INFLUENCE OF SYSTEM PARAMETERS ON PERFORMANCE OF REVERSIBLE SHOVEL FOR TRACTOR DRAWN CULTIVATOR

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Tillage is an energy intensive farm operation consuming about 40 per cent of the total energy input required for crop production. Tractor drawn cultivator is one of the most important tillage tools used by Indian farmer. It is primarily the type of tillage implement which is used for opening the land, preparing the seed bed for sowing of the seeds as well as after the crop has come up a few centimeter above the ground. Reversible shovel are primarily used for loosening and steering the soil. They are used on cultivators and are recommended for secondary tillage operation but most of the farmers also use this shovel for primary cultivation. The experiments were conducted in sandy loam soil using four nose angles shovel each at four rake angles (15°, 25°, 35° and 45°) and depth of operations (0.06, 0.09, 0.12 and 0.15 m) at 1.25 m/s speed of operation and soil moisture content of about 10.8 per cent under indoor soil bin conditions. Spoil furrow width and depth increased with the increase in rake angle and depth of operation for all nose angles shovel whereas reverse trend was observed for crescent height which decreased with increase in rake angle for all nose angles. Spoil area was directly proportional to rake angle and depth of operation for both nose angle shovels whereas, trench area decreased with increase in rake angle for both nose angle shovels. It was rake angle which affected more the spoil and trench area than depth of operation for both nose angles. 90° nose angle shovel gave highest spoil area (11.48 × 10⁻³ m²) and trench area (8.068 × 10⁻³ m²) among all the nose angle tested. The spoil resistance index increased with increase in rake angle and depth of operation for all nose angles shovel. 90° nose angle shovel gave 75 per cent higher spoil resistance index than 40° nose angle shovel within the test range of rake angles and depth of operations. 90° nose angle shovel resulted 29.58 per cent higher specific draft than 40° nose angle shovel with in the test range of rake angle and depth of operation. 90° nose angle shovel required about 38.62 per cent more power than 40° nose angle within the test range parameters.

**Keywords:** Soil profile, crescent height, spoil area, trench area, nose angle, rake angle, specific draft and power requirement
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CHAPTER I

INTRODUCTION

India is a vast country with 329.5 million hectares geographical area, with agriculture still being the main occupation of 70 per cent of Indian population. The population has been increasing at the rate of 1.8 per cent annually and will be about 1.3 billion by the end of 2030. This will require 260 to 264 million tones of food grains to feed the population (Suman et al., 2003). Total cropped area in India is about 142 million hectares, out of which 90 million hectares is rainfed. The productivity and suitability of crops in these areas is low. This has to be increased from the available resources and the second green revolution from the dryland (Paroda, 1999).

The growth of agricultural mechanization has been rapid during last four decades. The mechanization of Indian agriculture has played dominant role in increasing agricultural production, productivity and profitability by timely farm operations, saving in cost of operation, maximizing utilization efficiency of agricultural inputs by their judicious applications and reducing losses. The newly developed appropriate technology of farm mechanization with improvement in existing design, newer material and production techniques will cater the needs of todays farms (Manian et al., 2002). The growth in large scale adoption of agricultural tools and machinery in the country has been possible due to the efforts, not only by organized sectors but also by small village and craftsmen scale industries.

1.1 Agricultural Mechanization in India

Farm mechanization is one of the way outs for all the issues of agricultural operations. Farm mechanization technique can be taken by agriculturists to enhance both productivity and profitability (Pawar and Aware, 2007). In developing countries like India mechanization means improved tool, implement, machinery or structure that assists in enhancement of workers output which enables in removing or reducing drudgery or stress (Manian et al., 2002). Use of farm machinery depends upon the farm power sources available in the country for various tractive and stationary operations. For enhancing mechanization, the farm power available will have to be increased from present level of 1.35 kW/ha to 2.00 kW/ha by 2020 (Pandey, 2005).

With picking up of high yielding varieties based on agricultural technologies the tractorization of agricultural operations started gaining its importance. An increase of about 27.6 per cent in tractor production from 2.5 lakh (2004-05) to 3.19 lakh (2006-07) in the
country reflects the increase use of tractors for various operations (Pandey, 2008). A rising trend of about 223 per cent in growth of power operated agricultural machinery such as power sprayer/ duster, M.B and disc plough, disc harrow, cultivator, seed drill, planter and thresher from 1991-92 to 2000-2001 suggests the inclination of Indian farmers towards mechanizing agricultural operations (Singh and Chand 2002).

Rajasthan has the largest area of 10.62 lakh hectares under cultivation among all states with total production of food grain of 21 lakh tonnes (Anonymous 2006). Variety of hand tools, animal and tractor operated implements and machines are used by the farmers in Rajasthan for various farm operations. The secondary tillage implements like cultivator, disc harrow, bund farmer have become popular among farmers for better and timely seed bed preparation. Increase in the number of tractor operated farm machines like MB plough, disc plough, cultivator, seed cum fertilizer drill etc. have been observed in the common areas in Rajasthan (Anonymous, 2007).

Tillage is an energy intensive farm operation consuming about 40 per cent of the total energy input required for crop production (Yadav et al., 2006). It is basic operation in farming and is generally performed to breakup and pulverizes the soil and allows the free movement of air and water in order to promote plant growth. Field soils loosened by tillage tend to become compact as the crops grow. The weeds destroyed by tillage grow once again and land tends to return to the state that existed before tillage, therefore it becomes necessary to do tillage before growing every crop (Culpin, 1988).

1.2 Justification and scope of study:

Cultivator is one of the most important tillage tools used by Indian farmer (Yadav et al, 2006). Many organic farmers say that a pass with the cultivator has the same effect on the crop in dry weather as a half inch of rain (Klaas and Martens, 2005). It is primarily the type of tillage implement which is used for opening the land, preparing the seedbed for sowing of the seeds as well as after the crop has come up a few centimeter above the ground (Jain and Philip, 2003). The field cultivators are often used as secondary tillage tools for seedbed preparation. Reversible shovel, sweep, half sweeps, furrower etc. are the different types of tools that can be attached to a cultivator shank for different applications. These tines are simple in design and have been used by various researchers in an attempt to gain insight into soil-tool interactions (Makanga et al., 1997). The draft of the shovel is sensitive to rake angle (lift angle). This is defined as the angle, in a vertical plane parallel to the direction of travel, between a tool axis and the soil surface (Anonymous 1998, William and Glen, 1967). The studies indicate that draft increases with the increase in the rake angle, Tanner (1960).
reported that efficiency of shovel measured in terms of draft per unit width of disturbed soil is extremely sensitive to rake angle.

Reversible shovel and sweeps are primarily used for loosening and steering the soil. They are used on cultivators and are recommended for secondary tillage operation. Most of the farmers also use this shovel for primary cultivation. They are used in seed drills for opening the furrow and placement of seeds. They do not usually have an inverting effect and penetrate more easily in hard grounds because of less upward soil reaction. Nose angle of reversible shovel significantly affect the penetration of tine into the soil which ultimately influences draft requirement and soil disruption (Richey et al. 1961). BIS code (BIS-6023) recommends a nose angle of $90^\circ$ for reversible shovel where as presently commercially available reversible shovel for tractor drawn cultivators are having nose angles ranging from $40^\circ$ to $75^\circ$. Present study is aimed to compare the performance of commercially available reversible shovels with the recommended by the BIS code.

A suitable combination of rake angle and nose angle of reversible shovel will reduced the draft requirement (power requirement) and maximize soil disruption at different depths of working for various farm applications. Therefore soil-tool-tillage complex needs to be studied for a given location and tool geometry for better tool performance.

1.2.1 Soil disruption

Tillage implements disrupt the soil profile and rearrange the soil components. Soil disruption is the measure of effectiveness of tillage implement. It can be surface soil disruption or spoil which is a measurement of the amount of soil displaced above the original soil surface by the tillage process. The subsurface disruption is the area that is disrupted below the soil surface or trenched area (Raper and Sharma, 2004). The depth of tillage depends on the crop and soil characteristics and also on the source of power or energy available.

Soil profile after tillage operation, is important in several aspects, such as incorporating manure and crop residues protecting soil from air and water erosion. The study of soil profile by tillage has progressed slowly due to its complexity which involves many factor, such as soil types and properties, types of tillage tools and the operational parameters.

A good seedbed is generally considered to imply finer particles and greater firmness in the vicinity of seeds. In arid and semi arid areas with high average soil temperature and dry spells, there is a need to break the soil, which becomes very hard. A pointed tool like chisel or
bar point are used on country plough to break soil without inverting or disturbing crop residue in order to collect and store rain water and reduce wind erosion and evaporation losses. Under such conditions lister plough, rigid tine cultivator, duck foot sweeps and other similar equipment are useful and can be operated for one or two passes. One of the important parameter for performance evaluation of shovel is soil disruption. The disruption depends on type of soil, depth, speed of operation and design of tine on which it is mounted.

However, agriculture in the country has changed substantially and producers are now interested in much more than tillage energy. Many producers are now adopting conservation tillage systems that incorporate fewer passes of secondary tillage. Primary tillage as done with an in-row cultivator may be followed directly with a planter. Quantitative evaluation of tillage implement performance requires a measurement of induced forces from the soil-tool interaction and a measure of soil conditions to determine when and how much change occurred in the soil. Generally, quantitative descriptions of implement performance are difficult because no standard methods exist for adequately describing soil conditions.

1.2.2 Power requirement

The availability of draft and power requirement data of tillage implements is an important factor in selecting suitable tillage implements for a particular farming operation. They are utilized by farm managers and consultants to determine correctly the proper size of tractor required for a given farm operation (Janobi and Suhaibani, 1998).

Draft and power requirements are important parameters for measuring and evaluating performance of tillage implements. They are considered as essential data when attempting to correctly match a tillage implement to a tractor and also needed for decisions that will be used in future energy management of agricultural machinery. Optimum use of energy is an important design criterion for any agricultural machine. Many studies have been conducted to measure draft and power requirement of tillage implements under various soil conditions.

Power source in agriculture is of great importance in determining the level of agricultural mechanization and development. In the farm there are three sources of power for carrying out operations, the human power for limited amount of work which seldom exceeds subsistence level, animal power, which is mainly used for draft work or transport of goods and people and the mechanical power through tractor which will continue to be an absolute necessity for agricultural production. This power is required for two kinds of work, dynamic for pulling or draft of implements and static for operating machines (Dahab et al., 2007).
Many design and material changes in tillage and planting equipment have occurred during the past 15 years. Implement width, operating depth and speed are factors that affect draft and power of a tillage implement. They also depend on soil conditions and geometry of tillage implement (Harrigan and Rotz, 1995).

Keeping these points in view the present study was conducted to provide information on soil disruption, spoil resistance index, specific draft and power requirement for cultivator shovels to improve soil conditions in sandy loam soil. The specific objective of this study is as under:

Objective:

To study the effect of rake angle, nose angle and depth of operation of reversible shovel on soil disruption, specific draft and power requirement for tractor drawn cultivator in sandy loam soil.

CHAPTER II

REVIEW OF LITERATURE

In this chapter an attempt has been made to review the literature related to the effect of rake angle, nose angle and depth of operation on soil disruption and power requirement of reversible shovel.

2.1 Effect of Rake Angle on Soil Disruption and Power Requirement
Payne and Tanner (1959) studied the effect of draft on rake angle of tine blades in the range of 20\(^0\) to 160\(^0\). They concluded that the draft was less for tine rake angle between 20\(^0\) to 50\(^0\). The 160\(^0\) rake angle had five times greater draft as compared to 20\(^0\) rake angle.

Tanner (1960) studied the effect of various rake angles on horizontal and vertical forces. His results were similar to those quoted by Payne and Tanner (1959). The scatter was much greater in the clay than other soils. This was due to adhesion and change in the size of the stationary cone on the tine face.

