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Effect of tool and operational parameters on performance of tillage implements

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■ ABSTRACT : This article reviews the basic relationships between the soil parameters, tool geometry and operational parameters on the nature of soil disturbance and draft of the tillage tool. These relations will assist designers and operators of tillage implement or tillage tool in selecting the optimal design of the soil working elements and their supporting frame.

■ KEY WORDS : Tool geometry, Operational parameters, Tillage tools, Soil disturbance, Rake angle, Draft

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Tillage is the manipulation of soil and its main objective is to provide optimum environmental conditions for plant growth. In crop production system tillage is the prime most operation and it has its own importance in it. In spite of many researches on tillage, still tillage has not become an exact science. Even though our objective is to fulfill the optimum environmental conditions for the growth of plant, we can not quantitatively identify the desired soil conditions. Similarly, a force applied to a tillage tool to produce a given effect of changes.

In selection of tillage implements the type and degree of soil disturbance are the prime factors which are considered with the draft and penetration force requirements for efficient operation. Draft requirement of any tillage implement is a function of soil properties, tool geometry, working depth, travel speed and width of the implement (Gill and Vanden Berg, 1968).

Optimization of tillage tool geometry and working conditions minimizes the total energy input for a given tillage by reducing number of tillage operation (Marakoglu and Carman, 2009) and these parameters have extensive influence on performance of any tillage tool. In this review paper it has been tried to review the previous works to acquaint the effect of these parameters on performance of any tillage tools.

Effect of soil parameters on tillage tool performance:

Soil is the loose surface material consisting of inorganic particles and organic matter. Soil provides the structural support and the source of water and nutrients for plants used in agriculture. Soil properties *i.e.*, mainly soil type, moisture content, bulk density have greater level of influence on performance of any tillage implements because any tillage tool moving in a soil at a constant velocity will encounter soil forces acting upon the implement or tool.

Soil moisture content is a very important factor in regard to both draft and quality of work (Manuwa and Ademosun, 2007) because soil strength is related to the nature of the soil and its physical condition (Kepner *et al*., 1978). Breakup energy requirement of any soil will decrease as the increase in soil moisture and it will increase beyond particular moisture level. Tillage forces of a driest soil were greater when opposed or compared to all other soil moisture levels (Raper and Sharma, 2002). The similar trend was observed by the (Rashidi *et al*., 2013) and reported the highest draft force of 484 kgf was observed in 11.27 per cent soil moisture content and lowest 427 kgf in 22.87 per cent soil moisture content that is draft force decreased with increase in soil moisture content. This is due to the lubricating effect of moisture films surrounding soil articles and also to a decrease in soil strength imported by the moisture (Al-suhaibani *et al*., 2010; Al- Janobi and Al-Suhaibani, 1998; Mckyes and Maswaure, 1997; Grisso *et al*., 1996; Bowers, 1989 and Collins and Fowler, 1996).

Ademosun (1990) reported the decrease in draft linearly with increase in soil moisture content within 12 to 16% in sandy loam soil. In the year (1989) Guptha and Surendranath also reported that draft increased with decreased moisture content from 6.9 to 18.9% d.b. further increase in moisture made the steep rise in draft in clay. For this steep rise they have given the reason that the increased cohesion at higher moisture contents requiring greater force for failure. In another consideration some soils adhere to metals when soil moisture is increased; there by increasing draft force (Nichols, 1925 and 1931 and Chancellor, 1994).

According to Manuwa and Ademosun (2007) draft force increase with increase in moisture content and there results is in full agreement with Guptha and Surendranath (1989) findings which have got in clay soil. The rate of increase decreased as the moisture content increased because the cohesion of the soil was weakened by increased moisture content. When comes to effect of moisture content on soil disturbance. After plough furrow depth, height of ridge and soil rupture distance increased with increase in moisture content.

However, the maximum width of soil cut, maximum width of soil throws and ridge to ridge distance decreased with increase in moisture content and the maximum width of soil throw decreased with increase in moisture content but increased with tine width. They gave reason that soil particles or aggregates were heavier and highly held by cohesive forces within and therefore would not flow or move like when they had lesser water content.

