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Development of Profilometer for Measuring Area of Soil Disturbance by Narrow Tillage Tools

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ABSTRACT: Soil profilometer was developed for estimating the area of soil disruption by tillage tools. It was designed and constructed using steel, aluminium and wood panel materials. It has a dimension of 80 by 75 cm height and width respectively.To estimate area of soil disruption, four instrumented subsoilers were simultaneously hitched to the tool bar of the tool carrier.The tool carrier was attached to the drawbar of a 31.6 kW (MF 415) tractor and pulled through the soil bin to loosen the soil at 20, 30, 40 and 50 cm depths of operation. Soil disturbance were measured during operation at the outdoor soil bin. The subsoilers used in loosening the soil were straight shank (SSS), semi-parabolic (SPS), parabolic 'C' shank (CSS) and winged (WSB).All the subsoilers were operated at 27^o rake angle. SSS was also operated at 37^o rake angle, SSS37. After calibration the profilometer was placed across the tilled soil to measure the area of soil disturbance for each subsoiling operation. Data collected were analyzed to establish relationships betweenthesubsoiler types, depths of operation and soil disturbance.The SSS37 showed the highest soil loosening ability at all the depths followed by WSB, SPS, SSS and CSS respectively. Thus, at 50 cm highest working depth SSS had 0.0451 m^2 followed by SPS with 0.0487 m^2, while CSS, WSB and SSS37 had 0.0403, 0.0683 and 0.1061 m^2 respectively.

Keywords: Depth,Profilometer, Rake Angle, Soil Disturbance, Subsoiler,

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I. INTRODUCTION

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. Tool parameters such as tool geometry - width, rake angle, aspect ratio, and other parameters such as speed, cone index, bulk density, porosity and soil moisture 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 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).

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 andYiming, 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 islimited because sunlight and hidden forms or shadowsinterfere with the readings, while high temperaturesaffect the performance of the sensitive measuringdevices (Pardini, 2003; Darboux and Huang, (2003). Moreno *et al.* (2008) conducted study to developa new method for measuring soil surface roughness thatwould be more reliable by using the principle underlyingshadow analysisis the direct relationship between soilsurface roughness and the shadows cast by soil structures under fixed sunlight conditions. They showed that shadow analysis yielded results significantlycorrelated to the pin meter findings, but with theadvantage that the time invested in gathering field datawas 12 to 20 times shorter.

Another work has beencarried out by Borselli and Torri (2010) in order toreproduce reliable rough surfaces able to maintainstable, un-erodible surfaces to avoid changes ofretention volume during tests by a set of roughnessindices was computed for each surface by usingroughness profiles measured with a laser profile meter, and roughness is well represented by quantiles of theAbbot–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 structureusing photographs and discussed the thickness of the sand–steel interface.

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.

The objective of this work is to develop a soil profilometer for accurate measurement of area of soil disturbance during tillage operations.

II. MATERIALS AND METHOD

2.1 Experimental Site

The experiment was carried out at the Department of Agricultural and Environmental Engineering, Federal University of Technology, FUTA, Akure; located on geographical coordinate, $7^{o}15^{'}0^{''}$N and $5^{o}11^{'}42^{''}$E.

2.2 Design Considerations of Profilometer

The design of Profilometer for measuring soil disturbance during the study took into considerations the following:

a. Weight of material – light material was selected such that the profilometer can easily be portable.
b. Height and Width of equipment: the height and width of the equipment was such that it can measure soil disturbance to depth and width of 50 and 75 cm respectively.
c. Stability of equipment: the equipment must be stable so as to be able to stand on its own during operation.
d. Smoothness of the equipment surface for easy pasting and removal of the graph paper.

2.3 Components Design of Profilometer

Design of the width of profilometer for measuring width of soil failure was carried out base on the work of Godwin (2007),, where he specified the width of soil disturbance to be 1.5 x depth of tool operation for narrow or simple tines and 2.0 x depth of tool operation for wide or winged tines.

Hence for a subsoiler having a width of 6.0 cm to be operated to a depth of 50 cm the total width of soil disturbance was 1.5 x 50 = 75 cm (750 mm). The width of soil disturbance was therefore estimated at 75 cm.

