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Draughts, Power Requirements and Soil Disruption of Subsoilers

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ABSTRACT

Draughts, power requirements and soil disruption of tillage tools are important parameters useful for their effective design, fabrication and performance during operation for effective agricultural mechanisation. Subsoilers have gained much ground in their application for alleviating soil compaction; and are attracting awareness in their utilization for conservative tillage practices. Subsoiler is a tractor mounted implement used to loosen and break up soil hard-pan at depths up to 60 cm and above the level of a traditional disk plough, mouldboard plough, chisel plough or rotary plough. Development and performance evaluation of subsoilers and their energy requirements during operation has been of great concern to engineers and farmers as these have direct and indirect effects on the efficiency of tillage operations. Draughts reduction, minimal power utilisation and increased soil disruption and pulverisation are some of the main performance indicators of subsoilers. Hence several researchers have studied various subsoilers and parameters to minimize draught force and total power requirements with considerable increase in soil pulverisation. Consideration should be given to the design of shanks shape of subsoiler, as they are very important to the efficiency and effectiveness of subsoiling. Thus, variation in power requirements depends on subsoiling depth, soil water conditions and the amount of compaction. In order to achieve better soil disturbance, reduced draught force and energy requirements, and less traction resistance, the application of vibratory (oscillatory) and rotary subsoilers in modern day design and development of subsoilers are preferred for lower overall demand on engine power.

Keywords: *Draughts, Power Requirements, Soil Disruption, Subsoilers, Deep Tillage*

INTRODUCTION

Draughts, power requirements and soil disruption of tillage tools are important parameters useful for their effective design, fabrication and performance during operation for effective agricultural mechanisation. Development and performance evaluation of tillage tools and their energy requirements during operation has been of great concern to engineers and farmers as these have direct and indirect effects on the efficiency of tillage operations.

Tillage tools are mechanical devices used for applying forces to the soil to cause one or more of cutting, movement, fracturing, loosening, overturning and pulverization of the soil to prepare a seed bed. Subsoiler is a tractor mounted implement used to loosen and break up soil at depths below the level of a traditional disk plough, mouldboard plough, chisel plough or rotary plough. Most tractor mounted cultivation tools will break up and turn over surface soil to a depth of 15-20 cm, while a subsoiler will break up and loosen soil to twice those depths. Typically a subsoiler mounted to a Compact Utility Tractor will reach depths of about 30 cm and above. The subsoiler is a tillage tool which will improve growth in all crops where soil compaction is a problem. The design provides deep tillage, loosening soil deeper than a tiller or plough.

Agricultural subsoilers has the ability to disrupt hardpan down to 60 cm depth and more [1-2]. Draft reduction, optimum power utilisation and increased soil disruption and pulverisation are some of the main performance indicators of subsoilers. Hence several researchers have studied various parameters to minimize draft force and total power requirements and considerable soil loosening [3]. This attempt is therefore made to review the draught, power requirements and soil disruption of subsoilers.

DRAUGHT AND ENERGY REQUIREMENTS FOR SUBSOILERS

Draught is an important parameter for measurement and evaluation of implement performance [4]. The specific draught of agricultural tools and implements varies widely under different conditions, being affected by such factors as the soil type and condition, ploughing speed, plough type, shape, friction characteristics of the soil-engaging surfaces, share sharpness, and shape, depth of ploughing, width of furrow slice, type of attachments, and adjustment of the tool and attachments. A great deal of work has been done in evaluating these various factors and investigating possible means for reducing draught [5]. Rational design must be based on knowledge of tool performance and soil parameters [6]. For efficient tillage, both must be considered with the aim of minimizing specific resistance, which is draught per unit area of soil disturbance [7 - 8].

Quantification of force response relations for the soil cutting process can be used by the equipment designer for improving cutting element design, and for mathematically simulating whole vehicle performance. Traditional tools have been designed in the light of empirical experimentation based on low speed tests and quasi-static theory of soil cutting. Experimental results cannot be directly extrapolated for use with high speed tools because the results would be unrealistic. The developed concepts in soil dynamics depend on controlled experiments. Soil-bin facilities are usually employed for such controlled studies. The use of microcomputer based data acquisition and control system has greatly enhanced data collection and processing and ensured better monitoring of the parameters varied during the experiments in the soil-bins [9].

A high-energy input is required to disrupt hardpan layer to promote improved root development and increased draught tolerance. Significant savings in tillage energy could be achieved by site-specific management of soil compaction. Site-specific variable-depth tillage system can be defined as any tillage system which modifies the physical properties of soil only where the tillage is needed for crop growth objectives. It was revealed that the energy cost of subsoiling can be decreased by as much as 34% with site-specific tillage as compared to the uniform-depth tillage technique currently employed by farmers. There is also a 50% reduction in fuel consumption by site-specific or precision deep tillage. Tillage implement energy is directly related to working depth, tool geometry, travel speed, rake angle, width of the implement, and soil properties [10]. Soil properties that contribute to tillage energy are moisture content, bulk density, cone index, soil cohesion and adhesion, and soil texture [11]. It has been reported that draught on tillage tools increases significantly with speed and the relationship varies from linear to quadratic.

[12]As reported by [8] estimated draught and soil disturbance of conventional and winged subsoilers working at depth of 0.35 m to be 20.43 kN and 0.098 m^2, and 26.58 kN and 0.184 m^2 respectively. He then recommended approximate practical spacing for simple and winged tines for good soil loosening as: (i) 1.5 x depth of work for simple tines;(ii) 2.0 x depth of work for winged tines.[13] Further stated that variation in power requirements depends on subsoiling depth, soil water conditions and the amount of compaction. Power to pull a subsoiler will depend on the number of shanks being pulled and tractive conditions. For most soil conditions optimum tractive efficiency can be obtained in the 10 to 15 percent slip range. If slip is more than 15 percent or less than 10 percent, ballast should be added or removed, respectively.