Osman (1964) studied tine blades with rake angle of 30\(^0\), 50\(^0\), 70\(^0\), 90\(^0\) and 105\(^0\) at constant depth of 2.54 cm in three different soils. He found that the draft increased when rake angle varied from 30\(^0\) to 50\(^0\). The draft was independent of rake angle below 30\(^0\).

Gebrbenset and Johnson (1992) studied the performance of coulter with rake angle varying from 70\(^0\) to 130\(^0\) for width of 15 mm and 40 mm and speed of 0.3 m/s and 3 m/s. They found that at speed of 3 m/s the horizontal force increased linearly with rake angle. At speed of 0.3 m/s and for 15 mm and 40 mm wide coulter it was constant for rake angles between 90\(^0\) and 110\(^0\), and 110\(^0\) and 130\(^0\) respectively. They reported that depth stability was best for rake angle 130\(^0\) in light sandy soil.

Sharma et al., (1992) studied flat tines operating in dry sand under quasi-static conditions for different rake angles varying from 15\(^0\) to 90\(^0\). The tines were operated at 20 cm width and 5 cm depth. For rake angles from 15\(^0\) to 52\(^0\) the inclined shear surface emerged directly from the tine tip. For the rake angles from 52\(^0\) to 90\(^0\), the inclined shear surface was at a distance from the tine tip. The distance of the inclined shear surface from the tine tip increased with the increase in rake angle and the shear started from the tine tip parallel to the direction of tine travel with no soil disturbance below the tine tip.

Hanna et al., (1993) studied the goryachkin crushing and lifting theories for prediction of soil flow across a sweep. They revealed that flow changed with rake angle, but not with speed or depth. Soil flows on the sweep did not deviate appreciably (more than 5\(^0\)) from the vertical plane parallel to the direction of travel.

Desbiolles et al., (1997) studied effect of tine rake angle of wingless subsoiler tine, low lift subsoiler tine, high lift subsoiler tine and curved blade chisel tine having rake angles of 18\(^0\), 30\(^0\), 38\(^0\) and 45\(^0\) respectively in sandy-loam and clay soil at different working depths (15 to 45 cm). They concluded that curved blade chisel tine required higher draft than the
other tines with increase in depth due to its higher rake angle. The tool index relationship for measuring the draft for these tines was also developed.

Makange et al. (1997) studied the effect of tine rake angles (50°, 90°, and 130°) and aspect ratios (depth/width) in dry loam soil. They observed that soil reactions of cyclic nature were affected by tine design parameters.

Jaysuriya and Salokhe (2002) studied the tine rake angles of 50°, 90°, and 130° (70 mm width and 150 mm long) working at an effective depth of 120 mm. They concluded that tine with 90° rake angle required higher forces and exerted more power, while the tine with 50° rake angle was found to be most effective in terms of soil loosening and power consumption. Tine with 130° rake angle was found ineffective for soil tillage, due to its vertical force component being very high as compared to other tines. This resulted in more soil compaction and pulverization.

Tong and Ballel (2006) studied the effect of rake angles (15° to 75°) of a chisel plough and soil bulk density on angle of soil failure plane, rupture distance, width of side crescent and frictional, overburden, cohesion and adhesion soil cutting factors. The experiment was carried out at two locations. The results showed that the angle of failure plane decreased with the rake angle. The rupture distance decreased with the rake angle from 15° to 55° and then increased. The width of the side crescent increased as the rake angle increased. The cohesion factor increased as the rake angle increased. The maximum and minimum values were more at rake angle of 75° and 15° rake angle respectively. The draft force decreased up to 45° rake angle.

2.2 Effect of Nose Angle on Soil Disruption and Power Requirement

Abernathy and Porterfield (1969) In soil bin containing light sandy soil, evaluated runner type furrow opener. It had vertical angle ranging from 90° to 150° and nose angle from 15° to 60°. They obtained more furrow depth for openers with larger vertical and nose angles.

Shrivastava and Panwar (1986) studied two lift angles of shovel (0° horizontal and 90° vertical) and three sweep angle (0° flat, 60° and 90°). They found that horizontal furrow opener of 90° sweep angle and 45° approach angle (nose angle) resulted minimum pull.

Hanna et al., (1993) studied sweep nose angles of 57°, 67°, 68° and rake angles 13.5°, 16°, and 44° at forward speed of 5, 7, and 9 km/h and depths of 5 and 10 cm. They concluded
that with increase in rake angle and nose angle at depths, increased soil movement, ridge height and draft of sweep this was due to movements of soil on the sweep.

Mamman and Oni (2005) studied the model chisel furrower having nose angles of 10°, 20°, and 30° and slide angles of 5°, 10°, 15°, 20° at the travel speed of 0.02, 0.05, 0.10, 0.15 m/s and tillage depth of 2.5, 5, 7.5, and 10 cm. They concluded that draft increased with increase in speed, tillage depth, nose angle and slide angle of furrower.

Altuntas et al., (2006) studied three types of furrow openers viz; shoe, hoe, and shovel having nose angles of 140°, 60°, and 35° and tool rake angles of 150°, 70°, and 30° with forward speed of 2.02, 3.28 and 4.50 km/hr. They lowest draft was found for shovel type furrow opener with the nose angle of 60° and tool rake angle of 70°.

Darmora and Pandey (2006) evaluated the performance of a shovel type furrow opener and BIS standard shovel having nose angle of 40° at uniform speed and depth of 0.562 m/s and 60 mm respectively. They concluded that draft requirement varied from 55 N to 59 N. This draft was about 18 to 19 per cent less in comparison to BIS standard shovel type furrow opener.

Darmora (2007) studied shovel type furrow opener having nose angles of 20°, 40°, 60°, and 80° and rake angles of 30°, 40°, 50°, and 60° at working depth of 4, 6, 8, and 10 cm under sandy loam soil. He concluded that soil was redistributed in a wider and flatter area with increasing nose angle and with slight increase in ridge height. The increase in nose angle gave more soil being tossed away resulting in increased furrow depth. Increased draft with increasing nose and rake angle attributed to higher soil disturbance. Multiple regression equation were also developed to predict the draft requirement.

Verma et al., (2007) studied three types of furrow opener viz shovel, shoe, and inverted T having nose angles 45°, 55°, and 60° and rake angles 25°, 30°, and 35° at two speed of operation 1.00 and 2.25 km/h. They concluded that inverted T type furrow opener required less draft, less soil disturbance and lowest clogging frequency due to minimum nose and rake angle as compared to shoe and shovel type furrow opener.

2.3 Effect of Depth of Operation on Soil Disruption and Power Requirement

Summers et al., (1986) studied draft relationship for primary tillage in Oklahoma soil and concluded that the draft was directly proportional to depth of operation and varied linearly for moldboard plough, chisel plough, disc plough and sweep plough.
Garner et al., (1987) studied tractor performance for subsoiling and subsoil-bedding in five different coastal plain soil conditions. They concluded that draft requirement increased as subsoiling depth increased.

Hanna et al., (1993) studied the effect of sweep geometry on soil movement for speed 5, 7 and 9 km/h and depth of operation 50 and 100 mm. They concluded that faster speeds and steeper rake angles (13.5° to 44°) created larger ridges. Change in surface height which was significantly affected by tool depth and speed.

Iqbal et al., (1994) studied the draft requirement of selected primary and secondary tillage implements at a speed of 2.5 km/h in silt clay loam soil at 13.2 per cent moisture content. They found that the draft of cultivator, chisel plow and subsoiler increased linearly with the increase in the depth of cultivation.

Younis et al., (1994) carried out a study for predicting variation in draft requirement with depth for different tillage implements at University of Agriculture, Faisalabad, Pakistan. The implements were pulled through the soil at desired depth with a constant speed of 2.5 km/h. The depth of cultivation varied form 15 to 45 cm. The draft requirement of disc harrow and disc plough were 4710, 5101 and 6925 N and 4905, 6867 and 9810 N for 15, 20 and 25 cm depth of operation respectively. The relationship between draft requirement and the depth of operation was linear for cultivator. The draft requirement per centimeter of cutting width at shallow depth was very close for all the implements.

Janobi and Suhaibani (1998) studied the effect of speed and depth of operation on draft for major primary tillage implements (mould board plough, disk plough, and offset disk harrow) operating in sandy loam soil. They found that specific draft was significantly affected by depth. A regression equation to predict draft of these implements with an increase in depth was also developed.

Loghavi et al., (1999) studied the effect of three levels of soil moisture content (10-12, 13-15 and 16-18% d.b.) and ploughing depth (15, 20 and 25 cm) on draft, specific draft, and drawbar power requirements of a 3-bottom disc plough in a clay loam soil. The effect of ploughing depth was highly significant on draft and drawbar power requirement of disc plough. The mean values of these two parameters significantly increased with ploughing depth, while specific draft showed a mild decreasing trend.

Raper et al., (2000) investigated draft and energy requirement for shallow (0.18 m) and deep tillage (0.33 m) for cotton crop. They concluded that shallow tillage took
approximately 50 per cent of the draft and energy requirement that of deep tillage. Soil strength decreased below the depth of compacted soil in shallow tillage.

Raper and Sharma (2004) evaluated straight shank and “minimum- tillage” shank in coastal plain soil in the soil bin of National Soil Dynamics Laboratory Auburn, Alabama. They concluded that the “minimum- tillage” shank reduced soil disruption compared to the straight shank. They also reported that lower soil moisture significantly increased the amount of spoil and trench area compared to all other soil moisture levels.

Raper (2005) developed two parameters, spoil resistance index and trench specific resistance to assess draft soil disruption and below ground soil disruption. He concluded that the below ground soil disruption should be maximized while above ground soil disruption should be minimized.

Mamman and Oni (2005) investigated the effect of draft on the performance of geometrically similar model chisel furrows. The experiment was carried out in an artificial soil in an indoor soil bin. The operating parameters were tool travel speed (0.02, 0.05, 0.10, 0.15 m/s) and tillage depth (2.5, 5, 7.5, 10 cm). They concluded that the draft increased with increase in tool travel speed as tillage depth, nose and slide angles, and cutting edge height increased. Draft increased with increase in tillage depth as nose and slide angles, and cutting edge height increased. Tillage depth of 7.5 cm had more influence on the draft of the model tools. The choice of the model tool depended on soil failure pattern at shallow depth, size and quality of furrow created at deeper depths.

Darmora and Pandey (2006) evaluated a shovel type furrow opener of a combined seed and fertilizer drill and the performance was evaluated standard shovel type furrow opener at a uniform speed and depth of 0.562 m/s and 60 mm respectively at an average soil moisture contain of 10 per cent (db). They concluded that the shovel type furrow opener created 12 per cent less soil disturbance in comparison to standard shovel type furrow opener.

Sahu and Raheman (2006) developed a methodology to predict the draft requirement of combination tillage implements in any soil and operating conditions. The draft requirement of a reference tillage tool (single disk), three scale-model individual (moldboard plow, cultivator and disk gang) and two combination (moldboard plow with disk gang and cultivator with disk gang ) tillage implements at different depths (5, 7.5 and 10 cm), speeds (1.2, 2.2, 3.2, 4.2 km/h), wet bulk densities ( in the range of 1.27-1.85 g/cm³) and cone index penetration resistance (445-1450 kPa) were determined in soil bin filled with sandy clay loam soil. They found that the developed equation predicted draft of both combination tillage.
implements within an average absolute variation of 18.0 per cent and 13.5 per cent respectively

Arvidsson (2006) studied draft requirement for different tillage implements. He concluded that specific draft during primary tillage operation was generally lower for a mould board plough than for chisel or disc implements.

Kasisira and Plessis (2006) studied the effect of rear and front subsoiler in sandy clay loam soil. It was operated at a constant speed of 1.5 kmph. The rear subsoiler was operated at a constant depth of 600 mm. Depth of front subsoiler and the spacing were varied. For each run, cross-sectional area of the disturbed soil-profiles were measured at different sections. They concluded that the cross-sectional area per unit draft increased linearly, with spacing between the rear and front subsoilers. The efficiency of the subsoilers in this configuration was maximum when the longitudinal spacing was such that the soil failed by the front subsoiler was allowed to stabilize before the rear subsoiler reached it. The maximum cross-sectional area failed per unit draft was recorded when the depth of the front subsoiler was equal to about 80% of the operating depth of the rear subsoiler.

