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Effect of Side-Wings on Draught: The Case of Ethiopian *Ard* Plough (*Maresha)*

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Abstract

Ethiopian farmers have been using an ox-drawn breaking plough, known as *ard* plough – *maresha,* for thousands of years. *Maresha* is a pointed, steel-tipped tine attached to a draught pole at an adjustable shallow angle. It has narrow side-wings, attached to the left and right side of it, to push soil to either side without inverting.

The aim of this paper is to explore the effect of side-wings on draught using a field soil bin test facility. To this end, a mobile and an *in-situ* soil bin test system, for online measurements of draught, was designed and developed. This research considered tool geometry (*maresha* plough with and without side-wings) and rake angle (shallow – 8°, medium deep – 15°, and deep – 24°, representing primary, secondary and tertiary tillage processes in Ethiopia, respectively).

Maresha plough with side-wings has greater contact area, between the moving soil and tool, than its wingless counterpart. When the ploughshare surface and soil slide relative to one another, the draught expected to increase with contact area, as adhesion and friction resistance increases with area. However, experimental analysis indicated that the *maresha* with side-wings required less draught compared to *maresha* without side-wings ($p < 0.001$). This might be attributed to the effect of side-wings on crack propagation by a wedging effect to enhance and facilitate subsequent ploughing.

This paper also dealt with the effect of rake angle on draught. Though the depth setup was getting smaller $d1<d2<d3$ for the successive tillage runs, analysis showed increment in draught force ($p < 0.001$) with rake angle. This might be attributed to higher soil compaction that comes with depth and downward force resulting from repeated use of *maresha* every season to the same depth for thousand years.

Although more and rigorous studies should be undertaken considering soil, tool, and operational parameters to arrive at conclusive results, this paper gave some insights regarding effect of side-wings on *maresha* plough and rake angle on draught. This shows that there is still room for improvement of *maresha* plough geometry for minimum draught requirement and optimum soil manipulation.

Key words: *Ard*, Data acquisition system, Depth, Draught, Mobile and *in-situ* soil bin, *maresha*, Rake angle, Side-wings.

1. Introduction

Various researchers have undertaken studies on effect of plough share including its component attachments' contributions on draught requirement and soil loosening.

The two types of tine design are usually referred to as narrow tines and winged or sweep-type tines (Spoor, 2006). For compacted surface layers, there is likely to be a need to reduce the confining resistance ahead of the deeper tines; this is achievable using shallower narrow tines working ahead of deeper tines, which preferably should be winged (Spoor, 2006). Spoor and Godwin (1978) investigated deep loosening of soil by rigid tines, the attachment of wings to the tine foot and the use of shallow tines to loosen the surface layers ahead of the deep tine increases soil disturbance particularly at depth, reduces the specific resistance, increases the critical depth and allows more effective soil rearrangement. With sweeps or wings attached to the sides of many of chisel tines, subsoilers, slant tines and oscillating tines, the overall soil disturbance increased for a minimal increase in energy expended (Smith, 1973; Trousse and Humbert, 1959; Balaton, 1971; Lindner, 1974; Schulte, 1974; as cited in Spoor and Godwin, 1978).

Raper (2005) showed subsoilers with straight shanks required higher tillage draught compared to the bentleg shanks. The SDN subsoiler shank (straight shank, Deere, narrow point) required 9.25 kN, which was the largest draught required, while the smallest draught of 5.85 kN was measured for the BBP shank (Bentleg, Bigham Brothers, Paratill).

Marandi *et al*. (2010) used soil bin incorporating a carriage having capable of testing three prototypes of tools in a test run. Georgison (2010) investigated the effect of various settings on tool loading to improve the design of the soil engaging components of a rotary tine aerator. Awad-Allah *et al.* (2009) investigated the dynamics of single and multiple tines at different cutting speeds and depths with and without an added vibratory motion. Ranta *et al*. (2009) analyzed the influence of the kinematic regime of discs in different soil conditions on the soil bed quality. Marakoglu and Carman (2009) evaluated the effects of design parameters of a cultivator share on draught and soil loosening in a soil bin, described by Carman and Dogan (2000). Dedousis (2007) investigated the soil forces and disturbance from different disc geometries and shapes using soil bin developed by Hann and Giessibel (1998). Under the same set up, Vozka (2007) determined draught, area of disturbance, and specific resistance of the selected implements.

Sahu and Raheman (2006) predicted the draught requirements from the knowledge of the draught requirements of reference tillage tools in a reference soil condition, in which the setup included soil processing system. Mamman and Oni (2005) used a soil bin facilities to determine the effects of design parameters (slide and nose angles) and operating parameters (soil depth and tool travel speed) on the draught of model chisel furrowers. Durairaj and Kumar (2002) measured the forces acting on moldboard ploughs at six degrees of freedom, which used Clyde (1936) as a basis. Niyamapa and Salokhe (2000a&b) studied the force requirement, pressure distribution, and soil disturbance and force mechanics under vibratory tillage tools.

Manuwa (2002), Manuwa and Ademosun (2007), and Manuwa (2009) investigated the influence of soil parameters on draught. Manuwa and Ajisafe (2010), then, developed an overhead gantry to enhance system versatility with better working space by saving the time and labor required for soil preparation and experimentation. Rosa (1997) developed a monorail system, capable of driving soil tools – narrow tools – at a maximum steady speed of 10m/s under load and a maximum draught of 1.5KN. Ellipitical, triangular and flat tool shapes presented the lowest to highest draught requirements, respectively. The system was retrofitted to a small 10m long linear soil bin, yet was capable of maintaining target tool speeds of 0.5–10 m/s over 1 to 3 m distances (Rosa and Wulfsohn, 2008).

Benard (2010) applied the concept of bionic non-smooth surface to disc ploughs and experimented to examine the effects of different bionic units on reducing soil resistance. Qaisrani (1993) and Qaisrani *et al*. (1992&2010) applied dung beetle having a number of small convex surfaces made of ultra high molecular weight polyethylene (UHMW-PE) and stuck on the surfaces of mouldboard plough at an angle of 62^0 with the horizontal - based on the findings of Suminitrado *et al*. (1988) that most of soil movements on the plough surface happen at an angle of 62^0. Experiments showed that the modified ploughs had better scouring properties and required less draught than conventional tools.

Numerical Simulation of Soil-Tool Interactions were undertaken by using Finite Element Modelling techniques (Mouazen and Nemenyi, 1999; Plouffe *et al.*, 1999 a & b, Ibrahim *et al.*, 2015) and Discrete Element Method (Bravo *et al.,* 2012), and experimented using soil bin to verify the results calculated.

Although several reports on the effects tool design and operational conditions on the performances of different tillage tools and implements by means of a soil bin test system are available in the literature, there is a dearth of information on the Ethiopian traditional *ard* plough – *maresha* including effect of side wings on draught requirement.