The Profilometer had the following dimensions:

* 2 number 25 mm x 50 mm x 800 mm hollowed pipe
* 2 number 25 mm x 50 mm x 750 mm hollowed pipe
* 2 number 25 mm x 50 mm x 300 mm hollowed pipe
* 14 number 4 mm x 700 mm aluminium rods
* 750 mm x 750 mm x 20 mm ceiling board

2.4 Material Selection

Table 3.1: Name and properties of materials for fabrication of Profilometer

S/No.	Components	Type of material	Properties
1	Rectangular pipe	Medium carbon steel	High strength, rigidity and resistance to wear
2	4 mm diameter rod	Aluminium	Malleable, ductile
3	2 mm x 15 mm bar	Malleable steel	Malleable, ductile
4	Ceiling board	Panel wood	Tough and soft

2.5Fabrication of Components

Fabrication of components were carried out in Agricultural Engineering Workshop, Federal University of Technology, FUTA. Rectangular hollowed steel pipe of dimension 25 mm x 50 mm was cut using the electric hand cutting machine to sizes. 4 mm diameter malleable aluminium rod was cut to their sizes using hacksaw while ceiling board of 20 mm thickness was cut to the designed size with hacksaw. Welding was carried out to joined the appropriate parts.

2.6Description of Profilometer

The soil disturbance measurement profilometerwas 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 (Figures 1 and 2).

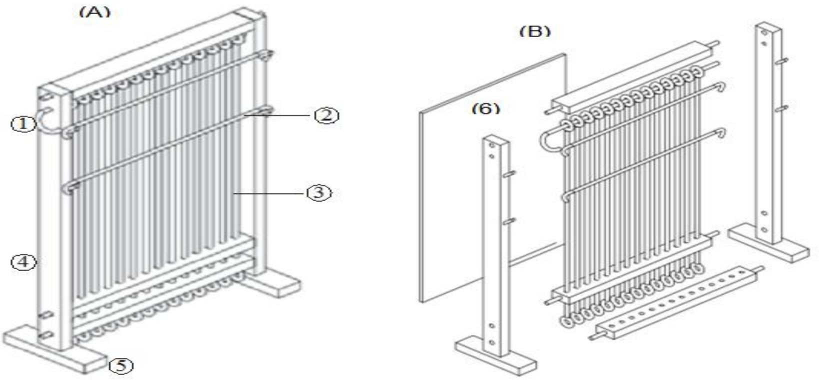

Figure 1: View of the profilometer (1) sliding rods holder, (2) sliding rods guide, (3) sliding rods, (4) frame and (5) stand (6) ceiling board

Figure 2: Shows the developed profilometer

2.7 Calibration and testing of Profilometer

2.7.1Calibration of Profilometer

In other to ensure that the constructed profilometer accurately measures soil disturbance, it had to be calibrated. The equipment was taken to the Science and Technology Education Post-Basic (STEP-B) Research field. A tillage tool was used to disturbed the soil to series of depths and widths. A steel rule was used in measuring the depth and width of the disturbance at a particular point to estimate the area. 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 (Kumar and Thakur, 2005). Also, on the paper the depth and width of disturbance were estimated. These values were compared with the values estimated using the steel rule. The process was repeated five times and the graph paper was adjusted accordingly on the board until the areas estimated by profilometer and the steel rule were not significantly different from each other. By doing this, the exact position for pasting the graph paper on the profilometer board was determined (see figure 3).