Manuwa and Ademosun (2007) studied the effect of three different tillage tines viz: very narrow tine, narrow tine and wide tine having width and thickness of tine was 1, 5.1 and 20 cm and 8 mm respectively, on soil disruption at moisture content of 6 to 22 per cent (d.b). soil disturbance parameters viz. ridge-to-ridge distance, width of crescent or width of furrow at the surface, total disturbed width, height of ridge, and furrow depth. They reported that maximum width of soil throw decreased with increase in moisture content but increased with tine width. All the soil disturbance parameters increased as soil cone index increased except height of ridge.

Yadav et al., (2007) studied the effect of rake angle, approach angle, tilt angle, blade width, blade thickness, speed, depth of operation and geometry on specific draft. They concluded that specific draft varied polynomially with approach angle and speed . They also found that specific draft increased with increase in soil moisture content.

2.4 Conclusions from Review

The review suggested that soil disruption is measure of effectiveness of tillage implement. This depend on soil condition, rake angle, nose angle, depth of operation and moisture content. The ridge spacing and the width of soil distribution significantly increased with increase in tillage depth. Draft and power requirement are some of the important parameters with minimum values of specific draft and are desirable as they indicate low
values of draft with maximum trench. The draft increased with the rake angle and nose angle at increased depth of operation.

The past studies indicate that the factors, namely rake angle, nose angle and depth of operation affect soil disruption, spoil resistance index, specific draft and power requirement. The results obtained from these studies have been considered while formulating the research plan in the present study.

CHAPTER II
REVIEW OF LITERATURE

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Gebrbenset and Johnson (1992) studied the performance of coulter with rake angle varying from 70° to 130° for width of 15 mm and 40 mm and speed of 0.3 m/s and 3 m/s. They found that at speed of 3 m/s the horizontal force increased linearly with rake angle. At
speed of 0.3 m/s and for 15 mm and 40 mm wide coulter it was constant for rake angles between 90° and 110°, and 110° and 130° respectively. They reported that depth stability was best for rake angle 130° in light sandy soil.

Sharma et al., (1992) studied flat tines operating in dry sand under quasi-static conditions for different rake angles varying from 15° to 90°. The tines were operated at 20 cm width and 5 cm depth. For rake angles from 15° to 52° the inclined shear surface emerged directly from the tine tip. For the rake angles from 52° to 90°, the inclined shear surface was at a distance from the tine tip. The distance of the inclined shear surface from the tine tip increased with the increase in rake angle and the shear started from the tine tip parallel to the direction of tine travel with no soil disturbance below the tine tip.

Hanna et al., (1993) studied the goryachkin crushing and lifting theories for prediction of soil flow across a sweep. They revealed that flow changed with rake angle, but not with speed or depth. Soil flows on the sweep did not deviate appreciably (more than 5°) from the vertical plane parallel to the direction of travel.

Desbiolles et al., (1997) studied effect of tine rake angle of wingless subsoiler tine, low lift subsoiler tine, high lift subsoiler tine and curved blade chisel tine having rake angles of 18°, 30°, 38° and 45° respectively in sandy-loam and clay soil at different working depths (15 to 45 cm). They concluded that curved blade chisel tine required higher draft than the other tines with increase in depth due to its higher rake angle. The tool index relationship for measuring the draft for these tines was also developed.

Makange et al., (1997) studied the effect of tine rake angles (50°, 90°, and 130°) and aspect ratios (depth/width) in dry loam soil. They observed that soil reactions of cyclic nature were affected by tine design parameters.

Jaysuriya and Salokhe (2002) studied the tine rake angles of 50°, 90°, and 130° (70 mm width and 150 mm long) working at an effective depth of 120 mm. They concluded that tine with 90° rake angle required higher forces and exerted more power, while the tine with 50° rake angle was found to be most effective in terms of soil loosening and power consumption. Tine with 130° rake angle was found ineffective for soil tillage, due to its vertical force component being very high as compared to other tines. This resulted in more soil compaction and pulverization.

Tong and Ballel (2006) studied the effect of rake angles(15° to 75°) of a chisel plough and soil bulk density on angle of soil failure plane, rupture distance, width of side
crescent and frictional, overburden, cohesion and adhesion soil cutting factors. The experiment was carried out at two locations. The results showed that the angle of failure plane decreased with the rake angle. The rupture distance decreased with the rake angle from 15° to 55° and then increased. The width of the side crescent increased as the rake angle increased. The cohesion factor increased as the rake angle increased. The maximum and minimum values were more at rake angle of 75° and 15° rake angle respectively. The draft force decreased up to 45° rake angle.

2.2 Effect of Nose Angle on Soil Disruption and Power Requirement

Abernathy and Porterfield (1969) In soil bin containing light sandy soil. evaluated runner type furrow opener. It had vertical angle ranging from 90° to 150° and nose angle from 15° to 60°. They obtained more furrow depth for openers with larger vertical and nose angles.

Shrivastava and Panwar (1986) studied two lift angles of shovel (0° horizontal and 90° vertical) and three sweep angle (0° flat, 60° and 90°). They found that horizontal furrow opener of 90° sweep angle and 45° approach angle (nose angle) resulted minimum pull.

Hanna et al., (1993) studied sweep nose angles of 57°, 67°, 68° and rake angles 13.5°, 16°, and 44° at forward speed of 5, 7, and 9 km/h and depths of 5 and 10 cm. They concluded that with increase in rake angle and nose angle at depths, increased soil movement, ridge height and draft of sweep this was due to movements of soil on the sweep.

Mamman and Oni (2005) studied the model chisel furrower having nose angles of 10°, 20°, and 30° and slide angles of 5°, 10°, 15°, 20° at the travel speed of 0.02, 0.05, 0.10, 0.15 m/s and tillage depth of 2.5, 5, 7.5, and 10 cm. They concluded that draft increased with increase in speed ,tillage depth, nose angle and slide angle of furrower.

Altuntas et al. (2006) studied three types of furrow openers viz; shoe, hoe, and shovel having nose angles of 140°, 60°, and 35° and tool rake angles of 150°, 70°, and 30° with forward speed of 2.02, 3.28 and 4.50 km/hr. They lowest draft was found for shovel type furrow opener with the nose angle of 60° and tool rake angle of 70°.

Darmora and Pandey (2006) evaluated the performance of a shovel type furrow opener and BIS standard shovel having nose angle of 40° at uniform speed and depth of 0.562 m/s and 60 mm respectively. They concluded that draft requirement varied from 55 N to 59
This draft was about 18 to 19 per cent less in comparison to BIS standard shovel type furrow opener.

Darmora (2007) studied shovel type furrow opener having nose angles of $20^0$, $40^0$, $60^0$, and $80^0$ and rake angles of $30^0$, $40^0$, $50^0$, and $60^0$ at working depth of 4, 6, 8, and 10 cm under sandy loam soil. He concluded that soil was redistributed in a wider and flatter area with increasing nose angle and with slight increase in ridge height. The increase in nose angle gave more soil being tossed away resulting in increased furrow depth. Increased draft with increasing nose and rake angle attributed to higher soil disturbance. Multiple regression equation were also developed to predict the draft requirement.

Verma et al., (2007) studied three types of furrow opener viz shovel, shoe, and inverted T having nose angles $45^0$, $55^0$, and $60^0$ and rake angles $25^0$, $30^0$, and $35^0$ at two speed of operation 1.00 and 2.25 km/h. They concluded that inverted T type furrow opener required less draft, less soil disturbance and lowest clogging frequency due to minimum nose and rake angle as compared to shoe and shovel type furrow opener.

2.3 Effect of Depth of Operation on Soil Disruption and Power Requirement

Summers et al., (1986) studied draft relationship for primary tillage in Oklahoma soil and concluded that the draft was directly proportional to depth of operation and varied linearly for moldboard plough, chisel plough, disc plough and sweep plough.

Garner et al., (1987) studied tractor performance for subsoiling and subsoil-bedding in five different coastal plain soil conditions. They concluded that draft requirement increased as subsoiling depth increased.

Hanna et al., (1993) studied the effect of sweep geometry on soil movement for speed 5, 7 and 9 km/h and depth of operation 50 and 100 mm. They concluded that faster speeds and steeper rake angles ($13.5^0$ to $44^0$) created larger ridges. Change in surface height which was significantly affected by tool depth and speed.

Iqbal et al., (1994) studied the draft requirement of selected primary and secondary tillage implements at a speed of 2.5 km/h in silt clay loam soil at 13.2 per cent moisture content. They found that the draft of cultivator, chisel plow and subsoiler increased linearly with the increase in the depth of cultivation.

Younis et al., (1994) carried out a study for predicting variation in draft requirement with depth for different tillage implements at University of Agriculture, Faisalabad, Pakistan.
The implements were pulled through the soil at desired depth with a constant speed of 2.5 km/h. The depth of cultivation varied from 15 to 45 cm. The draft requirement of disc harrow and disc plough were 4710, 5101 and 6925 N and 4905, 6867 and 9810 N for 15, 20 and 25 cm depth of operation respectively. The relationship between draft requirement and the depth of operation was linear for cultivator. The draft requirement per centimeter of cutting width at shallow depth was very close for all the implements.

Janobi and Suhaibani (1998) studied the effect of speed and depth of operation on draft for major primary tillage implements (mould board plough, disk plough, and offset disk harrow) operating in sandy loam soil. They found that specific draft was significantly affected by depth. A regression equation to predict draft of these implements with an increase in depth was also developed.

Loghavi et al., (1999) studied the effect of three levels of soil moisture content (10-12, 13-15 and 16-18% d.b.) and ploughing depth (15, 20 and 25 cm) on draft, specific draft, and drawbar power requirements of a 3-bottom disc plough in a clay loam soil. The effect of ploughing depth was highly significant on draft and drawbar power requirement of disc plough. The mean values of these two parameters significantly increased with ploughing depth, while specific draft showed a mild decreasing trend.

Raper et al., (2000) investigated draft and energy requirement for shallow (0.18 m) and deep tillage (0.33 m) for cotton crop. They concluded that shallow tillage took approximately 50 per cent of the draft and energy requirement that of deep tillage. Soil strength decreased below the depth of compacted soil in shallow tillage.

Raper and Sharma (2004) evaluated straight shank and “minimum-tillage” shank in coastal plain soil in the soil bin of National Soil Dynamics Laboratory Auburn, Alabama. They concluded that the “minimum-tillage” shank reduced soil disruption compared to the straight shank. They also reported that lower soil moisture significantly increased the amount of spoil and trench area compared to all other soil moisture levels.

Raper (2005) developed two parameters, spoil resistance index and trench specific resistance to assess draft soil disruption and below ground soil disruption. He concluded that the below ground soil disruption should be maximized while above ground soil disruption should be minimized.

Mamman and Oni (2005) investigated the effect of draft on the performance of geometrically similar model chisel furrowers. The experiment was carried out in an artificial
soil in an indoor soil bin. The operating parameters were tool travel speed (0.02, 0.05, 0.10, 0.15 m/s) and tillage depth (2.5, 5, 7.5, 10 cm). They concluded that the draft increased with increase in tool travel speed as tillage depth, nose and slide angles, and cutting edge height increased. Draft increased with increase in tillage depth as nose and slide angles, and cutting edge height increased. Tillage depth of 7.5 cm had more influence on the draft of the model tools. The choice of the model tool depended on soil failure pattern at shallow depth, size and quality of furrow created at deeper depths.

Darmora and Pandey (2006) evaluated a shovel type furrow opener of a combined seed and fertilizer drill and the performance was evaluated standard shovel type furrow opener at a uniform speed and depth of 0.562 m/s and 60 mm respectively at an average soil moisture contain of 10 per cent (db). They concluded that the shovel type furrow opener created 12 per cent less soil disturbance in comparison to standard shovel type furrow opener.

