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Instrumentation Assembly for Measuring Draughts of Subsoilers in Outdoor Soil Bin Facility

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ABSTRACT: Instrumentation system was assembled to measure draughts of subsoilers operating at different depths. The experiment was carried out on the outdoor soil bin facility at the Science and Technology Education Post-Basic (STEP-B) Research Field of the Federal University of Technology, FUTA, Akure; located on geographical coordinate, 7°15'0''N and 5°11'42''E. The instrumentation system consists of the following (a) Load cell (100 kN) – strain gauge type, (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 has 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. The load cell was calibrated and connected to the tool carrier using brackets. The other end of the load cell was also screwed with a bolt firmly and then hitched to the drawbar of a 31.6 kW (MF 415) Massey Fergusson tractor. The load cell cable was then extended to the instrumentation box attached to the left hand side of the tractor. This box housed other components of the instrumentation assembly.Four subsoilers were operated simultaneously at four levels of depth - 20, 30, 40 and 50 cm, by hitching each to the tool bar. The subsoilers were straight shank subsoiler (SSS), semi-parabolic subsoiler (SPS), parabolic 'C' shank subsoiler (CSS) and winged subsoiler (WSB).The logged data were downloaded into the computer system and analyzed using statistical package for social sciences (SPSS) version 21 and Microsoft Excel 2010 to establish relevant relationships between subsoiler draughts and tillage parameters in the form graphs. Results showed that the best subsoiler in terms of draught reduction was parabolic C-shank subsoiler (CSS) with 4.581 kN, followed by semi-parabolic subsoiler (SPS) with draught of 4.905 kN at depth of 40 cm. At this working depth the SSS, WSB and SSS37 had draughts of 6.874, 7.003 and 7.385 kN respectively.The load cell had a measuring accuracy of 99.9% as showed by the coefficient of linearity, R^2, during calibration.

Key Words: Draughts, Hard-Pan, Instrumentation, Soil-bin,Subsoilers, Assembly

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I. INTRODUCTION

Measurement of forces on tillage tools have been an issue of great concern in soil tillage dynamics.Draft 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 (Godwin, 1975;Leonard, 1980).Several researchers have worked on measurement of forces on tillage tools. Ademosun (2014) 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.

Dynamometeris 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 transduceris 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.

On the other hand, the load cell is a transducer that is used to convert a force into an electrical signal. This conversion is indirect and happens in two stages. Through a mechanical arrangement, the force being sensed 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 millivolts and according to (Robert and Louis, 1996, Ewetumo, 2011) 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 (Khan et al., 2006). This required simultaneous recording of at least three forces which involved very complicated instrumentation. 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.

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. Chung (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.
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 lightweight implements. 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 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 gages 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 (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. 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(Palmer, 1992).

Apart from three-point hitch dynamometer, several researchers have made effort to study over drawbar dynamometer such as: Zoerb *et al.* (1983), 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 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, in 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.

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.Ale *et al.* (2013) also made use of load cell coupled to a tool carrier and drawbar in measuring draught of tillage tool.

In his work on 'force requirements and soil disruption of straight and bentleg subsoilers for conservation tillage systems', Raper, L. R. (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.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. The resultant force on the shank was calculated by using the three measured forces, their directions and locations.

The objective of this work is toassemble electronic instrumentation for the acquisition and logging of draughtsof different subsoilers.

II. MATERIALS AND METHOD

2.1 Experimental Site

The experiment was carried out on the outdoor soil bin facility at the Science and Technology Education Post-Basic (STEP-B) Research Field of the Federal University of Technology, FUTA, Akure; located on geographical coordinate, $7^{o}15^{'}0^{''}$N and $5^{o}11^{'}42^{''}$E.

2.2 Description of Subsoiler Shanks

(a) Straight Shank Subsoiler (SSS)

This had a total height of 600 mm, thickness of 20 mm and width of 60 mm. It had a shoe of length 300 mm, with a cutting blade of length 230 mm and thickness of 150 mm. It has a lift cutting angle (rake angle) of 27^{0}, as recommended by Sakai *et al.* (1983) and used by Bandalan *et al.* (1999); and Kumar and Tharkur (2005).

(b) Winged subsoiler (WSB)

When two wings of 70 mm wide each were attached at opposite sides of the shoe, the result was winged subsoiler.

