Field efficiency was determined by standard procedure (section 3.7.8). Field efficiency of the tested rotavators during tillage operation is affected by different tilling depths. Therefore, two selected rotavators one horizontal and another vertical were operated at three different depths (7, 10, 13 cm) and the observations for the field efficiency were calculated. The detailed results /data and the analysis of variance (ANOVA) were given in the Appendix II. For statistical analysis only the mean values of field efficiency at different depths were taken from Appendix II and summarized in Table 4.10 which was graphically presented in the Figure 4.11(a) and

4.11(b). Both the figures showed the effects of depth of horizontal and vertical rotavators on field efficiency in the field no. 1 and 2.

Figure 4.11 (a) shows the effect of tilling depth of horizontal and vertical rotavator on field efficiency in field no. 1. The figure shows that the value of field efficiency, during tillage operation, increased when depth increased from 7 cm to 10 cm and then decreased at 13 cm depth for horizontal rotavator while decreased with depth in the case of vertical rotavator. The mean values of field efficiency were 86.90, 87.14 and 87.85 % for horizontal rotavator and 88.53, 88.55 and 89.02 % for vertical rotavator at the depth of 7, 10 and 13 cm respectively in the field no. 1.

The field efficiency increased by 0.28 % when tillage depth of horizontal rotavator increased from 7 to 10 cm and further it increased by 0.81 % when tillage depth increases from 10 to 13 cm. The field efficiency value increased by 0.02 % when tillage depth of vertical rotavator increased from 7 to 10 cm and further it increased by 0.53 % when tillage depth increased from 10 to 13 cm. Field efficiency is affected by tillage depth as well as with type of rotovator.

To determine the significant effect of tillage depth and type of rotavator on the field efficiency, F-tests were done and the results of the F-tests were shown in Table 4.10 (a). From the table it can be seen that the tilling depths have significant effect on field efficiency and that too at each depth and with the rotavator type. It is also clear from the Table that the vertical axis rotavator showed comparatively more field efficiency even at the same depth of tilling than horizontal one. Maximum field efficiency (89.02 %) was observed at 13 cm depth by vertical axis rotavator. Minimum field efficiency (86.90 %) was observed at 7 cm depth with horizontal axis rotavator.

Table 4.11 Comparison tests of different levels of depth and type of rotavators on field efficiency (%)

	(a) Field no. 1		(b) Field no. 2	
Depth (cm)	Horizontal rotavator	Vertical rotavator	Horizontal rotavator	Vertical rotavator
7	86.90**	88.53**	82.45**	86.21**
10	87.14**	88.55**	83.43**	86.67**
13	87.85**	89.02**	84.94**	86.68**

** -Significant at 1 % level

ns – Non significant.

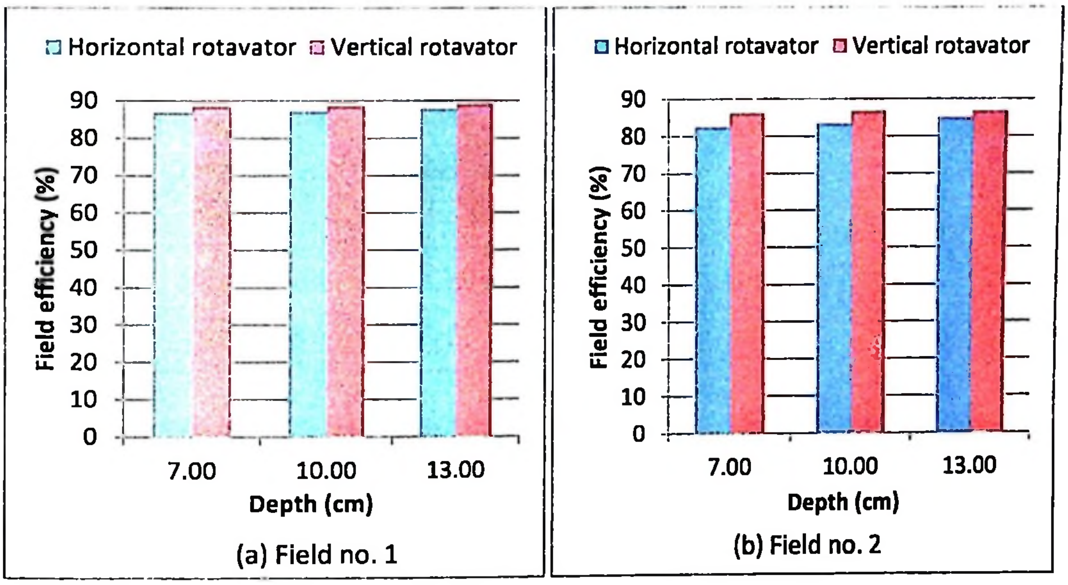

Figure 4.11 Effect of depth on field efficiency

Figure 4.11 (b) shows the effect of tilling depth of horizontal and vertical rotavator on field efficiency in field no. 2. The figure shows that the value of field efficiency during tillage operation increased from 7 cm to 10 cm depth and then decreased at 13 cm depth for horizontal rotavator while decreased with depth for the case of vertical rotavator. The mean values of field efficiency were 82.45, 83.43 and 84.94 % for horizontal rotavator and 86.21, 86.67 and 86.68 % for vertical rotavator at the depth of 7, 10 and 13 cm respectively in the field no. 2.

The field efficiency decreased by 1.19 % when tillage depth of horizontal rotavator increased from 7 to 10 cm and further it increased by 1.81 % when tillage depth increases from 10 to 13 cm. The field efficiency value increased by 0.53 % when tillage depth of vertical rotavator increased from 7 to 10 cm and further it increased by 0.01 % when tillage depth increased from 10 to 13 cm. Field efficiency is affected by tillage depth as well as with type of rotovator.

To determine the significant effect of tillage depth and type of rotavator on the field efficiency, F-tests were done and the results of the F-tests were shown in Table 4.10 (b). From the table it can be seen that the tilling depths have significant effect on field efficiency and that too at each depth and with the rotavator type. It is also clear from the Table that the vertical axis rotavator showed comparatively more field efficiency even at the same depth of tilling than horizontal one. Maximum field efficiency (86.68 %) was observed at 13 cm depth by vertical axis rotavator. Minimum field efficiency (82.45 %) was observed at 7 cm depth with horizontal axis rotavator.

4.2.4 Effect of depth on operating cost

Operating cost was determined by standard procedure (section 3.8). The selected rotavators horizontal and vertical were operated at three different depths (7, 10, 13 cm) and the observations for the operating cost were taken. The detailed results /data were given in the Appendix II. For statistical analysis only the mean values of operating cost at different depths were taken from Appendix II and summarized in Table 4.12 which was graphically presented in the Figure 4.12 (a) and 4.12 (b). Both figures show the effect of depth of horizontal and vertical rotavators on operating cost in the field no. 1 and 2.

Figure 4.12 (a) shows the effect of tilling depth of horizontal and vertical rotavator on operating cost in field no. 1. The figure shows that the value of operating cost of tractor increased continuously with tilling depth for both the rotavators. The mean values of operating cost obtained were Rs 1279, 1451 and 1668 per ha, for horizontal rotavator and Rs 1479, 1531 and 2002 per ha, for vertical rotavator at the depth of 7, 10 and 13 cm respectively in the field no. 1.

The operating cost increased by 13.45 % (Rs 172 per ha) when tillage depth of horizontal rotavator increased from 7 to 10 cm while it increased by 14.99 % (Rs 217 per ha) when tillage depth increases from 10 to 13 cm. The operating cost increased by 3.5 % (Rs 51 per ha) when tillage depth of vertical rotavator increased from 7 to 10 cm while it increased by 30.75 % (Rs 470 per ha) when tillage depth increased from 10 to 13 cm. The operating cost increased abruptly even increasing the tilling depth only by 3 cm from 10 cm for vertical rotavator. Operating cost is affected by tillage depth as well as with type of rotovator.

To determine the significant effect of tillage depth and type of rotavator on the operating cost, F-tests were done and the results of the F-tests were shown in Table 4.12 (a). From the Table it can be seen that the tilling depths have significant effect on operating cost and that too at each depth and with the rotavator type. It is also clear from the table that the vertical axis rotavator consumed comparatively more cost even at the same depth of tilling than horizontal one. Maximum operating cost (Rs 2002 per ha) was observed at 13 cm depth by vertical axis rotavator. Minimum operating cost (Rs 1279 per ha) was observed at 7 cm depth with horizontal axis rotavator.

Table 4.12 Comparison tests of different levels of depth and type of rotavators on operating cost (Rs/ha)

	(a) Field no. 1		(b) Field no. 2	
Depth (cm)	**Horizontal rotavator**	**Vertical rotavator**	**Horizontal rotavator**	**Vertical rotavator**
7	1279.07**	1479.37**	1366.10**	1656.44**
10	1451.09**	1531.22**	1504.15**	1659.51**
13	1668.68**	2002.01**	1573.75**	1999.01**

** -Significant at 1 % level

ns – Non significant.

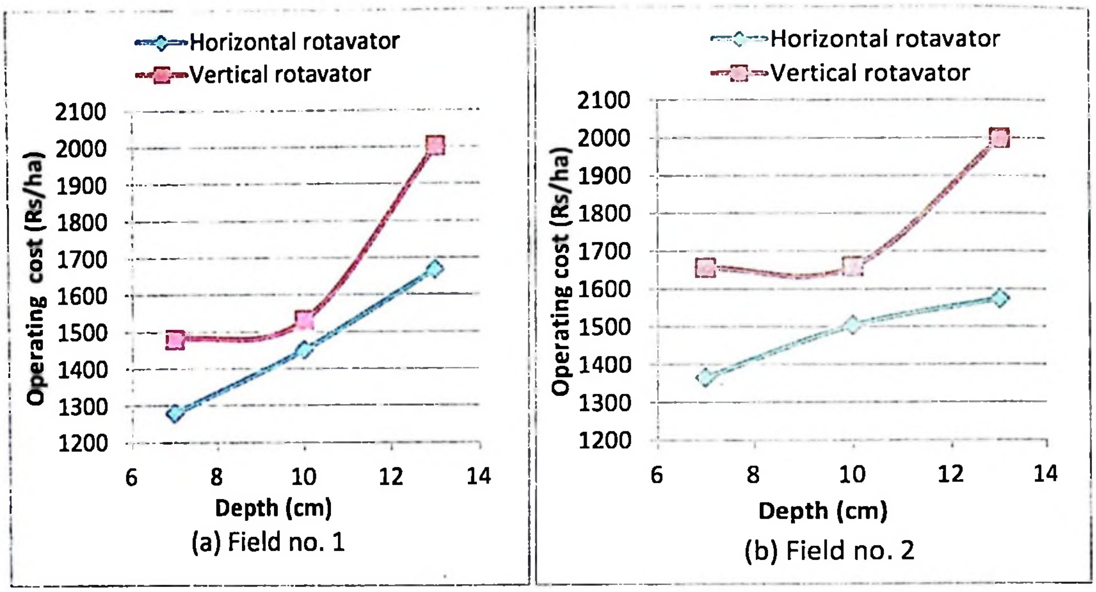

Figure 4.12 Effect of depth on operating cost

Figure 4.12 (b) shows the effect of tilling depth of horizontal and vertical rotavator on operating cost in field no. 2. The figure shows that the value of operating cost increased continuously with tilling depth for both the rotavators. The mean values of operating cost were Rs 1366, 1504 and 1573 per ha for horizontal rotavator and Rs 1656, 1659 and 1999 per ha for vertical rotavator at the depth of 7, 10 and 13 cm respectively in the field no. 2.

The operating cost increased by 10.11 % (Rs 138 per ha) when tillage depth of horizontal rotavator increased from 7 to 10 cm while it increased by 4.63 % (Rs 69 per ha) when tillage depth increases from 10 to 13 cm. The operating cost increased by 0.20 % (Rs 3 per ha) when tillage depth of vertical rotavator increased from 7 to 10 cm while it increased by 20.46 % (Rs 339 per ha) when tillage depth increased from 10 to 13 cm. The operating cost increased abruptly even increasing the tilling depth only by 3 cm from 10 cm for vertical rotavator rotavator. Operating cost is affected by tillage depth as well as with type of rotovator.

To determine the significant effect of tillage depth and type of rotavator on the operating cost, F-tests were done and the results of the F-tests were shown in Table 4.12 (b). From the table it can be seen that the tilling depths have significant effect on operating cost and that too at each depth and with the rotavator type. It is clear from the table that the operating cost of vertical axis rotavator is comparatively more even at the same depth of tilling than horizontal rotavator. Maximum operating cost (Rs 1999 per ha) was obtained at 13 cm depth by vertical axis rotavator. Minimum operating cost (Rs 1366 per ha) was obtained at 7 cm depth with horizontal axis rotavator.

4.2.5 Effect of forward speed on fuel consumption

The fuel consumption was determined by standard procedure (section 3.7.12). The amount of fuel consumed by tractor is affected by different operating speeds. Therefore, to determine the effect of speed on fuel consumption the selected rotavators were operated at three different speeds (1.50, 2.71, 4.10 km/h) and their results data and the analysis of variance (ANOVA) are given in the Appendix II. For statistical analysis the mean values of fuel consumption at different speeds are taken from Appendix II and summarized in Table 4.13. The effect of speed of horizontal and vertical rotavators on fuel consumption in the fields no. 1 and 2 are graphically presented in the Figure 4.13.