Sahu and Raheman (2006) developed a methodology to predict the draft requirement of combination tillage implements in any soil and operating conditions. The draft requirement of a reference tillage tool (single disk), three scale-model individual (moldboard plow, cultivator and disk gang) and two combination (moldboard plow with disk gang and cultivator with disk gang) tillage implements at different depths (5, 7.5 and 10 cm), speeds (1.2, 2.2, 3.2, 4.2 km/h), wet bulk densities (in the range of 1.27-1.85 g/cm³) and cone index penetration resistance (445-1450 kPa) were determined in soil bin filled with sandy clay loam soil. They found that the developed equation predicted draft of both combination tillage implements within an average absolute variation of 18.0 per cent and 13.5 per cent respectively.

Arvidsson (2006) studied draft requirement for different tillage implements. He concluded that specific draft during primary tillage operation was generally lower for a mould board plough than for chisel or disc implements.

Kasisira and Plessis (2006) studied the effect of rear and front subsoiler in sandy clay loam soil. It was operated at a constant speed of 1.5 kmph. The rear subsoiler was operated at a constant depth of 600 mm. Depth of front subsoiler and the spacing were varied. For each run, cross-sectional area of the disturbed soil-profiles were measured at different sections. They concluded that the cross-sectional area per unit draft increased linearly, with spacing between the rear and front subsoilers. The efficiency of the subsoilers in this configuration was maximum when the longitudinal spacing was such that the soil failed by the front subsoiler was allowed to stabilize before the rear subsoiler reached it. The maximum
cross-sectional area failed per unit draft was recorded when the depth of the front subsoiler was equal to about 80% of the operating depth of the rear subsoiler.

Manuwa and Ademosun (2007) studied the effect of three different tillage tines viz: very narrow tine, narrow tine and wide tine having width and thickness of tine was 1, 5.1 and 20 cm and 8 mm respectively, on soil disruption at moisture content of 6 to 22 per cent (d.b). soil disturbance parameters viz. ridge-to-ridge distance, width of crescent or width of furrow at the surface, total disturbed width, height of ridge, and furrow depth. They reported that maximum width of soil throw decreased with increase in moisture content but increased with tine width. All the soil disturbance parameters increased as soil cone index increased except height of ridge.

Yadav et al., (2007) studied the effect of rake angle, approach angle, tilt angle, blade width, blade thickness, speed, depth of operation and geometry on specific draft. They concluded that specific draft varied polynomially with approach angle and speed. They also found that specific draft increased with increase in soil moisture content.

### 2.4 Conclusions from Review

The review suggested that soil disruption is measure of effectiveness of tillage implement. This depend on soil condition, rake angle, nose angle, depth of operation and moisture content. The ridge spacing and the width of soil distribution significantly increased with increase in tillage depth. Draft and power requirement are some of the important parameters with minimum values of specific draft and are desirable as they indicate low values of draft with maximum trench. The draft increased with the rake angle and nose angle at increased depth of operation.

The past studies indicate that the factors, namely rake angle, nose angle and depth of operation affect soil disruption, spoil resistance index, specific draft and power requirement. The results obtained from these studies have been considered while formulating the research plan in the present study.
CHAPTER III
MATERIALS AND METHODS

This chapter deals with experimental set-up, instrumentation and experimental procedure used for conducting the various tests under indoor soil bin conditions. The present study was planned to observe the effect of rake angle, nose angle and depth of operations on soil disruption, spoil resistance index, specific draft and power requirement in sandy loam soil.

3.1 Experimental Set-up

The experimental set-up comprised of an indoor soil bin, a power transmission unit, control panel, tool frame and a soil compaction unit.

3.1.1 Soil bin

The size of the indoor soil bin used for the various experiments was 20400 mm × 2300 mm × 600 mm. It existed in the department. It was filled with sandy loam soil and average moisture content of about 9-12 per cent (db) was maintained at which various farm operation are usually performed (Fig 3.1 and Fig 3.2).

3.1.2 Power transmission unit

The power from a DC variable shunt wound motor of 3 hp was transmitted to the wheels of the trolley trough belt and pulley arrangement. A rectangular tool frame was clamped to the horizontal beam at 600 mm distance from the center. A view of power transmission unit is shown in Fig 3.3.

3.1.3 Control panel

The control panel consisted of a control switch and a voltmeter. A regulator was used to increase or decrease the rpm of motor for obtaining the desired operating speed for the operation (Fig 3.4).

3.1.4 Soil compaction unit

A MS cylindrical roller of 310 mm diameter and 610 mm length was used. The purpose of roller was to maintain uniform compaction and soil level throughout the test (Fig 3.5).

3.1.5 Tool frame

A tool frame of 450 mm length and 400 mm width was fabricated by 30 mm MS square section to test cultivator shovels in the soil bin (Fig 3.6). It was clamped on the
(All dimensions are in mm)


Fig 3.1 Schematic diagram of the experimental setup

Fig 3.2 General view of soil bin.
Fig 3.3 A view of the power transmission unit

Fig 3.4 Pictorial view of Control Panel
Fig 3.5 General view of compaction unit in soil bin
horizontal beam of power transmission unit. The shovel was mounted on a tine and was clamped on a sliding bar on the main frame (Fig 3.6 and Fig 3.7). The sliding bar arrangement took care of up and side thrust forces developed during the operation. Depth of operation was adjusted by adjusting the height of the tine. An arrangement was provided to fix load cell between the main frame and the tool clamp to which tine was clamped.

### 3.1.6 Speed of operation

The forward speed of tool trolley was controlled by variable speed motor through control panel.

It was calculated by using the formula given below:

\[
S = \frac{d}{t}
\]

where,

\( S = \) Forward speed of tool trolley, \( m/s \)
\( d = \) Distance travelled, \( m \)
\( t = \) Time required, \( sec \)

### 3.2 Selection of experimental parameters

Various tool system and other parameters considered in the present study are given in Table 3.1

#### 3.2.1 Shovels

Tractor drawn cultivator reversible shovels are commonly used for sowing, intercultural and tillage operation in the region (Fig 3.8). They are having different nose angles. The nose angles selected for the study were 40\(^0\), 65\(^0\), and 75\(^0\). The performance of the commercially available reversible shovel was also compared with the BIS reversible shovel having nose angle of 90\(^0\).

#### 3.2.2 Tines

Tines were fabricated from MS-flat having width and thickness of 38 mm and 18 mm respectively. Four tines were fabricated for changing the rake angle of shovel (Fig 3.9).

#### 3.2.3 Depth of operation

Depending on the use of cultivator shovels for various farm operation the experiments were conducted for depth of operation in the range of 0.06 m to 0.15 m.
Fig 3.6 Schematic view of tool frame

Fig 3.7 General view of tool frame
Fig 3.8 Reversible shovels used for the experiments

(c) Nose angle 75°
(d) Nose angle 90° (BIS)

(All dimensions are in mm)
Fig 3.9 Tines used for the experiments

Table 3.1 Various parameters considered in the study

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Parameters</th>
<th>Levels</th>
<th>Particulars</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>A. Tool Parameter</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Tool type</td>
<td>1</td>
<td>Reversible shovel</td>
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<tr>
<td></td>
<td>B. System Parameters</td>
<td></td>
<td></td>
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<tr>
<td>1.</td>
<td>Rake angle, degree</td>
<td>4</td>
<td>15, 25, 35, 45</td>
</tr>
<tr>
<td>2.</td>
<td>Nose angle, degree</td>
<td>4</td>
<td>40, 65, 75, 90</td>
</tr>
<tr>
<td>3</td>
<td>Depth of operation, m</td>
<td>4</td>
<td>0.06, 0.09, 0.12, 0.15</td>
</tr>
<tr>
<td>4.</td>
<td>Speed, m/s</td>
<td>1</td>
<td>1.25</td>
</tr>
<tr>
<td></td>
<td>C Parameters to be observed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Soil disruption, m²</td>
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<td></td>
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<tr>
<td>2</td>
<td>Spoil resistance index, kN-m²</td>
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<tr>
<td>3</td>
<td>Specific draft or Trench specific resistance, kN/m²</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Power requirement, hp</td>
<td></td>
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</tbody>
</table>

3.4 Parameters Measured during the Experiment

3.4.1 Soil preparation in soil bin

Sandy loam soil was used in the experiments. Soil was compacted by M.S. cylinder roller in layers to simulate the soil conditions observed in the field. The average cone index value was 1154 kPa. Soil moisture level of 9-12 per cent (db) was maintained during the experiments.

3.4.2 Cone index
The cone index was used as a measure of soil strength. It is resistance (force per unit area) offered by soil against deformation or disruption, and measured with cone penetrometer (Anonymous, 1998 and Wilkinson et al., 2002). Soil cone index was measured from zero to 15 cm depth of soil. A Field scout digital cone penetrometer was used (Fig 3.12). It consisted of 30-degree cone with a cone diameter of 12.62 mm and a 706.25 mm long circular shaft of 10 mm diameter attached to compaction meter. The penetrometer was inserted in to the soil at

![Diagram of cone penetrometer](image)

**Fig 3.10 Measurement of soil disruption in soil bin**
25-30 mm/s and replication observations were recorded (Appendix A-3). The specifications of the instruments are given in Appendix B-4.

3.4.3 Soil disruption

Tillage implement disrupt the soil profile and rearrange the soil disruption. It is the measure of effectiveness of tillage implement. Soil disruption can be classified as surface and subsurface soil disturbance. The surface soil disturbance or spoil is a measurement of the amount of soil displaced above the original soil surface by the tillage process and subsurface soil disruption is the area that is disrupted below the soil surface and trenched area (Raper and Sharma 2004). The parameters of the soil disruption include the following (Fig 3.10).

1. Half width of spoil area, b
2. Crescent height, h
3. Furrow depth, d
4. Ground level, G

Soil disruption was measured with the help of soil profilometer (Fig 3.11). The profilometer was fixed across the trench. The main scale was adjusted with knobs and spirit level to keep it horizontally. With the help of plum bob the vertical depth or height of the soil surface was determined at every 2 cm horizontal distance on the main scale (Fig 3.13). Replicated observations of soil disruption were recorded for each shovel. After completion of the surface disruption measurement the profilometer was kept installed and the manipulated soil mass was removed from the trench below the profilometer with hand without disturbing the instrument. The cross sectional area of spoil and trench were calculated. Care was taken to ensure that only soil loosened by tillage was removed

3.4.4 Moisture content
For the measurement of soil moisture content, various samples of soil were taken at different locations in the soil bin. These samples were oven dried in a hot air oven at 105 °C for 24 hours. At the end of 24 hours weight of sample boxes with dry soil and weight of empty boxes were taken. The soil moisture content was calculated by using the following formula:

\[
MC = \frac{W_3 - W}{W_2 - W_1} \times 100
\]

(3.2)

1. Plumb bob  
2. Horizontal scale  
3. Spirit level  
4. Supporting rod  
5. Knob

Fig 3.12 Schematic view of profilometer for measurement of soil disruption
Fig 3.13 Measurement of soil disruption in soil bin

Where, \( MC \) = Soil moisture content, per cent (db)

\[ W_1 = \text{Weight of empty moisture box, g} \]

\[ W_2 = \text{Weight of dry soil and the moisture box, g} \]

\[ W_3 = \text{Weight of wet soil and the moisture box, g} \]

3.4.5 Draft Measurement

To determine the draft a load cell with digital indicator was used (Fig 3.7). Specifications of the load cell and load cell indicator are given in Appendix B-1 and Appendix B-2. The load cell was calibrated by using a universal testing machine. The specifications of the Universal Testing Machine are given in Appendix B-3. Load cell was placed in between the tool clamp with sliding bar which slides along the rectangular frame and the point of attachment of frame to the tine. The draft readings of load cell were recorded from digital load cell indicator.