Hence, this paper mainly aims at undertaking experiments using field soil bin facility to understand the effect of side-wings on draught. Besides, it dealt with the effect of rake angle on draught.

2. Animal drawn implement (Ethiopian *ard* plough)

Animal drawn plough (*ard* plough) that differs very little from the old primitive plough is widely in use in Ethiopia. The first ever photograph of an Ethiopian farmer with his oxen and *marasha*, near Senkata (Tigray) in March 1868, is shown in Figure 1 (Nyssen *et al.*, 2011). Most of the components of the traditional implement are wooden except for the ploughshare and metal loops and leather strip or rope, a tying unit. It is a light implement weighing 17 to 26 kgs (Goe, 1987), which makes it handy enough for one person to carry over different terrain (Fig. 2a). A single person can manage to keep the oxen pull the implement along a straight line forward at a relatively constant speed by preventing the oxen from stopping and/or grazing (Fig. 2b). The relative simplicity and regenerative character of animal traction technologies, their strong indigenous nature and simple support systems, have resulted in their integration into small farm systems (Gebresenbet *et al.,* 1997a).

Recorded information showed, in 1939 Italians introduced a steel mouldboard plough (Fig. 3) at the small holder level, which was unsuccessful (Nyssen *et al.*, 2011). The Italians concluded that the Ethiopian farmers were conservative and do not want to adopt new technologies (Goe, 1987); and this showed farmers' ideas were not taken seriously and their traditional plough was not studied well. The reasons were its heavy weight, the requirement of complicated adjustments and the higher power requirements than that of the Ethiopian *ard*, especially in soils with higher clay contents (Goe, 1987; Goe and Astatke, 1989; Nyssen *et al.*, 2011).

Several organization and institutions have also been trying to modify, introduce, and develop various tillage implements, and to mention some are: FAO in 1950s (Goe, 1987); Alemaya

University and Jimma Agricultural Technical School in Ethiopia between 1955 and 1965 (Canaday, 1959; UNDP Report); Chilallo Agricultural Development Unit (CADU) later changed to Arsi Rural Development Unit (ARDU) in 1968 (Anon., 1969, 1970, 1971); Institute of Agricultural Research (IAR) of Ethiopia in 1976 (Berhane, 1979); The International Livestock Center for Africa (ILCA) (Astatke and Mathews, 1982; Astatke and Matthews, 1984); The Relief and Rehabilitation Commission (RRC) (Anon., 1981); the Agricultural Implements Research and Improvement Centre (AIRIC) in 1985 (Pathak, 1988); Selam Vocational Training and Farm Implements Production Center (Zaugg, 1992); The National Institute of Agricultural Engineering, Silsoe, UK (NIAE) (Starkey, 1988); Ethiopian Ministry of Agriculture (MOA) (Gebresenbet *et al.*, 1997a); and International Livestock Research Institute (ILRI) (Gebresenbet and Kaumbutho, 1997).

Gebresenbet *et al.* (1997a) showed that only a few researchers and farmers have been involved in innovation efforts in animal traction technology in Ethiopia with inadequate grasp of the context of the problems faced by many small farmers. Previous researches on animal drawn tillage implements relied on experience, culture, and trial and error (Gebregziabher *et al*., 2006). Inadequate knowledge on different tillage tool designs and the indiscriminate use of tillage tools is detrimental to long term improvement of soil quality and crop yields. Hence, a better understanding of soil-tool interaction calls for a systematic approach of researches including utilising indigenous knowledge and incorporating design features of traditional implements in the development process. This is because, designing an implement must take into account the agricultural and industrial systems, within which the implements are manufactured and operated.

3. Materials and Methods

3.1 Performance of traditional *maresha* plough in Ethiopia

With the *ard* design, *maresha* is a pointed, steel-tipped tine attached to a draught pole at an adjustable shallow angle and the soil is not inverted like the case with the mouldboard plough. Instead, the soil is broken or fractured, lifted and then pushed to the sides of the furrow, forming a V-shape furrow (Astatke, FAO) by the two narrow wooden side-wings fitted to each side of the share. The ground between the furrows, which is remained untouched, is broken up by additional ploughings (extra cross-tilling) carried out at different angles across a plot. According to farmers' explanation, side-wings help to increase the soil loosening efficiency (tilled area), helping Ethiopian farmers to meet timeliness for land preparation during sowing seasons.

Under typical farm conditions in the Ethiopian highlands, a pair of indigenous oxen is used to till with a draught force requirement of about 1.0 kN (Gebreslasie *et al*., 2004). Indigenous zebu breeds, weighing 270-330 kg, are mostly used for traction. The average working speed of oxen is 0.4 to 0.5 m/s (Geza, 1999), 0.63 m/s (Gebresenbet *et al*., 1997b), whereas the average speed using horses is 0.75 to 1.07 m/s (Geza, 1999). However, a pair of crossbred cows moves faster (an average of 0.894 m/s) than a pair of oxen, and exerts proportionally greater pulling force when operating in the same field (Gebresenbet *et al*., 1997b). The difference in speed is attributed to the greater body weight of the cows and the corresponding greater traction that could be generated. The operational speed of draught animals mainly depends on several factors such as training, animal species, operator, harnessing, the weight of the load to be pulled and climatic conditions (Gebresenbet *et al.*, 1997b).

Mouazen *et al.* (2007) found different contributions of each ox to the total traction with oxen of unequal strength. The stronger ox moved faster than the weaker ox, creating an asymmetric position of the yoke. In this situation, the weaker ox had to work harder - by spurring to walk a head of the stronger ox - to overcome the force transferred from the strong ox and correct the asymmetric position of the yoke.

Hence, the difficulties experienced in experiments on animal drawn implements due to unequal oxen strength and differences in pace of walking (Mouazen *et al.,* 2007), uncontrolled implement behaviour, and field conditions, thus, calls for a systematic approach.

3.2 Soil Bin Test System

The new tillage systems and the need for improved energy efficiency of tillage operations emphasize optimizing tillage tool design. Development of an efficient tillage tool for optimum soil manipulation and minimum draught requirement requires a clear understanding of the interface between soil and tillage tool supported by experimental and theoretical analyses

(Plouffe *et al.*, 1999 a & b; Mouazen and Neményi, 1998). These methodologies could significantly assist in optimizing the implement design and operational conditions aiming at minimum draught requirement and optimum soil manipulation performance. Despite continuous development of the theoretical description of interaction processes between soil and tillage tools, experimental approach is still irreplaceable not even the more and more intensive contribution of the newest software, could change this.