FORCES ON SUBSOILERS

[14] Reported that the draught requirement of any tillage implement was found to be a function of soil properties, tool geometry, working depth ,travel speed, and width of the implement [15]. Soil properties that contribute to tillage energy are moisture content, bulk density, soil texture and soil strength. The relationship between the draught of plane tillage tools and speed, has been defined as linear, second-order polynomial, parabolic and exponential.

[8]Reported forces acting on tillage tools to include: (i) horizontal or draught force: the amount of force required to pull or push the implement through the soil, (ii) vertical force: the implement force assisting or preventing penetration into the soil, and (iii) lateral or sideways forces. In parallel to the work referred to earlier, mathematical models have been developed to predict the magnitude of the soil forces acting upon implements of different geometry. These are based upon the general soil mechanics equation and enable the draught and vertical forces to be calculated from knowledge of the tool geometry, working depth, soil physical properties and the type of the soil disturbance pattern produced by the tool. They

have been integrated into a unified model described by [16] and formulated into a number of spreadsheets for the use of those who wish to estimate the effects of different implement geometry on the soil forces in a given soil and the effect of different soils on a given implement shape. The spreadsheets consider a range of implements, namely: (1) single and multiple tines, (2) land anchors, (3) discs, and (4) mould board ploughs.

MEASUREMENT OF TILLAGE FORCES USING INSTRUMENTATIONS

[9] and [17] Reported that measurement of forces on tillage tools have been an issue of great concern in soil tillage dynamics. Draught measurements are required for many studies including energy input for field equipment, matching tractor to an implement size, and tractive performance of a tractor. Vertical force affects weight transfer from implement to the tractor, and consequently, affects the tractive performance and dynamic stability of the tractor [18]. Several side loads can affect tractor's steering ability. However, side force is generally negligible during field operation [19].

Several researchers have worked on measurement of forces on tillage. [20] Explained four different types of instrumentations utilized in the measurement of forces on tillage tools. These are transducer, dynamometer, strain gauge and extended orthogonal ring transducer. Transducer is a device that converts a signal in one form of energy to another form of energy. Energy types include (but are not limited to) electrical, mechanical, electromagnetic (including light), chemical, acoustic and thermal energy. While the term *transducer* commonly implies the use of a sensor/detector, any device which converts energy can be considered a transducer.

Dynamometer is an instrument for determining power, usually by the independent measurement of forces, time and the distance through which the force is moved. A dynamometer must not only be able to measure the forces between itself and a tool, it must also be able to hold the tool in position so that the tool depth, width and orientation do not change during operation. Strain Gauges have replaced earlier used dynamometers with hydraulic units. With the advancement of technology, strain gauge force transducers have been developed. A direct-connected strain gauge that senses only the draught component of the pull has been put in place. Extended octagonal ring transducer is one of the most common methods used to measure specific forces on tillage tools. This transducer allows the measurement of forces in two directions and the moment in the plane of these forces [17].

On the other hand, the load cell is a transducer that is used to convert a force into an electrical signal. This deforms a strain gauge. The strain gauge measures the deformation (strain) as an electrical signal, because the strain changes the effective electrical resistance of the wire. A load cell usually consists of four strain gauges in a Wheatstone bridge configuration. Load cells of one strain gauge (Quarter Bridge) or two strain gauges (half bridge) are also available. The electrical signal output is typically in the order of a few mill volts and according to [21 -22] this requires amplification by an instrumentation amplifier before it can be used. The output of the transducer can be scaled to calculate the force applied to the transducer. The various types of load cells that exist include Hydraulic load cells, Pneumatic load cells and Strain gauge load cells. Load cells are currently being utilized in measuring different forces on tillage tools. The first attempt to measure the forces between tractor and mounted implement were made by measuring the forces in links themselves [23]. This required simultaneous recording of at least three forces which involved very complicated instrumentation. [24] Later developed a three-point hitch dynamometer which could be used with hydraulic linkage providing position and draught control, unlike his previous design which was for un-restrained linkages.

Measuring the drawbar power of tillage tools is accomplished by apparatuses such as hydraulic and mechanical dynamometers. Drawbar dynamometer is used for pull-type implements while the three-point hitch type is employed for mounted implements. The first attempts to measure the forces between tractor and mounted implement were made by measuring the forces in links themselves [23]. This required simultaneous recording of at least three forces which involved very complicated instrumentation. [25] Developed strain gauged pins for measuring the draught of a three-point link implement. These pines could only measure longitudinal component of force in each link and were only suitable for free linkage systems. [24]Improved the system proposed by [26]. The system used instrumented ball joints. These ball joints system had friction induced cross sensitivity problems. [24]Reduced this effect by using self-aligning ball bearings and longer beam length. This caused the equipment heavier, displaced the implement backwards and thus increased the bending moment. Moving the implement back from its nominal position affects the tractor-implement geometry and hence it's operating characteristics. The instrument could not fit on many tractors. Modification to the tractor was required to fit the system. The use of PTO was also obstructed.

[24] Later developed a three-point hitch dynamometer which could be used with hydraulic linkage providing position and draught control, unlike his previous design which was for un-restrained linkages. The shape was such that it can permit PTO use accordingly. Friction was minimized by use of self-aligning ball bearings. Cross-sensitivity was 2% on horizontal draught force and 0.5% on vertical forces. Modifications were needed if the instrument was to be used with mounted implement and was not fit to category I implements. The construction was bulky which weighted 120 kg. The implement was shifted back by 23 cm from its nominal position.

[27] Used six load cells mounted at different points within an 'A' shaped frame to measure horizontal, vertical and lateral forces. The measurements were made with little error. The implement moved back by 19 cm. [28] developed a quick attachment coupler using pins mounted as strain gauged cantilever beams. It eliminated the need for modification in either tractor or implement since it could be used with category II and III hitch dimensions. This dynamometer gave minimum sensing errors but the implement was pushed back by 21 cm.

