# DEVELOPMENT OF LIQUID ANIMAL MANURE INJECTOR EQUIPMENT WITH INSTRUMENTATION FOR DRAUGHT MEASUREMENT OF TILLAGE TOOLS

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## ABSTRACT

Liquid livestock manure injection equipment was developed based on the design criteria: easy adaptation, low draught force and suitability for different soil and crop residue conditions. The equipment featured two sweeps having a flat shape coulter and two shanks, coupled to 2 m wide implement frame. A 350 liters tank full of liquid manure was mounted on the frame during the experiment. The experiment was conducted with the equipment in sandy loam soil (11.52% clay, 24% silt and 64.48% sand) using convex sweeps with a forward speed of 3.49 km/h, depths of soil cut (50, 100 and 150 mm) and rake-angle of $30^o$. The soil dry bulk density (1.79 Mg/m$^3$), moisture content (25% wb) and soil strength (10.6 kPa) were also measured during the experiment. The soil disturbance profiles increase significantly with the depth of soil cut. The draught forces were also significantly increased with injection depth. The specific draught of the convex sweep was in the range of 2.68 to 9.87 kN per tool.

**KEYWORDS**: Convex sweep, rake-angle, depth of soil cut, tool forward speed, draught force, liquid livestock manure.

## 1. INTRODUCTION

Draught force is an important parameter for measuring and evaluating implement performance for energy requirements. It has been investigated by many researchers (Oni *et al*., 1992; Onwualu and Watts, 1998; Mamman and Oni, 2005). Existing injection tools require high draught force that increases the draught force requirement and the cost of operation. Injection depth, tool rake-angle, tool travel speed and tool cutting width all influence the draught force requirement (McKyes, 1985; Rahman and Chen, 2001). Land application of liquid manure using sweep injection tool has been recognized as a cost-effective and sustainable practice for manure utilization. Comparable crop yield can be achieved when using liquid manure to replace chemical fertilizers (Chen *et al.*, 1999).

The most common injection tools used include the knife, chisel, disc, and sweep. Knife often cannot create sufficient manure holding capacity for manure application rates required by crop. The chisel type injector cuts a slot into soil and allows the manure to flow down the slot (Godwin and Spoor, 1977). In addition, they penetrate deep into soil, therefore requiring more energy and often cannot create sufficient manure holding capacity for manure application rates required by the crops (Chen and Rahman, 1999). Discs have also been used for manure injection. However, disc does not actually inject the manure, but mix and cover the injected manure with the surface soil layer (Jokela and Cote, 1994). The rolling motion of a disc helps to cut through the soil surface (Chen and Heppner, 2002) at the same time tend to compact the soil and reduce pore space, thus decreasing infiltration rate ( Geohring and VanEs, 1994 ). Sweep type injector lifts the soil and allows the manure to flow in a wide horizontal band (laterally) at a shallow depth, and allows the soil surface to come back down over the liquid manure (Manuwa *et al*., 2012).

Sweep can be used for apply higher application rates in one pass than a knife injector, can apply in several passes. Sweep-type (winged) injection tool demonstrated the best performance for manure injection in terms of mixing soil with manure (Moseley *et al*, 1998). However, higher draught force is associated with this type of tool (Rahman and Chen, 2001), especially in clay soils.

The design of the prototype liquid manure injector was based on research work on the design of manure injection tools (Chen and Tessier, 2001; Manuwa *et al.,* 2011; Manuwa *et al.,* 2012) and also on previous studies on the evaluation of existing injection tools (Rahman and Chen, 2001; Rahman *et al*., 2001, Warner *et al*., 1991). Materials were sourced locally for affordability and ease of procurement. A medium size tractor (30- 50 kW) was considered appropriate as prime mover. The tool bars are strong and capable of varying work depth and rake angles of blade. The leading edge of the tool bar was designed to work at $45^o$ to the tool travel direction (Chen and Heppner, 2002). Sweeps were designed because they can create relatively larger cavities in soil. Sediment trap called chopper filter was put at the point where slurry was introduced into the tank to intercept anything that might damage the pump. The equipment was designed to inject manure into soil at varying depth and components replacement is a one-man job. Therefore, appropriate light weight high tensile strength steels were used.

The objectives of this paper are to report on: the development of a liquid livestock manure injector equipment; development of the instrumentation; and measurement of draught force under varying operational depth.

## 2. MATERIALS AND METHODS

Apart from the liquid livestock manure injector that was designed and fabricated for this study, the following materials/instruments were also used: 36 kW power tractor as prime mover for the manure injector; data logger (measure draught force); load cell; cone penetrometer with GPS to measure soil penetration resistance, measuring-tape and soil moisture meter to measure soil moisture content.