The soil bin test system, an experimental verification, allows the measurement of different soil-tool interactions. Soil bin facilities vary in scope from small indoor bins to large outdoor soil bins, depending on the objectives for which they are developed, space available, energy requirement, and financial constraints (Wismer, 1984). Soil bin systems could be straight or circular, movable with stationary tools or stationary with movable tools (Durant *et al.*, 1980). Design and experimentation with a soil bin can be effectively accomplished only if the complex interaction between the soil and the machine/tool is clearly understood (Al-Janobi and Eldin, 1997).

3.3 Animal Drawn Plough in Soil Bin

Although there is no information to research linking between *maresha* plough and soil bin experimentation in particular, there is little research on animal drawn implements other than *maresha* plough using soil bin test system. Aikins *et al*. (2007) developed an ox-drawn ridging plough using the Godwin-Spoor narrow tine soil force prediction model, and compared predictions with measurements of draught and vertical forces, and a cross-sectional area of soil disturbance. Loukanov *et al.* (2005) experimented with animal-drawn mouldboard plough to investigae effect of enamel coating on specific draught. Gebresenbet (1995) used a soil bin to measure the forces acting on a curved tool, and attempted to develop empirical prediction models of draught.

The few researches undertaken on animal drawn tool in an indoor soil bin facilities, i.e., with imported (disturbed) soil, thus, miss out the real-life situation where the plough interacts with the soil in its natural configuration and its spatial variability.

Taking account of challenges facing researches on animal traction tillage implements, along with the lessons drawn there from, and taking into account energy needs, soil variability and financial constrains, a mobile and an *in-situ* soil bin test facility was developed, and discussed in the next section.

3.4 Development of a mobile and an *in-situ* testing device

There are no specific theories on determining the dimensions of a soil container. In general terms, soil bins can be classified into large-scale soil bins and small-scale soil bins. The size of the soil bin influences the type of testing, the amount of data collected, and the number of test tools per test run. The significant difference between a large-scale and a small-scale soil bin is the overall length of the soil bin (Mahadi, 2005). Therefore, one can classify any soil bins longer than 20 m as large-scale bins and those shorter or equal to 20 m as small-scale soil bins (Mahadi, 2005). Small scale soil bin test systems were designed (Onwualu and Watts, 1989; Durant *et. al*, 1980; Godwin *et al*., 1980; Stafford, 1979; Siemens and Weber, 1964) with lengths ranging from 5 to 13 m.
Having reviewed soil bin test facilities, a mobile *in-situ* soil bin facility, which could be classified as small scale soil bin test system, was designed and developed to carry out soil-*maresha* interaction study (Fig. 4). A 20m long mobile facility assumed enough to move to another spots. The facility has three parallel rows/rail-tracks, in which, one row is featured with 20m long by 1.435m wide. It includes rails mounted on treated wooden sleepers. The rail has a moving carriage, towed by a two-wheel (walking) tractor using steel cable. The carriage is equipped with a test tool, instrumentation, and a data acquisition system for online measurement of draught.

3.4.1 Drive System

Traditional tillage in Ethiopia uses a pair of oxen to pull the ploughing implement. Because of mass inertia of the carriage, a greater force was necessary to trigger initial movement of the carriage, which was heavy to be done by a pair of oxen. Hence, a two-wheel (walking) tractor (15 hp, Model DF, Changzhou Dongfeng Agricultural Machinery Group Co., LTD – DFAM, with CHANGCHAI engine, China) was used, to produce enough draught to conduct the experiments.

Compaction induced by vehicle traffic has adverse effects on a number of key soil properties such as bulk density, mechanical impedance, porosity and hydraulic conductivity (Radford et al., 2000; Hamzaand Anderson, 2005). One approach that has been proposed to minimise machinery-induced compaction is to utilise controlled traffic systems whereby vehicle traffic and the resulting soil compaction is restricted to either permanent wheel tracks or sacrificial lanes across afield (Reeder, 2002; Hamza and Anderson, 2005). This leaves the cropped area either free of all traffic, or limits the impact of vehicle movement to certain periods in the production cycle (Chamen et al., 2003).

Taking into account the problem of machinery-induced compaction and wider wheelbase of power source (two-wheel tractor) than the working width of the testing device, a steel cable was used to pull the carriage with minimum elasticity. With this, experiments were carried out without affecting the initial soil conditions.

3.4.2 Draught

A load cell (from Celtron SQB-5tSS, the Netherlands), having a maximum load of 500 kg and a sensitivity of 2.99mV/V, was used to measure draught. The load cell attached as intermediate member to a spot between the plough shank and steel frame (Fig. 5). Designing sturdy structural attachment (steel frame) was necessary for a proper setup in order to measure the soil resistance on the surface of the tillage tool, without flipping, toppling, and tilting of carriage.
To avoid interference of soil with the measurement, the load cell was positioned above the soil surface instead of directly locating behind the ploughshare. As a result, the measuring position differed or at offset from the position of impact, which was considered during calibration. The design took account of allowing for a free contact of load cell with shank of plough, a contact

point where the draught is transferred. The free contact allowed for a force transfer without coupling effect, which couldnot be avoided with a solid connection. Besides, in order to allow forces to be absorbed by the frame and ensure proper measurement, the connection of *maresha* plough (shank) with the frame made using rotating end pin. In general, a load cell with free contact at one end with the plough shank (pinned with steel frame) and bolted at the other end (steel frame and the carriage,) was used to measure the total force required to pull the tillage tool through the soil.

3.4.3 Data Acquisition System

The data acquisition hardware (from IOtech, Ohio - USA) was placed in a frame mounted on the carriage together with external 12V battery power source. The hardware included: DBK43A (8-channel strain gage module); Daqbook/2000E (ethernet 16 bit, 200 kHz data acquisition system; including DaqView software); DBK34A (uninterruptible power supply for DC powered systems), and CA-37-3T (expansion cable from Daqbook to DBK modules).

A load cell was interfaced with a data logging system and a computer. The wiring between DBK 43A and load cell (supplied from different companies) was based on resistance measurement across the bridge points (Table 1).

The incoming milli volts (mV) from the load cell was rescaled to give kilograms i.e. with the setup and DASYLab 8.0.1 software package (National Instruments, Ireland), the data sets were read, interpreted, scaled, averaged, displayed and stored on the laptop.

3.4.4 Calibration of Load Cell

Calibration was undertaken to calculate tool draught based on the following assumptions:

- The location of area of centroid of *maresha* plough is the point (at point '***b***') of concentrated load measured, which is equivalent to the sum of distributed load of the soil resistance.

- 'C' stands for the vertical projected distance, in metre, from the area of centroid of *maresha* plough (point ***'b'***) to the weld connection point of ploughshare and plough shank ***'a'.*** Let the length between points ***'a'*** and '***b***' be L_{ab}, in meter, and rake angle be ***'α'*** in degree.