[29] Designed and developed a three-point hitch dynamometer for measurement of loads imposed on agricultural tractors by implement mounted on a standard three-point linkage conforming to category I, II or III. He reported that the 350 kg mass of the dynamometer limits its use with small tractors to light weight implements. This mass and the rearward displacement of the implement by 17.35 cm is slightly more than allowed by ASAE Standards S278.6. He also reported that the developed dynamometer has a force capacity of approximately 50 kN which provides adequate sensitivity at the low end of the designed tractor power range with sufficient strength for the high power range.

Another three-point hitch dynamometer was designed and manufactured by[30]. The dynamometer was capable of measuring tractor -implement forces in three dimensions, which could help in the design of tillage tools and evaluating tractor performance. They reported that the dynamometer consists of three arms, which slide in an inverted hollow T-shaped section. The sliding arrangement also facilitates attaching the dynamometer to implement without the need for quick coupler. The end of each sliding arm has inverted U-shaped cantilever beam. To measure the draught, two strain gauges were attached on each cantilever beam, and six strain gauges together with two other dummy gauges were arranged in a Wheatstone bridge so that only the draught force is measured. The dimensions of the dynamometer components were selected to match the Category I and II hitching systems with a capacity of 35 kN draught force.

Many other designs were developed. Some measured all the forces acting between the implement and tractor by using a six point dynamometer suspension system using load cells [27],[31]. Other systems measured longitudinal and vertical forces only, assuming lateral forces as zero. [32] Mounted strain gauges directly on the lower links of the tractor. He mounted these gauges on the linked arms to get tension and differential cantilever bridge. This system was calibrated for horizontal and vertical forces while applying load only up to 100 kg. The test results showed across-sensitivity of 2% in the differential cantilever (vertical force) bridge while 12.5% in the tension (horizontal force) bridge.

A bi-axial direct mounted strain gauged lower-links system for measurement of tractor-implement forces was designed by [23]. They developed and calibrated it for coincident and perpendicular loads up to 10 kN. The results revealed a high degree of linearity between bridge output voltage and force applied. They reported that the hysteresis effect between the calibration curves for increasing and decreasing applied coincident and perpendicular force was very small(<1.2%). They suggested that this system is the best suited where medium type equipment is used with a tractor. The use of a frame or frames in order to measure the forces between tractor and implement has the advantages of permitting easy resolution of the forces into horizontal draught, vertical force, and sideways force components and their respective moments, as well as being able to easily fit to any standard tractor and implement combination. Against this was the disadvantages of substantially changing the tractor and implement geometry by moving the implement backwards and vertically relative to the tractor and adding additional mass and resilience to the system [29].Apart from three-point hitch dynamometer, several researchers have made effort to study over drawbar dynamometer such as: [18 - 19],[32- 38].

According to [39] three hitch-point dynamometers with chassis (frame type dynamometer) are more flexible in application, that is, application is not limited to a special type of tractor. Hence a dynamometer equipped with chassis was designed and developed. The dynamometer consists of main frame (chassis),force transducers, connecting members, and a data acquisition system including a notebook computer (Toshiba Satellite 45 Notebook), data logger(CR10X), power supply (PS 12E), and leading cable. The designed dynamometer was fabricated to be used for measuring the resistance pull of the soil engaged implement. The dynamometer is considered to be used with a 2WD Mitsubishi tractor (MT-250D) which has a weight of 1200 kg and provides power of 25 kW. This tractor was selected since it was instrumented to measure parameters affecting the tractor performance in another research projects. To satisfy the later goal, the dynamometer was installed on the fore-mentioned tractor. Note the purpose of this dynamometer was to measure the draught of either single or multi-bottom tillage tools.

[39]Further revealed that computations related to the dynamometer chassis was accomplished based on the design parameters of the tractor and maximum horizontal force. The resultant force P, exerted by tractor is resolved into horizontal (FX), vertical (FY) and side (FS) components over lower link arms and accordingly, FX and FY over upper link arms of the three-point hitches. Among components of draught force, side force FS is less important, therefore measurement of this component was ignored and horizontal force merely was measured in upper link arm.

[40] Mounted shanks on a dynamometer car with a 3-dimensional dynamometer, which had an overall draught load capacity of 44 kN. Draught, vertical, side force, speed, and depth of operation were recorded.[41 Made use of load cells in the measurement and mapping of soil hard-pans and real-time control of subsoiler depth. Two load cells measured the resultant magnitude and direction of the soil reactions on the shank. Another two load cells measured forces perpendicular to the straight shank with a constant distance between them and another load cell measured the forces along the shank. According to them the two load cells were cantilevered with one side mounted to the centre of the shank's width and the other side connected to wheels running inside a hollowed beam. The wheels enabled the shank to be moved up and down for different depths with the aid of a hydraulic cylinder. The hydraulic cylinder was connected to the upper edge of the shank by the lengthwise load cell. The resultant force on the shank was calculated by using the three measured forces, their directions and locations.

[42] Reported that a tractor-mounted three-dimensional dynamometer was used to measure draught, vertical, and side forces in a Coastal Plain soil in Alabama. Three subsoiler systems were evaluated at different depths of operation: (i) Paratill "bentleg shanks", (ii) Terramax "bentleg shanks", and (iii) KMC "straight shanks". A portable tillage profiler was used to measure both above and below ground soil disruptions. Shallower sub soiling resulted in reduced sub soiling forces and reduced surface soil disturbance. The bent leg subsoilers provided maximum soil disruption and minimal surface disturbance and allowed surface residue to remain mostly undisturbed. Bent leg shanks provide optimum soil conditions for conservation systems by disrupting compacted soil profiles while leaving crop residues on the soil surface to intercept rainfall and prevent soil erosion.

SOIL DISRUPTION AND ITS MEASUREMENT

Soil disruption or disturbance is the amount of soil loosened by a tillage tool represented by its total area. Determination of soil disturbance or amount of soil loosened by a tillage tool is highly essential when considering the effect of tillage and soil parameters on soil disruption. Several authors [8]; [43] have revealed Parameters affecting soil loosening. These are tool parameters such tool geometry, width, height, curvature, rake angle, tool speed, depth of operation, soil consistency, soil structure, consolidation, soil strength, soil cohesion, soil adhesion, soil type, soil structure, soil texture, angle of internal soil friction, cone index, bulk density, porosity and soil moisture. These properties and factors have tremendous significant on the extent of soil disturbance during tillage operation.