Figure 4.13 (a) shows the effect operating speed of horizontal and vertical rotavator on fuel consumption in field no. 1. The figure shows that the value of fuel consumption of tractor increased continuously with operating speed for both the rotavators. The mean values of fuel consumption were 12.37, 12.56 and 13.34 l/ha for horizontal rotavator and 14.40, 15.10 and 15.87 l/ha for vertical rotavator at the speed of 1.50, 2.71 and 4.10 km/h respectively in the field no. 1.

The fuel consumption value increased by 1.54 % (0.19 l/ha) when operating speed of horizontal rotavator increased from 1.50 to 2.71 km/h while it increased by 6.21 % (0.78 l/ha) when operating speed increases from 2.71 to 4.1 km/h. The fuel consumption value increased by 4.86 % (0.70 l/ha) when operating speed of vertical rotavator increased from 1.5 to 2.71 km/h while it increased by 5.10 % (0.77 l/ha) when operating speed increased from 2.71 to 4.1 km/h. The fuel consumption increased with increasing the operating speed for both the rotavators. Fuel consumption is significantly affected with operating speed as well as type of rotovator.

To determine the significant effect of operating speed and type of rotavator on the fuel consumption, F-tests were done and the results of the F-tests were shown in

Table 4.9 (a). From the table it can be seen that the operating speeds have significant effect on fuel consumption and that too at each speed and with the rotavator type. It is also clear from the table that the vertical axis rotavator consumed comparatively more fuel even at the same speed than horizontal one. Maximum fuel consumption (15.87 l/ha) was observed at 4.10 km/h speed by vertical axis rotavator. Minimum fuel consumption (12.37 l/ha) was observed at 1.50 km/h depth with horizontal axis rotavator.

Table 4.13 Comparison tests of different levels of speed and type of rotavators on fuel consumption (l/ha)

	(a) Field no. 1		(b) Field no. 2	
Speed (km/h)	Horizontal rotavator	Vertical rotavator	Horizontal rotavator	Vertical rotavator
1.50	12.37**	14.4**	13.29**	15.47**
2.71	12.56**	15.10**	14.00**	16.07**
4.10	13.34**	15.87**	15.00**	16.79**

** -Significant at 1 % level

ns – Non significant.

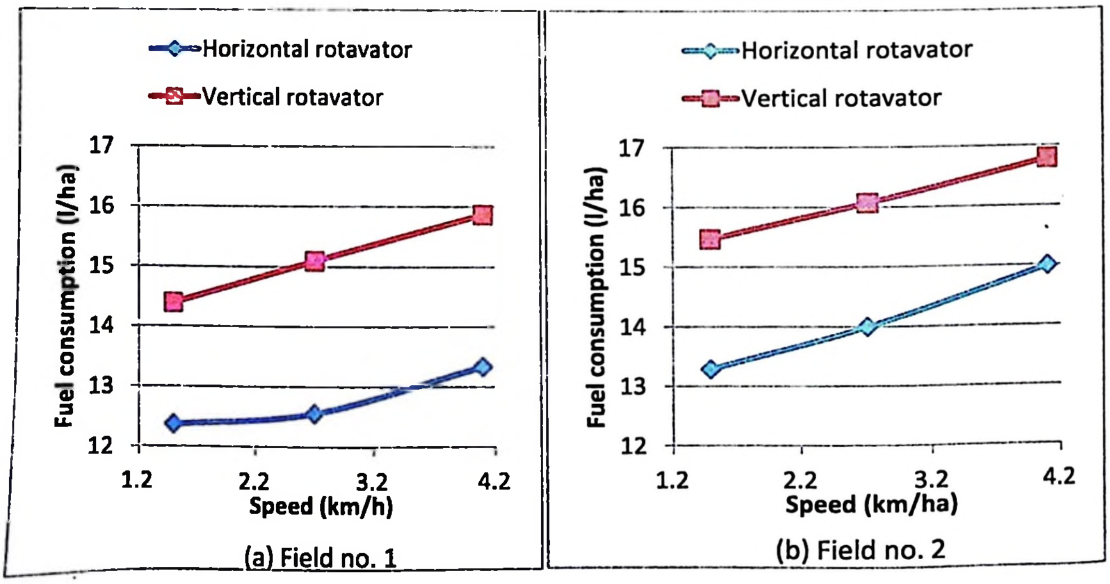

Figure 4.13 Effect of speed on fuel consumption

Figure 4.13 (b) shows the effect operating speed of horizontal and vertical rotavator on fuel consumption in field no. 2. The figure shows that the value of fuel consumption of tractor increased with operating speed for both the rotavators. The value of fuel consumption increased continuously in both horizontal rotavator and vertical rotavator. The mean values of fuel consumption were 13.29, 14.00 and 15.00 l/ha for horizontal rotavator and 15.47, 16.07 and 16.79 l/ha for vertical rotavator at the speed of 1.50, 2.71 and 4.10 km/h respectively in the field no. 2.

The fuel consumption value increased by 5.34 % (0.71 l/ha) when operating speed of horizontal rotavator increased from 1.5 to 2.71 km/h while it increased by 7.14 % (1.00 l/ha) when operating speed increases from 2.71 to 4.1 km/h. The fuel consumption value increased by 3.88 % (0.60 l/ha) when operating speed of vertical rotavator increased from 1.50 to 2.71 km/h while it increased by 4.48 % (0.72 l/ha) when operating speed increased from 2.71 to 4.10 km/h. The fuel consumption increased with increasing the operating speed for both the rotavators. Fuel consumption is significantly affected with operating speed as well as type of rotovator.

To determine the significant effect of operating speed and type of rotavator on the fuel consumption, F-tests were done and the results of the F-tests were shown in Table 4.13 (b). From the table it can be seen that the operating speeds have significant effect on fuel consumption and that too at each speed and with the rotavator type. It is also clear from the Table that the vertical axis rotavator consumed comparatively more fuel even at the same speed than horizontal one. Maximum fuel consumption (16.79 l/ha) was observed at 4.10 km/h speed by vertical axis rotavator. Minimum fuel consumption (13.29 l/ha) was observed at 1.50 km/h speed with horizontal axis rotavator.

The trend of fuel consumption in both the fields was same. However, the fuel consumption in field no. 1 was quite low compared to the field no. 2. This might be due to the optimum moisture content at field no. 1.

The observed trend signifies that fuel consumption varies with operating speed and tillage depth among other factors that affect fuel consumption during tillage as reported by Srisvastava (1993) and McLaughlin (1993). These researchers observed that soil texture, soil moisture content, soil compression ratio, plant residue and bulk density affect tractor fuel consumption during tillage operation. The results obtained from this study indicated that the tillage depth has more effect on the tractor fuel consumption than the operating speed. Therefore, the depth of tillage should be determined based on the root length of crop.

4.2.6 Effect of forward speed on energy consumption

Energy requirement was determined by standard procedure (section 3.7.13). The amount of energy required in tillage operation is affected by different operating speeds. Therefore, two selected rotavators one horizontal and another vertical were operated at three different speeds (1.50, 2.71, 4.10 km/h) and the observations for the consumed amount of energy were calculated. The detailed results /data and the analysis of variance (ANOVA) were given in the Appendix II. For statistical analysis only the mean values of energy requirement at different speeds were taken from Appendix II and summarized in Table 4.14 which was graphically presented in the Figure 4.1 (a) and 4.14 (b). Both the figures show the effect of speed of horizontal and vertical rotavators on energy requirement in the field no. 1 and 2.

Figure 4.14 (a) shows the effect of operating speed of horizontal and vertical rotavator on energy requirement in field no. 1. The figure shows that the value of energy requirement during tillage operation increased continuously with operating speed for both the rotavators. The mean values of energy requirement were 761.74, 779.27 and 790.48 MJ/ha for horizontal rotavator and 916.32, 948.47 and 971.08 MJ/ha for vertical rotavator at the speed of 1.5, 2.71 and 4.1 km/h respectively in the field no. 1.

The energy requirement increased by 2.50 % (17.53 MJ/ha) when operating speed of horizontal rotavator increased from 1.50 to 2.71 km/h while it increased by 1.44 % (11.21 MJ/ha) when operating speed increases from 2.71 to 4.10 km/h. The energy requirement value increased by 3.51 % (32.15 MJ/ha) when operating speed of vertical rotavator increased from 1.50 to 2.71 km/h while it decreased by 2.33 % (22.61 MJ/ha) when tillage speed increased from 2.71 to 4.10 km/h. Energy requirement is affected by operating speed as well as with type of rotovator.

To determine the significant effect of operating speed and type of rotavator on the energy requirement, F-tests were done and the results of the F-tests were shown in Table 4.14 (a). From the table it can be seen that the operating speeds have significant effect on energy requirement and that too at each speed and with the rotavator type. It is also clear from the Table that the vertical axis rotavator consumed comparatively more energy even at the same speed of operation than horizontal one. Maximum energy requirement (971.08 MJ/ha) was observed at 4.10 km/h speed by vertical axis rotavator. Minimum energy requirement (761.74 MJ/ha) was observed at 1.50 km/h speed with horizontal axis rotavator.

Table 4.14 Comparison tests of different levels of speed and type of rotavators on energy requirement (MJ/ha)

	(a) Field no. 1		(b) Field no. 2	
Speed (km/h)	**Horizontal rotavator**	**Vertical rotavator**	**Horizontal rotavator**	**Vertical rotavator**
1.50	761.74**	916.32**	842.88**	978.15**
2.71	779.27**	948.47**	854.58**	1013.40**
4.10	790.48**	971.08**	859.89**	1021.96**

** -Significant at 1 % level

ns – Non significant.

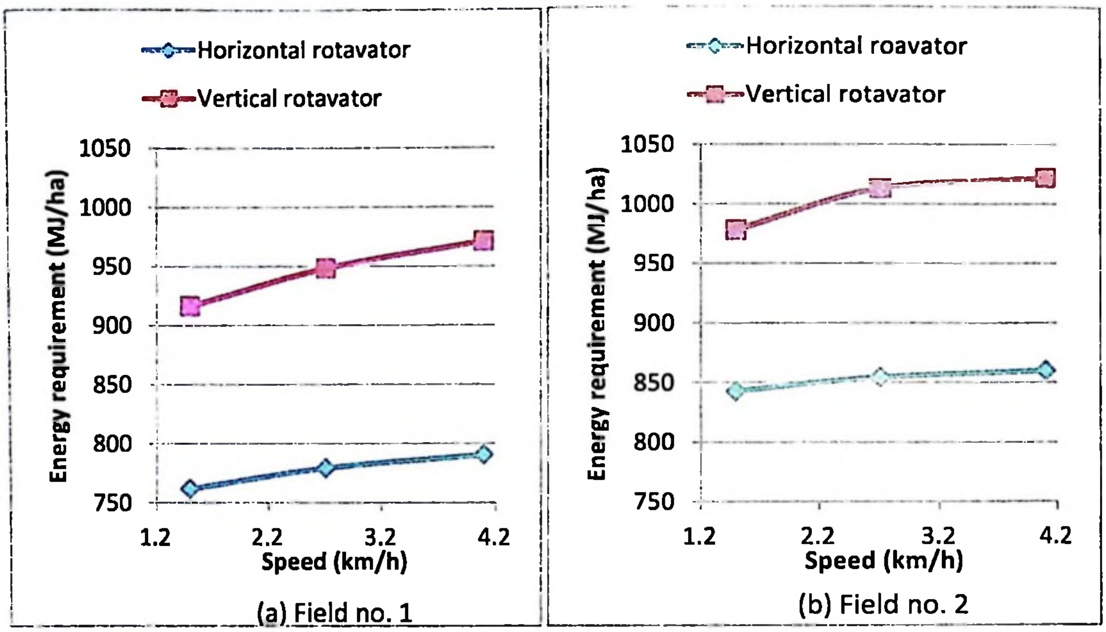

Figure 4.14 Effect of speed on energy requirement

Figure 4.14 (b) shows the effect of operating speed of horizontal and vertical rotavator on energy requirement in field no. 1. The figure shows that the value of energy requirement during tillage operation increased continuously with operating speed for both the rotavators. The mean values of energy requirement were 842.88, 854.58 and 859.89 MJ/ha for horizontal rotavator and 978.15, 1013.4 and 1021.96 MJ/ha for vertical rotavator at the speed of 1.50, 2.71 and 4.10 km/h respectively in the field no. 1.

The energy requirement increased by 1.39 % (11.7 MJ/ha) when operating speed of horizontal rotavator increased from 1.50 to 2.71 km/h and further it increased by 0.62 % (5.31 MJ/ha) when operating speed increases from 2.71 to 4.10 km/h. The energy requirement value increased by 3.60 % (35.25 MJ/ha) when operating speed of vertical rotavator increased from 1.5 to 2.71 km/h and further it increased by 0.84 % (8.56 MJ/ha) when tillage speed increased from 2.71 to 4.10 km/h. Energy requirement is affected by operating speed as well as with type of rotovator.

To determine the significant effect of operating speed and type of rotavator on the energy requirement, F-tests were done and the results of the F-tests were shown in Table 4.14 (b). From the table it can be seen that the operating speeds have significant effect on energy requirement and that too at each speed and with the rotavator type. It is also clear from the table that the vertical axis rotavator consumed comparatively more energy even at the same speed of operation than horizontal one. Maximum energy requirement (1021.96 MJ/ha) was observed at 13 cm speed by vertical axis rotavator. Minimum energy requirement (842.88 MJ/ha) was observed at 7 cm speed with horizontal axis rotavator.

