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MEASUREMENT OF TILLAGE FORCES AND SOIL DISTURBANCE OF SUBSOILERS

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ABSTRACT

Measurement of tillage forces, energy requirements and soil failure using instrumentations during subsoiling for alleviation of soil compaction and conservative tillage practices was considered. Several parameters that affect tillage forces and soil loosening are tool parameters such as tool geometry, width, height, curvature, rake angle, tool speed, depth of operation, soil consistency, soil structure, consolidation, soil strength, soil cohesion, soil adhesion and soil type. Others are soil structure, soil texture, angle of internal soil friction, cone index, bulk density, porosity and soil moisture. Different types of instrumentations such as transducer, dynamometer, strain gauge and extended orthogonal ring transducer have been utilized in the measurement of forces on tillage tools. Different instrumentations have been put in place for measurement of soil disturbance, including soil profile meter, digital imaging equipment and image tracking & analysis software, laser distance sensor, linear actuator, portable pc, and a lightweight aluminium frame that can quickly and accurately measure above and below-ground soil disruption caused by tillage. Understanding of accurate measurement of tillage parameters will help in the design of new tool shapes which will reduce tool draught, energy demand and increased soil disruption over a wide speed range.

KEYWORDS: *Subsoilers, Tillage Forces, Soil disturbance, Tillage Parameters, Measurement.*

1.0 INTRODUCTION

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. 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 (Odey *et al.*, 2018 b, Odey *et al.*, 2018 c).

Forces on tillage implement and soil disruption related to working depth, tool geometry, travel speed, rake angle, width of the implement, and soil properties (Gill and Vanden Berg 1968). Soil properties that contribute to tillage energy are moisture content, bulk density, cone index, soil cohesion and adhesion, and soil texture (Upadhyaya *et al.*, 1984). It has been reported that draught on tillage tools increases significantly with speed and the relationship varies from linear to quadratic (Godwin, 2007, Odey *et al.*, 2018 a).

Design, fabrication and evaluation of tillage tools performance, and their energy requirements during operation has been of great concern to engineers and farmers as this has very important effect on the efficiency of tillage operations. Studies have been useful in using instrumentations for measuring and evaluating forces, energy requirements and extent of soil failure during subsoiling. Categories of Subsoilers are Straight Shank and Bentleg, Angled or Curved Shank, Parabolic, Winged, Vibratory or Oscillating and Rotary Subsoilers (Odey and Manuwa, 2016, Odey *et al.*, 2018 b and Odey *et al.*, 2018 c).

The main objective of this article is to review the measurement of tillage forces and soil failure using instrumentations during subsoiling for alleviation of soil compaction and conservative tillage practices.

2.0 FORCES ON SUBSOILERS

Sahu and Raheman (2006) Reported that forces and draught requirements of any tillage implement was found to be a function of soil properties, tool geometry, working depth ,travel speed, rake angle and width of the implement. During operation at constant speed a tillage tool is subjected to three different force systems in equilibrium. These are; weight of the implement acting at the centre of gravity of the tool, forces acting between the tool and prime mover and soil reaction forces acting on the implement. The weight of the implement is an independent force system acting on the implement. The second and third force system are interdependent on each other and each of them is dependent on the weight of the implement (Glancey *et al.*, 1996).

Godwin (2007) also reported components of tillage forces on tools to include, (i) horizontal or draught force which is the amount of force required to pull or push the implement through the soil, (ii) vertical force which is the implement force assisting or preventing penetration into the soil, and (iii) lateral or sideways forces. These have then to be counterbalanced by implement weight or weight transfer from the tractor. In the case of more complex tools such as discs and mouldboard ploughs, lateral forces are considered than in narrow tools. In this case, the force needs to be as small as possible and/or counterbalanced by equal and opposite tillage forces in the case of disc harrows or from a landside (reaction plate or wheel) in the case of both disc and mouldboard ploughs.

Mathematical models have been developed to predict the magnitude of the soil forces acting upon implements of different geometry. They have been integrated into a unified model described by Godwin and O'Dogherty (2006) 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) mouldboard ploughs.

Odey and Manuwa, 2016 revealed that for purpose of clear understanding of the various parameters use in the design of subsoilers, the illustration of basic tillage implement geometry are presented in Figure 1.