Similarly Gill and Vanden Berg (1968) has mentioned that the soil strength will considerably increases as the soils loose the moisture continuously up to dry soil stage and he has also suggested that the time scheduling is very important and the operation which are performed under the optimum moisture content will substantially minimizes the energy requirements.

The reactions of soils to forces applied by tillage tools will depends on the dynamic properties of soil such as soil resistance to compression, resistance to shear, cohesion, adhesion and frictional resistance and these parameters will change according to the movement of soil (Kepner *et al*., 1978).

Regarding soil reaction forces Nichols (1931) has shown that reactive forces of all classes of soils are dominated by the film moisture on the colloidal particles and are directly related to soil moisture and colloidal content.

Similarly, any tillage tool involving in tillage operation will experience the sliding action of soil over its surface, during which friction exists between tool surface area and the soil particles, these friction components will directly affect the draft requirement of tillage tool. Kepner *et al.* (1978) have shown that when soil slide on metal, adhesive forces between the soil and the metal have a marked influence on the friction force. He has also stated that the adhesive forces are primarily due to the moisture films, and their magnitude varies with moisture content. The adhesive force has the effect of increasing normal load on the surface, thus increasing the tangential friction force. Wiesmer and Luth (1970) have shown that these frictional forces can account for 30 per cent of the total draft of a mould board plough.

Soil strength is one of the parameters, which decides the amount of energy required to produce a particular pulverization level. Kepner *et al.* (1978) have briefly given a note on the soil strength by different types of soils for example clay soils have higher breakup energy requirements than sandy or loams. Meanwhile he has also given special remarks on bulk density *i.e.* for a given soil, energy requirements increase with bulk density. According to John *et al*. (1987), at higher soil compaction, the bulk density will increase and the soil penetration resistance became high, consequently, the implements in the firm soils require a greater draft force to overcome a considerable amount of soil resistance, thus the draft force required to pull the implement in firm soil condition was greater than that of loose condition. Energy requirement of tillage tools directly related to the draft and also reflects on the soil condition, degree of compaction of agricultural soils, bulk density, and moisture content of soil and depth of soil (Mouazen, 2002). Similarly, Harrigan and Rotz (1994) reported that the draft force of a tillage increases with increase in bulk density.

The USDA tests indicated that soil type and soil condition have the most pronounced effect on soil reactions. Many researchers have given their experience with different types of soils and different types of tillage implements. For example, Nichols and reed have described the soil reaction to wide range of soil conditions encountered in tillage with mould board surfaces.

When it comes to the specific draft of plows, the soil type and soil condition are the two parameters which affect the specific draft as other parameters like plough speed, plough bottom shape, depth of ploughing, width furrow slice, type of attachments and adjustment of the plough. According O'collaghan and McCoy (1965) soil type and condition are by far the most important factors contributing to variations in specific draft and they have worked in different type of soils they have found different rules of specific draft based on their research work *i.e.* specific draft range from 1.4 to 2 N/cm^2 for sandy soils, upto 10 to 14 N/cm^2 for heavy gumbo soils, 2 to 5 N/cm^2 for sandy or silt loam soils, where as 4 to 8 N/cm^2 for clay loams and heavy clay soils.

Godwin and Spoor (1977) have described the draft of a standard tine as a product of two factors namely soil strength factor and tool geometry based on this Desbiolles *et al.* (1999) has given conceptual relationship between the soil strength factor and the cone penetration energy which has shown in the following Fig. 1. Similarly, with soil compaction draft increased with an increasing rate, as the cone index increased and it was because the soil strength (cohesion) increased with increased cone index (Manuwa and Ademosun, 2007; Horn, 1993 and Mouazen and Ramon, 2002). When it comes to soil disturbance, the height of ridge increased as the cone index increased for all tines. That was because of the strength or mechanical properties of the soil such as cohesion, angle of internal friction, bulk density increased as the cone index.