  Thus, $C = L_{ab} sin\alpha$ (1)

- ***L1,*** in metre, is the projected distance from point **'a'** to centre of the load cell - lower hole, point ***'d'***
- ***L2,*** in meter, is the distance between point **'d'** and Point **'c'** (pinned connection of plough shank on the steel frame)
- $F_{Load,\ Resistance}$, in Newton, is load applied for calibration purpose, representing assumed equivalent concentrated load, soil resistance on Plough
- $F_{Load\ Cell}$, in Newton, is force transferred to load cell.

For an analytical solution, using schematic and free body diagram (Fig. 6), at static force equilibrium, the force and moment equations are given by equations 2 and 3, respectively.

$$\sum F = 0,\ \vec{F}_{Load,Soil\,Resistance} - \vec{F}_{Pin} - \vec{F}_{LoadCell} = 0 \quad (2)$$

$$\sum M_{d,LoadCell} = 0, \vec{F}_{Load,Soil\,Resistance} \times (\mathrm{L1} + \mathrm{C}) - \vec{\mathrm{F}}_{Pin} \times L2 = 0 \quad (3)$$

Equating (2) and (3), the force measured by load cell, $F_{Load\ Cell}$, in Newton, is then given by equation (4), i.e.,

$$\vec{F}_{LoadCell} = \frac{F_{Load,Soil\,Resistance} \times (\mathrm{L1} + \mathrm{L2} + \mathrm{C})}{L2} \quad (4)$$

Where C is given by equation (1).

In addition to the analytic solution, calibration using software (GageCal) was necessary. Calibration with GageCal required setting the value of quiescent/Tare to zero for soil-tillage purpose, however, to measure weight the quiescent/tare value should be the weight of measuring platform. Name plate calibration was required adjusting for excitation, offset, gain, and scaling with respective potentiometers without connecting the load cell. Final setup in GageCal required connecting sensor and adjusting the offset using OFFSET potentiometer. The first offset adjustment was correcting the internal circuitries offset so that the calibration was as accurate as possible. Using electronic, GageCal shorted the channel's inputs together. Later on, the offset was to take into account the actual sensor.

There were two modules for scaling i.e. scaling channel with the analog input, and scaling module. In order to avoid double scaling, only the scaling module was used.

To minimize the noise in the raw data, hardware and digital filters were also used. The selection of hardware filter was based on experimentation with resistors (Table. 2) by positioning jumpers on DBK43A to filtering position, which activated the analog filter to cancel the noise. The properties of the filter were determined by a resistor, by placing in an electrical circuit. Experimentations showed that the standard filter with a frequency of 13.3Hz lowered most of the noise. Besides, a digital filter module was used to filter the incoming data, and a low pass filter at 135 Hz gave better data.

3.5 Design Parameters: Tool Geometry and Rake Angle

3.5.1 TOOL Geometry

The two plough geometries considered were: *maresha* without side-wings, and *maresha* with side-wings (Fig. 7).

3.5.2 Rake Angle

Depending on soil type and the type of crop cultivated, the land is ploughed 3 to 5 times before planting (Goe, 1999). Gete (1999) explained subsequent ploughings are deeper, except for the last tillage operation, which is done after broadcast sowing. The depth of tilling in the first pass reaches 5-10 cm depending on soil texture, degree of soil compaction, and moisture content. The final pass reaches down to a depth of 20 cm. Considering the three subsequent ploughing, i.e., primary, secondary and tertiary tillage processes in Ethiopia, in an experimental line, three ploughs were manufactured for each geometry type, i.e., for shallow, primary – α_1, 8°; medium deep, secondary – α_2, 15°; and deep, tertiary – α_3, 24° degree (Fig. 8).

The respective tool settings could be given by depths: $D1 = 0.1329L$, $D2 = 0.2516L$ and $D3 = 0.3406L$ where L is length of plough.

The study considered successive tillage process in an experimental line, i.e., the 1st tillage run performed on top undisturbed soil layer, however, the 2nd and 3rd successive tillage runs performed on furrows and underneath undisturbed soil layers left by 1st and 2nd tillage runs, respectively.

Hence, this paper considered 1st, 2nd, and 3rd tillage runs on undisturbed soil layesr having depths of *d1* (0.1329L = D1), *d2* (0.1187L = *D2*-*D*1), and *d3* (0.089L = *D3*-*D*2), respectively, for analysis, and assumed possible boundary effects are negligible.

3.6 Experimenting

3.6.1 Experimental Field

The experimental field is located at an altitude of 2150 meters above sea level, at the veterinary campus of Mekelle University, on the skirts of city of Mekelle, the regional capital of Tigray, Ethiopia. The experimental soil is classified as Vertisol. Despite their high agricultural potential, Vertisols are generally regarded as marginal soils, among others, high shrink-swell potential (Astatke *et al.*, 2002; Deckers *et al.*, 1998; Potter and Chichester, 1993) which leads to a high incidence of prolonged water-logging during the main rainy season from June to September (Astatke *et al.*, 2002). The soil was covered with grass and there were stones of various sizes in the soil.

3.6.2 Soil Size Distribution

The Bouyoucos Hydrometer method was used to determine the particle size distribution of the soil sample, shown in Table. 3.

3.6.3 Experimental Layout and Experimentation

The overall length, the stretch of the entire soil bin structure, is 20m. Deducting of front and rear pits for starting and ending experiments, the working length of the soil bin is 16m. The experimental design layout considered six experimental rows to have three replicates for each plough geometry types. As shown on Figure 4, the developed soil bin has three rows. Once experimenting on three rows was completed, three rails lines were relocated and installed in reference to the fourth rail to form additional three rail track - rows. Accordingly, experimenting on six rows became possible i.e. by dedicating rows 1, 3, 5 and rows 2, 4, 6 for the *maresha* without side-wings and *maresha* with side-wings, respectively.

With two plough geometry types, three rake angles for successive three tillage depths, and three replicates, a total of 2x3x3 experimental runs, equals 18 tillage runs were performed.

With such arrangement, the testing device could accommodate even more rows depending on the experimental requirement, number and type of tillage tools to be considered, and available space.

4. Data Analysis

Analysis was undertaken by box plot; and multivariate analysis was undertaken with one way ANOVA using MATLAB tool box. Linear regression and calculation of the Pearson correlation coefficient R and levels of significance (P) were used to measure the degrees of association based on analyses of variance. Histogram also used to see the draught density and distribution with rake angles.

5. Results and Discussions

5.1 Effect of Side-Wings on Draught

During a tillage operation various factors can affect energy requirement of a tool. These factors can be categorized in three main groups: (1) Soil parameters:soil physical, mechanical properties, and soil dynamics properties, (2) Tool parameters: tool type, tool shape and size, tool rake angle, tool sharpness, and tool material, and (3) Operational parameters: depth and speed.