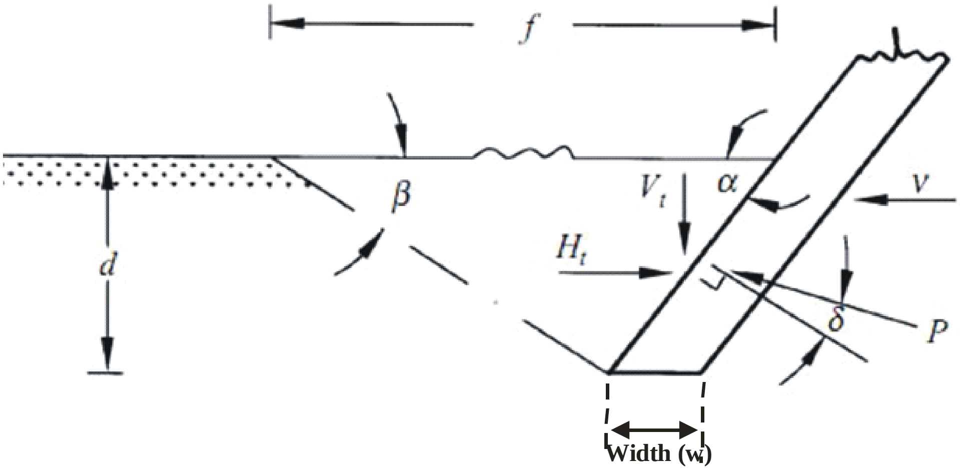

Figure 1: Schematic diagram of tine in digging position showing the respective parameters: *f*, Rupture distance, d, Tillage depth, β, Soil rupture angle, H_t, Draught, V_t, Vertical force, $\dot{\alpha}$, Rake angle, v, Speed, δ, angle of soil metal friction and w, width of tool (Odey and Manuwa, 2016).

2.1 Draught Requirement for Subsoilers

Draught is an important parameter for measurement and evaluation of implement performance (Grisso *et al.*, 1994). 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 (Manuwa and Ademosun, 2007). Rational design must be based on knowledge of tool performance and soil parameters (Stafford, 1984). For efficient tillage, both must be considered with the aim of minimizing specific resistance, which is draught per unit area of soil disturbance (Godwin *et al.*, 1984; Godwin, 2007).

The availability of draft requirement data for tillage implements is an important factor in selecting suitable tillage implement for a particular farming situation. Therefore, prediction of implement draught requirement is important for tractor selection and implements matching (Jones *et al.*, 2006). Spoor and Godwin (1978) as reported by Godwin (2007) 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.

3.0 MEASUREMENT OF TILLAGE FORCES USING INSTRUMENTATIONS

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 (Chen *et al.*, 2007). Several side loads can affect tractor's steering ability. However, side force is generally negligible during field operation (Leonard, 1980). Different types of instrumentations have been utilized in the measurement of forces on tillage tools. These are dynamometer, strain gauge, transducer (load cells) and extended orthogonal ring transducer (Ademosun, 2014).

3.1 Dynamometers

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 (Ademosun, 2014 and Odey *et al.*, 2018 b).

Measuring the drawbar power of tillage tools is accomplished by apparatuses such as hydraulic and mechanical dynamometers. The first attempts to measure the forces between tractor and mounted implement were made by measuring the forces in links themselves (Khan *et al.*, 2006). This required simultaneous recording of at least three forces which involved very complicated instrumentation. Scholtz (1966) improved the system proposed by Lal in (1959). Lal's system used instrumented ball joints. These ball joints system had friction induced cross sensitivity problems. Scholtz (1966) 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.

Scholtz (1966) 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.

Smith and Williford (1988) used instrumentation system consisting a three-point hitch dynamometer, speed monitors, and datalogger. A John Deere 4030* tractor was instrumented for measuring variables associated with the power requirements of agricultural implements. These variables included draft, vertical load, side load, speed and torque on the driving axles, ground speed, engine speed, and rate of fuel consumption. A Campbell Scientific CR7x data logger was programmed to measure and stored data values during each test run.

Palmer (1992) 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.

Smith and Williford (1988) stated further that forces between the tractor and implement were monitored with a three-point hitch dynamometer. The dynamometer was designed in a triangular shape and functioned as a quick-attach hitch in addition to measuring forces in three directions. It consisted of a front and rear section which were attached to the tractor and implement respectively. These sections were connected to each other by a pair of load sensing members at each of the three corners of the triangular frame. Each pair of the sensing members was configured so that one member sensed draft and the other sensed vertical and side loads. A total of nine load circuits were used in the dynamometer to define the forces between the tractor and implement.

Another three-point hitch dynamometer was designed and manufactured by Al-Jalil *et al.* (2001). 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.

Raper (2007) 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”.

Apart from three-point hitch dynamometer, several researchers have made effort to study drawbar dynamometer, notable among them are: Hoag and Yoerger (1975), Alam (1989), Leonard (1980), Tessier *et al.* (1992), Kirisci *et al.* (1993), Tessier and Ravonison (1997), McLaughlin (1996), McLaughlin *et al.* (2005) and Chen *et al.* (2007).

According to Alimardani *et al.*, (2008) three point-hitch 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 Sattelite 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.

Alimardani *et al.* (2008) 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.