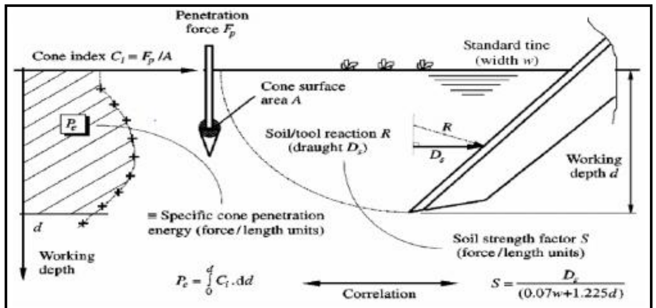

Fig. 1 : Conceptual relationship between the soil strength factor S and the cone penetration energy P_e

Effect of tillage tool geometry on tillage tool performance:

When it comes to tillage tool geometry it should be consider that the ultimate aim of tillage is to manipulation of a soil from a known condition to desired condition by any means in order to accomplish this objective we use tillage tools, which are mechanical devices used to apply forces to soil to cause desired soil condition. Many researchers have made possible approaches to get acquainted with mechanics of tillage tools to provide a method for describing the application of forces to soil and for describing the soil reaction to the forces. It has been made to review such scientific investigations in a possible manner.

A specific tillage tool will have the fixed geometrical shape, size, direction of travel, path of motion, orientation of the tool and which affect the resultant soil reactions and soil profile. The geometry of tools influences the stress distribution in the soil near the tool consequently, the effect of geometry affects penetration of tillage tool. The geometry may determine whether a tool acts as knife type tool that slides through the soil without sticking to its surface or whether it creates a compacted body of soil that sticks on its surface. Godwin (2006) reviewed the basic relationships between the geometry of tillage tools (Fig. 2) and soil physical properties on the nature of the soil disturbance ahead of the tool. These relationships are valuable to designers and operators of cultivation equipment in selecting the optimal design of the soil working elements and their supporting frame. According to USDA variations in the geometry of soil tillage tool systems result in different draft requirements for tillage and in different soil reactions and also the mode

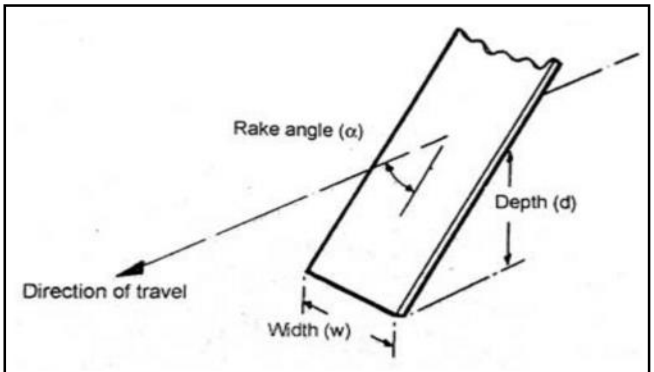

Fig. 2 : Basic tillage implements geometry

of soil action can be controlled by varying the geometry of the soil tool system so that forces, their distribution and soil reactions vary.

In tillage tool design, initial soil conditions, the shape of the tillage tool and the manner of movement of the tool becomes of primary importance. These factors define the manipulation of soil, but they cannot be clearly defined in a quantitative sense although qualitatively they represent distinct and complete elements in tillage tool design. The designer has complete control only over shape (Kepner *et al.*, 1978). The user of a tillage tool may vary the depth or speed of operation and may use the tool through a wide range of soil conditions. If tool shape is physically varied but the manner of movement and the initial soil conditions are kept constant, the forces required to move the tool and the resulting soil conditions vary as tool shape is varied. The available knowledge indicates that tool shape affects tool forces and the resultant soil condition. Consider the situation where the tool shape and manner of movement are kept constant but soil conditions are physically varied. Available knowledge indicates that for each initial soil condition, definite tool forces are required and a definite soil condition result. Smith and Williford (1988) reported that a parabolic subsoiler required reduced draft as compared to a conventional subsoiler and a triplex subsoiler and the reduction in draft associated with increased curvature may not always be true.