Figure 4.15 shows the source wise requirement for tillage operation. At field no. 1 using vertical rotavator, diesel-oil energy contributed the maximum amount of energy, *i.e* 88.14% (780.40 MJ/ha) of the total energy followed by machinery energy 10.31 % (91.33 MJ/ha). This is due to the fact that tillage operation needs diesel throughout the operation. The minimum source of energy consumed during tillage operation was 1.55 % (13.71 MJ/ha) consumed by operator.

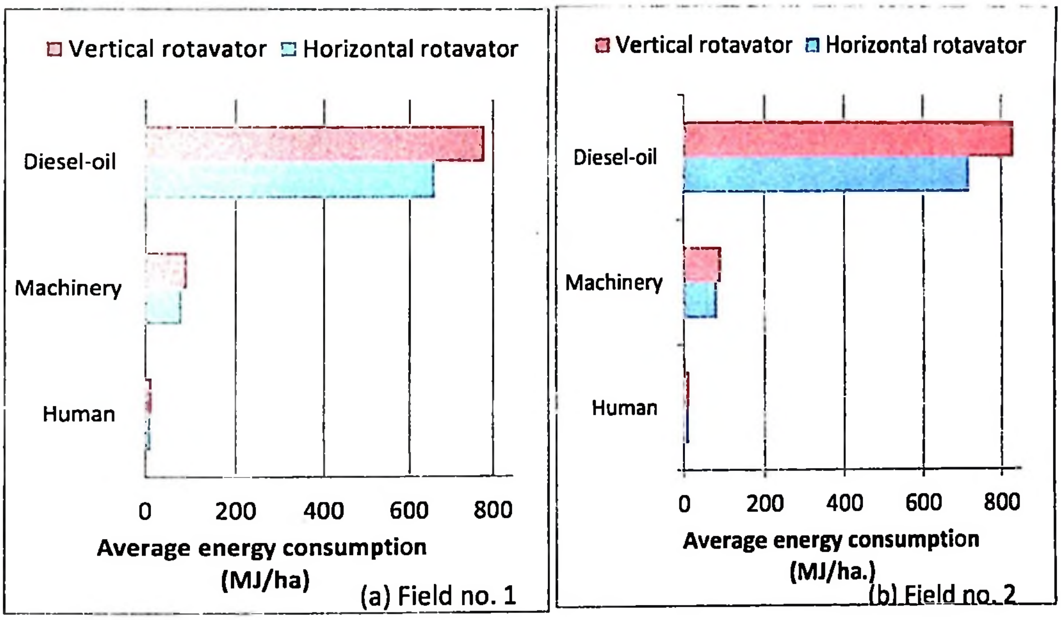

Figure 4.15 Energy consumed (MJ/ha.) in respect of tillage operation of vertical and horizontal rotavator

4.2.7 Effect of forward speed on field efficiency

Field efficiency was determined by standard procedure (section 3.7.8). Field efficiency of the tested rotavators during tillage operation is affected by different operating speeds. Therefore, selected rotavators horizontal and vertical were operated at three different speeds (1.50, 2.71, 4.10 km/h) and the observations for the field efficiency were calculated. The detailed results /data and the analysis of variance (ANOVA) were given in the Appendix II. For statistical analysis only the mean values of field efficiency at different speeds were taken from Appendix II and summarized in Table 4.14 which was graphically presented in the Figure 4.16 (a) and 4.16 (b). Both figures show the effects of speed of horizontal and vertical rotavators on field efficiency in the field no. 1 and 2.

Figure 4.16 (a) shows the effect of operating speed of horizontal and vertical rotavator on field efficiency in field no. 1. The figure shows that the value of field efficiency during tillage operation decreased with increase of speed for both rotavators. The mean values of field efficiency were 93.36, 87.83 and 80.71 % for horizontal rotavator and 94.89, 88.40 and 82.82 % for vertical rotavator at the speed of 1.50, 2.71 and 4.10 km/h respectively in the field no. 1.

The field efficiency decreased by 5.53 % when tillage speed of horizontal rotavator increased from 1.50 to 2.71 km/h while it decreased by 7.12 % when tillage speed increases from 2.71 to 4.10 km/h. The field efficiency value decreased by 6.49 % when tillage speed of vertical rotavator increased from 1.5 to 2.71 km/h while it decreased by 5.58 % when tillage speed increased from 2.71 to 4.10 km/h. Field efficiency is affected by tillage speed as well as with type of rotovator.

To determine the significant effect of tillage speed and type of rotavator on the field efficiency, F-tests were done and the results of the F-tests were shown in Table 4.15 (a). From the table it can be seen that the operating speeds have significant effect on field efficiency and that too at each speed and with the rotavator type. It is also clear from the table that the vertical axis rotavator had comparatively more field efficiency than horizontal rotavator. Maximum field efficiency (94.89 %) was observed at 1.50 km/h speed by vertical axis rotavator. Minimum field efficiency (80.71 %) was observed at 4.10 km/h speed with horizontal axis rotavator.

Table 4.15 Comparison tests of different levels of speed and type of rotavators on field efficiency (%)

	(a) Field no. 1		(b) Field no. 2	
Speed (km/h)	Horizontal rotavator	Vertical rotavator	Horizontal rotavator	Vertical rotavator
1.50	93.36**	94.89**	91.55**	93.51**
2.71	87.83**	88.40**	82.73**	85.16**
4.10	80.71**	82.82**	80.53**	80.89**

** -Significant at 1 % level

ns – Non significant.

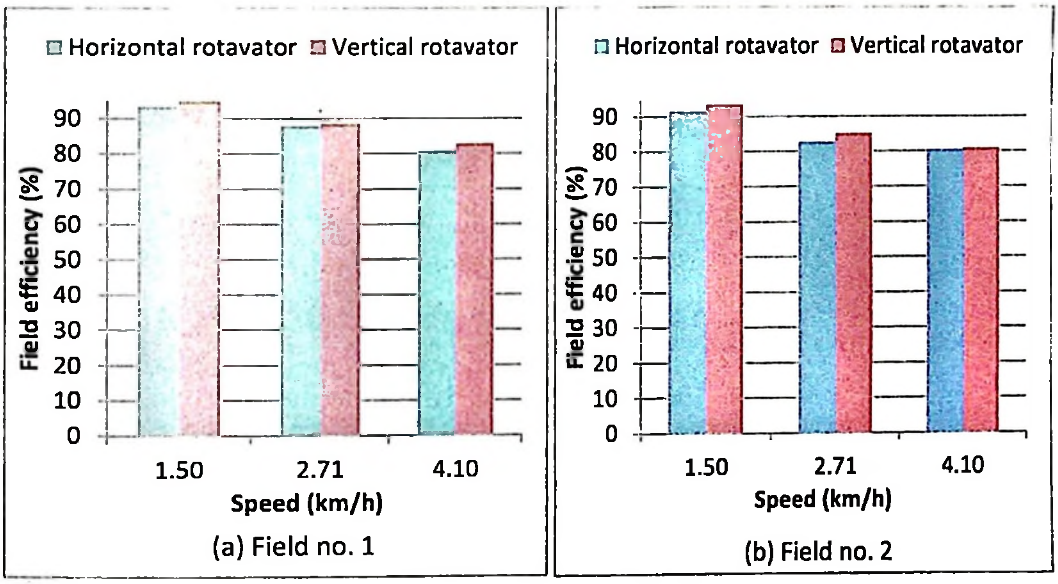

Figure 4.16 Effect of speed on field efficiency

Figure 4.16 (b) shows the effect of operating speed of horizontal and vertical rotavator on field efficiency in field no. 1. The figure shows that the value of field efficiency during tillage operation decreased with increase of speed for both rotavators. The mean values of field efficiency were 91.55, 82.73 and 80.53 % for horizontal rotavator and 93.51, 85.16 and 80.89 % for vertical rotavator at the speed of 1.5, 2.71 and 4.10 km/h respectively in the field no. 1.

The field efficiency decreased by 8.82 % when tillage speed of horizontal rotavator increased from 1.50 to 2.71 km/h and further it decreased by 2.20 % when tillage speed increased from 2.71 to 4.10 km/h. The field efficiency value decreased by 8.35 % when tillage speed of vertical rotavator increased from 1.50 to 2.71 km/h and further it decreased by 4.27 % when tillage speed increased from 2.71 to 4.10 km/h. Field efficiency is affected by tillage speed as well as with type of rotovator.

To determine the significant effect of tillage speed and type of rotavator on the field efficiency, F-tests were done and the results of the F-tests were shown in Table 4.15 (b). From the table it can be seen that the operating speeds have significant effect on field efficiency and that too at each speed and with the rotavator type. It is also clear from the table that the vertical axis rotavator had comparatively more field efficiency than horizontal rotavator. Maximum field efficiency (93.51 %) was observed at 1.50 km/h speed by vertical axis rotavator. Minimum field efficiency (80.53 %) was observed at 4.1 km/h speed with horizontal axis rotavator. In real sense, increasing operating speed will cause higher efficiency. But for this case efficiency decreased with the increase of speed, this is because we could not get the actual width of cut so the field efficiency decreased.

4.2.8 Effect of forward speed on operating cost

Operating cost was determined by standard procedure (section 3.8). To determine the effect of speed on operating cost of rotavator two rotavators, horizontal and vertical were operated at three different speeds (1.50, 2.71, 4.10 km/h) and the observations for the operating cost were taken. The detailed results /data were given in the Appendix II. For statistical analysis only the mean values of operating cost at different speeds were taken from Appendix II and summarized in Table 4.16 which was graphically presented in the Figures 4.17 (a) and 4.17 (b). Both the figures show the effects of speed of horizontal and vertical rotavators on operating cost in the field no. 1 and 2.

Figure 4.17 (a) shows the effect of operating speed of horizontal and vertical rotavator on operating cost in field no. 1. The figure shows that the value of operating cost of tractor increased continuously with operating speed for both the rotavators. The mean values of operating cost obtained were Rs 1719, 1426 and 1326 per ha for horizontal rotavator and Rs 1926, 1716 and 1544 per ha for vertical rotavator at the speed of 1.50, 2.71 and 4.10 km/h respectively in the field no. 1.

The operating cost decreased by 17.04 % (Rs 292 per ha) when tillage speed of horizontal rotavator increased from 1.50 to 2.71 km/h and further it decreased by 6.99 % (Rs 99 per ha) when tillage speed increased from 2.71 to 4.10 km/h. The operating cost decreased by 10.89 % (Rs 209 per ha) when tillage speed of vertical rotavator increased from 1.5 to 2.71 km/h and further it decreased by 10.02 % (Rs 172 per ha) when tilling speed increased from 2.71 to 4.1 km/h. The operating cost decreased due to decrease in total operating time and another variables cost factor for both the rotavators.

To determine the significant effect of tillage speed and type of rotavator on the operating cost, F-tests were done and the results of the F-tests were shown in Table 4.16 (a). From the table it can be seen that the operating speeds have significant effect on operating cost and that too at each speed and with the rotavator type. It is also clear from the table that the vertical axis rotavator used comparatively more cost even at the same speed of tilling than horizontal rotavator. Maximum operating cost (Rs 1926 per ha) was observed at 1.50 km/h speed by vertical axis rotavator. Minimum operating cost (Rs 1326 per ha) was observed at 4.10 km/h speed with horizontal axis rotavator.

Table 4.16 Comparison tests of different levels of speed and type of rotavators on operating cost (Rs/ha)

	(a) Field no. 1		**(b) Field no. 2**	
Speed (km/h)	**Horizontal rotavator**	**Vertical rotavator**	**Horizontal rotavator**	**Vertical rotavator**
1.50	1719.19**	1926.46**	1785.12**	2000.59**
2.71	1426.29**	1716.75**	1580.60**	1790.25**
4.10	1326.64**	1544.75**	1280.30**	1595.58**

** -Significant at 1 % level

ns – Non significant.

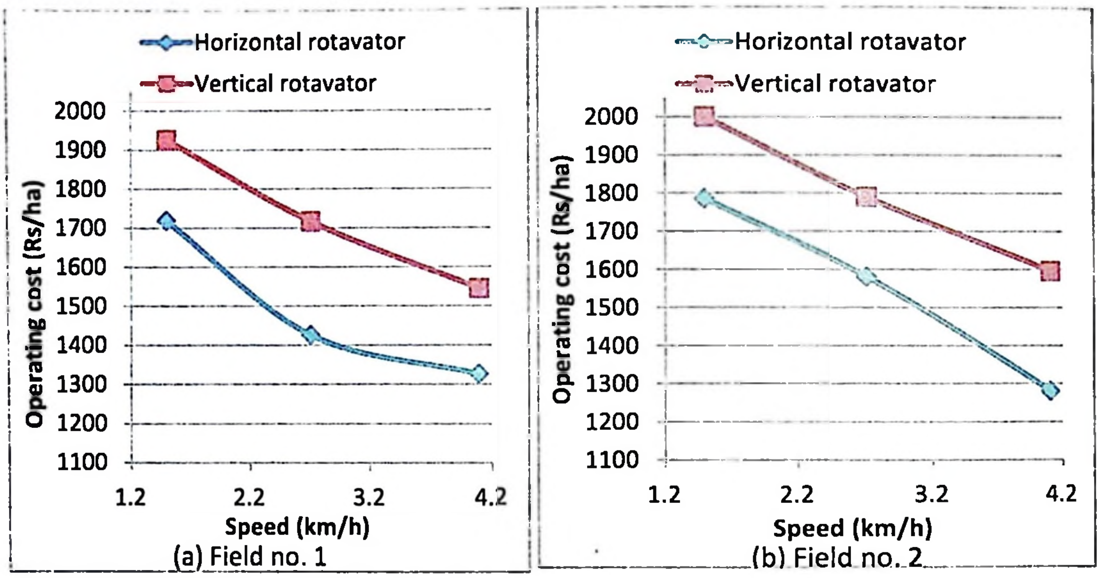

Figure 4.17 Effect of speed on operating cost

Figure 4.17 (b) shows the effect of operating speed of horizontal and vertical rotavator on operating cost in field no. 2. The figure shows that the value of operating cost of tractor increased continuously with operating speed for both the rotavators. The mean values of operating cost were Rs 1785, 1580 and 1280 per ha for horizontal rotavator and Rs 2000, 1790 and 1595 per ha for vertical rotavator at the speed of 1.50, 2.71 and 4.10 km/h respectively in the field no. 2.