Hence, researchers normally take into consideration the accurate measurement of the area of soil disruption. Several methods have been applied in doing this. According to [44] and [20], measurement of area of soil disruption by tillage tools was carried out by using the meter rule. According to them, a steel metric rule was laid on the original soil surface level across the trench. The distance measured between the ruler and the slot bottom represented the maximum furrow depth to mound height (after soil cut furrow depth) (Df), maximum width of soil disturbance (W),maximum width of soil throw (using a sweep) (MWS), ridge to ridge distance (S), height of ridge above soil surface (H), and maximum furrow depth to mound height (F).

[45] Explained a new measurement method for soil surface profile. This method includes new designed soil profile meter, digital imaging equipment and image tracking & analysis software. Using such modified soil profile meter can help to observe and measure changes that occur in irrigation channels, small ditches and to quantify changes at specific cross sections within soil furrows. The recorded profiles heights for different locations gave a perspicuous knowledge about the geometry of furrows and ditches shapes before and after seasonal irrigation process. According to[45] each type of tillage tool and ditch creating method generate a characteristic oriented roughness and profile pattern which is relatively easy to quantify using simple geometric models. Many common techniques for collecting soil surface data and the analysis of the respective dataset have been discussed. Pin meters are the devices most widely used for their simplicity. They consist in a single probe or a row of probes spaced at pre-established intervals and designed to slide up or down until the tip just touches the soil surface. Pin positions are recorded either electronically or manually [46 -47]. The chief disadvantage to this technique is its destructive impact on the soil surface while recording data in the field. [48] Designed and tested a portable meter under typical field conditions; the tool can measure depths up to 500 mm and easily be modified for usage with large ditches.

Measuring soil profiles by Laser technology also had very good laboratory results, but its field use is limited because sunlight and hidden forms or shadows interfere with the readings, while high temperatures affect the performance of the sensitive measuring devices [49 - 50]. [51] Conducted study to develop a new method for measuring soil surface roughness that would be more reliable by using the principle underlying shadow analysis is the direct relationship between soil surface roughness and the shadows cast by soil structures under fixed sunlight conditions. They showed that shadow analysis yielded results significantly correlated to the pin meter findings, but with the advantage that the time invested in gathering field data was 12 to 20 times shorter.

Another work has been carried out by [52] in order to reproduce reliable rough surfaces able to maintain stable, un-erodible surfaces to avoid changes of retention volume during tests by a set of roughness indices was computed for each surface by using roughness profiles measured with a laser profile meter, and roughness is well represented by quintiles of the Abbot–Firestone curve. Image analysis techniques have recently been employed to measure different soil parameters, example two dimensional displacement vectors in soils obtained by a block-matching algorithm [53], however, this algorithm is incapable of tracking individual particles, let alone their rotations. Several algorithms have been developed to track soil particles and measure their movements by detecting the edges of individual soil particles. [54] Observed the displacement distribution in the soil near the structure using photographs and discussed the thickness of the sand–steel interface.

[42] In his work ‘In-row subsoilers that reduce soil compaction and residue disturbance’, reported that, after each set of tillage experiments was conducted, a portable tillage profiler [55 - 56] was used to determine the width and volume of ‘spoil.’ The disturbed soil was then manually excavated from the trenched zone for each plot for approximately 1 m along the path of tillage to allow five independent measurements of the area of the sub soiled soil that was disturbed by the tillage event in each plot. This measurement is referred to as the ‘trench.’ Care was taken to ensure that only soil loosened by tillage was removed.

[57] Used a soil disturbance measurement profilometerto estimate the area of soil disruption. The instrument was made up of medium carbon steel frame and a wooden board (ceiling board). The total height of the equipment was 800 mm and a total width of 750 mm. The ceiling board was sandwiched between the frame and was supported firmly by four steel plates, two each on opposite sides of the equipment. A graph paper, 750 mm by 600 mm was pasted on the board. 14 holes were drilled at the base of the frame at same distance from each other. 14 number 4 mm diameter rods were inserted on the holes. Each of these rods was curved into round shape at both ends. The curved end on the upper side had 9 mm diameter.

Another rod, 8 mm diameter was passed across through the frame close to the top of the equipment. This horizontal rod passed through each of the vertical rods at the curved end. The vertical rods were guided in front by two horizontal rods placed across the equipment at two points. These had the ability to protect the vertical aluminium rods from falling off the board while sliding down during operation. The vertical aluminium rods can easily fall or slide down when the equipment is placed across a depressed soil and the horizontal rod at the top of the equipment is removed. Thus the vertical rods will slide downwards and rest according to the geometry of the disturbed soil. The tips of the vertical rods can easily be traced on the graph paper on the board.

The profilometer was then placed across the soil disturbed. Then the horizontal rod holding the vertical sliding rods was removed, allowing the aluminium rods to fall freely and rested according to the geometry of the soil disturbance. A marker was then used to trace the tips of the rods accordingly on the graph paper. There after the area on the graph was estimated in square centimeters (cm2) based on the number of squares below the reference line. Also, on the paper the depth and width of disturbance were estimated.

SUBSOILER DESIGNS AND THEIR EFFECTS ON DRAUGHT AND SOIL DISTURBANCE

[8]Revealed that aspect ratio (depth/width) and rake angle (α) are two major variables in the design and selection of the appropriate geometry for given tillage implements such as subsoiler. Wide blades and narrow tines with depth/width ratios less than 5 and rake angles less than 90^0 tend to fail the soil in crescent manner, with the wide blade creating a wide slot and narrow blade, narrow slot especially when the aspect ratio increases. As the depth/width ratio increases the soil failure changes such that there is a small crescent close to the soil surface but the soil at higher depth is forced laterally to produce a slot. Thus the transition from one type of failure to another is referred to as the critical depth (Figure 1). Rake angle has considerable effects on soil disturbance pattern as shown in Figure 2 below. As demonstrated by [58], tines of 50 mm and 100 mm widths operating at a depth of 150 mm, and rake angles 160^0, 90^0 and 20^0 respectively, disrupt the soil in a manner as shown.