(c) Semi-parabolic subsoiler (SPS)

This shank had a height of 600 mm, and was slightly curved towards the shoe, with its contact at the heel. The shoe had a length of 180 mm.

(d) Parabolic 'C' shank subsoiler (CSS)

This was completely curved, and had a "C" shape. It had a height of 600 mm, thickness of 20 mm and width of 60 mm.

2.3 Description of the Soil Bin and its Facilities

2.3.1 Soil Bin

Ale *et al.* (2013) and Manuwa *et al.* (2008) reported that the existing the soil bin facility is equipped with a soil bin with a dimension of 48,000 x 1500 x 1200 mm of length, width and height, respectively.

2.3.2 Implement Carriage System

The implement carriage was constructed using rectangular hollow section steel (RHS) of dimension 100 x 100 mm and is supported on four wheels mounted on the main frame by four wheel mounting brackets. The arrangement of the wheels was designed to run on the side railings of the soil bin. The carriage has a 3-point linkage and also an implement coupling recess to enhance the rigid coupling of the tool carriage sub-system.
The carriage dimension is 1,623 mm x 700 mm x 1,117 mm of length, width and height, respectively. The major functions of the carriage are: firstly to mount the carriage subsystem which in turn carries the toolbar in place; secondly, for mounting any tillage or traction devices such as traction or towed wheels for testing or for transportation. The carriage can be coupled to the power source through the 3-point linkage, and by using the bracket system through the drawbar.

2.3.3 Implement Carriage Sub-system

This is basically made up of a rectangular main frame designed to stand on four detachable steel legs. In the middle of the frame is welded a rake meter for varying the angle of approach (rake angle) of mounted tool or implement. Also, at that point below the rake meter is a mounting device to hold the tool bar rigidly in place. The carriage subsystem has dimension of 1,395 mm x 600 mm x 667 mm of length, width and height, respectively. Two mounting studs are also welded in place to secure rigidity with the implement carriage.

2.3.4 Tool bar and Fixing Device

The tool bar was fabricated from 55 mm square section solid bar (medium carbon steel) of length 1000 mm. A slot 24 mm wide and 100 mm deep was created on one side of the tool bar for the purpose of hitching each of the shanks. Three holes of 18 mm diameter were drilled 30 mm apart for bolting each shank firmly to the tool bar.

2.4 Soil Test

The soil bin and its environs was cleared and packed. The soil bin was mapped out and divided into 4 zones of length, 12,000 mm each, for study. The zones were captioned A, B, C, and D.

2.4.1 Soil Bulk Density:

Soil samples were taken from each of zones on the soil bin at 3 depths of 0-15, 16-30, 31-45 cm using soil core samplers for measurement of soil bulk density. Soil cores were driven into each depth of the soil and the collected soil was kept in an air tight polythene bag to avoid moisture loss. The samples were oven dried and weighted. The oven dried soil in the cores were allowed to cool. The bulk density was determined using equation (Blake and Hartge, 1986; D'Haene *et al.*, 2008).

2.4.2 Moisture Content:

Moisture meter (model – PMS – 714) was used to take soil moisture content in-situ at specific zones on the soil bin.

2.4.3 Soil Porosity:

Direct method was used in measuring the porosity. First, the bulk volume of the porous sample was determined, then the volume of the skeletal material with no pores was determined. Thus pore volume = total volume − material volume. This was done for each of the samples according to Blake and Hartge, 1986; D'Haene *et al.*, 2008.
Thus the data on soil test above were not made available in this report.

2.4.4 Cone Index:

In other to ascertain the degree of compaction of the soil on each zone of the soil bin, cone index was measured to depth of 50 cm using cone penetrometer (model - CP40II, RIMIK, Australia). The penetrometer is equipped with load cell, transducer, GPS and LCD screen.

2.5 Compaction of Soil in the Bin

The subsoiler shanks were designed to break hard pans of soil to a depth of 500 mm. Hard-pans of 2.0 MPa and above is highly detrimental to crop production. There was therefore the need to re-compact the soil after loosening with each of the subsoiler. The tractor was carefully driven to and fro along the soil bin with two wheels (front and back) in and two wheels (front and back) out of the soil bin. By doing this the soil was easily recompacted due to the immense weight of the tractor on it (Celik and Raper, 2012). The rollers were not found suitable for this purpose due to their low weight (85 kg) compare to that of the tractor (2,018 kg). After each recompaction the cone index was measured to ensure a surface and sub-soil compaction of at least 2.0 MPa and above.