Raper (2002) 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.

Raper and Schwab (2008) worked on the development of an in-row subsoiler attachment to reduce smearing, used a three-dimensional dynamometer attached between the tractor and the tillage implement at the time of tillage to measure tillage force. This device measured draft, vertical, and side forces required for each tillage treatment. A radar gun was used to obtain tillage speed, which was used along with draft to calculate deep tillage energy. A constant velocity of 4.5 k/hr was attempted to be maintained throughout the experiments.

3.2 Extended Octagonal Ring Dynamometer

Extended octagonal ring dynamometer 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. Onwualu (2002) carried out the design, construction, evaluation and use of an extended octagonal ring dynamometer for measurement of draught, vertical force and moment on a simple tillage tool are presented. The dynamometer was used to measure tool forces as functions of depth, rake angle and speed, for a wide plane blade. The dynamometer was designed for a maximum draught of 4.4 kN, vertical force of 4.0 kN and moment of 2.2 kN-m. Evaluation and calibration showed linear response (R2 = 0.99 to 1.00) for the relationship between applied load and output voltage and no hysteresis effect within the load range was observed. Actual sensitivity obtained were 0.332 μ V/N.V for draught, 0.726μ V/N.V for vertical force and 2.5μ V/N-m.V for moment. Maximum cross sensitivity was less than 6%. The dynamometer showed expected response of tool forces as affected by tool depth, rake angle and speed.

3.3 Strain Gauges

Strain Gauges have replaced earlier used dynamometers with hydraulic units. Reece (1965) 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. Chung *et al.* (1983) 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.

Tractor axle torque was measured with strain gauges bonded directly to the tractor axles between the axle housing and wheel. The torque signals and bridge excitation signals were routed through a slip ring assembly on the end of the axles to a protective guard which contained an instrumentation cable connected to the datalogger. 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 (Baker *et al.*, 1981; Chaplin *et al.*, 1987). Other systems measured longitudinal and vertical forces only, assuming lateral forces as zero. Kirisci *et al.* (1993) 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 a cross-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 Khan *et al.* (2006). 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 hysterisis 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 (Palmer, 1992).

3.4 Load Cells

A load cell is a transducer that is used to convert a force into an electrical signal. Load cell 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. 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. Transducer commonly implies the use of a sensor/detector, any device which converts energy can be considered a transducer (Ewetumo, 2011, Ademosun, 2014, 5 and Odey *et al., 2018 b*).

Baker *et al.* (1981) 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. Manor and Clark (2001) designed and built an instrumented subsoiler shank to measure the soil resistance while moving through the soil and for automatic control of the depth of several standard subsoiler shanks mounted on the same frame. According to the authors, three load cells measure the resultant magnitude and direction of the soil reactions on the shank. Two load cells measure forces perpendicular to the straight shank with a constant distance between them and another load cell measures the force along the shank. The two perpendicular load cells are cantilevers with one side mounted to the center of the shank’s width and the other side connected to wheels running inside a hollow beam. The wheels enable the shank to be moved up and down for different depths with the aid of a hydraulic cylinder. The hydraulic cylinder is connected to the upper edge of the shank by the lengthwise load cell. The resultant force on the shank is calculated by using the three measured forces, their directions and locations. The instrumented shank was calibrated and tested in the field. While preliminary in nature, the results indicate that when the shank tip is above a soil hardpan, the soil force on the tip acts upward, and becomes negative when the shank tip is below the hardpan. These results indicate that it may be possible to determine the depth of the hardpan by observing when the vertical force on the shank tip passes through zero as the shank depth is cycled above and below the hardpan.

Soil forces on deep tillage tools were measured by Chandon and Kushwaha (2002). Load cells were employed in measuring the forces. Draft, vertical, and side forces were measured using six load cells in a three orthogonal directions such that two load cells measured draft, three measured vertical force, and one measured the side force. A potentiometer was used to measure the working depth and a magnetic pickup to measure travel speed. Soil forces were measured at three operating speeds, and one working depth. The draft measurements for all the tools were compared to the predicted values generated from ASAE standard.

Manor and Clark (2001) 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.

Vaishnav (1983) used a six-load cell system to measure soil forces. The arrangement of the load cells was such that one load cell measured the draft, two measured the vertical force, and three measured the side force. The tool was attached to the bottom of the load frame, while the top of the frame was attached to the carriage. The forces from the tool were transmitted through six load cells to the carriage frame. This tool-force measuring system has been in use at the soil bin facility at the Department of Agricultural and Bioresource Engineering, University of Saskatchewan since 1978. According to Chandon and Kushwaha (2002), modifications have been made to arrange the load cells in a way that two in the direction of travel (draft), three in the vertical direction, and one measuring side force.