In addition to soil shear strength properties e.g., soil cohesion and soil-soil friction, draught requirement of soil engaging implements is also affected by soil-material friction. This paper assumed the effect of soil parameters and speed is similar for experimenting with two plough geometires except for soil-tool friction. Soil sliding resistance is made up of friction and adhesion forces that are brought about between the soil and material interface. A large proportion of the energy used to operate tillage tools goes to overcome frictional sliding resistance as soil moves over the tillage tools surfaces.

When a material surface and soil slide relative to one another, the frictional resistance of the contact surface must satisfy the Coulomb's equation (5):

$$F = CaA + P \tan\delta \quad (5)$$

Where, Ca= soil-material adhesion (Pa); δ= angle of soil/material friction (degree), P = normal force on surface (N), F = frictional resistance (N), and A = contact area (m^2).

In adhesive soil, the frictional resistance, F, is mainly produced by adhesion and can be minimized if the contact area (A) is reduced (Qian, et al., 1999). When tool surface and soil slide on one another, the frictional resistance expected to increase with interfacial contact area, according to Coulomb's law of soil shear strength (McKyes, 1985).

Considering the contact area between the moving soil and tool, *maresha* plough with side-wings has greater contact area than its wingless counterpart. However, results (refer Figs. 9) showed that *maresha* plough with side-wings required lower draught than *maresha* plough without side-wings ($p < 0.001$) despite the greater moving soil and tool contact area for *maresha* with side-wings as compared to *maresha* without side wings. Thus, the result might be attributed to side-wing shape and its wedging effect, which might helped for crack propagation and facilitate subsequent penetration by the plough share, i.e., reducing the soil resistance ahead of the plough share. This might be inline to the finding with paratill (Raper, 2005). However, other literature showed the opposite results, where smaller draught is recorded for tines without wings. For example, previous studies comparing draught of a wing-subsoiler with that of the same subsoiler geometry without wing showed the former to have about 15% larger draught as compared to the latter (Spoor and Godwin, 1978).

5.2 Effect of Rake Angle on Draught

With the respective rake angle, the tillage depth of undisturbed soil, i.e., *d1*, *d2*, and *d3*, setup was getting smaller for the three successive tillage runs in an experimental line.
From the data set, average of replicates was considered for analysis, i.e., 6 averages of 18 experimental runs representing 3 depths by two plough geometries.
Accordingly, the effect of rake angle on draught was investigated with histogram (Fig. 10) and showed the data density distribution for both *maresha* plough geometries is normal. It was also observed that with successive tillage runs, the data density of draught inclines to higher with rake angle for the respective tillage depths on undisturbed soil layers.
This was also supported by multivariant analysis that increase in rake angle resulted in higher draught for successive tillage runs despite the tool depth settings ($p < 0.001$). This might be attributed to soil compaction with depth and downward force of the ploughshare acting on the layer below, because of repeated tillages for thousand years.

6. Conclusions

In the face of numerous reports on studies of the effects of draught on the performance of different tillage tools and implements by means of soil bin test systems, sufficient information is lacking on experiments on the Ethiopian *maresha* plough with a soil bin test system. Besides, there is no information regarding the effect of side-wings of *maresha* plough on draught. .
The paper discussed the development of a mobile and *in-situ* soil bin test system, and with experimentation, insights observed on the effect of side-wings of *maresha* on draught, i.e., its wedging effect to enhance crack propagation and reducing the soil resistance ahead of the plough share.
Despite the fact that tool depth was getting smaller for the three successive tillage runs in an experimental line, higher rake angle also resulted in higher draught which could be explained in terms of soil compaction that comes with depth, and to downward force resulting from repeated tillages every season to the same depth for thousand years.

Hence, this work gave some insights for further investigation on the effect of different tool settings, and sizes and shapes of side-wings on soil failure pattern and draught requirement targeting setting of standards. Understanding of the effect a tool has on a particular soil will help in proper design of the Ethiopian *maresha* plough. Adjustments in plough design can also improve the quality of work enabling a tiller to select a different type of tool for each condition he encounters or wishes to establish.

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8. References

1) Aikins, S.H.M., and Kilgour, J. 2007. Performance evaluation of an ox-drawn ridging plough in a soil-bin, *Journal of Science and Technology*. **27** (2), 120–129.Al-Janobi, A., and Eldin, A.M. 1997. Development of a soil bin test facility for soil tillage tool interaction studies. *Research Bulletin*. **72,** 5-26. Agricultural Research Center, King Saud University.Anon. 1969. Progress Report No. 1. Implement Research Section. Publication No. 32. Chilalo Agricultural Development Unit (CADU), Addis Ababa, Ethiopia.
2) Anon. 1970. Progress Report No. 2. Implement Research Section. Publication No. 52. Chilalo Agricultural Development Unit (CADU), Addis Ababa, Ethiopia.
3) Anon. 1971. Progress Report No. 3. Implement Research Section. Publication No. 79. Chilalo Agricultural Development Unit (CADU), Addis Ababa, Ethiopia.

4) Anon. 1981. Relief and Rehabilitation Activities and Programmes. Submitted to the United Nations Conference on Least Developed Counties. Relief and Rehabilitation Commission (RRC), AddisAbaba, Ethiopia.

5) Astatke, A. Research on the draught animal power systems in Ethiopia. http://www.fao.org/Wairdocs/ILRI/x5483B/x5483b1c.htm.

6) Astatke, A., Jabar, M., Mohamed-Saleem, M.A., Erkossa, T. 2002. Development and testing of low cost animal drawn minimum tillage implements: Experience on Vertisols in Ethiopia. Agricultural Mechanization in Asia, Africa, and Latine Amlerica. Vol.33 No.2.

7) Astatke, A., Matthews, M.D.P., 1984. Cultivation Research in the Highlands Programme of ILCA. Addis Ababa.

8) Awad-Allah, M. A., Mahgoub, H. M., Abo-Elnor, M. E., Shahin, M. A. 2009. Experimental Investigation of the Effect of Vibration during Tillage Process of Multi Shank Plow Blade. 13th International Conference on *Aerospace Sciences & Aviation Technology*, ASAT- 13, Paper: ASAT-13-CT-33May 26 – 28, 2009, Military Technical College, Kobry Elkobbah, Cairo, Egypt.

9) Balaton, J. 1971. Study ofthe draught of subsoilers. Translation TT 74-53143, ARS, USDA and NSF Washington D.C.