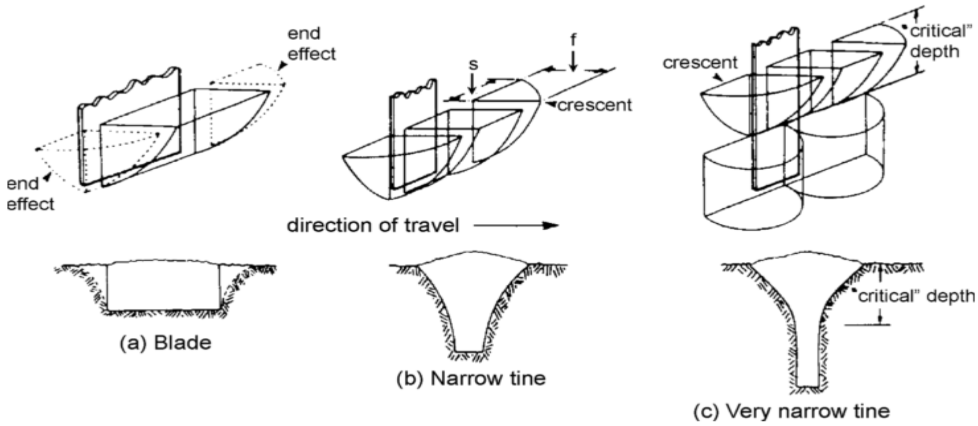

Figure1: *Effect of implement depth/width ratio on pattern of soil failure;* ***Source:****[59].*

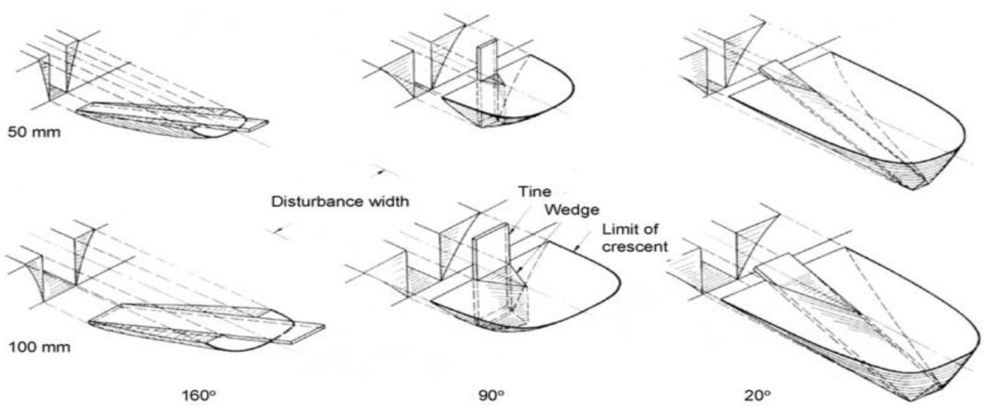

Figure2: *Effect of rake angle on soil disturbance patterns for tines of 50 mm and 100 mm widths operating at a depth of 150 mm, and 160^0, 90^0 and 20^0 rake angles respectively; Source:[58]*

Wings or sweeps attached to the foot of the tine modify the type of soil disturbance as shown by the work of [12] in Figure 3,by doubling the disturbed area for an increase in draught force of 30%. This significantly increases the effectiveness of the operation, by reducing the specific resistance (draught/disturbed area) by 30%. The soil condition also affects the type of failure for a given implement shape with the drier and more dense soils tending to produce crescent failure to a greater depth than the wetter, looser soils.

The work of [7] shows how tine spacing can affect the soil disturbance pattern produced by a pair of tines operating at the same depth in Figure 4.The effect of this on the resulting draught force, area of disturbance and specific resistance is presented in Figure 5.From this work and that from studies on subsoiling equipment by [12] the practical spacing recommended for good soil loosening are approximately:(i) 1.5 x depth of work for simple tines;(ii) 2.0 x depth of work for winged tines.

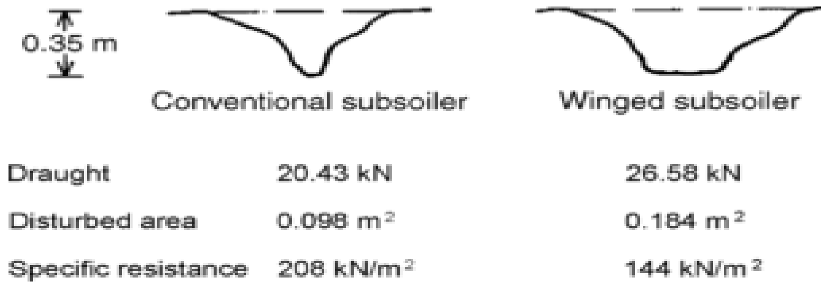

Figure3: *Effect of adding wings to subsoiler tines on the draught force, soil disturbance pattern and specific resistance in a compact dry claysoil;* ***Source:****[12].*

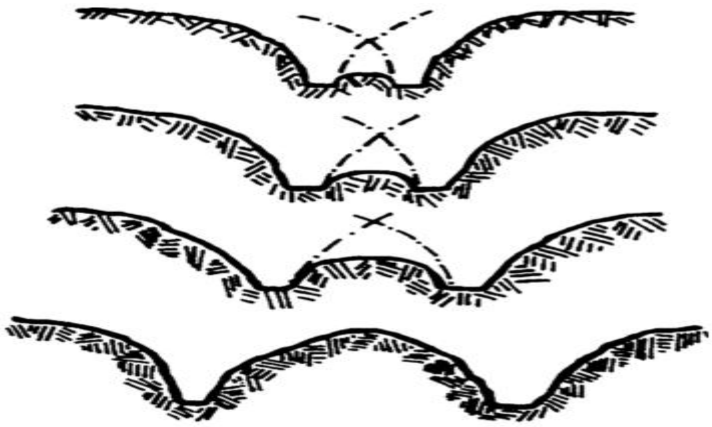

Figure4: *Profile cross-sections of soil disturbance produced at different tine spacing in acompact sandyloam soil(tine:25 mmwide,45^{0}rakeangle, 150mm working depth);* ***Source:****[7].*