Force-shape relation have got wide emphasis in research studies when comes to primary tillage implements. Shape is the most difficult abstract factor to vary; perhaps that factor should be the first to be quantitatively developed rather than some other, such as speed. Although speed can obviously be quantitatively related at least to draft, the relation is probably not the most useful one for design. From the practical point of view shape should receive first priority even though speed or depth relations can be more easily obtained. The user of tillage tools can easily control soil manipulation by changing the manner of movement of the tool, such as depth, speed and width of cut. Usually user will have certain range within which the tool must be operated for example- a practical range for ploughing may be 10 to 20 cm deep and 5.6 to 8.9 km/h. Then shape is the most important factor which should be truly designed for these restricted conditions of depth and speed of operation.

Mould board ploughs are the most widely used soil loosening and turning tools, but subsoilers requires largest draft force to move them through the soil. Nichols *et al.* (1958) measured the draft of a series of subsoilers with macro shapes that ranged from the normal straight configurations to deeply curved configuration. Draft was measured in several soil conditions, and the results indicated that the subsoiler with the most curves required the least draft. In a highly compacted and cohesive soil the curved tool required from 7 to 20 per cent less draft than did the straight tool and the resultant soil breakup was approximately the same for all the tool shapes and finally they stated that the curved subsoiler presented an operational difficulty and they made no effort to the shape or to relate shape to draft except in the qualitative manner. In a similar research carried by Upadhyaya *et al.* (1984) also found a straight shank mounted at an inclination to the vertical gave reduced draft measurements compared to a curved subsoiler in sandy loam soil. Jori and Radics (2011) developed a combined evaluation system based on performance and draft data to select the most favorable shank type and found better performance and draft requirement in curved types than conventional straight shank. Tillage at optimum tool geometry and working conditions will minimize the number of subsequent tillage operations required. Therefore, the total energy for a given tillage system will decrease, it is important to know the draft requirements for different tool geometry (Marakoglu and Carman, 2009).

According to Kaburaki and Kisu (1959) knowledge of factors that govern the movement of soil particles such as sizes of soil particles, angle of inclination of a plane tool surface will be helpful in the design of tools, since it becomes important to be able to direct the sliding of soil along predetermined paths. These paths may direct the movement of the soil so that a minimum energy may be required for the movement or so that shearing strains will break up the soil.

A compacted mass of soil may gather on a blunt tip and move with the tool as an intricate part of the tool. During which, primarily soil- soil friction is active since most sliding is between soil and soil. Even though a point blunted or rounded, it may have little influence on the external appearance of the compacted soil body and on the force required to move in the soil (Zelenin, 1950). Again, when comes to the shape of the tool, scouring also dependent on shape of the tool. It means self-cleaning of the soil through a sliding action. In operation where scouring is adequate, soil flows over a tool along a path that is determined by the shape of the tool. Since co-efficient of soil metal friction of non-adhesive soil is normally less than that of soil- soil friction, less force required to move a tool through soil if sliding occurs along the metal surface. The absence of scouring creates the situation in which soil bodies are formed. Those adhering soil bodies increases the size of tool hence it leads to the change in geometry of tools to the extent, from which direction of flow of soils may change in to undesired directions. Simultaneously co-efficient of soil-soil friction becomes greater than co-efficient of soil-metal friction along the tool, which may lead to the increase in draft of the tillage tool (Dinglinger, 1932; Rathje, 1932; Zelenin, 1950; Payne, 1956; Tanner,1960 and Kaburaki and Kisu, 1959).

When comes to the forces on tools, these forces remain constant only as long as the geometric conditions of the tools are maintained. It is impossible to maintain similar geometric conditions. In a tillage tool operating under field conditions because of wear problem caused by rocks, roots and non-homogenous soil layers and abrasion changes the geometry of the tool and this may change the forces on the tool (Gavrilov and Koroschkin, 1954). Mean while exact data are not available to indicate the extent to which geometrical changes caused by wear affect soil reactions or forces on tools.