The operating cost decreased by 13.66 % (Rs 239 per ha) when tillage speed of horizontal rotavator increased from 1.50 to 2.71 km/h while it decreased by 12.16 % (Rs 184 per ha) when tillage speed increased from 2.71 to 4.10 km/h. The operating cost decreased by 8.66 % (Rs 169 per ha) when tillage speed of vertical rotavator increased from 1.50 to 2.71 km/h and further it decreased by 11.26 % (Rs 201 per ha) when tillage speed increased from 2.71 to 4.10 km/h. The operating cost decreased due to total time required to finish operation was reduced for both the rotavators. Thus operating cost was inversely with tillage speed.

To determine the significant effect of tillage speed and type of rotavator on the operating cost, F-tests were done and the results of the F-tests were shown in Table 4.16 (b). From the table it can be seen that the operating speeds have significant effect on operating cost and that too at each speed and with the rotavator type. It is also clear from the table that the vertical axis rotavator consumed comparatively more cost even at the same speed of tilling than horizontal one. Maximum operating cost (Rs 2000 per ha) was observed at 1.50 km/h speed by vertical axis rotavator. Minimum operating cost (Rs 1280 per ha) was observed at 4.10 km/h speed with horizontal axis rotavator.

4.3 Comparative Performance of the Rotavators

The performance of the horizontal and vertical rotavators was evaluated based on quality of work and economic point of view. The comparative results are shown in the following manner:

- **Qualitative Comparative performance of rotavators**
- **Economically comparative performance of rotavators**

4.3.1 Qualitative comparative performance of rotavators

The main function of rotavator is tilling and pulverising the soil. The qualitative performance of both the rotavators was measured in terms of soil mean weight diameter, soil penetration resistance, soil bulk density and soil disturbed area by varying different tilling depths and operating speeds. The comparative results are shown below.

4.3.1.1 Effect of tilling depth on qualitative parameters

The combined results of horizontal and vertical rotavators with 3 different tilling depths on qualitative parameters are presented in Table 4.17.

The results show that, in the same depth of cut vertical axis rotavator pulverized soil more thoroughly than horizontal one. Maximum SMWD, bulk density and cone index values were observed by horizontal axis rotavator while the minimum values were observed with vertical axis rotavator. High percentage of soil disturbed area was observed by vertical axis rotavator. The effect of different tilling depths of rotavators on soil physical properties can be seen in Figure 4.18.

Table 4.17 Effect of tiling depth of rotavators on qualitative parameters

Sr. No	Parameter	Field no. 1		Field no. 2	
		HR	VR	HR	VR
1	Soil mean weight diameter (mm)				
	(a) At depth 7 cm	4.17	3.86	4.61	4.39
	(b) At depth 10 cm	4.28	3.87	4.69	4.40
	(c) At depth 13 cm	4.31	3.87	4.72	4.40
2	Soil penetration resistance (kPa)				
	(a) At depth 7 cm	44.90	44.59	54.50	50.00
	(b) At depth 10 cm	54.05	50.90	60.81	57.65
	(c) At depth 13 cm	58.55	54.05	64.41	60.81
3	Bulk density (g/cm^3)				
	(a) At depth 7 cm	1.12	1.10	1.20	1.19
	(b) At depth 10 cm	1.17	1.15	1.25	1.23
	(c) At depth 13 cm	1.33	1.20	1.35	1.29
4	Soil disturbed area (%)				
	(a) At depth 7 cm	88.04	92.22	85.40	91.98
	(b) At depth 10 cm	89.84	94.36	88.00	93.81
	(c) At depth 13 cm	91.32	94.43	91.19	93.89

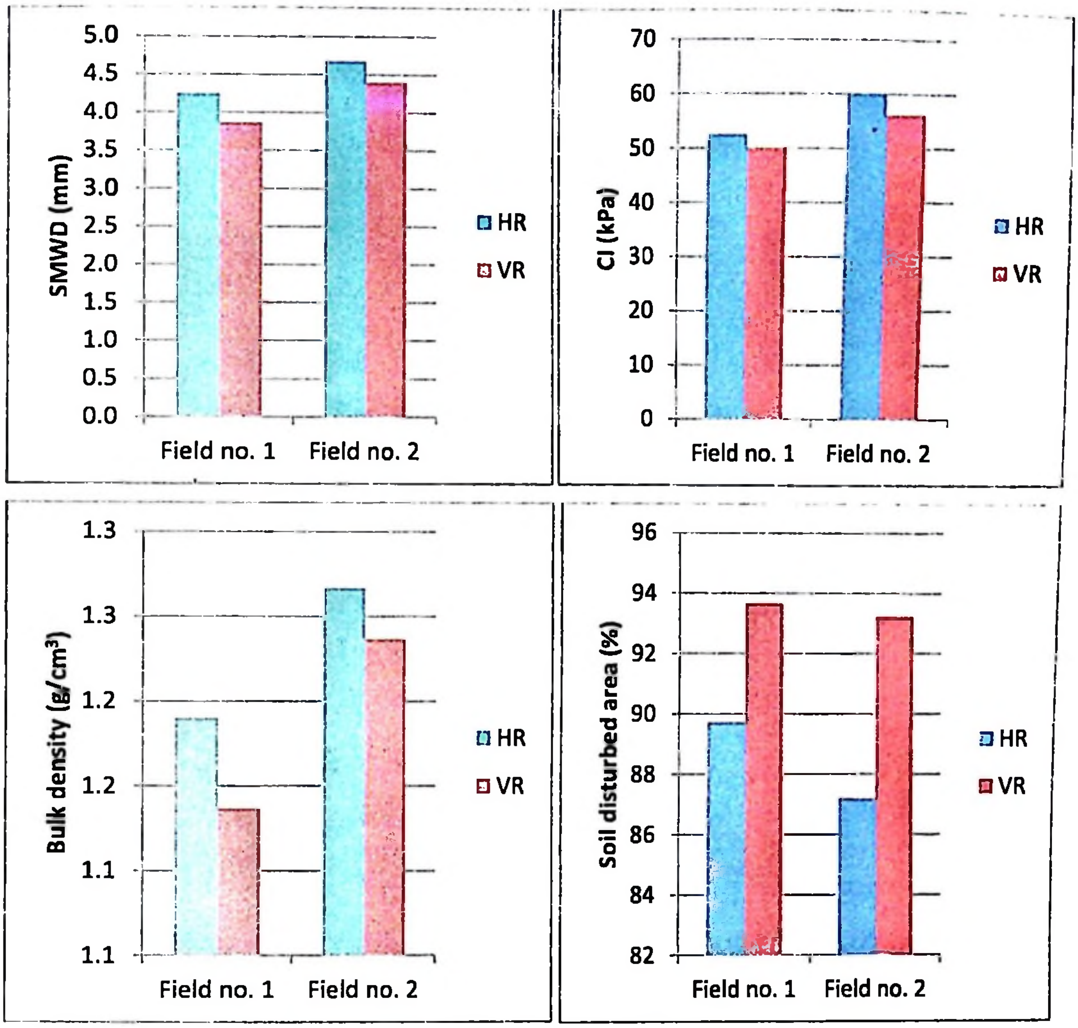

Figure 4.18 Effect of tilling depth of rotavators on soil physical properties

Desirable results of soil quality in terms of soil mean weight diameter, soil penetration resistance, soil bulk density and soil disturbed area were obtained at 10 cm depth as compared to another two tilling depths (7 cm and 13 cm). Both the rotavators showed better results at the 11.78 % moisture content as compared to 10.51 % moisture content.

4.3.1.2 Effect of operating speed on qualitative parameters

The combined results of horizontal and vertical rotavators with 3 different operating speeds on qualitative parameters are presented in Table 4.18.

The results shows that, in the same speed of cut vertical axis rotavator pulverized soil more than horizontal one. Maximum SMWD, bulk density and cone index values were observed by horizontal axis rotavator while the minimum values were observed with vertical axis rotavator. High percentage of soil disturbed area was observed by vertical axis rotavator. The effect of different operating speed of rotavators on soil physical properties can also be seen in Figure 4.19.

Table 4.18 Effect of speed on soil physical properties

Sr.No	Parameter	Field no. 1		Field no. 2	
		HR	VR	HR	VR
1	Soil mean weight diameter (mm)				
	(a) At speed 1.5 km/h	4.27	3.87	4.68	4.39
	(b) At speed 2.71 km/h	4.29	3.87	4.70	4.39
	(c) At speed 4.1 km/h	4.37	3.87	4.77	4.40
2	Soil penetration resistance (kPa)				
	(a) At speed 1.5 km/h	43.55	41.89	51.8	48.65
	(b) At speed 2.71 km/h	55.4	52.25	62.61	57.65
	(c) At speed 4.1 km/h	58.55	55.4	65.31	62.16
3	Bulk density (g/m^3)				
	(a) At speed 1.5 km/h	1.14	1.11	1.18	1.16
	(b) At speed 2.71 km/h	1.17	1.13	1.27	1.26
	(c) At speed 4.1 km/h	1.27	1.16	1.36	1.29
4	Soil disturbed area (%)				
	(a) At speed 1.5 km/h	91.98	94.94	89.77	94.36
	(b) At speed 2.71 km/h	89.79	93.78	86.99	93.38
	(c) At speed 4.1 km/h	87.43	92.3	84.81	91.94

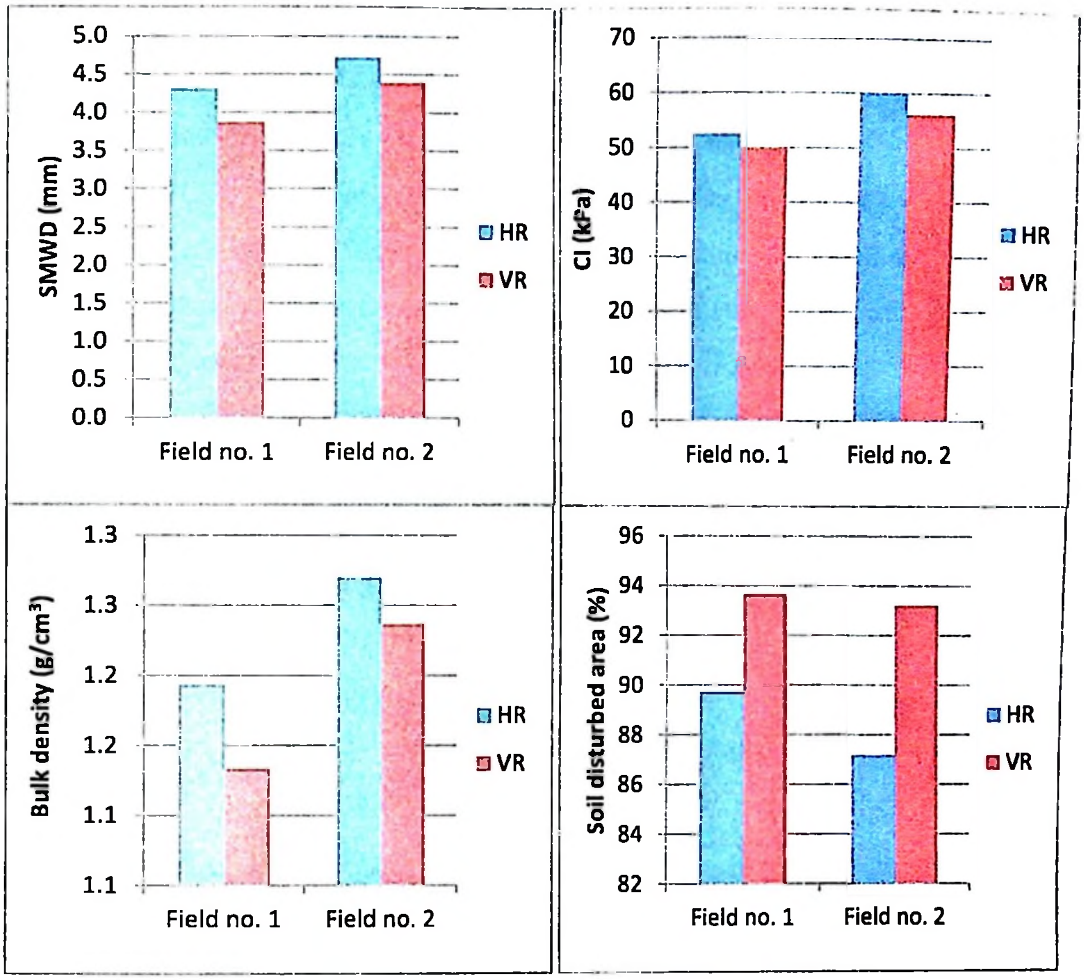

Figure 4.19 Effect of operating speed of rotavators on soil physical properties

Desirable results of soil quality in terms of soil mean weight diameter, soil penetration resistance, soil bulk density and soil disturbed area were obtained at 2.71 km/h speed as compared to another two operating speeds (1.50 and 4.10 km/h). Both the rotavators showed better results at the 11.78 % moisture content as compared to 10.51 % moisture content.