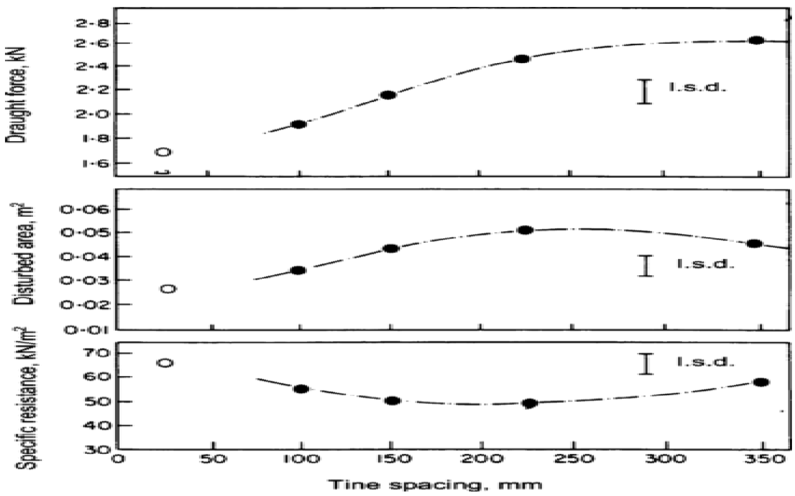

Figure5: *Relationship between tine spacing and draught force, disturbed area and specific resistance for a pair of 25mm wide tines operating at 165mm deep. Open circles represent a single 50 mm wide tine.* ***Source:****[7].*

The effect of rake angle is shown in Figure 6 from the work of [58] and [60]. This shows clearly how both the horizontal and vertical forces increase with rake angle. The data also clearly demonstrate that for low draught and good penetration, implements should be designed with a low rake angle. The cross-over value for the vertical force from upward to downward force is atapproximately67.5^0 for a simple plane steel tine, where the critical rake angle$(\alpha_c)^0$ =90 - δ (where the angle of soil metal friction (δ) is approximately 22.5^0).

The horizontal force increases at an increasing rate for a 90^0 rake angle tine operating in uniform soil conditions shown in Figure 7.Thevertical force increases at a similar rate but is generally of smaller magnitude; this, however, is a function of the rake angle of the tine, as shown in Figure2 above.

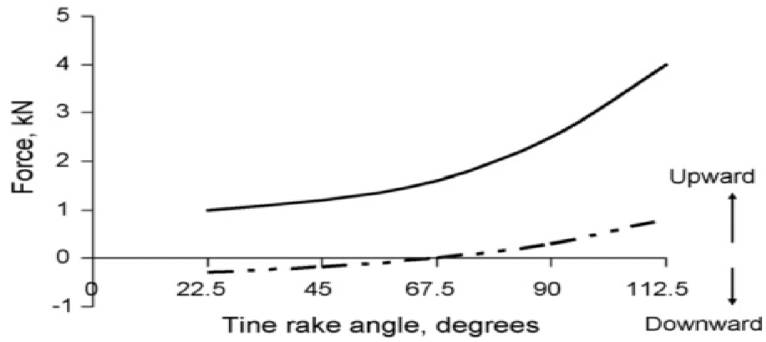

Figure6: *Effect of tine rake angle on horizontal (solid) and vertical (broken) forces,* ***Source:****[8].*

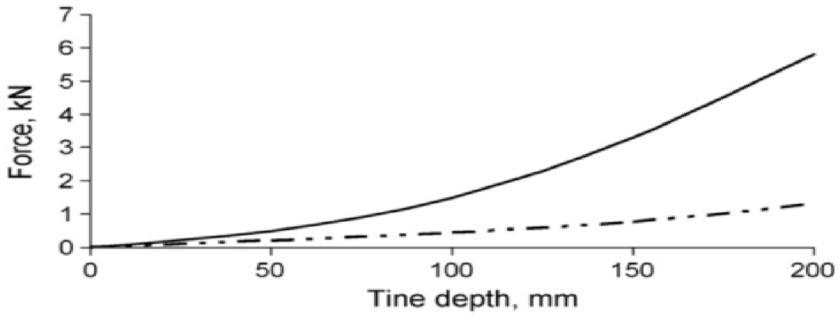

Figure7: *Effect of tine depth on the horizontal (solid) and vertical (broken) forces acting on a 90^0 rake angle tine,* ***Source:****[8].*

Further results from [60] shown in Figure 8, confirm the data by [61], and demonstrate how the implement width effect the magnitude of the horizontal and vertical force. The results of data from [62] for a tillage tine of width (w) 30 mm and a depth (d) of 25 mm operating at speeds up to 20 km/ h are given in Figure9, these results are similar to those found by [6] where the force increases with speed. [8] Revealed that implements designed with rake angles less than 90^0 (α<90^0) tend to cut, loosen, invert and smoothen the soil while implements with rake angles equal to or greater than 90^0 (α = > 90^0) tend to consolidate, disintegrate and compact the soil during operation (Figure 10).