2.6 Instrumentation system

The instrumentation system consists of the following (a) Load cell (100 kN) – strain gauge type (No. 100201022 and output, 2.50mV/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 is equipped with software, SquirelView Plus edition, version 5.3.6. The software has 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.

2.7 Calibration of Load cell

A 100 kN (10 t) load cell selected for use in measuring draught of subsoilers was calibrated in Soil and Tillage Laboratory of the Department of Agricultural Engineering, FUTA. The following tools were used for calibration: 6 number ten kilogramme (10 kg) weights, 10 t load cell, amplifier, volt meter and 6 v set of batteries. The load cell was kept on a stable floor and was connected to the amplifier and the volt meter, both of which were setup on the table. The arrangement was then connected 6 v set of batteries. And the initial voltmeter reading was noted (Ale *et al.*, 2013, Ademosun *et al.*, 2014).

Each of the 10 kg weights was then transferred one after the other on the stable load cell, and the voltmeter readings were noted. The 10 kg weights were unloaded from the load cell one after the other and the corresponding voltmeter readings were noted (see Fig. 1). The experiment was repeated thrice and the mean values of the corresponding voltmeter readings were recorded. A graph of kg force (N) against volts (V) was plotted and a characteristics equation and R^2 values were noted.

Figure 1: Showing (A) Placement of weights on the load cell during calibration, (B) voltmeter and amplifier connecting during load cell calibration and (C) connection of laptop computer to data logger during field test.

2.8 Instrumentation Assembly and Measurement of Draughts

The instrumentation assembly was made up of a 10 tonne load cell attached to the tool carrier load cell brackets using a 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 (print circuit board), which was connected to the load cell, data logger, and a pair of 6 V dry cell batteries (12 V). The data logger was also connected to the laptop for the monitoring and downloading of the acquired data (see Figures 2 – 5 below).

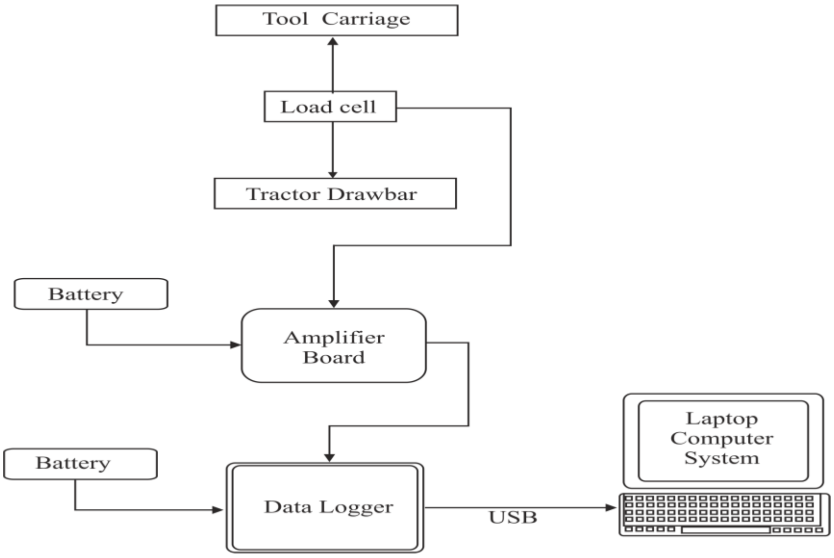


Figure 2: Schematic arrangement of the Instrumentation System for measuring draughts