4.3.2 Economically comparative performance of rotavators

The economic performance of both the selected horizontal and vertical rotavators were evaluated and compared in terms of fuel consumption, energy requirement, field efficiency and operating cost by varying 3 tilling depths and 3 operating speeds. The comparative results are shown in the following manner:

- **Effect of depths on economic performance of machine**
- **Effect of speeds on economic performance of machine**

4.3.2.1 Effect of depths on economic performance of rotavators

The comparative economic performance of both the rotavators at two different fields by varying 3 tilling depths was measured in terms of fuel consumption, energy requirement, field efficiency and operating cost. The comparative results were presented in Table 4.19 and graphically shown in the Figure 4.20. Vertical rotavator consumed more fuel, more energy and its operating cost was also found more in both the fields as compared to the horizontal rotavator. The field efficiency of the vertical rotavator was also found comparatively more and this might be because of maximum utilization of its operating width as compared to horizontal rotavator. In case of horizontal rotavator there was much difference between theoretical and actual operating width. Out of two fields, Field no. 2 (m.c. 11.78 %) gave better results as compared to Field no. 1 (m.c. 10.51 %), and this might be because of optimum moisture content of field no. 2 as compared to moisture content of Field no. 1. Thus the field condition of the soil in term of moisture content also played an important role in the performance of the rotavators at different tilling depths.

Table 4.19 Effect of depth on economical comparative performance

Sr. No	Parameter	Field no. 1		Field no. 2	
		HR	VR	HR	VR
1	Fuel consumption (l/ha)				
	(a) At depth 7 cm	10.69	12.73	11.39	13.88
	(b) At depth 10 cm	11.97	14.22	13.43	15.12
	(c) At depth 13 cm	15.62	18.46	16.61	19.34
2	Energy requirement (MJ/ha)				
	(a) At depth 7 cm	664.13	794.48	706.01	826.52
	(b) At depth 10 cm	735.72	874.6	854.1	925.63
	(c) At depth 13 cm	941.63	1166.79	997.24	1161.37
3	Field efficiency (%)				
	(a) At depth 7 cm	86.90	88.53	82.45	86.21
	(b) At depth 10 cm	87.14	88.55	83.43	86.67
	(c) At depth 13 cm	87.85	89.02	84.94	86.68
4	Operating cost (₹)				
	(a) At depth 7 cm	1279.07	1479.37	1366.10	1656.44
	(b) At depth 10 cm	1451.09	1531.22	1504.15	1659.51
	(c) At depth 13 cm	1668.68	2002.01	1573.75	1999.01

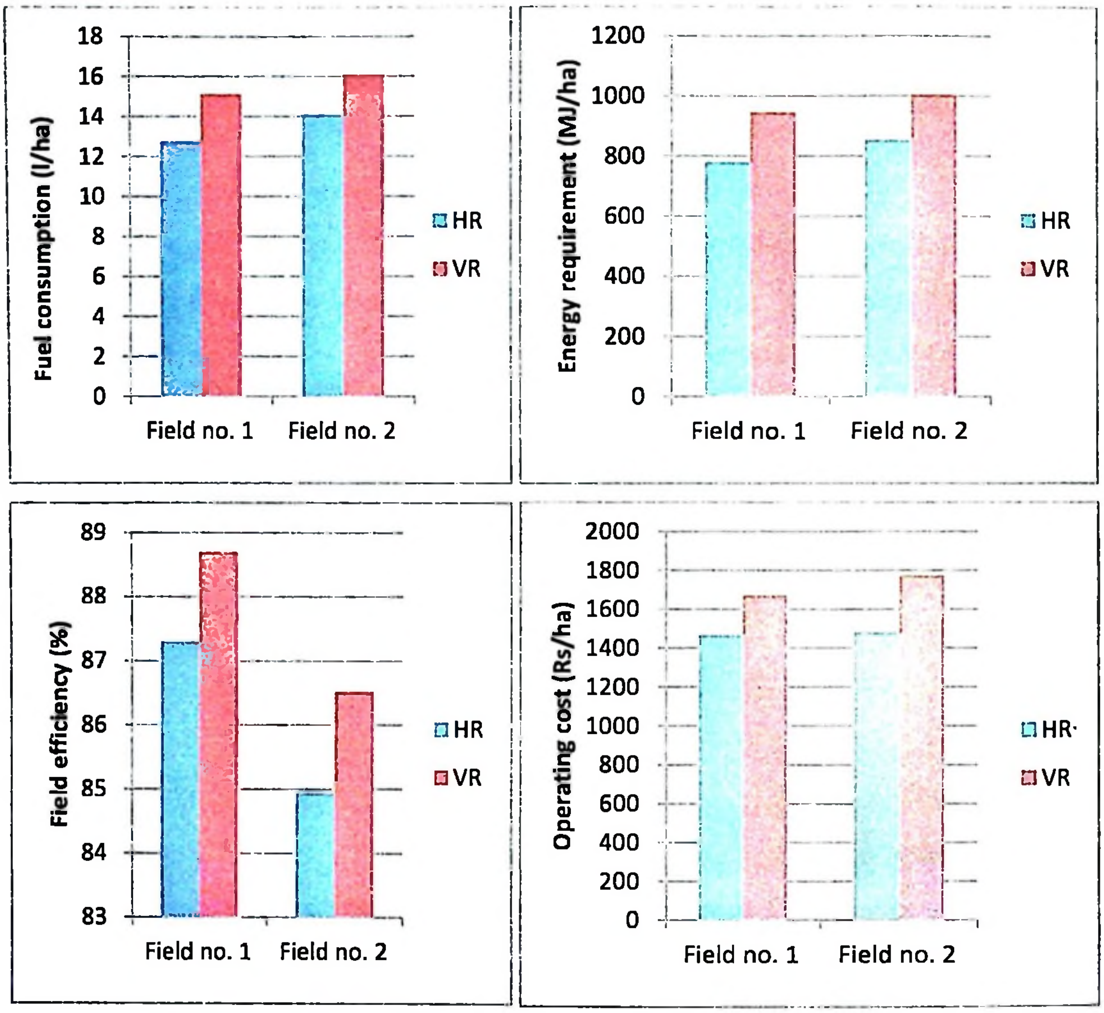

Figure 4.20 Effect of depth on economic performance of the rotavators

4.3.2.2 Effect of operating speed on economic performance of rotavators

The combined results of horizontal and vertical rotavators with 3 different operating speeds on economic performance of rotavators was measured in terms of fuel consumption, energy requirement, field efficiency and operating cost are presented in Table 4.20.

According to Figure 4.21, Vertical rotavator consumed more fuel, more energy and its operating cost was also found more in both the fields as compared to the horizontal rotavator. This means, the cost of operating vertical axis rotavator is higher than that obtained by horizontal axis rotavator at the same operating speed. The field efficiency of the vertical rotavator was also found comparatively more and this might be because of maximum utilization of its operating width as compared to horizontal rotavator. In case of horizontal rotavator there was much difference between theoretical and actual operating width. Out of two fields, Field no. 2 (m.c. 11.78 %) gave better results as compared to Field no. 1 (m.c. 10.51 %), and this might be because of optimum moisture content of field no. 2 as compared to moisture content of Field no. 1. Thus the field condition of the soil in term of moisture content also played an important role in the performance of the rotavators at different operating speeds.

Table 4.20 Effect of operating speed of rotavators on economic performance

Sr. No	Parameter	Field no. 1		Field no. 2	
		HR	VR	HR	VR
1	Fuel consumption (l/ha)				
	(a) At speed 1.5 km/h	12.37	14.40	13.29	15.47
	(b) At speed 2.71 km/h	12.56	15.10	14.00	16.07
	(c) At speed 4.10 km/h	13.34	15.87	15.00	16.79
2	Energy requirement (MJ/ha)				
	(a) At speed 1.5 km/h	761.74	916.32	842.88	978.15
	(b) At speed 2.71 km/h	779.27	971.08	854.58	1013.40
	(c) At speed 4.10 km/h	790.48	948.47	859.89	1021.96
3	Field efficiency (%)				
	(a) At speed 1.5 km/h	93.36	94.89	91.55	93.51
	(b) At speed 2.71 km/h	87.83	88.40	82.73	85.16
	(c) At speed 4.10 km/h	80.71	82.82	80.53	80.89
4	Operating cost (₹ /ha)				
	(a) At speed 1.5 km/h	1719.19	1926.46	1785.12	2000.59
	(b) At speed 2.71 km/h	1426.29	1716.75	1580.60	1790.25
	(c) At speed 4.10 km/h	1326.64	1544.75	1280.30	1595.58

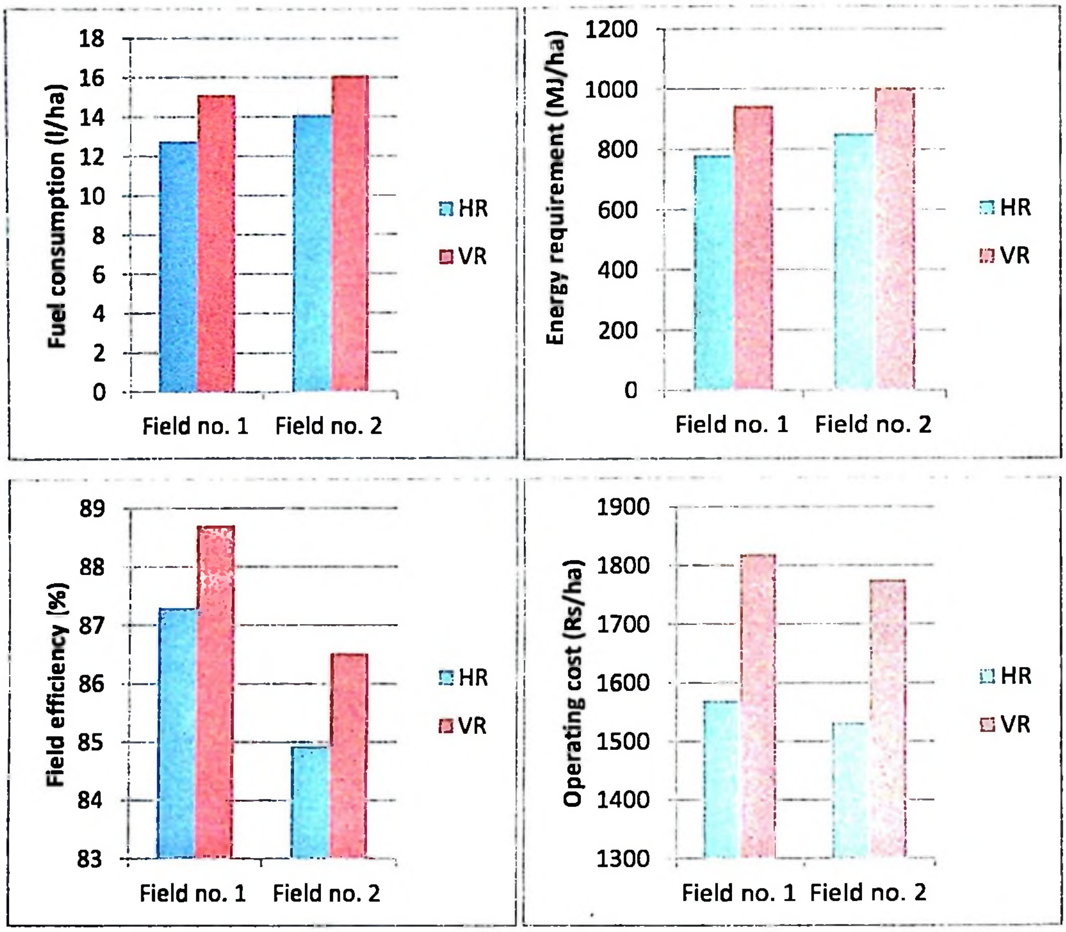

Figure 4.21 Effect of speed on economic performance of the rotavators

Low operating cost was obtained when using horizontal axis rotavator at optimum soil moisture content (11.78 %). The values of energy requirement increased abruptly with the increase of tilling depth from 10 cm and operating speed from 2.71 km/h.

Summary & Conclusions _

CHAPTER V

SUMMARY AND CONCLUSIONS

5.1 Summary

Rotavator mixes and pulverizes the tilled soil well; resulting in a good clod size distribution. The number of tillage passes required to achieve an acceptable tilth quality, using rotavator is also significantly reduced in comparison to the series of operations that would result in the same tilth quality with the use of passive tools.

In spite of more popularity of horizontal axis rotavators, vertical rotavators are also being manufactured. But very few studies have been conducted on comparative performance of vertical rotavators with horizontal rotavators. Interest in tillage research using horizontal or vertical rotavator prompted this study to investigate the effects of operating parameters i.e. tilling depth and operating speed on soil physical properties, and consequently on machine performance. Three tillage treatments, namely rotavator (2), operating speed (3) and tillage depth (3) were applied in two different fields. After tillage, soil quality in terms of soil mean weight diameter, soil penetration resistance, bulk density and soil disturbance area were measured. Other machine performance parameters in terms of fuel consumption, energy requirement, field efficiency and operating cost were also measured at two different fields in College of Agricultural Engineering and Technology, Junagadh Agricultural University, Junagadh.