3.4.6 Spoil resistance index

The spoil resistance index was determined by multiplying the draft and spoil cross-sectional area as follows (Raper, 2005). It assists in assessing differences due to draft forces and soil cross-sectional area.

\[
SRI = D \times SCA
\]

---------- (3.3)

Where, \( SRI \) = Spoil resistance index, kN m\(^2\)

\( D \) = Draft, kN

\( SCA \) = Spoil cross-sectional area, m\(^2\)

3.4.7 Specific draft or Trench specific resistance (TSR)
It is defined as draft per unit trench cross-sectional area of the tilled furrow. It is advantageous for TSR to be small, because this indicated small values of draft coupled with large values below ground disruption. It was determined by using the following formula.

\[ TSR = \frac{D}{TCA} \]

Where, \( TSR \) = Trench specific resistance, kN/m²  
\( D \) = Draft, kN  
\( TCA \) = Trench cross-sectional area, m²

3.4.8 Power requirement

Power requirement of tillage implement is very important from the design point of view. The strength and rigidity of the implement and the size of the power unit (tractor) depend on power requirement. It was calculated by the following formula:

\[ \text{Power requirement (hp)} = \frac{\text{Draft (kN)} \times \text{Speed (m/s)}}{0.736} \]  

-------- (3.5)

3.5 Test procedure

The experiments were conducted to study the effect of nose angle, rake angle and depth of operations of reversible shovel on soil disruption, specific draft and power requirement for tractor drawn cultivator in sandy loam soil. The experiments were conducted at nose angles of 40°, 65°, 75°, 90°, rake angles of 15°, 25°, 35°, 45° and depth of operations of 0.06 m, 0.09 m, 0.12 m, 0.15 m at 1.25 m/s speed of operation. Reversible shovel, commonly used on tractor drawn cultivator in the region (40°, 65° and 75°) for tillage, sowing and intercultural operation were selected for the study and compared their performance with BIS shovel (90° nose angle). The soil moisture content 9-12 per cent and average cone index 1154 kPa maintained during the experiment. Draft was measured using a load cell and corresponding spoil resistance index, specific draft and power requirement were calculated
CHAPTER IV
RESULTS AND DISCUSSION

The present study was conducted to observe the effect of nose angle (40\(^0\), 65\(^0\), 75\(^0\), and 90\(^0\)), rake angle (15\(^0\), 25\(^0\), 35\(^0\), 45\(^0\)) and depth of operation (0.06 m, 0.09 m, 0.12 m and 0.15 m) of reversible shovel on soil disruption, specific draft and power requirement for tractor drawn cultivator in sandy loam soil. The experiments were conducted at speed of operation of 1.25 m/s at average soil moisture content of 10.8 per cent (db) under indoor soil bin conditions.

The results obtained during the experiments have been extensively discussed in this chapter under the following headings:

1) Effect of nose angle, rake angle and depth of operation on soil disruption.
2) Effect of nose angle, rake angle and depth of operation on spoil resistance index.
3) Effect of nose angle, rake angle and depth of operation on specific draft.
4) Effect of nose angle, rake angle and depth of operation on power requirement.

4.1 Effect of Nose Angle, Rake Angle and Depth of Operation on Soil Disruption

In the study the soil disruption is a measurement of the amount of soil displaced above the original soil surface (spoil) and below ground level (trench) by the tillage process (Raper and Sharma, 2004 and Raper, 2005).

4.1.1 Effect of nose angle, rake angle and depth of operation on soil profile of shovels

The spoil and trench profiles created by two shovels with 40\(^0\) and 65\(^0\) nose angle at different rake angles and depth of operations are presented in Fig 4.1 and Fig 4.2. The figures show that spoil furrow width and spoil furrow depth increased with increase in either rake angle or depth of operation for both the shovels. This may be attributed due to increase in rake angle and depth of operation which resulted in tossing of more soil and redistributing it in a wider length outside the trench. Similar findings are also reported by Darmora (2007).

At lower rake angle and depth of operation both shovels resulted in same spoil furrow width (0.24 m). At higher rake angle, 65\(^0\) nose angle shovel resulted in 33 per cent more furrow width than 40\(^0\) nose angle shovel (0.36 m). At higher depth of operation both shovels behaved in a similar way under similar conditions.
Fig 4.1 Spoil and trench profiles at different rake angles and depth of operations for 40° nose angle shovel
Fig 4.2: Spoil and trench profiles at different rake angles and depth of operation for 65° nose angle shovel. 

- **Spoil**
- **Trench**

**Rake Angles and Depths**
- Rake angle 15°: Depth 0.06 m
- Rake angle 25°: Depth 0.06 m
- Rake angle 35°: Depth 0.06 m
- Rake angle 45°: Depth 0.06 m

**Horizontal Distances**
- Horizontal Distance (10² m)
  - Depth 0.06 m
  - Depth 0.09 m
  - Depth 0.12 m
  - Depth 0.15 m

**Speed of Operation**
1.25 m/s
At lower depth, 65° nose angle shovel resulted in about 25 per cent and 28 per cent higher spoil furrow depth as compared to 40° nose angle shovel (0.032 m and 0.035 m) at lower (15°) and higher (45°) rake angle respectively. At higher depth of operation (0.15 m) similar behavior was observed resulting in about 29.50 per cent and 16.41 per cent increase in furrow depth than 40° nose angle shovel (0.061 m and 0.067 m) at lower (15°) and higher (45°) rake angle.

It was observed that at lower rake angle and depth of operation 65° nose angle shovel resulted in 10.34 per cent higher crescent height than 40° nose angle shovel (0.0145 m). This value increased to 10.52 per cent when rake angle increased to 45°. At higher depth of operation 65° nose angle shovel resulted in higher crescent height of 0.081 m and 0.0855 m as compared to that of 40° nose angle shovel (0.079 m and 0.0785 m) respectively. This may be attributed due to the increase soil movement due to increase in nose angle and rake angle. Darmora (2007) had also reported that nose angle and rake angle affect the crescent height.

Fig 4.3 and Fig 4.4 shows spoil and trench profiles created by two shovels with nose angle 75° and 90° (BIS) shovel at different rake angles and depth of operations. It was observed from these figures that spoil furrow width and spoil furrow depth increased with increase in either rake angle or depth of operation for both shovels. Similar reasons as that of shovels may be postulated for this behavior.

At lower rake angle and depth of operation both shovels resulted in same spoil furrow width (0.26 m). At higher depth of operation (0.15 m), 90° nose angle (BIS) shovel resulted in 14.28 per cent more spoil furrow width than 75° nose angle shovel (0.48 m) at 45° rake angle. This may be attributed due to the higher nose angle which resulted in more soil throw with lower crescent height at higher depth of operation.

At lower depth, 90° nose angle (BIS) shovel resulted in about 10.52 per cent and 15 per cent higher spoil furrow depth as compared to 75° nose angle shovel (0.038 m and 0.04 m) at lower (15°) and higher (45°) rake angle respectively. At higher depth of operation (0.15 m) 12.12 per cent and 15.94 per cent increase in furrow depth was observed as compared to 75° nose angle shovel (0.066 m and 0.069 m) at lower (15°) and higher (45°) rake angle respectively.

It was observed that at lower rake angle and depth of operation 90° nose angle shovel resulted in 8 per cent higher crescent height than 75° nose angle shovel and it increased to 14.66 per cent when rake angle increased up to 45° (0.043 m). At higher depth of operation where 90° nose angle shovel gave higher crescent height values (0.09 m and 0.089 m).
Fig 4.3 Spoil and trench profiles at different rake angles and depth of operation for 75° nose angle shovel

- Rake angle 15°
- Rake angle 25°
- Rake angle 35°
- Rake angle 45°

Horizontal Distance (10^2) m

Depth, (10^-2) m

Depth 0.06 m
Depth 0.09 m
Depth 0.12 m
Depth 0.15 m

Speed of operation 1.25 m/s
Fig 4.4 Spoil and trench profiles at different rake angles and depth of operation for 90° nose angle (BIS) shovel

Speed of operation 1.25 m/s
as compared to that of 75° nose angle shovel (0.0825 m and 0.086 m) at 15° and 45° rake angle respectively. This may be due to increased nose angle which resulted in more soil movement outside the furrow. Similar findings have been reported by Sharma et al.,(1992) that nose angle affects the crescent height of furrow.

4.1.2 Comparison among shovels with different nose angles

All shovels showed similar increasing trends for spoil furrow width, spoil furrow depth and crescent height at all rake angle and depth of operations. The data revealed that 90° nose angle shovel gave more spoil furrow width and furrow depth at all rake angle and depth of operation. At lower depth of operation (0.06 m) 90° nose angle shovel resulted 8.33 per cent and 33.33 per cent more furrow width than 40° nose angle shovel at lower (15°) and higher (45°) rake angle respectively. Whereas at higher depth of operation (0.15 m) it resulted in about 20 per cent and 39 per cent increase in furrow width. The effect was more at higher depth of operation and rake angles especially in the case of spoil furrow width. At lower depth of operation (0.06 m) 90° nose angle shovel gave 31.25 per cent and 31.42 per cent higher furrow depth as compared to 40° nose angle shovel at 15° and 45° rake angle respectively. Whereas at higher depth of operation (0.15 m), 90° nose angle shovel resulted 29.50 per cent and 29.85 per cent higher furrow depth. It was observed that at lower depth of operation (0.06 m), 90° nose angle shovel resulted 96.29 per cent and 186.67 per cent higher crescent height as compared to 40° nose angle shovel at 15° and 45° rake angle respectively. At higher depth of operation (0.15 m) it increased to 13.92 per cent and 13.37 per cent respectively.
4.1.3 Effect of nose angle, rake angle and depth of operation on spoil area

The ANOVA table (Table 4.1) shows that nose angle, rake angle and depth of operation and their interactions affect significantly the spoil area.

**Table 4.1 Analysis of variance for nose angle, rake angle and depth of operation on spoil area (x10^-3 m^2)**

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nose angle</td>
<td>226.902</td>
<td>3</td>
<td>75.634</td>
<td>7563.398**</td>
</tr>
<tr>
<td>Rake angle</td>
<td>2240.21</td>
<td>3</td>
<td>746.737</td>
<td>74673.693**</td>
</tr>
<tr>
<td>Depth</td>
<td>73.49</td>
<td>3</td>
<td>24.4967</td>
<td>2449.668**</td>
</tr>
<tr>
<td>Nose angle × rake angle</td>
<td>6.88666</td>
<td>9</td>
<td>0.765185</td>
<td>76.518**</td>
</tr>
<tr>
<td>Nose angle × depth</td>
<td>15.3309</td>
<td>9</td>
<td>1.70344</td>
<td>170.344**</td>
</tr>
<tr>
<td>Rake angle × depth</td>
<td>2.27777</td>
<td>9</td>
<td>0.253086</td>
<td>25.309**</td>
</tr>
<tr>
<td>Nose angle × rake angle × depth</td>
<td>3.57269</td>
<td>27</td>
<td>0.132322</td>
<td>13.232**</td>
</tr>
<tr>
<td>Error</td>
<td>1.28</td>
<td>128</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>7856.21</td>
<td>192</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>2568.6703</td>
<td>191</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Significant at 1 % level**

Figure 4.5 shows that spoil area increased with increase in rake angle and depth of operation for all shovels. Table 4.2 and Table 4.3 presents mean values of spoil area of nose angle, rake angle and depth of operations for two and three variables respectively. From Table 4.2 it was seen that 90° nose angle (BIS) shovel resulted in more spoil area than other shovels at all rake angles and depth of operations. 75° and 90° nose angle shovel gave 8.70 per cent and 34.50 per cent more spoil area than 40° nose angle shovel with in the test range of parameters respectively. The effect of rake angle was more on spoil area than the depth of operation. With the increase in depth of operation at a rake angle the rate of increase in spoil area was highest for 90° nose angle (BIS) shovel. This was more (176.20%) at lower rake angle (15°) than at higher rake angle 45° (93.05%). This may be due to less volume of spoil as compared to other nose angles shovel. With increase in nose angle the shovel threw more soil out of trench there by increasing spoil furrow depth which led to increase in spoil area. 75° and 65° nose angle at operating depth of 0.06 m and 40° nose angle shovel at 0.12 m depth of operation at rake angle 25° and 35° resulted in non significant change in the spoil area respectively (Table 4.3).
Table 4.2 Mean values of spoil area (x $10^{-3} \text{ m}^2$) showing the interaction effect of nose angle, rake angle and depth of operations (two variables).