Adamchuk et al. (2004) developed an instrumented deep−tillage implement for sensing soil mechanical resistance. Variable−depth tillage has the potential for economic and environmental benefits to modern crop production. The prototype instrumentation system was developed based on a conventional implement for deep tillage. It was equipped with two load cells and two sets of strain gauges for sensing the load applied to the implement during tillage. Two linear pressure distribution models (full and redundant) were used to describe the change of soil mechanical resistance with depth. These models were then used to compare estimates of soil mechanical resistance applied to the point of the deep−tillage implement based on predicted and measured values. Varying tillage depth according to local soil conditions prevents the waste of energy and preserves soil ecology.

Nigon *et al.* (2013) designed, fabricated and tested a device capable of implement draft measurement utilizing widely available load cells. The Badger Dyno uses Digi-Star Dual Axis Differential Bending Beam – Neck Down (DBND) load cells that are dimensionally similar to load cells widely used on agricultural equipment. The Badger Dyno conforms to ASABE drawbar standards and easily attaches to nearly all tractor drawbars and implement hitches. Additionally, this low cost, relatively lightweight device is capable of accurately measuring implement forces in both the horizontal and vertical directions so that the angle of pull can be calculated. Finally, the Badger Dyno uses an off-the-shelf load cell monitor widely used in agricultural applications. The monitor has simple data acquisition capability, further increasing its functionality and utility.

Odey *et al*. (2018 b and c) developed an instrumentation system for measuring the draught of narrow tillage tools. The instrumentation system consisted of the following (a) Load cell (10 t, 100 kN) – strain gauge type (No. 100201022 and output, 2.50 m V/V), (b) Load cell bracket, (c) Load cell amplifier board (print circuit board), (d) Data logger – Grant – SQ2040/2F16 and (e) HP Laptop computer system. The data logger was equipped with software, SquirelView Plus edition, version 5.3.6. The software had the ability to download logged data from the logger into the computer. In other to view the data it must be converted by SquirrelView for Analysis or exported to excel (.xls) format.

According to Odey *et al*. (2018 b and c), the instrumentation assembly was made up of the load cell attached to the tool carrier load cell brackets using screw bolt. The other end of the load cell was also screwed with a bolt firmly and then hitched to the tractor drawbar. The load cell cable was then extended to the instrumentation box attached to the left hand side of the tractor. This box housed the instrumentation amplifier circuit board, which was connected to the load cell, data logger, and powered by a pair of 6 V dry cell batteries (12 V). The data logger was also connected to the laptop and synchronized using the characteristics equation that was got from the graph plotted during the calibration of the load cell. This arrangement was put in place for the downloading of the acquired draught from the data logger (Figure 2).

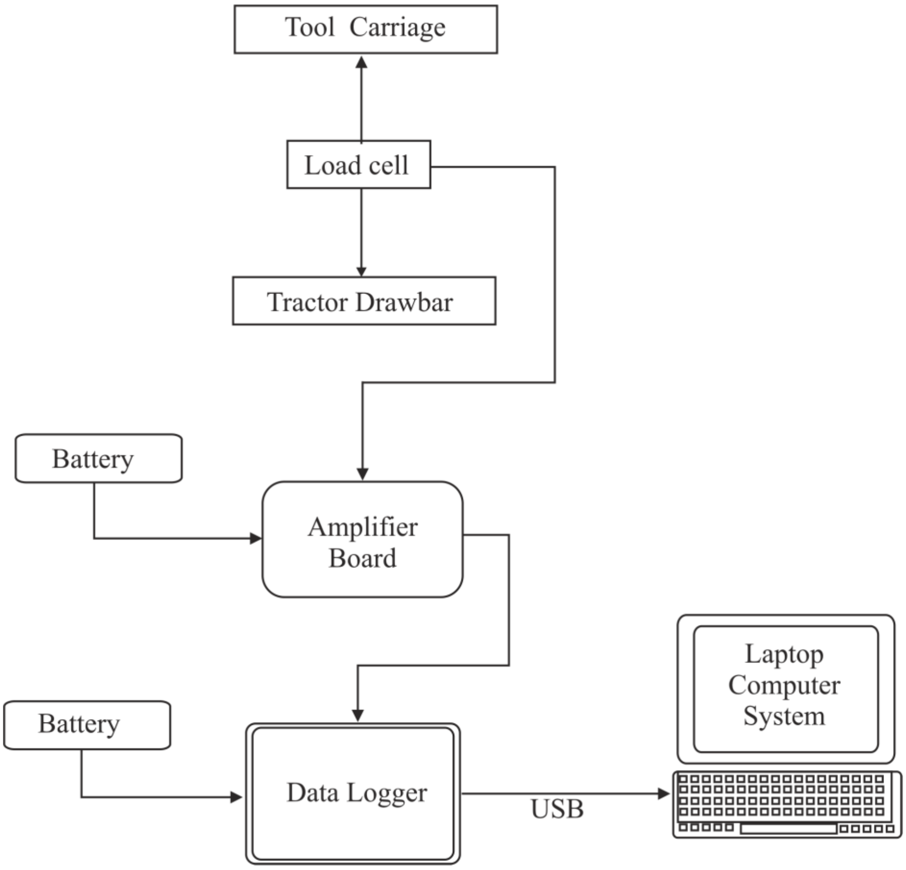

Figure 2: Schematic arrangement of the Instrumentation System for measuring draughts (Source: Odey *et al.*, 2018 c).