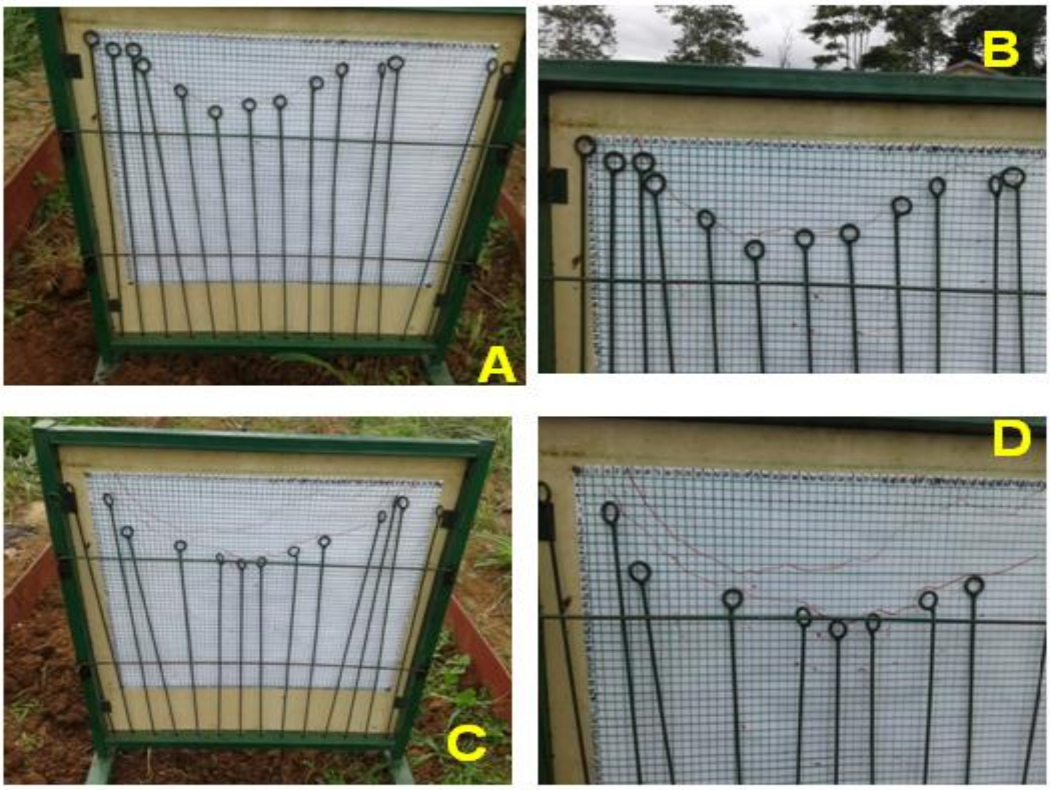

Figure 3: Estimation soil disturbance (A – D)showing on the developed profilometer

2.7.2Testing of Profilometer

Testing of the profilometer was done 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.To estimate area of soil disruption, four instrumented subsoilers were simultaneously hitched to the tool bar of the tool carrier. The tool carrier was attached to the drawbar of a 31.6 kW (MF 415) Massey Fergusson tractor and pulled through the soil bin to loosen the soil at 20, 30, 40 and 50 cm depths of operation. Soil disturbance were measured during operation at the outdoor soil bin located at the Science and Technology Education Post Basic (STEP-B) Research Farm. The subsoilers are:

(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). The shoe had two holes located 40 mm apart on the sides for the attachment of wings using bolts. The shoe also had two holes drilled 70 mm apart for bolting the cutting blade. The cutting blade can easily be attached to the shoe with the use of bolts and nuts and was replaceable.

(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) Pazabolic '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.

Each of the subsoilers was hitched to the tool bar of the tool carrier and attached to the tractor. This was pulled through the soil to loosen it. The SSS was also operated at 37°rake angle to compare the area of soil disturbance at this angle to 27° rake angle. Four depths of operations such as 20, 30, 40 and 50 cm were considered for each subsoiler. The profilometer was then used to measure the area of soil that was loosened by each of the subsoilers at each depth of operation. Three measurements were taken for each depth of operation and their mean values recorded. The data generated were subjected to analysis using statistical package for social sciences (SPSS) version 21 and Microsoft Excel 2010 to establish relationship between subsoiler types, depths of operation and soil disturbance in the form of graphs.

III. RESULTS AND DISCUSSION

3.1Calibration of Profilometer

Figure 4 shows the graph for the calibration of profilometer. It has a coefficient of linearity, R^2 of 0.999 and a characteristics equation of $y = 0.998x - 3.292$, with a standard error of 2.09.

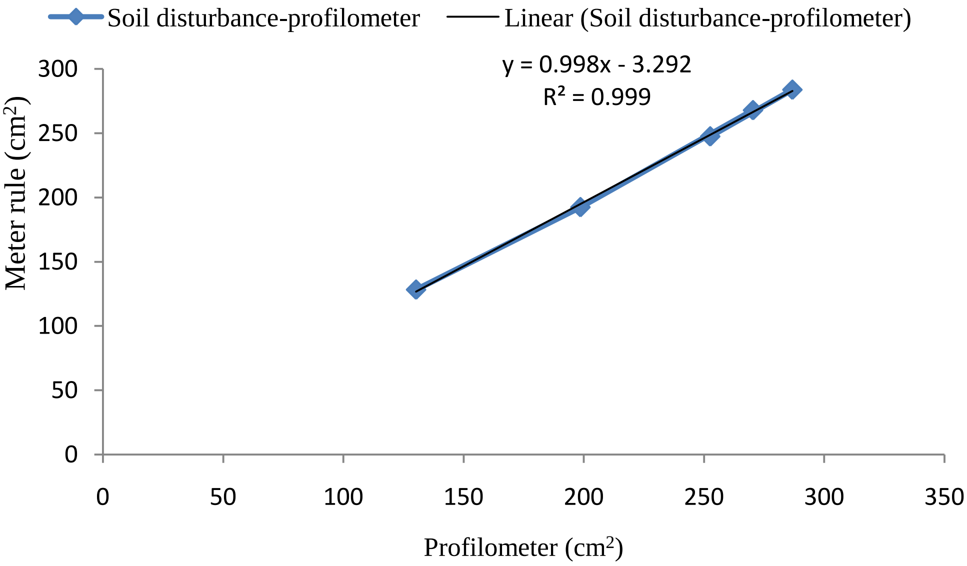

Figure 4: Curve showing soil disturbance measured using meter rule and profilometer