### 2.1 Equipment Description

The liquid manure injector equipment was designed, fabricated and assembled in the workshop of Agricultural Engineering Department of the Federal University of Technology, Akure, Ondo State, Nigeria. The liquid manure injection equipment was formed by two injection tools (sweeps) mounted on a pull type, 2 m length implement frame. A tool spacing of 60 mm was selected based on the conclusion drawn by Warner and Godwin (1988) that tool spacing smaller than 65mm was suggested for uniform crop response. The sweep was bolted to lower end of the c-shank and the c-shank was coupled to the depth adjuster. The two depth adjusters were mounted on the implement frame. Figure1 shows the main components of the liquid manure injector equipment except the tank and the equipment frame that were not shown here. The parts are; fluid-flow regulator arc (A), depth-adjusting mechanism (B), coulter bar (C), coulter (D), convex sweep (E), rake-angle regulating arc (F), furrow covering plate (G), liquid manure delivery tube (H), furrow covering plate shaft (I) and c-shank (J).

The manure delivery tube was welded to the covering plate and mounted on a 30 mm shaft (furrow covering plate shaft). Coulter was coupled to the coulter shaft and the coulter shaft attached to the front side of the depth adjuster. The pipe network installed on the frame featured a 100-mm PVC hose which do receive manure from the pump and allow it to be distributed to each of the two injection tools through flexible 50 mm PVC hoses.

Figure 1: Manure injector components

Table 1: Design specifications of the Liquid Manure Injector Equipment

| Components | Dimension (mm) | Components | Dimension (mm) |
|---|---|---|---|
| **Frame** (Rectangular hollow pipe): | | **Furrow covering plate**: | |
| Length | 2000 | Length | 220 |
| Width | 980 | Height | 150 |
| Thickness | 100 | Thickness | 7 |
| Rectangular cross-section | 5 | Furrow covering plate shaft | 30 |
| Mast height | 457 | | |
| Lower hitch point spread | 686 | | |
| **Sweep**: | | **C-shank** : | |
| Length | 200 | Diameter | 50 |
| Width | 224 | | |
| Thickness | 8 | | |
| **Manure delivery pipe**: | | **Coulter**: | |
| Diameter | 57 | Circumference | 400 |
| Length | 300 | Thickness | 8 |
| **Coulter bar**: Diameter | 40 | **Tank capacity** | 350 litres |

The hoses (50 mm diameter) were fitted inside the manure-delivery-tubes which were made of 75 mm diameter galvanized pipe. The tank was mounted to the implement frame top using bolts and nuts. Four wheels were coupled to the frame with the help of 200 mm by 200 mm by 30 mm steel plate bracket. The mounting bracket was welded to the top of the wheel hub. The bracket plates were fastened to the frame using four 25 mm thickness bolts and nuts (Fig. 1). The geometric dimensions of the equipment are as shown on Table 1. The injection equipment was pulled by a 415 MF tractor during the experiment. The soil of the experimental plot was tilled at a greater depth than the maximum experimental design depth before the experiment.

## 2.2 Calibration of the Load Cell

The load cell was calibrated using a dead load system. The load cell (20 tons) was used in collection of draught data in the field. The characterization was done in the laboratory of Physics Department, of The Federal University of Technology, Akure, Ondo State, Nigeria on 23rd April, 2013. During the calibration, Loads were added to the cell (200 – 1200 N) and the corresponding voltages were recorded and tabulated (Data not shown). Figure 2 shows the calibration graph.