10) Benard, C., JianQiao LI., LiGe, W., and Emmanuel, S.T. 2010. Effects of bionic non-smooth surface on reducing soil resistance to disc plowing. *Science China. Technological Sciences.* **53** (11), 2960–2965 doi: 10.1007/s11431-010-4128-8

11) Berhane, T. 1979. Study on the Ox-Drawn Equipment for the Production of Cowpea, Maize, Cotton and Groundnut under Irrigation in the Middle Awash Valley—Melka Werer. Agricultural Engineering Bulletin No. 1. Institute of Agricultural Research, Addis Ababa, Ethiopia.

12) Canaday, E. 1959. Imperial Ethiopian College of Agriculture and Mechanical.

13) Carman, K., and Dogan, H. 2000. The determination of performance draught force for different tillage tools. *Proceeding of the National Congress on Agricultural Mechanization*. Erzurum, Turkey, pp: 102-108.

14) Chamen, T., Alakukku, L., Pires, S., Sommer, C., Spoor, G., Tijink, F., Weisskopf, P., 2003. Prevention strategies forfield traffic-induced subsoil compaction: a review. Part 2. Equipment and field practices. *Soil and Tillage Research*. **73**, 161–174.

15) Clyde, A.W. 1936. Measurement of forces on soil tillage tools. *J. Agric. Engg*. **17**: 1-6.

16) Deckers, J.A., Nachtergaele, F.O., Spaargaren, O.C. (Eds). 1998. World Reference Base for soil Resources.

1) Dedouis, A. P. 2007. An investigation into the defign of precision weeding mechanisms for inter and intra-roweed control. Cransfield University School of Applied Sciences. PhD Thesis.

2) Durairaj, C.D., and Kumar, V.J.F. 2002. Soil reaction of selected bullock drawn plows in two extreme soils. *Madras Agric*. **89**(7-9), 414-419.

3) Durant, D.M., Perumpral, J.V., and Desai, C.S. 1980. Soil-Bin Test Facility for Tillage Tool Interaction Stides. Proceedings. Winter Meeting. *American Society of Civil Engineeers*. Engineering Mechanics Division. Volume 108, Issues 4-6.

4) Gebregziabher,S., Mouazen, A.M., Van Brussel, H., Ramon, H., Nyssen, J., Verplancke, H., Mintesinot Behailu, Deckers, J., De Baerdemaeker, J. 2006. Animal drawn tillage, the Ethiopian *ard* plow – *Maresha*: A Review. *Soil and Tillage Research*. **89**(2), 129-143.

5) Gebresenbet, G. 1995. Optimization of Animal Drawn Tillage Implements: Part I, Performances of a Curved Tillage Implement. *J. agric. Engng Res.***62**, 173-184.

6) Gebresenbet, G., Gibbon, D., Astatke, A. 1997a. Draught Animal Power: Lesson from past research and development activities in Ethiopia and indicators for the future needs. 13/14 IRDCurrents. Current issues in international rural developments.

7) Gebresenbet, G., Ercole Zerbini, E., Astatke, A., Kaumbutho, P. 1997b. Optimization of Animal Drawn Tillage Implement Systems: Part 2, Development of a Reversible Plow and a Ridger. *J. agric. Engng Res.* **67**, 299 – 310.

8) Gebresenbet, G., Kaumbutho, P.G. 1997. Comparative analysis of the field performances of a reversible animal drawn prototype and conventional mouldboard ploughs pulled by a single donkey. *Soil and Tillage Research*. **40**, 169–183.

9) Gebreslasie, M., Gebregziabher, S., Mouazen, A.M., De Baerdemaeker, J., Deckers, J., Nyssen, J., Hubert, V. 2004. Soil-tillage tool interaction for the vertisols of the Ethiopian highlands: a review (Poster). In: Proceeding of the European Agricultural Engineering *AgEng Leuven* 2004. Conference, 12–16 September, Leuven, Belgium, pp. 830–831.

10) Georgison, R.R. 2010. Forces on a rotary tine aerator under normal working conditions. Department of Agriculture and Bioresource Engineering, University of Saskatchewan, Saskatoon.

11) Gete, Z. 1999. Application and adaptation of WEPP to the traditional farming system of the Ethiopian highlands. In: Paper Presented at the Conference of the International Soil Conservation Organisation, Lafayette.

12) Geza, M. 1999. Harnessing techniques and work performance of draught horse in Ethiopia. In: Starkey, P., Kaumbutho, P. (Eds.), Meeting the Challenges of Animal Traction. A Resource Book of the Animal Traction Network for Eastern Africa (ATNESA), Harrare, Zimbabwe. Intermediate Technology Publications, London, p. 326.

13) Godwin, R. J. Spoor, G. Leeds-Harrison, P.. 1981. An Experimental Investigation into the Force Mechanics and Resulting Soil Disturbance of Mole Ploughs. *J. agric. Engng Res.* **26**, 477-497.

14) Godwin, R.J., Spoor, G., Kilgour, J. 1980. The design and operation of a simple low cost soil bin, *J. Agric. Engg Res.* **25** (1), 99–104.Goe, M.R. 1987. Animal traction on small holder farms in the Ethiopian Highlands. PhD thesis, Department of Animal Science, Cornell University, Ithaca, New York, USA.

15) Goe, M.R. 1999. Influence of slope and stone cover on tillage operations in the Ethiopian highlands. *Soil and Tillage Research*. **49**, 289– 300.

16) Goe, M.R., Astatke, A., 1989. Development of draught animal power systems in Ethiopia. In: Paper Presented at the Second ACIAR International Workshop on Draught Animal Power, 3–6 July, Bogor, Indonesia.

17) Hamza, M.A., Anderson, W.K., 2005. Soil compaction in cropping systems. A review of the nature, causes and possible solutions. *Soil and Tillage Research*. **82**, 121–145.

18) Hann M.J. and Giessibel J. 1998. Force measurements on driven discs. *J. agr. Engng Res.* **69** (2), 149-158.

19) Ibrahmi, A., Bentaher, H., Hamza, E., Maalej, A., Mouazen, A.M. 2015. Study the effect of tool geometry and operational conditions on mouldboard plough forces and energy requirement: Part 2. Experimental validation with soil bin test. *Computers and Electronics in Agriculture* **117**, (268–275.

20) Lindner, H. 1974. Zur technologie und okonomie der tiefockerung verdichteter boden mit dem anbautieflockerer B371. Arch. Acker-u-Ptlanzenbau u Bodenkd., Berlin, **18** (8) S. 629-638.

21) Loghavi, M., and Khadem, M.R. 2006. Development of a Soil Bin Compaction Profile Sensor. *J. Agric. Sci. Technol. Vol. 8: 1-13.*

22) Loukanov, I.A., Uzaik, J., Michalek, J. 2005. Draught requirements of enamel coated animal drawn mouldboard plough. *Res. Agr. Eng*., **51** (2), 56–62.

23) Luebcke, H. N. 1944. Report to land drainage division, MAFF.