Lift angle of the tool is also associated with the geometry of the tool. The relation between the lift angle of the blade and the draft force is an important issue that many researchers have been focusing on (Godwin, 2007). The effect of lift angle was studied by several researchers for simple tillage tools, considering this angle as the rake angle (Alelko and Seig, 2000; Chi and Kushwaha, 1990) and they showed that draft force of a simple blade used in sandy loam with different densities increased with rake angle. In a comparison of the mean values of the draft force for different lift angles made by Godwin and O' Dogherty (2007) showed increasingly trends of the draft force with lift angles upto 90^0 and then decreased at 120^0 for all working depths and forward speeds. At lift angles by increasing the working depths and forward speed the draft force increases. By increasing the lift angles, the applied normal stress on the soil increases and hence the shear strength of the soil increases. Consequently, the draft force tends to increase (Abbaspour-fard *et al.*, 2014).

The same tendency was observed by the Ibrahmi (2015) for the variation of draft and vertical forces with cutting angle lift angle, speed and depth. They observed linear increase in draft with both the cutting and lifting angles, whereas the vertical force decreased linearly with both the cutting and lifting angles. The study of the soil disturbance showed that the operating conditions speed, depth and cutting angles of the mould board plough had an important effect on the quality of the tillage.

The study of the Payne and Tanner (1959); Godwin and Spoor (1977) and Godwin (2007) showed the effect of rake angle on horizontal and vertical forces in Fig. 3 and on soil disturbance patterns for tines in Fig. 4. The data clearly demonstrated how both horizontal and vertical forces increase with rake angle and for low draft and good penetration, implements should be designed with a low rake angle. In many situation procedures may have choices when selecting a set of shanks to perform operation however they may not have scientific information about which shank will results more draft force and which shank will leave soil in a best condition for future field operations. Therefore Raper (2002) conducted an experiment to determine the shank with minimal draft force requirements and soil disruption characteristics surprisingly; the bent leg shanks had the lowest draft requirements for both soil types. Bent leg shanks had lowest above ground soil disruption and straight shank with wide point had the largest below ground soil disruption. Siemens *et al.* (1965) concluded analytically as well as from experimental results that a rake angle of 25^0 gave the lowest draft. The rake angle of the furrow opener which gave minimum specific draft was reported by Mathur and Pandey (1992) as 28^0 for a lateritic sandy clay loam. Tool rake angle was the major contributory factor on draft efficiency as compared to forward velocity and working depth (Marakoglu and Carman, 2009).

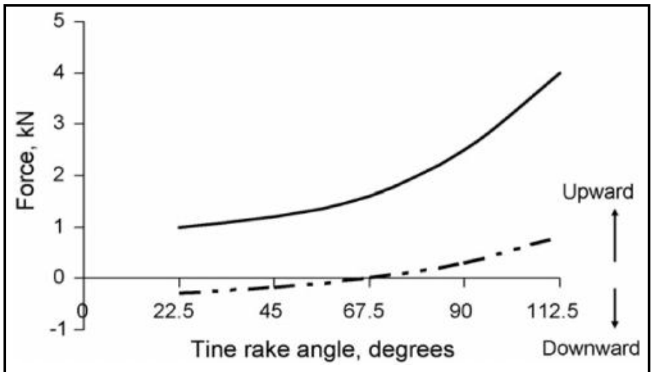

Fig. 3 : Effects of tine rake angle on horizontal (solid) and vertical forces (broken)

Badegoankar *et al*. (2010) also observed an increase in horizontal and vertical forces with increasing depth for all experimental shanks having different bend length, bend angle and width. The analysis of variances of their research showed that the effect of design parameters of shank and operational variables and their interactive effect on draft and vertical force were significant.