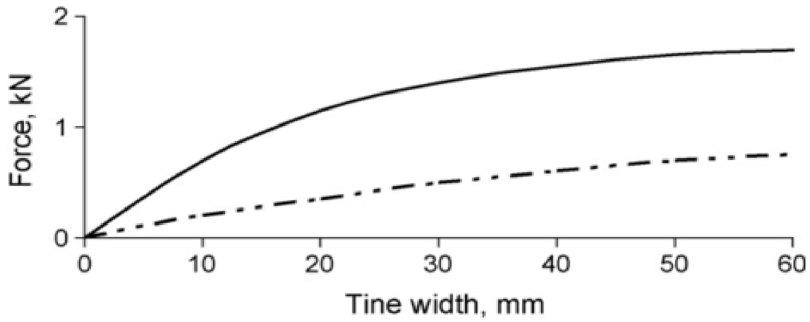

Figure8: *Effect of tine width on the horizontal (solid) and vertical (broken) forces acting on a 908 rake angle tine,* ***Source:****[8].*

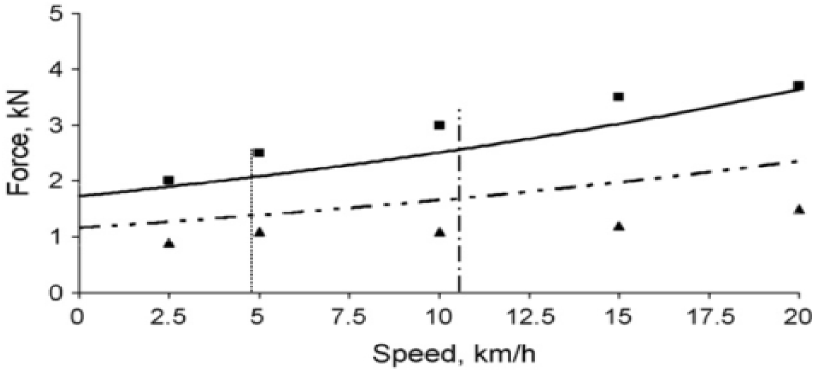

Figure9: *Effect of tine speed on the measured() and predicted (solid line) horizontal force and the measured () and predicted (broken line) vertical force acting on a 40^0-rake angle, 30mm wide, 250mmdeep tine in frictional soil;* ***Source:****[62].*

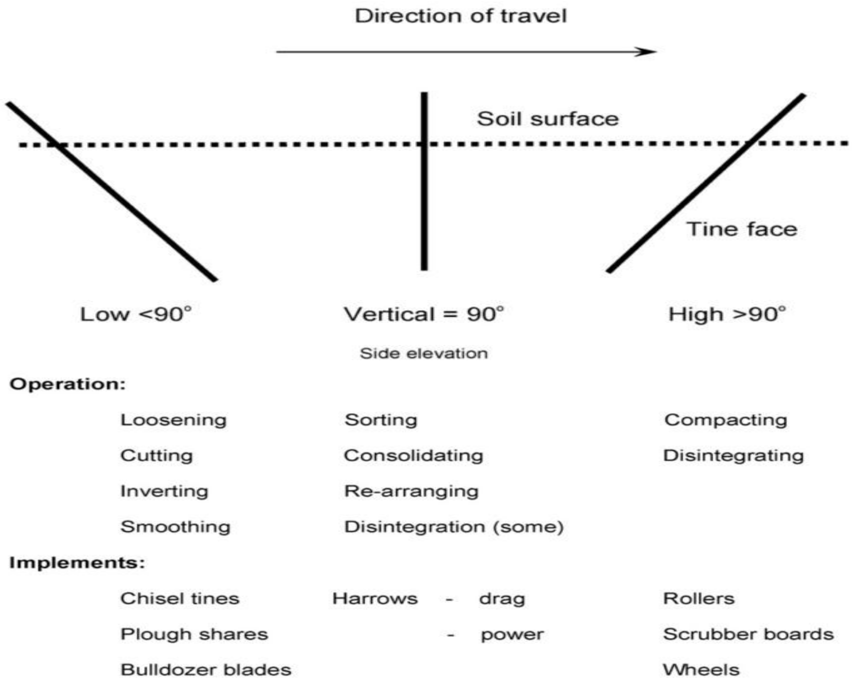

Figure10: *Optimal tine rake angles for a range of soil operations and basic implements,* ***Source:****[8]*

CATEGORIES OF SUBSOILERS AND THEIR DRAUGHT AND POWER REQUIREMENTS

[63] Revealed different categories of subsoilers. Subsoiler shapes such as Swept shank, Straight shank, Curved (semi-parabolic) shank, Parabolic shank, Winged type and no-wing type, rotary, Vibration and non-vibration types, Coulter subsoiler, Coulter with blades subsoiler, Coulter with blades and reversing subsoiler were considered. There exists different shapes of shank designs in subsoiler. Shank design affects subsoiler performance, shank strength, surface and residue disturbance, effectiveness in fracturing soil, and the horsepower required to pull the subsoiler [43], [64]. Such shapes are Swept shank, Straight shank, Curved (semi-parabolic) shank, Parabolic shank, Winged type and no-wing type, rotary, Vibration and non-vibration types, Coulter subsoiler, Coulter with blades subsoiler, Coulter with blades and reversing subsoiler. Thus, subsoilers are designed with various shapes depending on the form of sub soiling operation that will be performed. An important consideration concerning sub soiling is the amount of soil disruption for different soil conditions to increase the long-term benefits of sub soiling [65]. [66] Reported that many subsoilers have been designed and tested, using a number of sub soiling techniques for alleviating compacted layers of various types and conditions of soils.

[11] Found that a straight shank subsoiler mounted at a positive rake angle gave reduced draught compared to curved subsoiler in sandy loam soils. Comparisons between an angled and a curved shank in two soil bins by [56], showed that shank positioned at a 52^0 angle from the horizontal plane in the direction of travel had a lower draught requirement compared to a curved shank. [67] and[68] Worked on conventional,

parabolic, and triplex subsoilers affirmed that the parabolic subsoiler draught ranged from 11 to 16% less than that for the conventional subsoiler over the speed range tested.[1] Reported that a large track-laying tractor in the order of 50t mass was needed for three winged subsoilers operating at 90 cm depth.