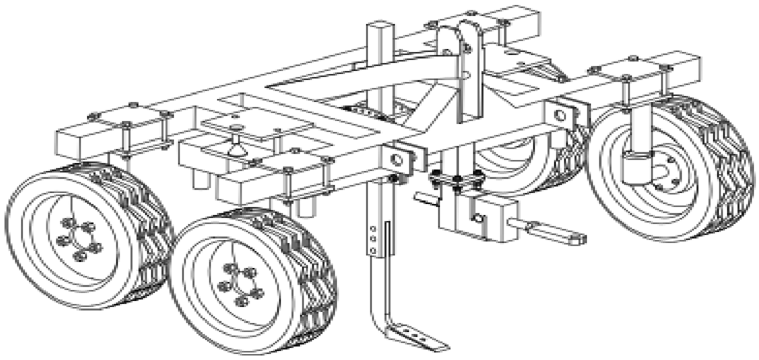
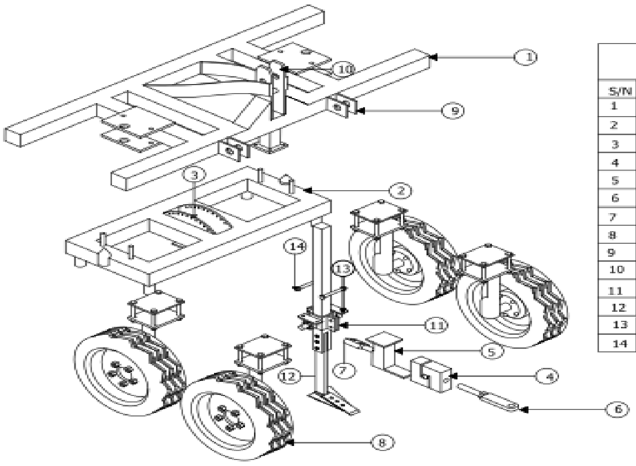


Figure 3: Semi-parabolic subsoiler attached to the tool bar of the carrier with load cell in position



PART LIST

S/N	DISCRIPTION	QTY
1	IMPLEMENT CARRIAGE	1
2	IMPLEMENT CARRIGE SUB-SYSTEM	1
3	RAKE METER	1
4	LOAD CELL	1
5	LOAD CELL SEAT	1
6	LOAD CELL BRACKET (FRONT)	1
7	LOAD CELL BRACKET (BACK)	1
8	IMPLEMENT CARRIAGE WHEEL	4
9	LOWER LINK ATTACHMENT	2
10	UPPER LINK ATTACHMENT	1
11	TOOL BAR HOLDER	1
12	TOOL BAR	1
13	BEARING	1
14	BOLT AND NUT	30

Figure 4: Exploded view of the tool carrier with winged subsoiler and load cell attached

Figure 5: Showing (A) Tool carrier coupled to the tractor, (B) Straight shank subsoiler and load cell in position and (C) Semi-parabolic subsoiler and load cell in position

III. RESULTS AND DISCUSSION

3.1 Cone Index and Moisture Content of Soil Bin before Compaction, after Compaction and after Subsoiling

The initial average cone index values taken at various points on the soil bin showed that cone index at the depth of 0-20 cm was between 0.18 - 0.44 MPa. While the cone index at the depth of 21 - 30 cm was at the range of 0.5 - 1.35 MPa. In another development, the cone index at the depth of 31-50 cm for the points under consideration was between 0.9 - 1.7 MPa. Thus the cone index at random points on the soil bin at the three levels of depth were increased to 2.0 MPa and above due to tractor-induced compaction. The high cone index values of the soil bin was reduced considerably as a result of subsoiling. Thus the artificial hard pan created was broken, and the cone index at the three levels of depth was reduced to a range of 0.10-0.60 MPa. This corroborates the findings of Raper (2007) where the cone index and bulk density of soil were reduced after subsoiling.

The range of moisture content at the three levels of depth for different location on the soil bin before compaction, after compaction and after subsoiling revealed a significant difference between them. Thus the moisture contents at the levels of depth under consideration were observed to be between 8-19 % before compaction, 10-17 % after compaction and 9-16 % after subsoiling. This shows that compaction and subsoiling had significant effects on the range of soil moisture at different depths.The soil bin textural class was sandy clay (49 % sand, 47 % clay, and 14 % silt), with average porosity of 26 %.

3.2 Output Voltage of Load Cell Due to Load

Fig.6 shows the graph of weight (N) and output voltage of instrumentation amplifier during calibration of the system. It revealed that the graph is linear. The coefficient of linearity, R^2 is very high with a value of 0.999. This shows that the equipment was highly calibrated. It has a linear equation of y = 1332x -831.0 as shown.