4.0 SOIL DISRUPTION AND ITS MEASUREMENT

Soil disruption is the amount of soil loosened by a tillage tool represented by its total area. Determination of soil disturbance or amount of soil failure by a tillage tool is highly essential when considering the effect of tillage and soil parameters on soil disruption. Several authors (Godwin, 2007 and Kees, 2008) have revealed parameters affecting soil loosening to include tool parameters such tool geometry, width, height, curvature, rake angle, tool speed, depth of operation and other parameters such as 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.

Different instrumentations have been put in place for measurement of soil disturbance, including soil profile meter, digital imaging equipment and image tracking & analysis software, laser distance sensor, linear actuator, portable pc, and a lightweight aluminium frame that can quickly and accurately measure above and below-ground soil disruption caused by tillage.

4.1 Meter Rule

Researchers normally take into consideration the accurate measurement of the area of soil disruption. Several methods have been applied in doing this. According to Ale *et al.*, 2013 and Ademosun *et al.*, 2014, 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).

4.2 Profiler, Laser, Digital Imaging and Software Technology

Hegazy (2013) 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 Hegazy (2013) 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 (Römkens *et al*., 1986 and Wagner and Yiming, 1991). The chief disadvantage to this technique is its destructive impact on the soil surface while recording data in the field. Kornecki *et al*. (2008) 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 (Pardini, 2003; Darboux and Huang, (2003). Raper *et al.* (2002) constructed a portable tillage profiler (PTP) using a laser distance sensor, a linear actuator, a portable pc, and a lightweight Aluminium frame that can quickly and accurately measure above and below-ground soil disruption caused by tillage.

4.3 Portable Tillage Profiler

Raper (2007) 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 (Raper et al., 2004; Raper, 2005) 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 subsoiled 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.

Moreno *et al.* (2008) 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 Borselli and Torri (2010) 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 quantiles 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 (Guler *et al.*, 1999), 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. Hu and Pu (2004) observed the displacement distribution in the soil near the structure using photographs and discussed the thickness of the sand–steel interface.

4.4 Profilometer

Odey *et al.* (2018 b) designed fabricated and used a soil disturbance measurement profilometer to 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 (Odey and Manuwa, 2018).

According to the authors, 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 centimetres (cm^2) based on the number of squares below the reference line. Also, on the paper the depth and width of disturbance could be estimated (Kumar and Thakur, 2005, Odey and Manuwa, 2018).

5.0 SUBSOILERS DESIGNS AND THEIR EFFECTS ON DRAUGHT FORCES AND SOIL DISTURBANCE

Godwin (2007) 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 900 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. Rake angle has considerable effects on soil disturbance pattern. Thus tines of 50 mm and 100 mm widths operating at a depth of 150 mm, and rake angles 1600, 900 and 200 respectively.

Wings or sweeps attached to the foot of the tine modify the type of soil disturbance 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 Godwin *et al.* (1984) showed how tine spacing can affect the soil disturbance pattern produced by a pair of tines operating at the same depth. From this work and that from studies on subsoiling equipment by Godwin (2007) 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.

6.0 CONCLUSION

This article reviews the measurement of tillage forces and soil failure using instrumentations during subsoiling for alleviation of soil compaction and conservative tillage practices. This is necessary in order to facilitate the design of new tool shapes which will reduce tool draught, energy demand and increased soil disruption over a wide speed range. Different types of instrumentations have been utilized in the measurement of forces on tillage tools. These are transducer, dynamometer, strain gauge and extended orthogonal ring transducer.

Several parameters affecting soil loosening are tool parameters such as 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. Researchers normally take into consideration the accurate measurement of the area of soil disruption. Hence different instrumentations are put in place for such purpose. These include soil profile meter, digital imaging equipment and image tracking & analysis software, laser distance sensor, linear actuator, portable pc, and a lightweight Aluminium frame that can quickly and accurately measure above and below-ground soil disruption caused by tillage.