Transmitting power directly to tillage tools by oscillating them, appears to provide an opportunity for reducing drawbar pull. [64]Reported that to achieve effective sub soiling with a medium size tractor (30-45 kW), a four-shank vibrating subsoiler was developed. More than 60% of draught reduction was obtained when operated. [69]Studied vibrating subsoilers and found that draught ratio decreased rapidly when the velocity ratio increased to 2.25. [70]Reported that the lower draught requirement typically measured under oscillatory tillage reduces the reliance on less efficient drawbar power, such that a lower overall demand on engine power may occur. [2] Compared vibratory and non-vibratory shank to find out their influence on draught requirements. It was revealed that the traction resistance with the vibratory subsoiler was 6.9 % - 17 % less than that of non-vibratory one.

[71] Measured the effects of loosening practices on subsoil compaction with deep rotary tillage subsoiling to a depth of 600 mm the soil recompacted within three years to the same or worse physical properties.[72]Reiterated that the usage of rotary subsoilers can be partially justified by the higher efficiency of power being transferred to the soil rather than through the tractor wheels when shanks are pulled through the soil. [73] Used a rotary subsoiler to improve infiltration in a frozen soil for newly planted winter wheat. It was found that water storage in winter was significantly increased, and runoff and erosion were decreased as compared with the conventional subsoilers. [66] Recorded that rotary subsoiling is a new concept, not widespread in common hardpan loosening practices and had rarely been studied or used in commercial agriculture.

ADEQUATE USE OF SUBSOILERS

Compacted layers are typically 30 – 55 cm deep. Ideally, the shank's tip should run 2.5 - 5 cm (1-2 inches) below the compacted soil layer. If the shank's tip is too deep, subsoiling may increase compaction because the compacted layer will not be fractured. Shank spacing will vary depending on soil moisture, soil type, degree of compaction, and the depth of the compacted layer. Spacing should be adjustable so the worked area can be fractured most efficiently. Shank spacing of 75 – 105 cm (30 – 42 inches) is preferred for adequate subsoiling (Figure 11). Horsepower requirements depend on soil moisture, the depth and thickness of the compacted layer, and to a lesser extent, the soil type. Each shank may require from 30 to 75 horsepower.

Equipment speed can affect subsoiling. Travel speed that is too high can cause excessive surface disturbance, bring subsoil materials to the surface, create furrows, and bury surface residues. Travel speed that is too slow may not lift and fracture the soil adequately. Contractors may prefer to travel more quickly to improve their profit per acre. It is best to follow the ground contour whenever possible while subsoiling. This helps increase water capture, protect water quality, and reduce soil erosion, especially in burned areas or areas susceptible to erosion. Stay clear of waterways, ditches, and other areas where subsoiling could affect hydrology. Shanks should be lifted out of the ground frequently to clear stumps, rocks, and logs and to remove slash from the subsoiler. It might be wise to consult your local silviculturist for advice on subsoiling next to trees and other established plants. Always be cautious of areas that might have buried utility lines, culverts, or diversion channels. Flag or mark such areas before subsoiling [13],[8]; [43].

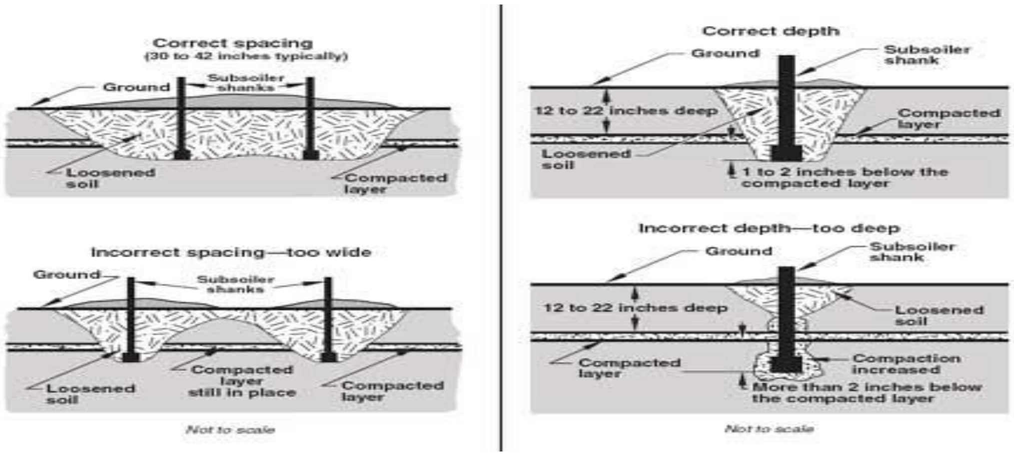

Figure11: *Correct and incorrect spacing and depth of operation of subsoilers.* ***Source:*** *[43]*

CONCLUSION

Draughts and power requirements of subsoilers for increased soil pulverisation was studied. Consideration should be given to the design of shanks shape of subsoiler, as they are very important to the efficiency and effectiveness of subsoiling. Shanks should be designed to handle rocks, large roots, and highly compacted soils. Thinner shanks are suited for agricultural use. Thicker shanks hold up better in rocky conditions, but require larger, more powerful equipment to pull them and disturb the surface more. Bent offset shanks, such as those found on Para till subsoilers, have a sideways bend. Subsoiler shanks may be parabolic (curved) shaped or straight and with or without wings. In generalthe power required to pull a parabolic shank is less than a straight shank. The addition of wings to either parabolic or straight shanks increases the power requirement. Sub soiling requires very high draft and mechanical energy. Draft requirements depend on soil type and condition, manner of tool movement, and tool shape.

Therefore, for a given soil type and condition, draft requirements depend on geometry of the subsoiler shank, travel speed, and depth of operation. Thus, variation in power requirements depends on subsoiling depth, soil water conditions and the amount of compaction. In order to achieve better soil disturbance, reduced draft force and energy requirements, and less traction resistance, the application of vibratory (oscillatory) and rotary subsoilers in modern day design and development of subsoilers are preferred for lower overall demand on engine power.

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