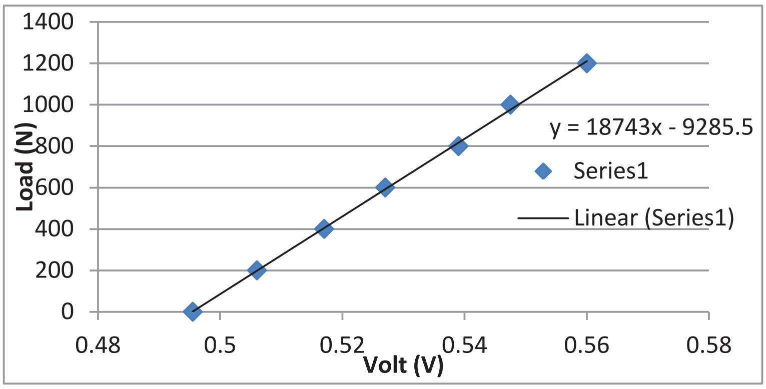


Figure 2: Load cell calibration graph

Figure 3: 20-ton Load cell

### 2.3 Design/Circuit of the Strain Gauge Amplifier

The load cell was used along with the strain gauge amplifier and the data lodger in the field for draught force measurement. The schematic diagram of the strain gauge amplifier is as shown in Figure 3. The Output voltage from sensor is 2.5mV (from sensor data sheet), also, sensor power input is 12V at 30mV. (Expected total output voltage). Therefore $V_2$ is 30mV (max) and $V_1$ is assumed to be insignificant i.e $V_1$ = 0. Expected sensor power output = 5VDC at 50mA (from data logger sheet), therefore $V_{out}$ = 5V (Figure 4). Figure 4 and 5 show the amplifier and the data lodger respectively.

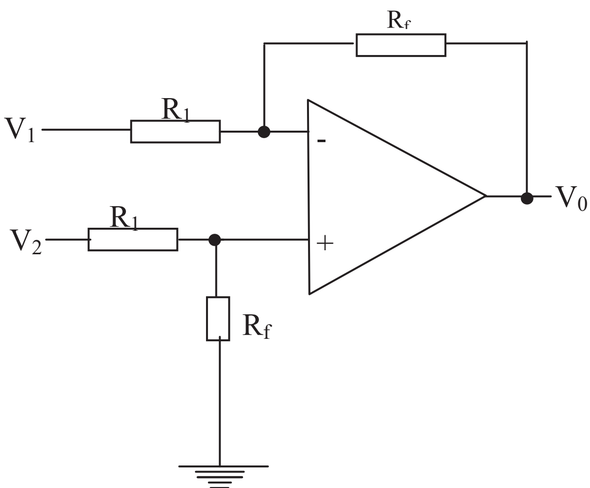


Figure 3: Schematic Circuit Diagram of the Differential Strain Gauge Amplifier (LM 358).

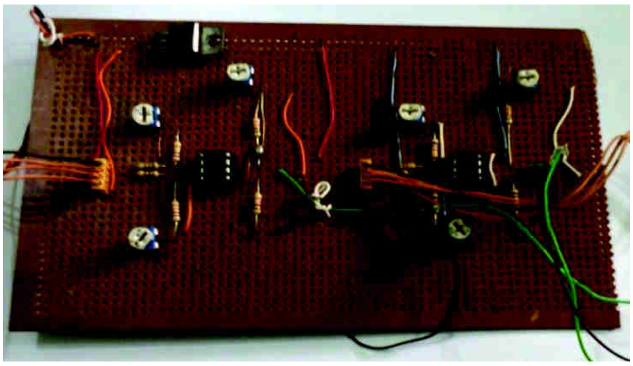

Figure 4: An Amplifier showing its component circuits


Outside part

Figure 5: Data loggers

## 2.4 Soil Preparation and Measurements

Field experiment was conducted at the Science and Technology Post-Basic (STEP-B) Research Farm of The Federal University of Technology, Akure, Ondo State, Nigeria. It is on longitude $7^o$ $15^1$N and latitude $5^o$ $15^1$ E on an elevation of 210 m. The field had a sandy loam (11.52% clay, 24% silt and 64.48% sand, by weight) with 200-mm high cereal stubble. The field was ploughed below maximum experimental depth (150 mm) before the experiment using disc plough and it was latter harrow. The soil has dry bulk density (1.79 $Mg/m^3$) and moisture content (25% wet basis) at the time of field experiment. Also, soil strength (10.6 kPa) was measured using a cone penetrometer (CP40II, Serial No. 130G0254, Rimik Electronic 1079 Rothvon St. Toewoumba QLD 4350, Australia) with 12.83 mm cone diameter and 30 degree angle based on ASAE standard (ASAE, 1995).

## 2.5 Details of Experimental Designs and Treatments

To examine the effects of the depth on draught force using a convex sweep with coulter ($CS_{wc}$), a completely randomized experiment (three replications) with all combinations of three injection depths (50, 100, and 150 mm) and a tool forward speeds of 3.49 km/h were used. The selected depths and speeds are commonly used by producers for manure injection. Each experimental plot has a dimension of 3 m wide and 100 m long allowing for one pass of the manure injection equipment. Rake angle of $30^o$ was maintained throughout the experiment. During the experiment, furrow covering plate was not mounted on the equipment.

## 2.6 Soil Disturbance Measurement

The machine was stopped while tine still engaging with soil and the actual depths (D) of soil cut were measured in each plot. 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 for two sweeps (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).