REFERENCES

1. Adamchuk, V. I.; Skotnikov, A. V.; Speichinger, J. D.; and Kocher, M. F. (2004). Development of an Instrumented Deep−Tillage Implement for Sensing of Soil Mechanical Resistance. Transactions of the ASAE, 47(6): 1913−1919. ISSN 0001−2351.
2. Ademosun, O. C. (2014). Soil Tillage Dynamics in Nigeria: Potentials Prospects and Challenges. Proceedings of Nigerian Branch of International Soil Tillage Research Organisation. ISTRO-Nigeria Symposium, Akure, ISSN – 978-187-472-4, 26-31.
3. Alam, M. M. (1989). Soil Reaction Forces on Agricultural Disc Implements. A Thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy in Agricultural Engineering, The University of Newcastle, New Castle University Library, 089052875, Thesis L3518.
4. Ale, M. O, Ademosun, O. C., Manuwa, S. I., Agbetoye, L. A. S., Adesina, A, and Ewetumo, T. (2013). Assembly and Performance Evaluation of the Instrumentation System of a Soil bin for Tillage Study. Proceedings of The Nigerian Institution of Agricultural Engineers, 2013; 34.
5. Alimardani, R., Fazel, Z., Akram, A., Mahmoudi, A. and Varnamkhasti, M.G. (2008). Design and Development of a three-point hitch dynamometer. Journal of Agricultural Technology, 4(1): 37–52.
6. Al-Jalil, H.F. (2001). Khdair, A. and Mukahal, W. Design and performance of an adjustable three-point hitch dynamometer. Soil and Tillage Research, 62: 153-156.
7. Baker, G. L., Smith, A. and Clowick, R.f. (1981). Three point hitch dynamometer for directional force measurements. ASAE, 81-1044.
8. Borselli, L., Torri, D. 2010. Soil roughness, slope and surface storage relationship for impervious reas. Journal of Hydrology, 393: 389–400.
9. Chandon, K. and Kushwaha, R. L. (2002). Soil Forces on Deep tillage Tools. Written for presentation at the AIC 2002 Meeting CSAE/SCGR Program Saskatoon, Saskatchewan, July 14 - 17, 2002.

10. Chaplin, J., Lueders, M. and Zhao, Y. (1987). Three point hitch dynamometer design and calibration. ASAE Applied Engineering in Agriculture, Feb. 1987; 10-13.
11. Chen, Y., McLaughlin, N.B. and Tessier, S. (2007). Double extended octagonal ring (DEOR) drawbar dynamometer. Soil and Tillage Research, 93: 462-471.
12. Chung, Y.G., Marley, S.J. and Buchele, W.F. (1983). Development of a three-point hitch dynamometer. ASAE paper No. 83-1066.
13. Darboux, F., Huang, C.H. 2003. An instantaneous profile laser scanner to measure soil surface microtopography. Soil Sci. Soc. Am. J., 67: 92–99.
14. Ewetumo, T. (2011): Development of 3D-Magnetometer for Real-Time Measurement of the Geomagnetic Field Strength.Ph.DThesis, Physics, FUT., Akure, Nigeria, 58-63.
15. Gill, W. R., and Vanden Berg, G. E. (1968). Design of Tillage Tools. Chapter Five in Soil Dynamics in Tillage and Traction, Agriculture HandBook, 316: 211-297. Washington, D.C.: U.S. Government Printing Office.
16. Glancey J. L; Upadhyaya S K; Chancellor W J; Rumsey, J. W. (1996). Prediction of agricultural implement draught using an instrumented analog tillage tool. Soil and Tillage Research, 37: 47–65.
17. Godwin, R. J. (2007). A review of the effect of implement geometry on soil failure and implement forces, Soil & Tillage Research, 97: 331–340.
18. Godwin, R. J., O‟Dogherty, M. J. (2006). Integrated soil tillage force prediction models. J. Terramechanics, 24(4): 32 - 41.
19. Godwin, R.J., Spoor, G., Somroo, M. S. (1984). The effect of tine arrangement on soil forces and disturbance. J. Agric. Eng. Res., 29: 47–56.
20. Grisso, R. D. Perumpral, J. V. and Desai, C. S. (1994). A soil-tool interaction model for narrow tillage tools. ASAE, paper No. 80-1518, St. Joseph, Mi. 20 pp.
21. Guler, M., Edil, T.B., Bosscher, P.J. 1999. Measurement of particle movement in granular soils using image analysis. J Comput Civil Eng, ASCE, 13(2): 116–22.
22. Hegazy, R. (2013). Soil Surface Profile Computation using Portable Profile Meter with Image Processing and Tracking Technique. Global Journal of Researches in Engineering General Engineering, 13(3): Version 1.0.
23. Hoag, D. L. and Yoerger, R. R. (1975). Analysis and design of load rings. Transactions of ASAE, 19: 995-1000.
24. Hu, L., Pu, J. (2004). Testing and modeling of soil–structure interface. J Geotech Geoenviron Eng, 130(8): 851–60.