24) Mahadi, M.R. 2005. Development of a soil bin test facility for soil dynamics study. Master thesis. Department of Biosystems Engineering, University of Manitoba, Canada.

25) Mamman, E. and K.C. Oni, K.C. 2005. Draught Performance of a Range of Model Chisel Furrowers. *Agricultural Engineering International: the CIGR Ejournal.* Manuscript PM 05 003. Vol. VII. November, 2005.

26) Manuwa, S. I. 2002. Development of an Equipment of Soil Tillage Dynamics and Evaluation of Tillage Parameters. Unpublished Ph.D Thesis in the Department of Agricultural Engineering, The Federal University of Technology, Akure, Nigeria.

27) Manuwa, S.I. 2009. Performance evaluation of tillage tines operating under different depths in a sandy clay loam soil. *Soil and Tillage Research*. **103**, 399–405.

28) Manuwa, S.I., Ademosun, O.C. 2007. Draught and soil disturbance of model tillage tines under varying soil parameters. Agricultural Engineering International: the *CIGR Ejournal*, Manuscript PM 06 016, vol. IX.

29) Manuwa, S.I., and Ajisafe, A.A. 2010. Development of Overhead Gantry as Complementary Equipment to Indoor Soil Bin Facility. *Research Journal of Applied Sciences.* **5**(2):92-95.

30) Marakoglu, T., Carman, K. 2009. Effects of Design Parameters of a Cultivator Share on Draught Force and Soil Loosening in a Soil Bin. *Journal of Agronomy.* **8**(1), 21-26.

31) Mardani, A., Shahidi, K., Rahmani, A., Mashoofl, B., and Karimmaslak, H. 2010. Studies on a long soil bin for soil-tool interaction. *Cercetări Agronomice în Moldova* Vol. XLIII , No. 2 (142)

32) McKyes, E. 1985. Soil Cutting and Tillage. *Elsevier Science* Publishers B.V. 217pp.

33) Mouazen, A.M,, Nemenyi, M., Schwanghart, H., Rempfer, M. 1999. Tillage tool design by the finite element method: Part 2. Experimental validation of the finite element results with soil bin test, *J. agr. Engng Res.* 72, 53-58.

34) Mouazen AM & Nemenyi M. 1998. A review of the finite element modelling techniques of soil tillage. *Mathematics and Computers in Simulation.* **48**(1), 23-32.

35) Mouazen, A.M., Smolders, S., Meresa, F., Gebregziabher, S., Nyssen, J., Verplancke, H., Deckers, J., Ramon, H., De Baerdemaeker, J. 2007. Improving animal drawn tillag*e system in Ethiopian high*land*s. Soil and Tillage Research.* **95**, 218-230.

36) Niyamapa, T. and V.M. Salokhe. 2000a. Force and pressure distribution under vibratory tillage tool. *J. Terramechanics*. **37**, 139-150.

37) Niyamapa, T. and V.M. Salokhe. 2000b. Soil disturbance and force mechanics of vibrating tillage tool. *J. Terramechanics.* **37**,151-166.

38) Nyssen, J., Govaerts, B.,, Araya, T., Wim M. Cornelis, Bauer, H., Mitiku Haile, Sayre, K., Deckers, J. 2011. The use of the marasha ard plough for conservation agriculture in northern Ethiopia. *Agron. Sustain. Dev.* **31**, 287–297.

39) Oehler, T. 1933. Der Kulturtechniker. Vol. 36, 1933 p. 200.

40) Onwualu A.P. and K.C. Watts. 1989. Development of a soil bin test facility. *ASAE Paper* No. 89- 1106, ASAE, St Joseph: Michigan.

41) Pathak, B.S., 1988. Survey of Agricultural Implements and Crop Production Techniques. Research Report 1/1988. Institute of Agricultural Research, Ethiopia.

42) Plouffe, C., Lague, C., Tessier, S., Richard, M., McLaughlin, N. 1999a. Validations of moldboard plow simulation with FEM on a heavy clay soil. *ASAE* Paper No. 98-1065. ASAE, St. Joseph.

43) Plouffe, C., Lague, C., Tessier, S., Richard, M., McLaughlin, N. 1999b. Moldboard plow performance in a clay soil: simulation and experiment. *ASAE* Paper No. 98-1066. ASAE, St. Joseph, MI.

44) Potter, K.N., and F.W. Chichester. 1993. Physical and chemical properties of a vertisol with continous controlled traffic, no till management. *Trans. ASAE.* **36**:95-99

45) Qaisrani, A.R. 199). The effects of modified and unsmoothed surfaces on the draught of bulldozing plates and mouldboard plows. A Ph.D. Dissertation, Jilin University of Technology, Changchun, China.

46) Qaisrani, A.R., Chen B.C., Ren, L.Q. 1992. Modified and unsmoothed surfaces - a means to reduce plowing resistance. *Agricultural Engineering Journal. **1***: 115-124.

47) Qaisrani, R, Jian-qiao, LI, Khan, M.A., Rashid, I. 2010. Soil Adhesion Preventing Mechanism of Bionic Bulldozing Plates and Mouldboard Plows. Advances in Natural Science. The 3rd International Conference of Bionic Engineering. Vol. 3, No. 2, pp. 100-107.

48) Qian, C., R. Luquan, C. Bingcong, Y. Beizhan. 1999. Using characteristics of Burrowing Animals to reduce soil –tool Adhesion. *Transactions of the American Society of Agricultural Engineers*. **42** (6), 1549 – 1556.

49) Radford, B.J., Bridge, B.J., Davis, R.J., McGarry, D., Pillai, U.P., Rickman, J.F., Walsh, P.A., Yule, D.F., 2000. Changes in the properties of a Vertisol and responses of wheat after compaction with harvester traffic. *Soil and Tillage Research*. **54**, 155–170.

50) Ranta, O., Drocas, I., Stanila, S., Molnar, A., and Marian, O. 2009. Influence of Disc Kinematic Regime Used in No Tillage Technology, on Germinative Bed Cone Index. *Bulletin UASVM Agriculture*. **66** (1)/2009. Print ISSN 1843-5246; Electronic ISSN 1843-5386

51) Raper, R. L. 2005. Force requirements and soil disruption of straight and bentleg subsoilers for conservation tillage system. Applied Engineering in Agriculture. *American Society of Agricultural Engineers*. ISSN 0883−8542. **21**(5), 787−794.

52) Reeder, R.C., 2002. Controlled traffic. In: Lal, R. (Ed.), .Encyclopedia of Soil Science. Marcel Dekker, New York, pp. 233–235.