<table>
<thead>
<tr>
<th>Nose angle (degree)</th>
<th>Depth, m</th>
<th>Rake angle (degree)</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.06</td>
<td>0.09</td>
<td>0.12</td>
</tr>
<tr>
<td></td>
<td>0.06</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>0.09</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>0.12</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>0.15</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Source

- **SE**
  - Nose angle: 0.014
  - Rake angle: 0.014
  - Depth: 0.014
- **LSD (0.05)**
  - Nose angle × rake angle: 0.029
  - Nose angle × depth: 0.029
  - Rake angle × depth: 0.029
Fig 4.5 Effect of rake angle on spoil area at different depth of operations and different nose angle shovels
Table 4.3 Mean values of spoil area (x 10^3 m^2) showing the interaction effect of nose angle, rake angle and depth of operation (three variables).

<table>
<thead>
<tr>
<th>Nose angle (degree)</th>
<th>Depth, m</th>
<th>0.06</th>
<th>0.09</th>
<th>0.12</th>
<th>0.15</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rake angle, (degree)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>25</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>35</td>
<td>35</td>
<td>35</td>
<td>35</td>
<td>35</td>
<td>35</td>
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<tr>
<td>45</td>
<td>45</td>
<td>45</td>
<td>45</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: SE, LSD (0.05)
Nose angle × rake angle × depth: SE 0.058, LSD (0.05) 0.162
4.1.4 Effect of nose angle, rake angle and depth of operation on trench area

The ANOVA table (Table 4.4) shows that for nose angle, rake angle and depth of operation and their interactions affect significantly the trench area.

Table 4.4 Analysis of variance for nose angle, rake angle and depth of operation on trench area ($\times 10^{-3} \text{m}^2$)

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nose angle</td>
<td>12.1656</td>
<td>3</td>
<td>4.0552</td>
<td>405.520**</td>
</tr>
<tr>
<td>Rake angle</td>
<td>1995.84</td>
<td>3</td>
<td>665.28</td>
<td>66527.999**</td>
</tr>
<tr>
<td>Depth</td>
<td>5.22555</td>
<td>3</td>
<td>1.74185</td>
<td>174.185**</td>
</tr>
<tr>
<td>Nose angle × rake angle</td>
<td>1.81065</td>
<td>9</td>
<td>0.201183</td>
<td>20.118**</td>
</tr>
<tr>
<td>Nose angle × depth</td>
<td>0.379051</td>
<td>9</td>
<td>0.0421167</td>
<td>4.212**</td>
</tr>
<tr>
<td>Rake angle × depth</td>
<td>0.381297</td>
<td>9</td>
<td>0.0423664</td>
<td>4.237**</td>
</tr>
<tr>
<td>Nose angle × rake angle × depth</td>
<td>0.741379</td>
<td>27</td>
<td>0.0274585</td>
<td>2.746**</td>
</tr>
<tr>
<td>Error</td>
<td>1.28</td>
<td>128</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>6404.212</td>
<td>192</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>2016.5436</td>
<td>191</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Significant at 1% level

Figure 4.6 shows that trench area increased with increase in depth of operation and decrease with increase in rake angle for all shovels. Table 4.5 and Table 4.6 presents mean values of trench area of nose angle, rake angle and depth of operation for two and three variables respectively. From Table 4.5 it was seen that $90^\circ$ nose angle (BIS) shovel resulted in more trench area ($0.008068 \text{m}^2$) than other nose angle shovels at all rake angle and depth of operation. $65^\circ$ and $90^\circ$ nose angle shovel gave 1.34 and 2.64 per cent more trench area than $40^\circ$ and $75^\circ$ nose angle shovel. Whereas $90^\circ$ nose angle shovel resulted 8.65 per cent higher trench area as compared to $40^\circ$ nose angle at all rake angles and depth of operation. This may be due to the higher nose angle of shovel that disturbed soil in larger zone.

Similar to spoil area, the rake angle affected more the trench area than the depth of operation (Table 4.5). However at the $90^\circ$ nose angle trench area increased 196.68 per cent at $15^\circ$ rake angle and at $45^\circ$ rake angle to 208.62 per cent when depth of operation increased from 0.06 m to 0.15 m (Table 4.6). This may be attributed due to the higher in nose angle and rake angle which caused more soil movement as compared to other nose angle shovels.
Fig 4.6 Effect of rake angle on trench area at different depth of operations and different nose angles shovel
Table 4.5 Mean values of trench area \((x \times 10^{-3} \text{ m}^2)\) showing the interaction effect of nose angle, rake angle and depth of operations (two variables).

<table>
<thead>
<tr>
<th>Nose angle (degree)</th>
<th>Depth, m</th>
<th>Rake angle (degree)</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.06</td>
<td>0.09</td>
<td>0.12</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Depth</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0.06 m</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3.740</td>
<td>6.175</td>
<td>9.625</td>
<td>12.275</td>
<td>7.954</td>
</tr>
<tr>
<td>0.09 m</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3.640</td>
<td>6.010</td>
<td>9.445</td>
<td>12.145</td>
<td>7.810</td>
</tr>
<tr>
<td>0.12 m</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3.555</td>
<td>5.875</td>
<td>9.310</td>
<td>11.865</td>
<td>7.651</td>
</tr>
<tr>
<td>0.15 m</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3.445</td>
<td>6.645</td>
<td>9.120</td>
<td>11.350</td>
<td>7.515</td>
</tr>
<tr>
<td>Mean</td>
<td>7.954</td>
<td>7.810</td>
<td>7.651</td>
<td>7.515</td>
<td>3.595</td>
<td>5.926</td>
<td>9.375</td>
<td>12.039</td>
<td></td>
</tr>
</tbody>
</table>

Source                     SE     LSD \((0.05)\)
Nose angle                 0.014  0.040
Rake angle                 0.014  0.040
Depth                      0.014  0.040
Nose angle \times rake angle 0.029  0.081
Nose angle \times depth    0.029  0.081
Rake angle \times depth    0.029  0.081

Table 4.6 shows that at lower depth of operation \((0.06 \text{ m})\) \(40^\circ\) nose angle shovel gave non significant change in trench area when rake angle increased from \(15^\circ\) to \(25^\circ\), \(15^\circ\) to \(35^\circ\) and \(15^\circ\) to \(45^\circ\). Similarly \(65^\circ\) nose angle resulted non significant change in trench area when rake angle increased from \(15^\circ\) to \(25^\circ\) and \(25^\circ\) to \(35^\circ\) at 0.06 m depth and \(25^\circ\) to \(35^\circ\) at 0.09 m depth. Also at a depth of 0.12 m nose angle increased from \(40^\circ\) to \(75^\circ\) and \(65^\circ\) to \(75^\circ\) at rake angle \(15^\circ\) to \(25^\circ\) and \(25^\circ\) to \(35^\circ\) resulted non significant change in trench area. Similarly for depth of 0.09 m nose angle increase from \(65^\circ\) to \(90^\circ\) and \(65^\circ\) to \(75^\circ\) at rake angle \(15^\circ\) to \(35^\circ\) and \(15^\circ\) to \(25^\circ\) resulted in non significant change. This suggested that similar trench area could be obtained for different nose angles through specific combinations of rake angles and depth of operations.
Table 4.6 Mean values of trench area ($\times 10^3$ m$^2$) showing the interaction effect of nose angle, rake angle and depth of operation (three variables).

<table>
<thead>
<tr>
<th>Nose angle (degree)</th>
<th>Depth, m</th>
<th>0.06</th>
<th>0.09</th>
<th>0.12</th>
<th>0.15</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0.06</td>
<td>0.09</td>
<td>0.12</td>
<td>0.15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15</td>
<td>25</td>
<td>35</td>
<td>45</td>
</tr>
</tbody>
</table>

Source: SE, LSD (0.05)
Nose angle x rake angle x depth 0.058 0.162
4.2 Effect of nose angle, rake angle and depth of operation on spoil resistance index (SRI)

The ANOVA table (Table 4.7) shows that the nose angle, rake angle and depth of operation and their interactions significantly affect the spoil resistance index.

**Table 4.7 Analysis of variance for nose angle, rake angle and depth of operation on spoil resistance index (x \(10^{-3}\) kN-m\(^2\))**

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nose angle</td>
<td>46.0346</td>
<td>3</td>
<td>15.3449</td>
<td>12245.305**</td>
</tr>
<tr>
<td>Rake angle</td>
<td>485.326</td>
<td>3</td>
<td>161.775</td>
<td>129097.622**</td>
</tr>
<tr>
<td>Depth</td>
<td>18.5135</td>
<td>3</td>
<td>6.17118</td>
<td>4924.638**</td>
</tr>
<tr>
<td>Nose angle (\times) rake angle</td>
<td>15.9145</td>
<td>9</td>
<td>1.76828</td>
<td>1411.100**</td>
</tr>
<tr>
<td>Nose angle (\times) depth</td>
<td>2.75843</td>
<td>9</td>
<td>0.306492</td>
<td>244.582**</td>
</tr>
<tr>
<td>Rake angle (\times) depth</td>
<td>8.52516</td>
<td>9</td>
<td>0.94724</td>
<td>755.904**</td>
</tr>
<tr>
<td>Nose angle (\times) rake angle (\times) depth</td>
<td>1.36503</td>
<td>27</td>
<td>0.0505566</td>
<td>40.344**</td>
</tr>
<tr>
<td>Error</td>
<td>0.1604</td>
<td>128</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1935.421</td>
<td>192</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>578.597</td>
<td>191</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Significant at 1% level**

Fig 4.7 shows that spoil resistance index increased with the increase in rake angle and depth of operation for all shovels. Table 4.8 and Table 4.9 presents the mean values of spoil resistance index of nose angle, rake angle and depth of operation for two and three variables respectively. From Table 4.8 it was seen that 90\(^0\) nose angle (BIS) shovel resulted in higher spoil resistance index (2.965 x \(10^{-3}\) kN-m\(^2\)) than other nose angle shovels at all rake angles and depth of operation.

65\(^0\) and 90\(^0\) nose angle shovel gave 9.92 per cent and 31.77 per cent higher spoil resistance index than 40\(^0\) and 75\(^0\) nose angle shovel within the test range of rake angle and depth of operations. Similarly 90\(^0\) nose angle shovel resulted 75.13 per cent higher spoil resistance index than 40\(^0\) nose angle shovel at all rake angles and depth of operations. The higher spoil area values of 90\(^0\) nose angle shovel compensated the higher draft requirement resulting in higher spoil resistance index. This may be due to more spoil area and draft force.

It was observed that at minimum rake angle of 15\(^0\), the 65\(^0\) nose angle shovel resulted 36.32 per cent more spoil resistance index than 40\(^0\) nose angle shovel. The 90\(^0\) nose angle...
Fig 4.7 Effect of rake angle on spoil resistance index at different depths and different nose angles shovels
Table 4.8 Mean values of spoil resistance index (x $10^{-3}$ kN-m$^2$) showing the interaction effect of nose angle, rake angle and depth of operation (two variables).