25. Jones, A. J.; Bashford, L. L.; Grisso, R. D. (1996). Subsoiling in Nebraska. Published by corporate Extension, Institute of Agriculture and Natural Resources; University of Nebraska-Lincoln. Nebraska Corporate Extension, NF96-258.
26. Kees, Gary. 2008. Using subsoiling to reduce soil compaction. Tech. Rep. 0834–2828–MTDC. Missoula, MT: U.S. Department of Agriculture, Forest Service, Missoula Technology and Development Center, 14.
27. Khan, J., Godwin, R.J., Kilgour, J. and Blackmore, B.S.(2006). Design and calibration of a direct mounted strain gauged lower links system for measurement of tractor-implement forces. ARPN Journal of Engineering and Applied Science, 1(1): 22-25.
28. Kirisci, V., Blackmore, B.S., Godwin, R.J. and Blake, J. (1993). Design and calibration of three different three-point linkage dynamometers. ASAE/CSAE Paper No. 93-1009. ASAE, St. Joseph, MI.
29. Kornecki, T.S., Fouss, J.L., Prior S.A. 2008. A portable device to measure soil erosion/deposition in quarter-drains. Soil Use and Management, 24: 401-408.
30. Kumar, A. and Thakur, T. C. (2005). An investigation into comparative test of Conventional and winged Subsoilers. A Presentation at the ASAE Annual International Meeting, Tampa Convention Centre, Tampa, Florida, USA. ASAE Paper No. 051061.
31. Leonard, J. J. (1980). An extended-octagon rigid drawbar dynamometer. Agricultural Engineering .Australia, 9: 3-8.
32. Manor, G. and Clark, R. L.(2001). Development of an Instrumented Subsoiler to Map Soil Hard-Pans and Real-Time Control of Subsoiler Depth. ASAE Annual International Meeting, Sacramento Convention Cente, Sacramento, California, USA, August, 2001.
33. Manuwa, S. I. and Ademosun, O. C. (2007). “Draught and Soil Disturbance of Model Tillage Tines Under Varying Soil Parameters”. Agricultural Engineering International: the CIGRE journal. PM 06 016, IX.
34. McLaughlin, N.B. (1996). Correction of an error in equations for extended ring transducers. Transactions of ASAE, 39: 443-444.
35. McLaughlin, N.B., Chen, Y. and Tessier, S. (2005). Effect of strain gage misalignment on cross sensitivity in extended ring transducers. CSAE Paper 05-063. CSAE, Winnipeg, MB, Canada.
36. Moreno, R.G., SaaRequejo, A., Tarquis Alonso, A.M., Barrington, S., Díaz, M.C. 2008. Shadow analysis: A method for measuring soil surface roughness. Geoderma, 146: 201–208.

37. Nigon, B. J., Dietsche, S. C., Strehmel, C. J., Shinners, K. J. and Larson, R. (2013). Badger dyno: an easily adopted tractor hitch dynamometer, Project undertaken at Biological Systems Engineering, University of Wisconsin, Madison, USA.
38. Odey Simon O. and Manuwa Seth I. (2018). Development of Profilometer for Measuring Area of Soil Disturbance by Narrow Tillage Tools. International Journal of Research in Engineering and Science (IJRES), 6(1): 26-32.
39. Odey Simon O., Ovat Friday A. and Orok Okon O. (2018 a). Draughts, Power Requirements and Soil Disruption of Subsoilers. International Journal of Emerging Engineering Research and Technology, 6(9): 24-38.
40. Odey, S. O. and S. I. Manuwa. (2016). Design Steps of Narrow Tillage Tools for Draught Reduction and Increased Soil Disruption – A Review. Agric Eng. Int: CIGR Journal, 18(1): 91-102.
41. Odey, S. O., Manuwa, S. I. and Ewetumo, T. (2018 b). Development and Performance Evaluation of Instrumented Subsoilers in Breaking Soil Hard-pan. Agricultural Engineering International: CIGR Journal, 20(3): 85–96.
42. Odey, S. O., Manuwa, S. I. ans Ewetumo, T. (2018 c). Instrumentation Assembly for Measuring Draughts Of Subsoilers In Outdoor Soil Bin Facility. International Journal of Research in Engineering and Science (IJRES), 06(02): 01–10.
43. Odey, Simon O. and Manuwa, Seth I. (2018). Subsoiler Development Trend in the Alleviation of Soil Compaction for Sustainable Agricultural Production. International Journal of Engineering Inventions, 7(8): 29-38.
44. Odey, Simon Ogbeche (2018). Overview of Engineering Problems of Soil Compaction and Their Effects on Growth and Yields of Crops. European Journal of Advances in Engineering and Technology, 5(9): 701-709.
45. Onwualu, A. P. (2002). An extended octagonal ring dynamometer for measurement of forces on a simple tillage tool. Nigerian Journal of Technology, 21(1): 46–59.
46. Palmer, A.L. (1992). Development of a three-point linkage dynamometer for tillage research. Journal of Agricultural Engineering Research, 52: 157-167.
47. Palmer, A.L. (1992). Development of a three-point linkage dynamometer for tillage research. Journal of Agricultural Engineering Research, 52: 157-167.
48. Pardini, G. 2003. Fractal scaling of surface roughness in artificially weathered smectiterich soil regoliths. Geoderma, 117(2203): 157–167.