The field data were statistically analyzed, using two-way analysis of variance (ANOVA) for the factorial randomized complete design with three replicates. The software used was Microsoft Excel (2007) using ANOVA procedure. The ANOVA procedure was used to evaluate the significance of each parameter and the interactions between parameters on soil physical properties and energy consumption. Mean values at each treatment combination were statistically analyzed to determine soil response to the field operating parameters. Comparisons among treatment means, when significant, were conducted using F-test at $p = 0.01$ and 0.05 level.

5.2 Conclusions

The following conclusions were drawn from the study:

1. Vertical axis rotavator was found better with respect to quality of work as it pulverized soil better resulted in minimum values of soil mean weight diameter (3.86 mm), penetration resistance(41.89 kPa) and bulk density of soil (1.10 gcm^{-3}) at the depth of 7 cm with the operating speed of 1.50 km/h at field no.1 (11.78 % moisture content).While the minimum values of soil mean weight diameter (4.16 mm), penetration resistance(43.55 kPa) and bulk density of soil (1.12 gcm^{-3}) by horizontal axis rotavator were obtained in the same field conditions and with the same operating parameters.
2. Over all, the vertical axis rotavator has shown the better results in term of tilling quality of work by giving the lower values of soil mean weight diameter, penetration resistance and bulk density of soil in both the fields and with all the operating parameters as compared to horizontal axis rotavator.
3. The maximum values of soil mean weight diameter, penetration resistance and bulk density of soil were observed 4.77 mm, 65.31 kPa and 1.36 gcm^{-3} by horizontal axis rotavator and 4.40 mm, 62.16 kPa and 1.29 gcm^{-3} by vertical axis rotavator at the depth of 13 cm and at operating speed of 4.1 km/h at field no.2 (10.58 % moisture content). These results were also supported the comparatively better performance of the vertical rotavator for better tilling quality of soil.
4. The maximum and the minimum percentage of soil disturbed area were found 94.94% & 92.30% by vertical axis rotavator and 91.98% & 87.43% by horizontal axis rotavator respectively in the field no1. In the same manner the maximum and the minimum percentage of soil disturbed area were found 94.36% & 91.94% by vertical axis rotavator and 89.77% & 84.81% by horizontal axis rotavator respectively in the field no2. Thus the vertical axis rotavator was found better as it disturbed soil more as compared to horizontal axis rotavator.
5. Out of two operating parameters of both the rotavators, depth affected more on all the soil physical properties except on SMWD by vertical rotavator.
6. Over all, the horizontal axis rotavator has shown the better results in term of economic by giving the lower values of fuel consumption, energy requirement

and operating cost in both the fields and with all the operating parameters as compared to vertical axis rotavator. As shown in resullt horizontal axis rotavator consumed minimum fuel (10.69 l/ha), energy (664.13 MJ/ha) and low operating cost (Rs 1279.07) at the depth of 7 cm with the operating speed of 1.50 km/h at field no.1. While the minimum values of fuel consumption (11.39 l/ha), energy requirement (706.01 MJ/ha) and operating cost (Rs 1366.10) by vertical axis rotavator were obtained in the same field conditions and with the same operating parameters.

7. Both the rotavators, horizontal and vertical axis showed the best results in terms of tilling quality of soil and economic point of view at the depth of 10 cm with the operating speed of 2.71 km/h.
8. In general, to get the better performance by both the rotavators, they should be operated at the depth of 10 cm with the operating speed of 2.71 km/h, as beyond 10 cm depth and 2.71 km/h speed the overall performance including fuel consumption, energy requirement, operating cost and tilling quality of soil affected negatively.

Suggested future work

SUGGESTED FUTURE WORK

1. It is important to further replicate this investigation on more operating parameters like varying rotor speed (rpm) of the rotavators.
2. To study the rotavator operating parameters on soil physical properties and measure their effect on crop yield.

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Appendices

APPENDIX - I

Physio-chemical characteristics of experimental soil (Medium black soil)

Sr. No.	Particular	Unit	Value
1	Bulk density	g/m^3	1.45
2	Particle density	g/cm^3	2.55
3	Electrical conductivity	dsm^{-1}	0.20
4	pH		8.87
5	Soil Texture		
	Coarse	Per cent	7.57
	Sand	Per cent	20.72
	Silt	Per cent	33.65
	Clay	Per cent	38.06
6	Porosity	Per cent	37.95
7	Hydraulic conductivity	m/day	22.20
8	Infiltration rate	cm/h	3.0
9	Field capacity	Per cent	27.7
10	Permanent wilting point	Per cent	13.85
11	Exchangeable sodium Percentage	Per cent	4.5
12	SAR		0.034
13	Nutrient		
	Nitrogen	kg/ha	210.00
	Phosphorus	kg/ha	12.00
	Potash	kg/ha	450.00

APPENDIX- II

INTERACTION AND ANOVA TABLES.

II1. Mean table for soil mean weight diameter at field no. 1

(a) RxS Table

	R1	R2	Mean
S1	4.21	3.86	4.04
S2	4.22	3.87	4.05
S3	4.31	3.86	4.09
Mean	4.25	3.87	

(b) RxD Table

	R1	R2	Mean
D1	4.16	3.86	4.01
D2	4.27	3.87	4.07
D3	4.31	3.87	4.09
Mean	4.25	3.87	

(c) SxD Table

	S1	S2	S3	Mean
D1	4.00	4.01	4.04	4.01
D2	4.05	4.06	4.10	4.07
D3	4.07	4.08	4.12	4.09
Mean	4.04	4.05	4.09	

(d) RxSxD Table

	R1	R2
S1D1	4.13	3.86
S1D2	4.24	3.86
S1D3	4.27	3.87
S2D1	4.14	3.87
S2D2	4.24	3.87
S2D3	4.29	3.87
S3D1	4.22	3.85
S3D2	4.34	3.87
S3D3	4.37	3.87

II2. Mean table for soil mean weight diameter at field no. 2

(a) RxS Table

	R1	R2	Mean
S1	4.63	4.40	4.51
S2	4.65	4.40	4.52
S3	4.74	4.40	4.57
Mean	4.67	4.40	

(b) RxD Table

	R1	R2	Mean
D1	4.61	4.40	4.50
D2	4.69	4.40	4.54
D3	4.72	4.40	4.56
Mean	4.67	4.40	

(c) SxD Table

	S1	S2	S3	Mean
D1	4.47	4.49	4.55	4.50
D2	4.52	4.53	4.57	4.54
D3	4.54	4.55	4.59	4.56
Mean	4.51	4.52	4.57	

(d) RxSxD Table

	R1	R2
S1D1	4.55	4.39
S1D2	4.65	4.40
S1D3	4.68	4.40
S2D1	4.58	4.40
S2D2	4.67	4.40
S2D3	4.70	4.40
S3D1	4.71	4.40
S3D2	4.74	4.40
S3D3	4.77	4.40

II3. Mean table for cone index at field no. 1

(a) RxS Table

	R1	R2	Mean
S1	43.55	41.89	42.72
S2	55.40	52.25	53.82
S3	58.55	55.40	56.98
Mean	52.50	49.85	

(b) RxD Table

	R1	R2	Mean
D1	44.90	44.59	44.74
D2	54.05	50.90	52.47
D3	58.55	54.05	56.30
Mean	52.50	49.85	

(c) SxD Table

	S1	S2	S3	Mean
D1	34.24	48.65	51.35	44.74
D2	44.59	54.73	58.10	52.47
D3	49.32	58.10	61.48	56.30
Mean	42.72	53.82	56.98	

(d) RxSxD Table

	R1	R2
S1D1	32.00	36.48
S1D2	45.94	43.24
S1D3	52.70	45.94
S2D1	50.00	47.29
S2D2	56.75	52.70
S2D3	59.46	56.75
S3D1	52.70	50.00
S3D2	59.46	56.75
S3D3	63.51	59.46

II4. Mean table for cone index at field no. 2

(a) RxS Table

	R1	R2	Mean
S1	51.80	48.65	50.22
S2	62.61	57.65	60.13
S3	65.31	62.16	63.73
Mean	59.91	56.15	

(b) RxD Table

	R1	R2	Mean
D1	54.50	50.00	52.25
D2	60.81	57.65	59.23
D3	64.41	60.81	62.61
Mean	59.91	56.15	

(c) SxD Table

	S1	S2	S3	Mean
D1	44.59	54.05	58.10	52.25
D2	51.35	61.48	64.86	59.23
D3	54.73	64.86	68.24	62.61
Mean	50.22	60.13	63.73	

(d) RxSxD Table

	R1	R2
S1D1	45.94	43.24
S1D2	52.70	50.00
S1D3	56.75	52.70
S2D1	58.10	50.00
S2D2	63.51	59.46
S2D3	66.21	63.51
S3D1	59.46	56.75
S3D2	66.21	63.51
S3D3	70.27	66.21

II5. Mean table for bulk density at field no. 1

(a) RxS Table

	R1	R2	Mean
S1	1.14	1.11	1.13
S2	1.17	1.13	1.15
S3	1.27	1.16	1.21
Mean	1.19	1.13	

(b) RxD Table

	R1	R2	Mean
D1	1.07	1.10	1.08
D2	1.17	1.15	1.16
D3	1.33	1.16	1.25
Mean	1.19	1.13	

(c) SxD Table

	S1	S2	S3	Mean
D1	1.05	1.06	1.14	1.08
D2	1.14	1.16	1.18	1.16
D3	1.18	1.23	1.33	1.25
Mean	1.13	1.15	1.21	

(d) RxSxD Table

	R1	R2
S1D1	1.05	1.05
S1D2	1.15	1.14
S1D3	1.22	1.15
S2D1	1.05	1.08
S2D2	1.16	1.15
S2D3	1.30	1.16
S3D1	1.11	1.16
S3D2	1.21	1.15
S3D3	1.48	1.17

II6. Mean table for bulk density at field no. 2

(a) RxS Table

	R1	R2	Mean
S1	1.18	1.16	1.17
S2	1.27	1.26	1.26
S3	1.36	1.29	1.32
Mean	1.27	1.24	

(b) RxD Table

	R1	R2	Mean
D1	1.20	1.19	1.19
D2	1.25	1.23	1.24
D3	1.35	1.29	1.32
Mean	1.27	1.24	

(c) SxD Table

	S1	S2	S3	Mean
D1	1.12	1.23	1.24	1.19
D2	1.16	1.25	1.31	1.24
D3	1.23	1.32	1.42	1.32
Mean	1.17	1.26	1.32	

(d) RxSxD Table

	R1	R2
S1D1	1.12	1.11
S1D2	1.17	1.15
S1D3	1.23	1.22
S2D1	1.24	1.22
S2D2	1.25	1.24
S2D3	1.32	1.32
S3D1	1.25	1.23
S3D2	1.32	1.30
S3D3	1.49	1.35

II7. Mean table for percentage of soil disturbed area at field no. 1

(a) RxS Table

	R1	R2	Mean
S1	91.98	94.94	93.46
S2	89.79	93.78	91.79
S3	87.43	92.30	89.86
Mean	89.73	93.67	

(b) RxD Table

	R1	R2	Mean
D1	88.04	94.22	91.13
D2	91.32	94.43	92.88
D3	89.84	92.36	91.10
Mean	89.73	93.67	

(c) SxD Table

	S1	S2	S3	Mean
D1	93.42	91.38	88.59	91.13
D2	93.97	93.29	91.37	92.88
D3	92.99	90.69	89.63	91.10
Mean	93.46	91.79	89.86	

(d) RxSxD Table

	R1	R2
S1D1	91.72	95.12
S1D2	92.24	95.70
S1D3	91.97	94.00
S2D1	88.34	94.42
S2D2	91.98	94.60
S2D3	89.06	92.31
S3D1	84.05	93.13
S3D2	89.74	93.00
S3D3	88.49	90.77

II8. Mean table for percentage of soil disturbed area at field no. 2

(a) RxS Table

	R1	R2	Mean
S1	89.77	94.36	92.06
S2	86.99	93.38	90.18
S3	84.81	91.94	88.38
Mean	87.19	93.23	

(b) RxD Table

	R1	R2	Mean
D1	87.99	93.89	90.94
D2	91.19	93.81	92.50
D3	82.40	91.98	87.19
Mean	87.19	93.23	

(c) SxD Table

	S1	S2	S3	Mean
D1	92.33	90.75	89.75	90.94
D2	94.27	92.94	90.29	92.50
D3	89.60	86.87	85.10	87.19
Mean	92.06	90.18	88.38	

(d) RxSxD Table

	R1	R2
S1D1	89.90	94.75
S1D2	93.53	95.00
S1D3	85.87	93.33
S2D1	87.28	94.21
S2D2	91.95	93.92
S2D3	81.74	92.00
S3D1	86.78	92.71
S3D2	88.08	92.50
S3D3	79.58	90.62

II9. Mean table for fuel consumption at field no. 1

(a) RxS Table

	R1	R2	Mean
S1	12.37	14.40	13.39
S2	12.56	16.13	14.35
S3	13.34	15.87	14.61
Mean	12.76	15.47	

(b) RxD Table

	R1	R2	Mean
D1	10.69	12.73	11.71
D2	11.97	14.22	13.09
D3	15.62	19.46	17.54
Mean	12.76	15.47	