<table>
<thead>
<tr>
<th>Nose angle (degree)</th>
<th>Depth, m</th>
<th>Rake angle (degree)</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.06</td>
<td>0.09</td>
<td>0.12</td>
</tr>
<tr>
<td>40</td>
<td>1.449</td>
<td>1.586</td>
<td>1.782</td>
</tr>
<tr>
<td>65</td>
<td>1.575</td>
<td>1.731</td>
<td>1.938</td>
</tr>
<tr>
<td>75</td>
<td>1.852</td>
<td>2.092</td>
<td>2.363</td>
</tr>
<tr>
<td>90</td>
<td>2.317</td>
<td>2.707</td>
<td>3.174</td>
</tr>
<tr>
<td>Depth</td>
<td>0.06 m</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>0.09 m</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>0.12 m</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>0.15 m</td>
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</tr>
<tr>
<td>Mean</td>
<td>1.798</td>
<td>2.029</td>
<td>2.314</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Source</th>
<th>SE</th>
<th>LSD (0.05)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nose angle</td>
<td>0.005</td>
<td>0.014</td>
</tr>
<tr>
<td>Rake angle</td>
<td>0.005</td>
<td>0.014</td>
</tr>
<tr>
<td>Depth</td>
<td>0.005</td>
<td>0.014</td>
</tr>
<tr>
<td>Nose angle x rake angle</td>
<td>0.010</td>
<td>0.029</td>
</tr>
<tr>
<td>Nose angle x depth</td>
<td>0.010</td>
<td>0.029</td>
</tr>
<tr>
<td>Rake angle x depth</td>
<td>0.010</td>
<td>0.029</td>
</tr>
</tbody>
</table>

resulted more spoil resistance index than 75° nose angle shovel at a 0.06 m depth of operation. Similarly with the increase in depth (0.15 m) 65° and 90° nose angle resulted in 12.64 per cent and 35.99 per cent more spoil resistance index than 40° nose angle and 75° nose angle shovel. This may be due to higher draft force and spoil area which contributed increase in spoil resistance index.

At 90° nose angle and at lower (0.06 m) and higher (0.15 m) depth of operation, spoil resistance index increased by 57.02 and 33.84 per cent when the rake angle increased from 15° to 45°. At lower depth of operation 90° nose angle gave 25.10 per cent more spoil resistance index than 75° nose angle whereas at higher depth of operation this value was 36 per cent (Table 4.8). This may be due to higher draft caused by 90° nose angle is at higher depth of operation. Table 4.9 shows that at lower depth of operation (0.06 m) 40° nose angle gave non significant change in spoil resistance index at rake angle 45° and 35°. Similarly at 0.12 m depth 90° nose angle and 65° nose angle at rake angle 25° and 15° resulted in non significant change in spoil resistance index.
Table 4.9 Mean values of spoil resistance index ($x 10^{-3}$ kN-m$^2$) showing the interaction effect of nose angle, rake angle and depth of operation (three variables).

<table>
<thead>
<tr>
<th>Nose angle (degree)</th>
<th>Depth of operation</th>
<th>Rake angle (degree)</th>
<th>Rake angle (degree)</th>
<th>Rake angle (degree)</th>
<th>Rake angle (degree)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.06 m</td>
<td>0.09 m</td>
<td>0.12 m</td>
<td>0.15 m</td>
<td></td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>25</td>
<td>35</td>
<td>45</td>
<td>15</td>
</tr>
<tr>
<td>40</td>
<td>0.178</td>
<td>0.204</td>
<td>0.234</td>
<td>0.278</td>
<td>0.662</td>
</tr>
<tr>
<td>65</td>
<td>0.224</td>
<td>0.286</td>
<td>0.332</td>
<td>0.376</td>
<td>0.770</td>
</tr>
<tr>
<td>75</td>
<td>0.360</td>
<td>0.427</td>
<td>0.521</td>
<td>0.601</td>
<td>0.923</td>
</tr>
<tr>
<td>90</td>
<td>0.483</td>
<td>0.660</td>
<td>0.831</td>
<td>1.021</td>
<td>1.173</td>
</tr>
</tbody>
</table>

Source: SE LSD (0.05)
Nose angle x rake angle x depth 0.020 0.057
4.3 Effect of nose angle, rake angle and depth of operation on specific draft

The ANOVA table (Table 4.10) shows that nose angle, rake angle and depth of operation and their interactions affect significantly the specific draft

**Table 4.10 Analysis of variance for nose angle, rake angle and depth of operation on specific draft (kN/m²)**

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nose angle</td>
<td>1098.71</td>
<td>3</td>
<td>366.237</td>
<td>3608.788**</td>
</tr>
<tr>
<td>Rake angle</td>
<td>634.602</td>
<td>3</td>
<td>211.534</td>
<td>2084.391**</td>
</tr>
<tr>
<td>Depth</td>
<td>1174.8</td>
<td>3</td>
<td>391.599</td>
<td>3858.694**</td>
</tr>
<tr>
<td>Nose angle × rake angle</td>
<td>18.9326</td>
<td>9</td>
<td>2.10362</td>
<td>20.728**</td>
</tr>
<tr>
<td>Nose angle × depth</td>
<td>14.2572</td>
<td>9</td>
<td>1.58413</td>
<td>15.610**</td>
</tr>
<tr>
<td>Rake angle × depth</td>
<td>8.26882</td>
<td>9</td>
<td>0.918757</td>
<td>9.053**</td>
</tr>
<tr>
<td>Nose angle × rake angle × depth</td>
<td>10.241</td>
<td>27</td>
<td>0.379296</td>
<td>3.737*</td>
</tr>
<tr>
<td>Error</td>
<td>12.9901</td>
<td>128</td>
<td>0.101485</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>9284.4285</td>
<td>192</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>2959.8094</td>
<td>191</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Significant at 1% level

Fig 4.8 shows that specific draft increased with rake angle at all depth of operations. Table 4.12 and Table 4.13 presents the mean values of specific draft of nose angle, rake angle and depth of operation for two and three variables respectively. From Table 4.12 it was seen that 90° nose angle (BIS) shovel resulted in higher specific draft (27.209 kN/m²) than other nose angle shovels at all rake angles and depth of operation. 65° and 90° nose angle shovel resulted 16.35 per cent and 12.53 per cent higher specific draft than 40° and 75° nose angle shovel with in the test range parameters. Similarly trend was observed for 90° nose angle shovel which resulted 29.58 per cent higher specific draft than 40° nose angle shovel. This may be attributed due to increase in draft and low trench area with the increase in nose angle at all levels of rake angles and depth of operations (Appendix D). Darmora 2007 and Maman and Oni (2005) reported that increase in draft with increase in depth attributed to increase in soil weight of shared soil segments on the shovel. Table 4.13 indicated that at operating depth of 0.15 m, 65° and 40° nose angle at rake angle 45° and 35° resulted non significant change in specific draft. Similarly 90° and 65° nose angle at rake angle 45° and 35° resulted non significant change at respective depth. For 90° and 40° nose angle at rake angle 45° and 35° and 25° and 15° resulted non significant change in specific draft at 0.12 m and 0.09 m depth of operation respectively
Table 4.11 Mean values of specific draft (kN/m²) showing the interaction effect of nose angle, rake angle and depth of operation (two variables).

<table>
<thead>
<tr>
<th>Nose angle (degree)</th>
<th>Depth, m</th>
<th>Rake angle (degree)</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.06</td>
<td>0.09</td>
<td>0.12</td>
</tr>
<tr>
<td></td>
<td>Depth</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.06 m</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>0.09 m</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>0.12 m</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>0.15 m</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Source SE LSD (0.05)
Nose angle 0.046 0.129
Rake angle 0.046 0.129
Depth 0.046 0.129
Nose angle × rake angle 0.092 0.257
Nose angle × depth 0.092 0.257
Rake angle × depth 0.092 0.257
Fig 4.8 Effect of rake angle on specific draft at different depth of operation and different nose angle shovels
Table 4.12 Mean values of specific draft (kN/m²) showing the interaction effect of nose angle, rake angle and depth of operation (three variables).

<table>
<thead>
<tr>
<th>Nose angle (degree)</th>
<th>0.06</th>
<th>0.09</th>
<th>0.12</th>
<th>0.15</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Depth, m</td>
<td>Rake angle (degree)</td>
<td>Rake angle (degree)</td>
<td>Rake angle (degree)</td>
</tr>
<tr>
<td></td>
<td>0.06</td>
<td>0.09</td>
<td>0.12</td>
<td>0.15</td>
</tr>
<tr>
<td>15</td>
<td>25</td>
<td>35</td>
<td>45</td>
<td>15</td>
</tr>
</tbody>
</table>

Source: SE, LSD (0.05)
Nose angle x rake angle x depth  0.184  0.515
A linear regression analysis was done to obtain the relationship of the form (Eqn. 4.1) between specific draft and forward speed at different depth of operations for various nose angles was developed the regression constants for the equation are given in Table 4.14.

\[
SD = ms + C_1
\]

Where, SD = Specific draft, kN/m²
s = Forward speed of operation, m/s
C_1 = Regression constant

The \(R^2\) values indicate that the relationship predicts the specific draft values fairly well.

<table>
<thead>
<tr>
<th>Depth, m</th>
<th>Nose angle (degree)</th>
<th>Source Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.06</td>
<td>40</td>
<td>Nose angle 0.334552</td>
<td>3</td>
<td>0.111517</td>
<td>39371.317**</td>
</tr>
<tr>
<td>0.09</td>
<td>65</td>
<td>Rake angle 4.57483</td>
<td>3</td>
<td>1.52494</td>
<td>538383.131**</td>
</tr>
<tr>
<td>0.12</td>
<td>75</td>
<td>Depth 0.139631</td>
<td>3</td>
<td>0.0465438</td>
<td>16432.348**</td>
</tr>
<tr>
<td>0.15</td>
<td>90</td>
<td>Nose angle × rake angle 0.0337486</td>
<td>9</td>
<td>0.00374984</td>
<td>1323.888**</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Nose angle × depth 0.00523119</td>
<td>9</td>
<td>0.000581243</td>
<td>205.209**</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rake angle × depth 0.0466017</td>
<td>9</td>
<td>0.00517797</td>
<td>1828.090**</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Nose angle × rake angle × depth 0.00265831</td>
<td>27</td>
<td>9.8456E-005</td>
<td>34.760**</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Error 0.00362553</td>
<td>128</td>
<td>2.83245E-006</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total 19.4964</td>
<td>192</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Corrected Total 5.1372503</td>
<td>191</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Significant at 1 % level

4.3 Effect of Nose angle, Rake angle and Depth of Operation on Power requirement

The ANOVA table (Table 4.14) shows that nose angle, rake angle and depth of operation and their interactions affect significantly the power requirement.
Figure 4.9 shows that power requirement increased with increase in rake angle at all depth of operations for all nose angle shovels. Table 4.16 and Table 4.17 presents the mean values of power requirement of nose angle, rake angle and depth of operation for two and three variables respectively. From Table 4.16 it was seen that the slope of the curves show that increase in rake angle affects power requirement more than the depth of operation. The BIS code recommended shovel (90° nose angle) required more power than other nose angles at all rake angle and tillage depths. 65° nose angle and 90° nose angle required 4.33 per cent and 16.01 per cent more power than 40° and 75° nose angle respectively, with in the test range of rake angle and depth of operation. This may be attributed due to the effect of nose angle which resulted in higher draft values.

Table 4.17 shows that at depth of 0.09 m nose angle 75° and 40°, 90° and 75°, and 65° and 40° gave non significant change in power requirement at rake angle 45° and 15°, 25° and 45°, and 25° and 35 respectively. Also nose angle 90° and 75° gave non significant change when rake angle increased from 15° to 35° at 0.06 m depth of operation.

Table 4.15 Mean values of power requirement (hp) showing the interaction effect of nose angle, rake angle and depth of operation (two variables).