## 2.7 Draught Force Measurement

During the experiment, the equipment was operated with a 350 liters tank full of liquid manure since it was designed to apply it. It is also reasonable to assume that the weight of the liquid manure will add to the equipment draught force. Therefore, the issues of running the equipment dry as in the case of McLaughlin and Campbell. (2004) was not applied. The load cell was installed between the tractor draw-bar hitch and the implement hitch of the injection equipment. Alignment of stakes at either end of the plot provided a visual cue to the operator to start and stop the data logger.

As the injection equipment made the pass on each plot, draught force data were recorded using the ProDAS data acquisition system (Data-logger). The mean value of all readings from each plot was used for data analysis. Three runs were performed with the injection tools lifted above the ground in the field, and the average value was used as the rolling resistance of the wheels of the injector equipment. This value was subtracted when calculating the draught force for each plot.

## 2.8 Data Analysis

Analysis of variance (ANOVA) was performed to examine the main effects of experimental factors and their interaction. Differences between treatments were obtained using Duncan's Multiple Range tests. Statistical inferences were made at the 0.05 level of significance using SPSS 17.0.

# 3. RESULTS AND DISCUSSION

The picture of the liquid livestock manure injector equipment that was designed, fabricated and assembled in the Agricultural Engineering Work-shop of The Federal University of Technology, Akure, Ondo State, Nigeria is as shown in Figure 6.

Figure 6: Liquid manure injector equipment

### 3.1 Effect of Depth on Soil Surface Disturbance

Injector equipment operating depth was controlled by wheels on the tool bar which provided a means of reaching the same design depth (50, 100 and 150 mm). The tool caused soil crumbling and pushed the soil sideways as it moved through the soil at 50 and 100 mm depth. When cutting the soil at 150 mm depth, it was separated as two continuous soil beams (Koolen and Kuipers, 1983) along the center of the tool path. The beams were lifted up more than being moved sideways by the tool. The soil failure pattern at the two shallow depths (50 and 100 mm) can be described as “multiple failure planes”, while that at 100 mm depths as “unbroken soil beams” as reported by Koolen and Kuipers (1983) for soil cutting with a blade. The general trend of soil surface disturbance produced as a result of depth at which the tool engage the soil was that the greater depth of soil cut resulted in higher values of W, MWS, Hi, and Fi (Table 2), reflecting a larger soil surface area being disturbed by the tool. The effect of depth on soil surface disturbance was statistically significant at all depth for W, MWS, Df and Fi (Table 2). The effect of depth on soil surface disturbance was not statistically significant (Chen and Heppner, 2002) on Si between the depth of 50 and 100 mm but found to be significant between 100 and 150 mm depth. Also, Hi was not statistically significant within 100 and 150 mm depth (Table 2). Greater depth caused a larger Hi, representing a rougher soil surface and greater spread (Si) of the mounds implies that soil moves more away from the center of tool path. Rahman and Chen (2001) reported similar trends for other sweep-type injection tools. Figure 7 illustrates the soil surface profile obtained during the experiment.

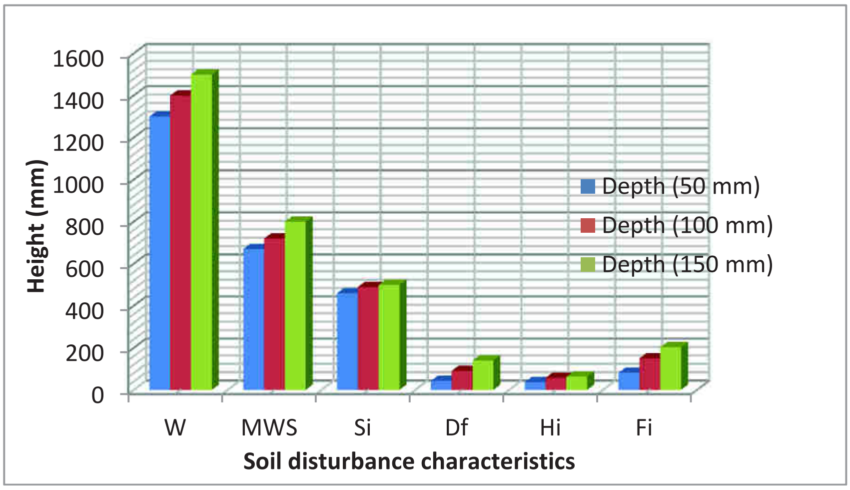


Figure 7: Soil surface disturbance characteristic/depth at 3.49 km/h speed using $CS_{wc}$

Table 2: Characteristics of soil surface profile produced as a result of depth of soil cut

| Treatments | Soil surface disturbance | | | | | |
|---|---|---|---|---|---|---|
| Depth (mm) | W | MWS | S | Df | H | F |
| 50 | 1311.00a | 680.00c | 466.00a | 44.00a | 39.50a | 83.50a |
| 100 | 1435.00b | 722.00b | 500.00a | 93.00b | 60.00b | 151.50b |
| 150 | 1517.50c | 810.50a | 513.50b | 141.50c | 67.50b | 209.00c |

*Means in the same column that are followed by different letters are significantly different ($P<0.05$) according to Duncan multiple’s range test.