(c) SxD Table

	S1	S2	S3	Mean
D1	11.40	11.69	12.04	11.71
D2	12.79	12.93	13.56	13.09
D3	15.97	18.42	18.23	17.54
Mean	13.39	14.35	14.61	

(d) RxSxD Table

	R1	R2
S1D1	10.48	12.32
S1D2	11.72	13.86
S1D3	14.92	17.02
S2D1	10.69	12.68
S2D2	11.73	14.14
S2D3	15.26	21.58
S3D1	10.90	13.19
S3D2	12.46	14.65
S3D3	16.67	19.78

II10. Mean table for fuel consumption at field no. 2

(a) RxS Table

	R1	R2	Mean
S1	13.29	15.47	14.38
S2	14.24	16.07	15.16
S3	13.89	16.79	15.34
Mean	13.81	16.11	

(b) RxD Table

	R1	R2	Mean
D1	11.39	13.88	12.64
D2	13.43	15.12	14.27
D3	16.61	19.34	17.98
Mean	13.81	16.11	

(c) SxD Table

	S1	S2	S3	Mean
D1	12.15	12.72	13.04	12.64
D2	13.76	14.99	14.07	14.27
D3	17.24	17.78	18.92	17.98
Mean	14.38	15.16	15.34	

(d) RxSxD Table

	R1	R2
S1D1	11.11	13.19
S1D2	12.75	14.77
S1D3	16.02	18.45
S2D1	11.43	14.00
S2D2	14.95	15.02
S2D3	16.35	19.20
S3D1	11.63	14.45
S3D2	12.58	15.56
S3D3	17.46	20.37

III1. Mean table for energy requirement at field no. 1

(a) RxS Table

	R1	R2	Mean
S1	789.27	916.32	852.79
S2	761.74	971.08	866.41
S3	790.48	948.47	869.48
Mean	780.50	945.29	

(b) RxD Table

	R1	R2	Mean
D1	664.13	794.48	729.31
D2	735.72	874.60	805.16
D3	941.63	1166.79	1054.21
Mean	780.50	945.29	

(c) SxD Table

	S1	S2	S3	Mean
D1	741.09	716.82	730.02	729.31
D2	818.77	786.72	810.00	805.16
D3	998.52	1095.70	1068.42	1054.21
Mean	852.79	866.41	869.48	

(d) RxSxD Table

	R1	R2
S1D1	682.84	799.34
S1D2	752.10	885.44
S1D3	932.86	1064.17
S2D1	656.77	776.86
S2D2	714.74	858.69
S2D3	913.71	1277.68
S3D1	652.79	807.24
S3D2	740.33	879.67
S3D3	978.32	1158.51

II12. Mean table for energy requirement at field no. 2

(a) RxS Table

	R1	R2	Mean
S1	842.88	978.15	910.51
S2	859.89	1013.40	936.65
S3	854.58	1021.96	938.27
Mean	852.45	1004.50	

(b) RxD Table

	R1	R2	Mean
D1	706.01	926.52	816.26
D2	854.10	925.63	889.86
D3	997.24	1161.37	1079.31
Mean	852.45	1004.50	

(c) SxD Table

	S1	S2	S3	Mean
D1	785.13	841.91	821.75	816.26
D2	875.89	905.39	888.31	889.86
D3	1070.53	1062.64	1104.76	1079.31
Mean	910.51	936.65	938.27	

(d) RxSxD Table

	R1	R2
S1D1	720.24	850.01
S1D2	813.02	938.76
S1D3	995.38	1145.67
S2D1	700.95	982.87
S2D2	899.60	911.17
S2D3	979.11	1146.17
S3D1	696.84	946.67
S3D2	849.67	926.95
S3D3	1017.23	1192.28

II13. Mean table for field efficiency at field no. 1

(a) RxS Table

	R1	R2	Mean
S1	93.36	94.89	94.12
S2	87.83	88.40	88.11
S3	80.71	82.82	81.76
Mean	87.30	88.70	

(b) RxD Table

	R1	R2	Mean
D1	87.14	89.02	88.08
D2	87.85	88.55	88.20
D3	86.90	88.53	87.72
Mean	87.30	88.70	

(c) SxD Table

	S1	S2	S3	Mean
D1	93.89	87.72	82.63	88.08
D2	94.49	88.28	81.85	88.20
D3	94.00	88.34	80.82	87.72
Mean	94.12	88.11	81.76	

(d) RxSxD Table

	R1	R2
S1D1	93.10	94.67
S1D2	93.87	95.11
S1D3	93.10	94.89
S2D1	87.37	88.07
S2D2	88.11	88.44
S2D3	88.00	88.68
S3D1	80.95	84.31
S3D2	81.58	82.11
S3D3	79.60	82.03

II14. Mean table for field efficiency at field no. 2

(a) RxS Table

	R1	R2	Mean
S1	91.55	93.51	92.53
S2	82.73	85.16	83.95
S3	80.53	80.89	80.71
Mean	84.94	86.52	

(b) RxD Table

	R1	R2	Mean
D1	83.43	86.67	85.05
D2	82.45	86.21	84.33
D3	88.94	86.68	87.81
Mean	84.94	86.52	

(c) SxD Table

	S1	S2	S3	Mean
D1	92.39	84.41	78.37	85.05
D2	92.18	83.78	77.04	84.33
D3	93.03	83.66	86.74	87.81
Mean	92.53	83.95	80.71	

(d) RxSxD Table

	R1	R2
S1D1	91.57	93.20
S1D2	90.80	93.56
S1D3	92.28	93.78
S2D1	83.45	85.36
S2D2	82.80	84.75
S2D3	81.95	85.36
S3D1	75.28	81.46
S3D2	73.74	80.33
S3D3	92.58	80.89

II18. Analysis of variance results for effect of velocity, depth and type of rotavator by considering SMWD at field no. 2

Source of variation	Degrees of freedom	Sum of squares	Mean square	Fcal	TEST	Ftab 5%	Ftab 1%
Replication	2	0.0064	0.0032	5.95	**	3.28	5.29
Rotavator	1	0.9707	0.9707	1813.76	**	4.13	7.44
Speed	2	0.0397	0.0198	37.08	**	3.28	5.29
Depth	2	0.0376	0.0188	35.12	**	3.28	5.29
RxS	2	0.0358	0.0179	33.47	**	3.28	5.29
RxD	2	0.0372	0.0186	34.72	**	3.28	5.29
SxD	4	0.0056	0.0014	2.60	NS	2.65	3.93
RxSxD	4	0.0059	0.0015	2.78	*	2.65	3.93
Error	34	0.0182	0.0005	C.V. % =0.56			
Total	**53**	**1.1570**		"t" value =2.03			

* - Significant at 5 per cent level of probability

** - Significant at 1 per cent level of probability

NS - Non significant.

II19. Analysis of variance results for effect of velocity, depth and type of rotavator by considering cone index at field no. 1

Source of variation	Degrees of freedom	Sum of squares	Mean square	Fcal	TEST	Ftab 5%	Ftab 1%
Replication	2	0.27	0.13	1.00	NS	3.28	5.29
Rotavator	1	102.44	102.44	759.53	**	4.13	7.44
Speed	2	2005.83	1002.92	7435.89	**	3.28	5.29
Depth	2	1241.03	620.51	4600.65	**	3.28	5.29
RxS	2	8.32	4.16	30.83	**	3.28	5.29
RxD	2	42.92	21.46	159.13	**	3.28	5.29
SxD	4	63.85	15.96	118.34	**	2.65	3.93
RxSxD	4	61.17	15.29	113.39	**	2.65	3.93
Error	34	4.59	0.13	C.V. % =0.72			
Total	**53**	**3530.41**		"t" value =2.03			

* - Significant at 5 per cent level of probability

** - Significant at 1 per cent level of probability

NS - Non significant.

II20. Analysis of variance results for effect of velocity, depth and type of rotavator by considering cone index at field no. 2

Source of variation	Degrees of freedom	Sum of squares	Mean square	Fcal	TEST	Ftab 5%	Ftab 1%
Replication	2	0.02	0.01	0.24	NS	3.28	5.29
Rotavator	1	187.70	187.70	5503.25	**	4.13	7.44
Speed	2	1763.80	881.90	25856.30	**	3.28	5.29
Depth	2	987.54	493.77	14476.76	**	3.28	5.29
RxS	2	8.05	4.02	117.94	**	3.28	5.29
RxD	2	4.94	2.47	72.43	**	3.28	5.29
SxD	4	1.12	0.28	8.23	**	2.65	3.93
RxSxD	4	25.13	6.28	184.16	**	2.65	3.93
Error	34	1.16	0.03	C.V. % =0.32			
Total	**53**	**2979.45**		**"t" value =2.03**			

* - Significant at 5 per cent level of probability

** - Significant at 1 per cent level of probability

NS - Non significant.

II21. Analysis of variance results for effect of velocity, depth and type of rotavator by considering bulk density at field no. 1

Source of variation	Degrees of freedom	Sum of squares	Mean square	Fcal	TEST	Ftab 5%	Ftab 1%
Replication	2	0.0051	0.0026	4.46	*	3.28	5.29
Rotavator	1	0.0424	0.0424	73.62	**	4.13	7.44
Speed	2	0.0597	0.0299	51.77	**	3.28	5.29
Depth	2	0.2269	0.1134	196.74	**	3.28	5.29
RxS	2	0.0220	0.0110	19.09	**	3.28	5.29
RxD	2	0.1328	0.0664	115.13	**	3.28	5.29
SxD	4	0.0263	0.0066	11.41	**	2.65	3.93
RxSxD	4	0.0382	0.0096	16.57	**	2.65	3.93
Error	34	0.0196	0.0006	C.V. % =2.05			
Total	**53**	**0.5731**		**"t" value =2.03**			

* - Significant at 5 per cent level of probability

** - Significant at 1 per cent level of probability

NS - Non significant.

II22. Analysis of variance results for effect of velocity, depth and type of rotavator by considering bulk density at field no. 2

Source of variation	Degrees of freedom	Sum of squares	Mean square	Fcal	TEST	Ftab 5%	Ftab 1%
Replication	2	0.0026	0.0013	4.10	*	3.28	5.29
Rotavator	1	0.0162	0.0162	50.16	**	4.13	7.44
Speed	2	0.2257	0.1128	349.55	**	3.28	5.29
Depth	2	0.1315	0.0658	203.77	**	3.28	5.29
RxS	2	0.0107	0.0053	16.52	**	3.28	5.29
RxD	2	0.0028	0.0014	4.38	*	3.28	5.29
SxD	4	0.0175	0.0044	13.58	**	2.65	3.93
RxSxD	4	0.0125	0.0031	9.64	**	2.65	3.93
Error	34	0.0110	0.0003	**C.V. % =1.43**			
Total	**53**	**0.5731**		**"t" value =2.03**			

* - Significant at 5 per cent level of probability

** - Significant at 1 per cent level of probability

NS - Non significant.

II23. Analysis of variance results for effect of velocity, depth and type of rotavator by considering soil disturbed area at field no. 1

Source of variation	Degrees of freedom	Sum of squares	Mean square	Fcal	TEST	Ftab 5%	Ftab 1%
Replication	2	43.59	21.80	67.37	**	3.28	5.29
Rotavator	1	193.42	193.42	597.79	**	4.13	7.44
Speed	2	101.78	50.89	157.27	**	3.28	5.29
Depth	2	33.11	16.56	51.17	**	3.28	5.29
RxS	2	4.97	2.48	7.68	**	3.28	5.29
RxD	2	26.12	13.06	40.36	**	3.28	5.29
SxD	4	6.62	1.65	5.11	**	2.65	3.93
RxSxD	4	10.93	2.73	8.44	**	2.65	3.93
Error	34	11.00	0.32	**C.V. % =0.62**			
Total	**53**	**431.54**		**"t" value =2.03**			

* - Significant at 5 per cent level of probability

** - Significant at 1 per cent level of probability

NS - Non significant.

II24. Analysis of variance results for effect of velocity, depth and type of rotavator by considering soil disturbed area at field no. 2

Source of variation	Degrees of freedom	Sum of squares	Mean square	Fcal	TEST	Ftab 5%	Ftab 1%
Replication	2	50.93	25.46	1116.03	**	3.28	5.29
Rotavator	1	498.68	498.68	21856.03	**	4.13	7.44
Speed	2	118.16	59.08	2589.28	**	3.28	5.29
Depth	2	266.26	133.13	5834.76	**	3.28	5.29
RxS	2	13.75	6.87	301.28	**	3.28	5.29
RxD	2	109.22	54.61	2393.43	**	3.28	5.29
SxD	4	10.01	2.50	109.67	**	2.65	3.93
RxSxD	4	6.58	1.64	72.05	**	2.65	3.93
Error	34	0.78	0.02	C.V. % =0.17			
Total	**53**	**1074.36**		"t" value =2.03			

* - Significant at 5 per cent level of probability

** - Significant at 1 per cent level of probability

NS - Non significant.

II25. Analysis of variance results for effect of velocity, depth and type of rotavator by considering fuel consumption at field no. 1

Source of variation	Degrees of freedom	Sum of squares	Mean square	Fcal	TEST	Ftab 5%	Ftab 1%
Replication	2	0.04	0.02	3.03	NS	3.28	5.29
Rotavator	1	98.01	98.01	16286.22	**	4.13	7.44
Speed	2	14.48	7.24	1202.93	**	3.28	5.29
Depth	2	330.98	165.49	27500.11	**	3.28	5.29
RxS	2	5.10	2.55	423.39	**	3.28	5.29
RxD	2	8.13	4.07	675.52	**	3.28	5.29
SxD	4	9.83	2.46	408.47	**	2.65	3.93
RxSxD	4	8.25	2.06	342.71	**	2.65	3.93
Error	34	0.20	0.01	C.V. % =0.55			
Total	**53**	**475.02**		"t" value =2.03			

* - Significant at 5 per cent level of probability

** - Significant at 1 per cent level of probability

NS - Non significant.