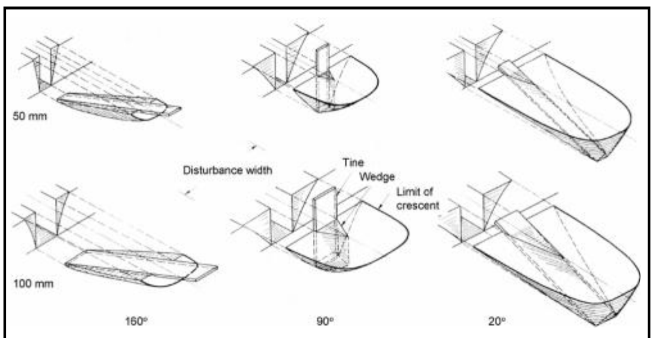

Fig. 4 : Effects of rake angle on soil disturbance patterns for tines of different widths operating at a particular depth

The effect of operational parameters on tillage tool performance:

Increased forward speed increases the draft with most tillage implements, mainly because of the more rapid acceleration of any soil that is moved appreciably. Soil acceleration increases draft for at least two reasons first- because acceleration forces increases the normal loads on soil engaging surfaces, thereby increasing frictional resistances, and second, because of the kinetic energy imparted to the soil. The magnitude of the effect of speed upon drafts depends on the relative magnitude of the components that are independent of speed and the components that increase with speed, as influenced by implement type and design and by soil type and condition (Keper *et al.*, 1978).

Many researchers have considered the relations between force and speed. Since the effect of speed on draft is large, it is of practical importance and an increase in speed increases draft (Telischi *et al.*, 1956). This trend has been sufficiently consistent so that quantitative relationships between speed and draft have been obtained (McKibben and Reed, 1952; Soehne, 1960). Research finding of Kushwaha and Linke (1996) reports that there is a critical speed range at which draft increased less with speed above the critical speed and soil deformation will also decrease above the critical speed. Onwualu and Watts (1998) also found that the draft and vertical force being a function of the speed and square of the speed while determining effect of speed on tillage tool force. The same result was observed by Spoor (1969) that is only because of the greater acceleration forces and these acceleration forces increase the reaction at the interface yielding higher sliding resistance and which intern contributes most to the increased draft. Collins and Fowler (1996) also reported that the forward speed was a significant determinant of the draft force.

Equation of draft prediction of ASABE standards (2009) indicated that by doubling the forward velocity, draft requirement increased but was not doubled. Also, many researchers confirmed this relationship between forward velocity and draft of primary tillage implements (Sahu and Raheman, 2006; Al-suhaibani *et al.*, 2006; Ranjbarian *et al.*, 2015).

Relation between the draft force and the forward speed is affected by the inertia of the accelerated soil mass and the rate of shear by the tillage tool which are both dependent on the soil type and condition (Swick and Perumpral, 1998). In general, the acceleration of soil mass increases by increasing the forward speed and the result is an increase in draft force. The soil shear resistance increases by increasing the shear rate and hence the forward speed. However, the effect of shear rate on soil shear resistance is greater with heavier soil texture. The greater effect of the forward speed on the rate of draft force at a shallower depth can be related to the freer movement of soil mass and more dynamic condition of these layers.

As for as operational parameters concern, depth of operation is also an important parameter which should be given more emphasis in force-tillage relation. In general, draft force increases with depth because with increasing depth, soil volume to be cut also increases in front of the tillage tool, which results in draft force (Ibrahmi *et al.*, 2015). Similar trend was observed by the Rashidi *et al.* (2013) *i.e.*, Tillage depth had strong influence on the pulling force of the tool in compare to the penetration angle and forward velocity. Usually all the tillage tools will yield increased draft due to increase in operating depth, larger surface area and more soil resistance, which requires more force to break up the soil. The reason for increased draft force is the high acceleration to the soil particles during their displacement. Badegaonkar *et al.* (2010) observed an increase in horizontal and vertical forces with increasing depth for all experimental shanks having different bend length, bend angle and width.