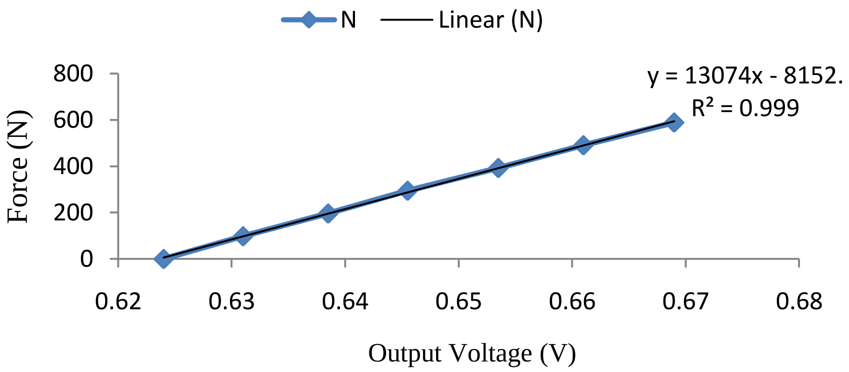


Figure 6: Outpout voltage from instrumentation amplifier due…

3.3 Draughts of Subsoilers

Draughts of subsoilers operating at different depths which were logged and downloaded are shown in figure 7. The use of CSS gave the lowest draught, followed by the SPS, SSS and WSB. The SSS37 working at an increased rake angle of 37^0 exerted the highest draught. Thus at operating depth of 20 cm, CSS exerted an average draught of 1,478.50 N, followed by SPS with 2,073.04 N. At this depth of operation, the SSS, WSB and SSS37 had 3,382.83, 3,718.42 and 3,811.60 N respectively.

On the other hand, at 40 cm working depth the CSS, SPS, SSS, WSB and SSS37 had draughts of 4581.02, 4905.09, 6874.48, 7003.40 and 7385.28 N respectively. Whereas at 50 cm operating depth, CSS had the lowest draught of 6,319.90 N and WSB had the highest draught of 9,121.30 N. Thus the CSS showed signs of bending as the operating depth increased from 30 cm to 40 and 50 cm. This revealed the handicap nature of CSS at high depth of operation due to surcharge or vertical pressure on the soil, which resulted in increase soil failure force. This corroborates the findings of Upadhyaya*et al.*, (1984) and also in accordance with the report of Kumar and Thakur, (2005).

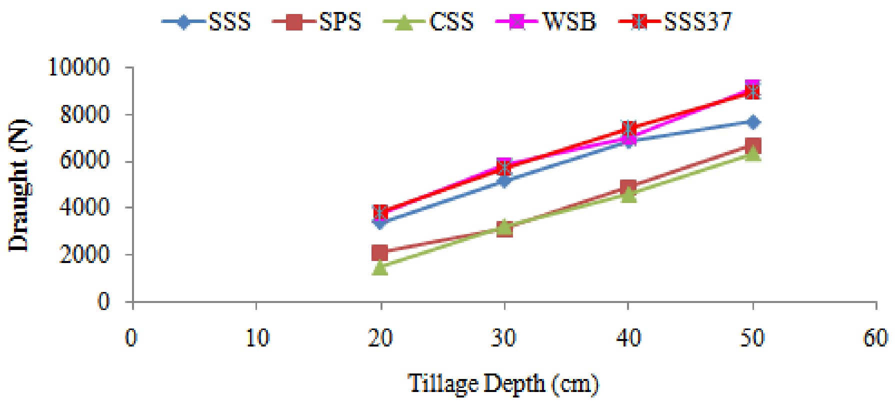


Figure 7: Draught of subsoiler shanks at different depths

The performance of subsoilers in terms of decrease in draught shows that the SPS and CSS had a decrease of 1309.79 N (39%) and 1904.33 N (56%) respectively compared to SSS at working depth of 20 cm. Thus the decrease in draught was observed for all the working depths. At 40 cm working depth, the decrease in draught for both subsoilers (SPS and CSS) compared with the SSS were 1969.38 N (29%) and 2293.46 N (33%) respectively.

On the other hand the WSB and SSS37 had an increase in draught of 335.59 N (10%) and 428.77 N (13%) respectively at working depth of 20 cm compared to SSS. While at 50 cm working depth the WSB and the SSS37 had increase draught of 1437.10 N (19%) and 1262.64 N (16%) compared to SSS respectively. Thus, in all the working depths, both subsoilers had varying increase in draught compared to the SSS.

IV. CONCLUSION

Conclusion is drawn from this study as follow:

1. Instrumentation system was assembled for the measurement of draught of different subsoiler shanks at different depths of operation in a soil bin.

2. Draught requirements of the subsoilers were: parabolic C-shank subsoiler (CSS) with 4.58 kN followed by semi-parabolic subsoiler (SPS) with draught of 4.91 kN at depth of 40 cm. At this working depth the SSS, WSB and SSS37 had draught of 6.87, 7.00 and 7.39 kN respectively.

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