II26. Analysis of variance results for effect of velocity, depth and type of rotavator by considering fuel consumption at field no. 2

Source of variation	Degrees of freedom	Sum of squares	Mean square	Fcal	TEST	Ftab 5%	Ftab 1%
Replication	2	0.08	0.04	0.32	NS	3.28	5.29
Rotavator	1	68.67	68.67	552.53	**	4.13	7.44
Speed	2	18.04	9.02	72.56	**	3.28	5.29
Depth	2	217.26	108.63	874.10	**	3.28	5.29
RxS	2	1.72	0.86	6.90	**	3.28	5.29
RxD	2	4.11	2.05	16.53	**	3.28	5.29
SxD	4	7.33	1.83	14.75	**	2.65	3.93
RxSxD	4	14.73	3.68	29.64	**	2.65	3.93
Error	34	4.23	0.12	C.V. % =2.35			
Total	53	336.15		"t" value =2.03			

* - Significant at 5 per cent level of probability

** - Significant at 1 per cent level of probability

NS - Non significant.

II27. Analysis of variance results for effect of velocity, depth and type of rotavator by considering energy requirement at field no. 1

Source of variation	Degrees of freedom	Sum of squares	Mean square	Fcal	TEST	Ftab 5%	Ftab 1%
Replication	2	4594.79	2297.39	385.53	**	3.28	5.29
Rotavator	1	349622.84	349622.84	58671.27	**	4.13	7.44
Speed	2	2136.24	1068.12	179.24	**	3.28	5.29
Depth	2	1060118.74	530059.37	88950.88	**	3.28	5.29
RxS	2	17423.14	8711.57	1461.92	**	3.28	5.29
RxD	2	28741.07	14370.54	2411.56	**	3.28	5.29
SxD	4	32227.36	8056.84	1352.04	**	2.65	3.93
RxSxD	4	29128.17	7282.04	1222.02	**	2.65	3.93
Error	34	202.61	5.96	C.V. % =0.28			
Total	53	1524194.95		"t" value =2.03			

* - Significant at 5 per cent level of probability

** - Significant at 1 per cent level of probability

NS - Non significant.

II28. Analysis of variance results for effect of velocity, depth and type of rotavator by considering energy requirement at field no. 2

Source of variation	Degrees of freedom	Sum of squares	Mean square	Fcal	TEST	Ftab 5%	Ftab 1%
Replication	2	4327.56	2163.78	421.00	**	3.28	5.29
Rotavator	1	318085.77	318085.77	61889.54	**	4.13	7.44
Speed	2	9419.95	4709.97	916.41	**	3.28	5.29
Depth	2	747631.57	373815.79	72732.86	**	3.28	5.29
RxS	2	2761.89	1380.94	268.69	**	3.28	5.29
RxD	2	17946.21	8973.11	1745.89	**	3.28	5.29
SxD	4	24386.91	6096.73	1186.23	**	2.65	3.93
RxSxD	4	36093.58	9023.40	1755.67	**	2.65	3.93
Error	34	174.75	5.14	C.V. % =0.25			
Total	**53**	**1160828.18**		**"t" value =2.03**			

* - Significant at 5 per cent level of probability

** - Significant at 1 per cent level of probability

NS - Non significant.

II29. Analysis of variance results for effect of velocity, depth and type of rotavator by considering field efficiency at field no. 1

Source of variation	Degrees of freedom	Sum of squares	Mean square	Fcal	TEST	Ftab 5%	Ftab 1%
Replication	2	0.05	0.02	1.00	*	3.28	5.29
Rotavator	1	25.05	25.05	1097.94	**	4.13	7.44
Speed	2	1361.72	680.86	29840.40	**	3.28	5.29
Depth	2	1.89	0.95	41.47	**	3.28	5.29
RxS	2	5.33	2.66	116.77	**	3.28	5.29
RxD	2	4.30	2.15	94.20	**	3.28	5.29
SxD	4	10.01	2.50	109.71	**	2.65	3.93
RxSxD	4	2.77	0.69	30.30	**	2.65	3.93
Error	34	0.78	0.02	C.V. % =0.17			
Total	**53**	**1411.89**		**"t" value =2.03**			

* - Significant at 5 per cent level of probability

** - Significant at 1 per cent level of probability

NS - Non significant.

II30. Analysis of variance results for effect of velocity, depth and type of rotavator by considering field efficiency at field no. 2

Source of variation	Degrees of freedom	Sum of squares	Mean square	Fcal	TEST	Ftab 5%	Ftab 1%
Replication	2	0.06	0.03	1.00	NS	3.28	5.29
Rotavator	1	31.80	31.80	1048.14	**	4.13	7.44
Speed	2	1325.73	662.87	21847.42	**	3.28	5.29
Depth	2	115.89	57.95	1909.84	**	3.28	5.29
RxS	2	10.13	5.07	166.98	**	3.28	5.29
RxD	2	105.25	52.63	1734.48	**	3.28	5.29
SxD	4	219.01	54.75	1804.62	**	2.65	3.93
RxSxD	4	225.99	56.50	1862.09	**	2.65	3.93
Error	34	1.03	0.03	C.V. % =0.20			
Total	53	2034.90		"t" value =2.03			

* - Significant at 5 per cent level of probability

** - Significant at 1 per cent level of probability

NS - Non significant.

II31. Analysis of variance results for effect of velocity, depth and type of rotavator by considering operating cost at field no. 1

Source of variation	Degrees of freedom	Sum of squares	Mean square	Fcal	TEST	Ftab 5%	Ftab 1%
Replication	2	175.21	87.61	1.00	NS	3.28	5.29
Rotavator	1	221427.39	221427.39	2527.56	**	4.13	7.44
Speed	2	7602.97	3801.49	43.39	**	3.28	5.29
Depth	2	223624.50	111812.25	1276.32	**	3.28	5.29
RxS	2	371529.43	185764.72	2120.47	**	3.28	5.29
RxD	2	84221.86	42110.93	480.69	**	3.28	5.29
SxD	4	788214.20	197053.55	2249.33	**	2.65	3.93
RxSxD	4	352020.61	88005.15	1004.56	**	2.65	3.93
Error	34	2978.58	87.61	C.V. % = 0.58			
Total	53	2051794.76		"t" value =2.03			

* - Significant at 5 per cent level of probability

** - Significant at 1 per cent level of probability

NS - Non significant.

II32. Analysis of variance results for effect of velocity, depth and type of rotavator by considering operating cost at field no. 2

Source of variation	Degrees of freedom	Sum of squares	Mean square	Fcal	TEST	Ftab 5%	Ftab 1%
Replication	2	3384.88	1692.44	0.72	NS	3.28	5.29
Rotavator	1	171996.50	171996.50	72.67	**	4.13	7.44
Speed	2	72294.17	36147.09	15.27	**	3.28	5.29
Depth	2	208158.17	104079.09	43.97	**	3.28	5.29
RxS	2	589658.29	294829.14	124.56	**	3.28	5.29
RxD	2	96268.09	48134.05	20.34	**	3.28	5.29
SxD	4	792105.15	198026.29	83.66	**	2.65	3.93
RxSxD	4	306054.60	76513.65	32.33	**	2.65	3.93
Error	34	80475.13	2366.92	**C.V. % =2.98**			
Total	**53**	**2320394.98**		**"t" value =2.03**			

* - Significant at 5 per cent level of probability

** - Significant at 1 per cent level of probability

NS - Non significant.

APPENDIX- III

III. Comparison of operating cost of rotavators at different depths

Sr. No.	Item	Tractor	Horizontal rotavator	Vertical rotavator
A.	Fixed cost			
1.	Purchase cost, ₹	485,000	87,000	60,000
2.	Salvage value, ₹	48,500	8,700	6,000
3.	Depreciation, ₹ /h	39.68	11.19	7.71
4.	Interest, ₹ /h	29.1	8.2	5.66
5.	Taxes, housing and insurance, ₹ /h	8.81	2.49	1.71
Total fixed cost, ₹ /h		77.59	21.88	15.08

B. Variable cost

		Field no. 1		Field no. 2	
		HR	VR	HR	VR
8.	Wages charges, ₹ /h labour	25	25	25	25
9.	Fuel charges, ₹ /h				
	a. At depth 7 cm	175.80	189.00	179.40	208.80
	b. At depth 10 cm	196.20	196.2	204.00	204.60
	c. At depth 13 cm	259.20	285.6	256.20	272.40
10.	Lubrication charges, ₹ /h				
	a. At depth 7 cm	43.95	47.25	44.75	52.20

	b. At depth 10 cm c. At depth 13 cm	49.05 64.80	49.05 71.4	51.00 64.05	51.15 68.10
11.	Repair and maintenance, ₹ /h	6.21	4.28	6.21	4.28
12.	**Variable cost, ₹ /h**				
	a. At depth 7 cm	250.96	265.53	255.36	290.28
	b. At depth 10 cm	276.46	274.53	286.21	285.03
	c. At depth 13 cm	355.21	386.28	351.46	369.78
13.	**Total operating cost (Tractor with rotavator), ₹ /h**				
	a. At depth 7 cm	350.43	358.20	354.83	389.75
	b. At depth 10 cm	375.93	367.20	385.68	384.50
	c. At depth 13 cm	454.68	478.95	450.93	469.25
14.	**Total operating cost (Tractor with rotavator), ₹ /ha**				
	a. At depth 7 cm	1279.07	1479.37	1366.10	1656.44
	b. At depth 10 cm	1451.09	1531.22	1504.15	1659.51
	c. At depth 13 cm	1668.68	2002.01	1573.75	1999.01

III2. Comparison of operating cost of rotavators at different speeds

Sr. No.	Item	Tractor	Horizontal rotavator	Vertical rotavator
A.	**Fixed cost**			
1.	Purchase cost, ₹	485,000	87,000	60,000
2.	Salvage value, ₹	48,500	8,700	6,000
3.	Depreciation, ₹ /h	39.68	11.19	7.71
4.	Interest, ₹ /h	29.1	8.2	5.66
5.	Taxes, housing and insurance, ₹ /h	8.81	2.49	1.71
Total fixed cost, ₹ /h		77.59	21.88	15.08

B. Variable cost

		Field no. 1		Field no. 2	
		HR	**VR**	**HR**	**VR**
8.	Wages charges, ₹ /h labour	25	25	25	25
9.	Fuel charges, ₹ /h				
	a. At speed 1.5 km/h	118.80	121.80	123.00	127.20
	b. At speed 2.71 km/h	210.00	231.60	223.80	232.80
	c. At speed 4.1 km/h	303.00	322.20	288.08	325.80
10.	Lubrication charges, ₹ /h				
	a. At speed 1.5 km/h	29.70	30.45	30.75	31.80

	b. At speed 2.71 km/h c. At speed 4.1 km/h	52.50 75.75	57.90 80.55	55.95 72.02	58.20 81.45
11.	Repair and maintenance, ₹ /h	6.21	4.28	6.21	4.28
12.	**Variable cost, ₹ /h** a. At speed 1.5 km/h b. At speed 2.71 km/h c. At speed 4.1 km/h	 179.71 293.71 409.96	 181.53 318.78 432.03	 184.96 310.96 391.31	 188.08 320.28 436.53
13.	**Total operating cost (Tractor with rotavator), ₹ /h** a. At speed 1.5 km/h b. At speed 2.71 km/h c. At speed 4.1 km/h	 279.18 393.18 509.43	 274.20 411.45 524.70	 284.43 410.43 490.78	 280.75 412.95 529.20
14.	**Total operating (Tractor with rotavator), ₹ /ha** a. At speed 1.5 km/h b. At speed 2.71 km/h c. At speed 4.1 km/h	 1719.19 1426.29 1326.64	 1926.46 1716.75 1544.75	 1785.12 1580.60 1280.30	2000.59 1790.25 1595.58

APPENDIX- IV

Details of the tractor used

Manufacturer	**John Deere**
Model	**5310**
Specifications	
Engine	
Type	55 hp, 2400 RPM, 3 cylinder Direct injection, liquid cooled with overflow reservoir
Air filter	Dry type, dual element
Transmission	
Clutch	Dual
Gear Box	9 Forward + 3 Reverse speeds
Speeds	Forward 2.10 - 28.80 km/h Reverse 3.45 -22.30 km/h
Brakes	Self-adjusting, self-equalising, hydraulically actuated oil immersed disc brakes
Hydraulics	
Lifting capacity	2000 kgf at lower link ends
3 Point linkage	Category II
Automatic depth & draft control	
Steering	
Type	Power
Power Take Off	
Type	Independent, 6 splines
RPM	540
Wheels & Tyres	
Front	6.5 x 20, 8 Ply Rate
Rear	16.9 x 28, 12 Ply Rate
Fuel Tank Capacity (l)	68

Electrical System	
88Ah, 12 volt battery	
40 Amp. alternator	
12 Volt, 2.5 kW starter motor	
Dimensions & Weight of Tractor	
Total weight	2315 kg
Wheel base	2050 mm
Overall length	3860 mm
Overall width	1865 mm
Ground clearance	450 mm
Turning radius with brakes	3300 mm