### 3.2 Effect of Depth on Draught Force

The average draught at 50, 100 and 150 mm depth were 2.90, 7.37 and 9.87 kN/ tool respectively using a forward speed of 3.49 km/h. These values are lower or comparable with those reported elsewhere. Lague (1991) reported that injection of manure into a firm clay soil at depths not exceeding 203 mm required between 5.03 kN/ tool and 6.19 kN/tool of draught force for a winged tool operating at a speed of 0.89 m/s. The range of draught forces of a winged tool reported by McKyes *et al*. (1977) was up to 6 kN/ tool at a 150-mm injection depth and the travel speeds up to 7.92 km/h in soil textures from sand to clay loam. Other studies report injector draught forces ranging from about 0.25 kN at 15 mm depth (McLaughlin and Campbell, 2004), to 1.4 kN for a coulter followed by a 220-mm wide sweep at 150-mm depth (Rahman *et al*. 2001), and 1.6 kN for a 570-mm wide sweep at 150-mm depth (Rahman and Chen 2001). The former was at a depth of only 15 mm while the latter two studies were in loamy sand in an indoor soil bin which might explain why the draught was lower than those reported for field studies with a clay soil. The result in figure 8 indicates that draught force is a function of depth and the square of depth. The square component comes from the contribution of the adhesion and soil acceleration forces over the tool. This relationship implies that the depth increases, the slope of the line (Figure 8) describing the relationship increases (Al-Janobi and Zein Eldin, 1997).

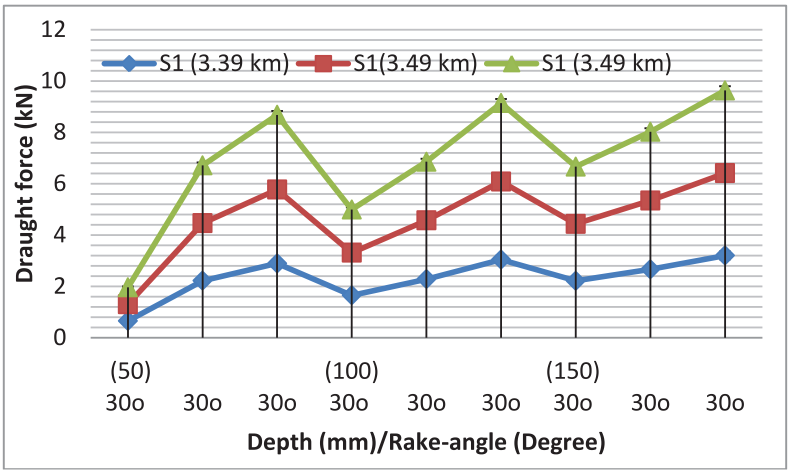

Figure 8: The relationship between depth of soil cut and draught force

It therefore implies that the draught force per unit depth of soil cut increases with depth of soil cut (50, 100 and 150 mm) which indicated increase in power requirement for the prime mover. The draught force was statistically significant with increase in injection depth (Data not shown). This implies that injection depth is important in the determination of the power required by the injection equipment.

## 4. CONCLUSIONS

Liquid manure injector equipment was designed. The tool used in the equipment is easy to be mounted to any frame of tillage implement via c-shank and the depth adjusting device. It can be used for various soil and field conditions. Measurements of field disturbance and draught force were undertaken. Soil disturbance increased significantly with injection depth. The convex sweep has a flat shaped coulter in its front. The draught forces of the equipment are in the range of 2.68 – 9.87 kN/tool. Its draught force significantly increased with injection depths. On the basis of this research and within the limits of the testing variables, it was concluded that the forces acting on convex sweeps under actual tillage conditions are a function of the depth Therefore injection depth should be as shallow as possible in order to reduce power requirement yet deep enough to cover manure during injection. Based on power requirement, it is suggested that the injection depth should be selected less than 100 mm to reduce draught force requirement for the tested sweep.

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