49. Raper, R. L. (2002). Force Requirements and Soil Disruption of Straight and Bentleg Subsoilers for Conservation Tillage Systems. ASAE Meeting Presentation. Paper No. 021139. St. Joseph, Mich.
50. Raper, R. L. (2005). Subsoiler shapes for site-specific tillage. Applied Engineering in Agriculture, 21(1): 25-30.
51. Raper, R. L. (2007). In-row subsoilers that reduce soil compaction and residue disturbance. Publication of American Society of Agricultural and Biological Engineers (ASABE), 23(3): 253-258. ISSN 0883−8542.
52. Raper, R. L. (2007). In-row subsoilers that reduce soil compaction and residue disturbance. Publication of American Society of Agricultural and Biological Engineers (ASABE), 23(3): 253-258. ISSN 0883−8542.
53. Raper, R. L. 2007. In-row Subsoilers that Reduce Soil Compaction and Residue Disturbance. Transaction of the American Society of Agricultural and Biological Engineers, 23(3): 253-258.
54. Raper, R. L. and E. C. Schwab (2008). Development of an In-row Subsoiler Attachment to Reduce Smearing. Presentation at ASABE Annual International Meeting, June 29 – July 2, 2008. Paper Number: 084256.
55. Raper, R. L., and Sharma, A. K. (2004). Soil Moisture effects on energy requirements and soil disruption of subsoiling of coastal plain soil. Transaction of the American Society of Agricultural Engineers, 47(6): 1899-1905.
56. Reece, A. R. (1965). A three point linkage dynamometer. Journal of Agricultural Engineering Research, 6: 45-50.
57. Römkens, M.J.M., Singarayar, S., Gantzer, C.J. 1986. An Automated Non Contact Surface Profile Meter. Soil Tillage Res., 6: 193–202.
58. Sahu, R. K.and Raheman, H. (2006). Draught Prediction of Agricultural Implements using Reference Tillage Tools in Sandy Clay Loam Soil. Journal of Biosystems Engineering, 94(2): 275–284. Published by Elsevier Ltd.
59. Scholtz, D. C. (1996). A three-point linkage dynamometer for restrained linkage. Journal of Agricultural Engineering Research, 11(1): 33-37.
60. Smith, L. A. and Williford, J. R. (1988). Power Requirements of Conventional, Triplex, and Parabolic Subsoilers. Transactions of the ASAE, 31(6): 1685–1688.
61. Smith, L. A. and Williford, J. R. (1988). Power Requirements of Conventional, Triplex,and Parabolic Subsoilers. Transactions of ASAE, 31(6): 1685-1688.

62. Spoor, G. and Godwin, R. J. (1978). Experimental Investigation into the deep loosening of soil by rigid tines. J. Agric. Eng. Res., 23(3): 243-258.
63. Stafford, J. (1984). The performance of a rigid tine in relation to soil properties and speed. J. Agric. Eng. Res., 24(1): 41–56.
64. Tessier, S. and Ravonison, N. (1997). Finite element analysis of extended octagonal ring transducers. Department of Soil and Food Engineering, University Laval, Quebec, Qc. Unpublished research report submitted to Agriculture and Agri-Food Canada, Ottawa, ON, Canada.
65. Tessier, S., Guilbert, A., McLaughlin, N.B. and Tremblay, D. (1992). A double EOR drawbar pull transducer for 3-d force measurement, CSAE Paper No. 92-406. Csae, Winnipeg, MB, Canada.
66. Upadhyaya, S. K., Williams, T. H., Kembie, L. J., Collins, N. E. (1984). Energy requirements for chiselling in coastal plain soils. Transaction of the American Society of Agricultural Engineers, 27(6): 1643-1649.
67. Vaishnav, A.S. (1983). Evaluation of disc coulters for a zero till system. Unpublished M.Sc. thesis. Department of Agricultural and Bioresource Engineering, University of Saskatchewan. Saskatoon, SK. S7N 5A9.
68. Wagner, L.E., Yiming, Y. (1991). Digitization of profile meter photographs. Trans. ASAE, 34(2): 12–416.