<table>
<thead>
<tr>
<th>Nose angle (degree)</th>
<th>Depth, m</th>
<th>Rake angle (degree)</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.06</td>
<td>0.09</td>
<td>0.12</td>
</tr>
<tr>
<td>40</td>
<td>0.245</td>
<td>0.264</td>
<td>0.291</td>
</tr>
<tr>
<td>65</td>
<td>0.260</td>
<td>0.280</td>
<td>0.295</td>
</tr>
<tr>
<td>75</td>
<td>0.295</td>
<td>0.320</td>
<td>0.342</td>
</tr>
<tr>
<td>90</td>
<td>0.335</td>
<td>0.371</td>
<td>0.399</td>
</tr>
<tr>
<td>Depth</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.06 m</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>0.09 m</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>0.12 m</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>0.15 m</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Mean</td>
<td>0.284</td>
<td>0.309</td>
<td>0.332</td>
</tr>
</tbody>
</table>

Source                SE       LSD (0.05)  
Nose angle            0.000   0.001  
Rake angle            0.000   0.001  
Depth                 0.000   0.001  
Nose angle × rake angle 0.000  0.001  
Nose angle × depth    0.000   0.001  
Rake angle × depth    0.000   0.001  

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Fig 4.9 Effect of rake angle on power requirement at different depth of operation and different nose angle shovels
Table 4.16 Mean values of power requirement (hp) showing the interaction effect (three variables) of nose angle, rake angle, and depth of operation

<table>
<thead>
<tr>
<th>Nose angle (degree)</th>
<th>Depth, m</th>
<th>0.06</th>
<th>0.09</th>
<th>0.12</th>
<th>0.15</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rake angle (degree)</td>
<td>Rake angle (degree)</td>
<td>Rake angle (degree)</td>
<td>Rake angle (degree)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>25</td>
<td>35</td>
<td>45</td>
<td>15</td>
</tr>
<tr>
<td>40</td>
<td>0.087</td>
<td>0.093</td>
<td>0.100</td>
<td>0.109</td>
<td>0.172</td>
</tr>
<tr>
<td>65</td>
<td>0.100</td>
<td>0.107</td>
<td>0.111</td>
<td>0.114</td>
<td>0.190</td>
</tr>
<tr>
<td>75</td>
<td>0.133</td>
<td>0.141</td>
<td>0.151</td>
<td>0.160</td>
<td>0.214</td>
</tr>
<tr>
<td>90</td>
<td>0.153</td>
<td>0.167</td>
<td>0.177</td>
<td>0.189</td>
<td>0.245</td>
</tr>
</tbody>
</table>

Source: SE: 0.001, LSD (0.05): 0.003

Nose angle x rake angle x depth
A linear regression analysis was done to obtain the relationship of the form (Eq. 4.2) between power requirement and forward speed at different depths of operation for various nose angles shovel. The values of regression constants are given in Table 4.17.

\[
PR = ms + C_2
\]

\[\text{------------------------} \quad (4.2)\]

Where, \( PR \) = power requirement, hp
\( s \) = forward speed of operation, m/s
\( C_2 \) = regression constant

The \( R^2 \) values indicate that the relationship predicts the power requirement values fairly well.

**Table 4.17 Linear regression constants for predicting power requirement at different depth of operations.**

<table>
<thead>
<tr>
<th>Depth, m</th>
<th>40</th>
<th>65</th>
<th>75</th>
<th>90</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>m</td>
<td>( C_2 )</td>
<td>( R^2 )</td>
<td>m</td>
</tr>
<tr>
<td>0.06</td>
<td>0.018</td>
<td>0.163</td>
<td>0.985</td>
<td>0.0031</td>
</tr>
<tr>
<td>0.09</td>
<td>0.051</td>
<td>0.169</td>
<td>0.996</td>
<td>0.0036</td>
</tr>
<tr>
<td>0.12</td>
<td>0.063</td>
<td>0.189</td>
<td>0.992</td>
<td>0.0045</td>
</tr>
<tr>
<td>0.15</td>
<td>0.052</td>
<td>0.198</td>
<td>0.993</td>
<td>0.0041</td>
</tr>
</tbody>
</table>

The results presented in this chapter give a comprehensive picture of interaction between tool and soil and the effect of parameters like nose angle, rake angle and depth of operation on the effectiveness of its utilization in sandy loam soil. The soil disruption pattern, spoil resistance index, specific draft and power requirement values could be of great help in selecting the tool and operating parameters to meet out the requirements of the designer and user.
CHAPTER V

SUMMARY AND CONCLUSIONS

India is a vast country with 329.5 million hectares geographical area. Agriculture is still the main occupation of 70 per cent of Indian population. The population has been increasing at the rate of 1.8 per cent annually and will be about 1.3 billion by the end of 2030. This will require 260 to 264 million tones of food grains to feed the population. Farm mechanization is one of the way outs for all the issues of agricultural operations. Farm mechanization technique can be taken by agriculturists to enhance productivity and profitability. The mechanization of Indian agriculture has played dominant role in increasing agricultural production, productivity and profitability by timely farm operations, saving in cost of operation, maximizing utilization efficiency of agricultural inputs by their judicious applications and reducing losses. In developing countries like India, mechanization means improved tool, implement, machinery or structure that assists in enhancement of workers output which enables in removing or reducing drudgery or stress. The use of farm machinery depends upon the farm power sources available in the country for various tractive and stationary operations. For enhancing mechanization the farm power available will have to be increased from present level of 1.35 kW/ha to 2.00 kW/ha by 2020.

Tillage is an energy intensive farm operation consuming about 40 per cent of the total energy input required for crop production. It is basic operation in farming and is generally performed to breakup and pulverizes the soil and allows the free movement of air and water in order to promote plant growth. Cultivator is one of the most important tillage tools used by the Indian farmer. Even many organic farmers say that a pass with the cultivator has the same effect on the crop in dry weather as a half inch of rain. It is primarily the type of tillage implement which is used for opening the land, preparing the seedbed for sowing of the seeds as well as after the crop has come up a few centimeter above the ground. Reversible shovel, sweep, half sweeps, furrower etc. are the different types of tools that can be attached to a cultivator tine for different applications.

Reversible shovel and sweeps are primarily used for loosening and steering the soil. They are used on cultivators and are recommended for secondary tillage operation. Most of the farmers also use this shovel for primary cultivation. They are used in seed drills for opening the furrow and placement of seeds. They do not usually have an inverting effect and penetrate more easily in hard grounds because of less upward soil reaction. Nose angle of reversible shovel significantly affect the penetration of tine into the soil. This influences draft requirement and soil disruption. BIS code reversible shovel (BIS-6023) recommends a nose angle of 90° where as presently commercially available reversible shovel for tractor drawn cultivators are having nose angles between 40° to 75°.
Present study is aimed to compare the performance of commercially available reversible shovels with the recommended BIS code. A suitable combination of rake angle and nose angle of reversible shovel will reduce the draft requirement (power requirement) and maximize soil disruption at different depths of working for various farm applications. Therefore soil-tool-tillage complex needs to be studied for a given location and tool geometry for better tool performance and energy.

Tillage implements disrupt the soil profile and rearrange the soil components. Soil disruption is the measure of effectiveness of tillage implement. It can be surface soil disruption or spoil which is a measurement of the amount of soil displaced above the original soil surface by the tillage process. The subsurface disruption is the area that is disrupted below the soil surface or trench area. The availability of draft and power requirement data of tillage implement is an important factor in selecting suitable tillage implement for a particular farming situation. They are utilized by farm managers and consultants to determine correctly the proper size of tractor required for a given farm operation. Nose angle, rake angle and operating depth are factors that affect the draft and power of a tillage implement. They also depend on soil conditions and geometry of tillage implement.

Keeping these points in view the present study was conducted to provide information on soil disruption, spoil resistance index, specific draft and power requirement for cultivator shovels to improve soil conditions in sandy loam soil with the following objective.

To study the effect of nose angle, rake angle and depth of operation of reversible shovel on soil disruption, specific draft and power requirement for tractor drawn cultivator in sandy loam soil.

5.1 Experimental Facilities

The experimental set-up comprised of an indoor soil bin, a power transmission unit, control panel, tool frame and a soil compaction unit. The size of the indoor soil bin used for the various experiments was 20.4 m × 2.30 m × 0.6 m. It was filled with sandy loam soil and average moisture content of about 10.8 per cent (d.b) and soil cone index 1154 kPa was maintained at which various farm operation are usually performed. A MS cylindrical roller of 310 mm diameter and 610 mm length was used to maintain uniform compaction and soil level through out the test to simulate field condition. Soil cone index was measured for 0 to 15 cm depth of operation. A tool frame of 450 mm length and 400 mm width was fabricated by 30 mm MS square section to test cultivator shovels in the soil bin. Depth of operation was adjusted by adjusting the height of tine. An arrangement was provided to fix load cell between the main frame and the tool clamp to which tine was clamped. A uniform speed of operation 1.25 m/s was maintained for all experiments. The nose angle of shovels
selected for the study were 40°, 65°, and 75°. The performance of these commercially available reversible shovel was compared with BIS code recommended reversible shovel of 90° nose angle. Four levels of rake angle viz; 15°, 25°, 35° and 45° was selected. Depending on use of cultivator shovels experiments was conducted at 0.06 m to 0.15 m depth of operation.

Standard procedure was followed for measurement of soil moisture content. One of shovel (nose angle 40°) was mounted on the fabricated tine (rake angle 15°) and clamped on the sliding bar of tool frame. Depth of operation of 0.06 m was maintained. Soil disruption was measured with the help of soil profilometer. Spoil area and trench area were measured. Similarly Steps were followed for other shovels and depth of operations.

5.2 Soil Disruption Pattern of Shovels

5.2.1 Spoil and Trench area

Spoil area increased with increased in nose angle at all levels of rake angle and depth of operation. 90° nose angle shovel resulted in more spoil area (0.01148 m²) than others nose angles tested at all rake angles and depth of operation. With increase in rake angle at depth of operation the rate of increase in spoil area was highest for 90° nose angle (BIS) shovel which was more (176.20 per cent) at lower rake angle (15°) than at higher rake angle 45° (93.05 per cent).

Trench area increased with increase in depth and decrease with increase in rake angle for all shovels. 90° nose angle (BIS) shovel resulted in more trench area than other nose angle shovels at all rake angle and depth of operation. With the increase in rake angle at depth of operation. The rate of increase in trench area was highest for 90° nose angle (BIS) shovel which was more (196.68 per cent) at lower rake angle (15°) than at higher rake angle 45° (208.62 per cent.)

5.3 Spoil resistance index of shovels

Spoil resistance index increased with the increase in rake angle at all depth of operation for all shovels. 90° nose angle (BIS) shovel resulted in more spoil resistance index (2965 x 10⁻³ kN-m²) than other nose angle shovels at all rake angle and depth of operation.

5.4 Specific draft of shovels
Specific draft increased with increase in rake angle at all depth of operations. 65° nose angle and 90° nose angle required 16.35 per cent and 12.53 per cent higher specific draft than 40° and 75° nose angle respectively.

5.5 Power requirement of shovels

Power requirement increased with increase in rake angle at all depth of operations for all nose angle shovels. 90° nose angle (BIS) shovel required more power than other nose angles at all rake angle and tillage depths. 65° nose angle and 90° nose angle required 4.33 per cent and 16.01 per cent more power than 40° and 75° nose angle respectively with in the test range of rake angle and depth of operation.

Based on the results of the study, following conclusions were drawn.

1. Spoil area increased with increase in rake angle at all depth of operation for all nose angle of shovels. Trench area decreased with increase in rake angle for all nose angle shovels. 90° nose angle (BIS) shovel gave highest spoil area (0.01148 m²) and trench area (0.008068 m²) among all the nose angle tested.

2. The spoil resistance index increased with increase in rake angle at all depth of operation for all nose angle of shovels. Spoil resistance index of BIS code 90° nose angle shovel resulted 75.13 per cent higher spoil resistance index than 40° nose angle shovel.

3. Specific draft increased with increase in rake angle at all depth of operation for all nose angle of shovels. The BIS code recommended 90° nose angle shovel resulted 29.58 per cent higher specific draft than 40° nose angle shovel.

4. Power requirement increased with increase in rake angle at all depth of operation for all nose angles of shovel. 90° nose angle shovel (BIS code) required 16 per cent more power than 75° nose angle and 65° nose angle shovel required 4.33 per cent more power than 40° nose angle shovel.


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