53) Rosa, U.A. 1997. Performance of Narrow Tillage Tools with Inertial and Strain Rate Effects. Department of Agricultural and Bioresource Engineering, University of Saskatchewan. Ph.D. thesis

54) Rosa, U.A. and Wulfsohn, D. 2008. Soil bin monorail for high-speed testing of narrow tillage tools. *Biosystems Engineering*. **99**, 444 – 454.

55) Sahu, R.K. and Raheman H. 2006. Draught Prediction of Agricultural Implements using Reference Tillage Tools in Sandy Clay Loam Soil. *Biosystems Engineering*. **94** (2), 275–284.

56) Schulte, K.H. 1974. Untersuchungen zur entwicklung effektiver Gerate und werkzeuge mit geringem zugkraftbedarf zur tieflockerung und gleichzeitigen einbringung bodenverbessernder materialien. *Arch. Acker-u-Pflanzenbau u Bodenkd*. **18** (8), 617-628.

57) Siemens J C and Weber J.A. 1964. Soil bin and model studies on tillage tests and traction devices. *Journal of Terramechanics*. **1**(2): 56 – 67.

58) Smith, J. 1973. Deanston subsoiZplough. 1973. In Farm Tools Through the Ages (M. Partridge), Chapter I. Osprey Publications.

59) Spoor, G. 2006. Alleviation of soil compaction: requirements, equipment and techniques. *Soil Use and Management.* **22**, 113-122.

60) Spoor, G., and Godwin, R.J. 1978. An experimental investigation into the deep loosening of soil by rigid tines. *J. agr. Engng Res.* **23**, 243-258.

61) Stafford J. V. 1979. The performance of a rigid tine in relation to soil properties and speed. *J. agr. Engng Res.* **24**, 41-56.

62) Starkey, P. 1988. Animal Drawn Wheeled Tool Carriers: Perfected Yet Rejected. Bertelsmann Publishing Group, Lengerich, Germany.

63) Stempowski. 1929. Le Drainage par Churrure Druineuse. Paris.

64) Suminitrado DC, Koike M, Konaka T, Yuzawa A, Kurioshi I. 1988. A mathematical model to predict the trajectory of soil motion on a mouldboard plow surface. Proceedings of the 2nd Asia-Pacific Conference of the International Society for Terrain Vehicle System, Bangkok, Thailand, 195-204.

65) Trousse, A. C., Humbert, R. P. 1959. Deep tillage in Hawaii: 1. Subsoiling. *Soil Sci.* **88** (3) 150.

66) UNDP. 2000. Plowing for progress: Ethiopia. Sharing innovation experience. *Sci. Technol.* **1**, 209–217. In: http://tcdc.undp.org/

67) Vozka, P. 2007. Comparison of alternative tillage systems. Cransfield University, School of Applied Sciences, National Soil Resources Institute. MSc Thesis

68) Wells, A. A. 1951. Soil mechanics and tilluge. Ph.D. Thesis, University of Cambridge.

69) Wismer, R.D. 1984. Soil bin facilities: characteristics and utilization. In Proc. 8th International conference, *International society for terrainvehicle systems.* Vol. III: 1201 - 1216.6 10 August, Cambridge, England.

70) Zaugg, H. 1992. Improving the supply and distribution of farm implements in Ethiopia: some experience and constraints. ATNESA Workshop 18–23, Lusaka, Zambia.

9. Figures

Fig. 1. Traditional plough: The first ever photograph of an Ethiopian farmer with his oxen and marasha, near Senkata (Tigray) in March 1868. © Royal Engineers of the British Army, reprinted with permission of the King's Own Museum, Lancaster, UK. (Nyssen *et al.*, 2011).

Fig. 2. Traditional plough, Photo, ILCA collection, Samuel Jutzi and Guido Gryseels (Nyssen *et al.*, 2011): (a) Mode of transport, and (b) during ploughing.

Fig. 3. Italian mouldboard ploughs imported into Ethiopia (near Mekelle, in 1938). Photo by Guidotti, "Gift of H.E. the Head of State to the inhabitants of Tigray" states the original legend of this photograph obtained from the Istituto Agronomico per l'Oltremare (Florence, Italy) (Nyssen *et al.*, 2011).

Fig. 4. A mobile and an *in-situ* soil bin test sytem with three rows: (a) 1, Dataloger and battery; 2, Rear carriage unit; 3, Steel frame; 4, Front carriage unit; 5, Rail; 6, Wooden Sleeper; 7, Extension of steel frame for loadcell and plough attachment; 8, Load cell; 9, Plough; 10, Free wheel (wheel gage), (b) 1, Two rails for one line - each with 10m length, forming a total of 20m length; 2, Rail Connector/plate; 3, Wooden Sleeper; 4, Carriage with Implement and data acquisition system; 5, Steel Rope for Pulling Carriage; 6, Two-wheel (Walking) Tractor; 7, Pit for defined experiment with starting and ending, and (c) 1, Carraige; 2, Data logger; 3, Battery; 4, Laptop.

Fig. 5. Steel Frame with load cell and pattachment: 1, Steel frame; 2, Load cell; 3, point contact between load cell and plough shank; 4, Plough shank; 5, *maresha* plough without side-wings; 6, *maresha* plough with side-wings.

Fig. 6. Load Cell: (a) Schematic of Load Cell Assembly and Acting Forces, and (b) Projected Free Body Diagram (View A-B)

Fig. 7. Traditional Ethiopian plough - *maresha*: (a) with side-wings (soil-tool contact surface area ~ 0.0376m^2), and (b) without side-wing (soil-tool contact surface area ~ 0.0184m^2).

Fig. 8. Tool rake angle and depth (α_1, α_2, and α_3 are rake angles for successive three tillage runs in an experimental line for depths setup of D1, D2, and D3, in which *d1*, *d2,* and *d3*, respectively, are tillage depths of undsisturbed soil layer.)

Fig. 9. Effect of tool geometry on draught: Box-plot (WW, with side-wing; WO, without side-wing; 1, 2, and 3 stands for three successive tillage runs, resepectively.)

Fig. 10. Effect of tillage depth on draught - Histogram: (a) *Maresha* with side-wings, (b) *Maresha* without side-wings

10. Tables

Table 1. DBK43A - Wiring and Color differences of IOtech - USA and Load Cell from Celtron, the Netherlands

Table 2. Filter and Resistor Relations

Table 3. Soil Size Distribution of the Experimental Site

Effect of side-wings on draught: The case of Ethiopian Ard plough (maresha)

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Solomon Gebregziabher, Karel De Swert, Wouter Saeys, Herman Ramon, Bart De Ketelaere, Abdul M. Mouazen, Petros Gebray, Kindeya Gebrehiwot, Hans Bauer, Jozef Deckers, Josse De Baerdemaeker, Effect of side-wings on draught: The case of Ethiopian Ard plough (maresha), Computers and Electronics in Agriculture, Volume 127, September 2016, pp131-140

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