3.2. Soil Disturbance of Subsoilers

The estimated soil disturbance, measured using the profilometer, by the different subsoilers working at various depths are shown in figure 5. As demonstrated in the figure, SSS37 showed the highest soil loosening ability at all the depths followed by WSB, SPS, SSS and CSS respectively. Thus, at 20 cm working depth, SSS had an estimated area of soil disturbance of 0.0325 m^2. While the SPS, CSS, WSB and SSS37 had 0.0342, 0.0312, 0.0453 and 0.0561 m^2 respectively. On the other hand at 50 cm highest working depth SSS had 0.0451 followed by SPS with 0.0487, while CSS, WSB and SSS37 had 0.0403, 0.0683 and 0.1061 m^2 respectively.

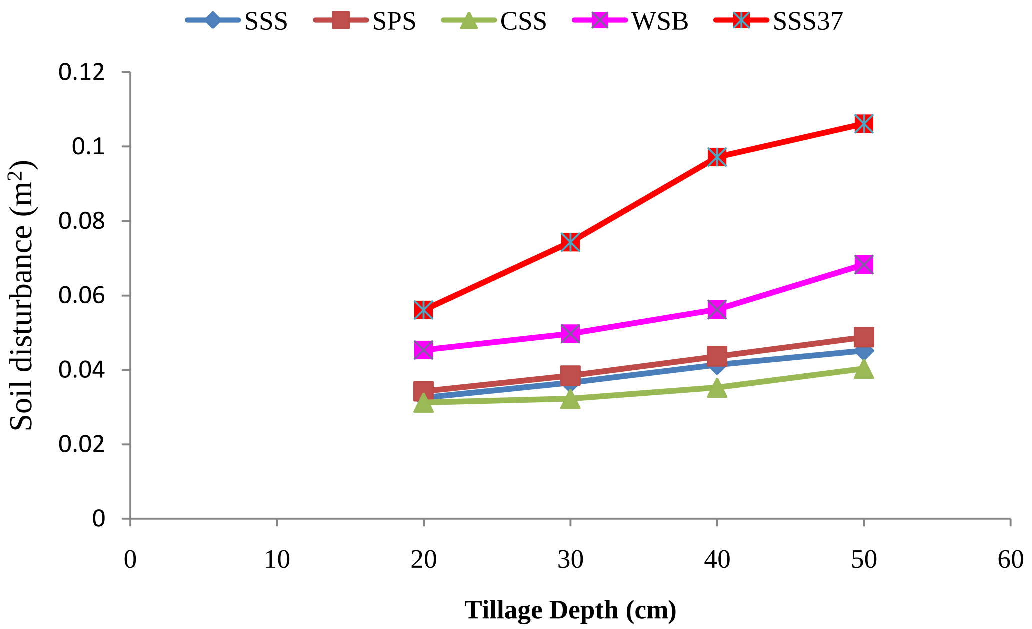

Figure 5: Estimated Soil disturbance by subsoilers operating at different depths

The large area of soil loosened by the SSS37 compared to SSS and other subsoilers revealed the importance of increased rake angle on subsoilers. Although this may call for more draught and energy usage by the prime mover. Thus the percentage increase in soil disturbance by SPS over SSS for 20, 30, 40 and 50 cm working depths were respectively 5, 5, 6 and 8%. While the percentage increase in soil disturbance of WSB over SSS were 39, 36, 36 and 51% at working depths of 20, 30, 40 and 50 cm respectively. Whereas the SSS37 had percentage increase of 72, 103, 135 and 135% over SSS at depths of 20, 30, 40 and 50 cm respectively.

IV. CONCLUSION

4.1 Conclusion

The following conclusion can be drawn from this research work:

1. Profilometer was designed, fabricated and tested during operation of subsoilers at the outdoor soil bin facility.
2. The profilometer gave easier and accurate result during soil disturbance measurement than the use of meter rule.
3. The straight shank subsoiler at 37^0 rake angle, SSS37 showed the highest soil loosening ability at all the depths followed by WSB, SPS, SSS and CSS respectively. Thus, at 50 cm highest working depth SSS had 0.0451 followed by SPS with 0.0487 while CSS, WSB and SSS37 had 0.0403, 0.0683 and 0.1061 m^2 respectively.
4. The profilometer gave easier and accurate result during soil disturbance measurement than the use of meter rule.

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