Al-suhaibani and Ghaly (2013) also reported that the ploughing depth had more pronounced effect on the draft than the forward speed. The reason behind it was increase in volume of the soil to be cut, moved and pulverized which required more force. The similar results were reported in the literature (Naderloo *et al.*, 2009; Abbaspur-Gilandeh *et al.*, 2006; Sahu and Raheman, 2006; Chen, 2002 and Al-Suhaibani *et al.*, 2010). While determining the nature of relationship between depth and force and speed and force Kiss and Bellow (1981) found significant effect of depth and speed over tillage tool force. According to them forward speed had less pronounced effect than depth of tillage because at higher depths more soil volume had resulted stiffer and denser soil because of over burden pressure and because of varying soil strength properties. The increase of the draft force with increasing working depth is usually related to the weight of the soil and thus its further consolidation. Moreover, with increasing working depth, the vertical component of soil reaction force is increased, causing more compaction effects on upper layers of the soil and then increasing draft forces (Godwin, 2007).

Based on their research Godwin and Spoor (1977) has given practical consideration to not work the equipment deeper than necessary and they feel small reduction in working depth can make a very significant difference to the magnitude of the horizontal force. They also have shown in Fig. 5 which indicates effect of tine depth on the horizontal and vertical forces acting on a 90^0 rake angle tine.

Nichols and Reaves (1958) reported that the improper operation can defeat the advantage of decreased draft with a curved subsoiler. Unless the curved tool is operated at its intended depth, all advantages of the curve may be lost. The advantage of proper use of the design is lost if operation is too deep; the curved subsoiler operates as though it were straight.

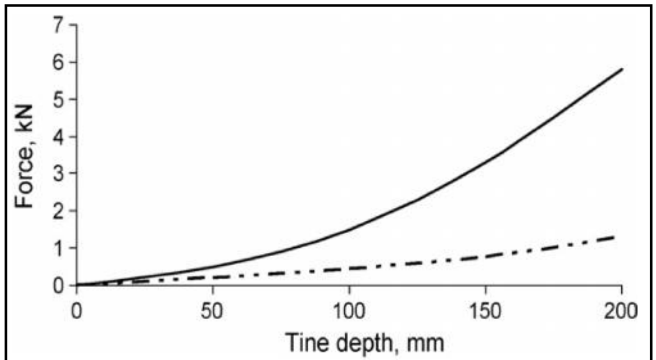

Fig. 5 : Effect of tine depth on the horizontal (solid) and vertical forces (broken)

Arvidsson *et al.* (2004) and Muysen *et al.* (2000) reported that the specific draft was affected by the depth of tillage, forward speed and differences in implement geometry. In general, with increasing cohesiveness of soil and degree of soil compaction, the specific draft increases with the depth which is related to the self-consolidation phenomenon in such soils. Fard *et al.* (2014) used the loam soil with some degree of cohesion and they observed the most linear increase of specific draft against the working depth.

As far as soil disturbance concerned Sapkale *et al.* (2010) reported that the spoil furrow width and depth increased with the increase in depth and speed of operation whereas reverse trend was observed for crescent height which decreased with increase in speed of operation. Spoil area was directly proportional to depth and speed of operation whereas, trench area decreased with increase in speed of operation for both sweeps. It was depth of operation which affected more the spoil and trench area than the speed of operation for reversible shovel. Shinde *et al.* (2011) observed similar trend and reason being that the increase in tillage depth and speed, which resulted in tossing of more soil and redistributing it in a wider length outside the trench. Whereas trench area increased with increase in depth and decrease with increase in speed of operation for both shovels and sweeps. Manuwa (2009) also reported that the soil disturbance parameters such as ridge to ridge distance, maximum width of soil cut, maximum width of soil throw, after furrow depth, height of ridge, rupture distance all increased as the depth of operation of the tool increased but less proportionately. Despande *et al.* (2015) reported that the working depth influenced the soil disturbance parameters but less proportionately. This is because the major factors that control the nature of soil failure or disturbance are the aspect ratio (depth/width ratio) and the rake angle.

Conclusion:

Many works have reviewed and a serious attempt has been made in this paper to provide a comprehensive knowledge about the effects of tool geometry, operational parameters and soil parameters on the performance of tillage implements. It should be concluded that there is a relationship between these parameters with draft, energy requirement and soil disruptions of any tillage tools. Spreadsheet based models are available to enable calculations of soil implement forces to be made and can be used to predict soil forces for a range of soil conditions and implement configurations.

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