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# A Mobile, *In-Situ* SoilBin Test Facilityto investigate the performance of *Maresha* Plough

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**Abstract**

Ethiopia is well known for its use of an*ard*ploughdating from antiquity– *maresha* - which fractures and disturbs the soil. However, hardly any notable progress of experimental research on this animal drawn tillage tool in the field has been made. Theattendant problems in current practise aresoil-*maresha* interaction, viz., uneven oxen strength along with different pace of walking, uncontrolled implement behaviour, and field conditions. Taking stock of the experimental researchon animal drawn tillage tools in general, most of the documented works on the dynamicsof the interaction between soil and animal drawn tillage tools tend to rely on trial-and-error based on factorsmainly based on experience and cultural context. As such, no systematic research tailored to systematically handle the link between *maresha* plough and soil bin experimentsexists. To this aim, this study developed a mobile *in-situ* soil bin facility in which the system was calibrated, tested and evaluated under outdoor experimental conditions, whereinonline measurements of draught, speed, and depth of tillage were carried out. The insights and observations gained from the experimentation werediscussed and reported in terms of smooth run, overload, cyclic forces, zero speed with minimal force, stoppage, speed measurement with no force, force measurement with no speed, and low speed with low force.

**Key words**: Cyclic forces, Draught, *In-situ,maresha*, Overload, Tillage depth, Tillage speed.

## 1. Introduction

The onset of harnessing on draught animal power to augment man's physical efforts in tillage dates back to the beginning of sedentary life and agriculture. Rolling down to the present system of agricultural crop production, motive power for crop production, harvesting and transportation has beenprovided by humans, draught animals, and motors/engines in various proportions (FAO, 2003; Pearson, 2005). In developing countries, about 80 %of the power input on farms is provided by draught animals and humans (Pearson, 2005). Schmitz (1990) estimated that animal drawn ploughs of various types have been used by about 75 %of farmers in North and East Africa, South-East Europe, the Near and Far East and Latin America.

Notwithstanding the growing contributions of tractor power to land preparation, animal traction is believed by many farmers, researchers, and policy makers to be an appropriate, affordable, and sustainable technology requiring few internal inputs (Bobobee, 2007). As such, the use of animal traction technology as an alternative farm power source for tillage in much of the Sub-Saharan Africa region is projected to continue(FAO, 2001) on account of its specific merits mainly due to: (1) theadjustable width of the ox-team, which is valuable in different types of cultivation, and the possibility to use oxen even in wet soil conditions, with lower cost of animal traction (Henriksson and Lindholm, 2000); (2) its relative simplicity and regenerative character, strong indigenous character, and simple support systems (Gebresenbet *et. al*, 1997 a&b); (3) the cost of spares, poor training of operators, and inadequate back-up service escalated by the rising costs of maintenance for modern machinery, making motorised machineryuneconomic even for contractors (Kaumbutho and Ithula, 1990; Kaumbutho and Mwago, 1993).

Prompted, in large part, by advantages,and alluding to "the past failures of tractor mechanisation projects in many developing countries" (Bobobee, 2007), there is renewed interest in research on the overall dynamicsof the interaction between soil and animal drawn tillage tools. Ethiopia is well-known for the use of an *ard*plough - *maresha* - which fractures and disturbs the soil and dates from antiquity. However, hardly any notable progress in terms of experimental research on animal drawn tillage tool in the field has been made concerning current practice and the attendant problems of soil-*maresha* interaction, viz., uneven oxen strength along with different pace of walking, uncontrolled implement behaviour, and field conditions.

Most documented work on the dynamicsof the interaction between soil and animal drawn tillage tools tends to have been reliant on trial-and-error procedures based on experience and cultural context. Apart from limited research work on animal drawn tillage tools in general, no research particularly tailored to systematically handle the link between *maresha* plough and soil bin experimentation exists.

Here, the gaps in experimental research works on animal traction tillage tools are discussed takinginto account soil variability and financial constraints. An experimental approachon the dynamicsof soil-*maresha* plough interaction using a mobile and *in-situ* soil bin test facility was developed. Specifically, this paper aims to: (1) describe the development of a mobile *in-situ* soil bin testing device; and (2) report the observations and insights gained from the field experiments.

## 2. Soil Bin Test Facility

At the broader level,research to gain a better insightsintothe soil-machine/tool continuum can be via the evaluation of soil-tool interaction through mathematical modelling(mechanics) or by experimental analysis (Onwualu, 1991). However, soil-tool tests are usually determined using experimental methods and are conducted either by performing field testing or in laboratory soil bin facilities. In the case of full-scale field testing, it has been reported that the results obtained cansometimes be of little valuedue to the wide variation of soil types and conditions found in the field (Al-Janobi and Eldin, 1997). However, the application of soil bin facilities tosoil-tillage tool interaction studies can largely overcomethese. The conceptis that controlled studies are possible in soil bins where the operating parameters can be controlled and the experiments closely observed and monitored avoiding many of the difficulties found in the field(Govindarajan, 1991; Manuwa *et al*.,2011).Well documented descriptions of theadvantages of soil bin experiments are provided in a compilation by ASAE (1994).

As an important facility for developing basic scientific understanding of agricultural soil mechanics in general, soil binscan act as scale model tests and experiments for soil-machine/tool interaction. They essentially consist of abin containing the soil, a tool carriage, a drive system, instrumentation and data acquisition systems (Govindarajan, 1991; Ani *et al*., 2014). Depending on the objectives for which they are developed, the space available, energy requirements, and financial constraints, soil bins vary in scope from small indoor equipment to large outdoor facilities and canbe straight or circular in construction (Wismer, 1984).

Nichols, who reported research in 1920,tends to be a name most associated with the early development and use of soil bins to study soil-machine interactions (Mardani *et al*., 2010; Ani *et al.*, 2014). Ever since, soilbins have been in use in researchinstitutes across the world. Establishments using soil bins include the National Soil Research Institute of Cranfield University (UK), theNationalTillageandMachineryLaboratory(NTML), intheUnitedStates, which has full-size wheels, tracks, vehicles, and tillage tools, and theU.S. Army TankAutomotive Center Land-Locomotive, to mention only three.[1]In 1984, there were about 36 different facilities in 12 countries with 90 soil bins constructed (Wismer, 1984).About 150 soil bins are probably in use around the world (Mahadi, 2005; ASME and ASAE, 1990; Gill *et al.,* 1994; Mardani *etal.*, 2010; Wood and Wells, 1983; Fielke andPendry, 1986; Martin and Buck, 1987; Onwualu and Watts, 1989&1998)

Overall, twobroaddivisionsofsoil-machine/toolinteractionstudies are performed in a soil bin (Mahadi, 2005): 1) applications oftoolsrelated tosoilengagingandmaterialsincorporationoperations; and 2) applicationsrelatedtotractivedevices,suchaswheelsandtracks. Soil bins can also be used to study the interaction between the machine and buried artefacts (Spandl, 2010). One distinguishing characteristic of each facility involves the component which arein motion (Wismer, 1984). Soil bins can be stationary while the soil processing and tool units are movable and vice versa (Durant *etal.*, 1980).

[1] Other institutions include: the VicksbergWaterways ExperimentalStation;CaterpillarTractorCo. (Mahadi, 2005; Clark and Liljedahl, 1968; ASME and ASAE, 1990;Gill *et. al.,* 1994);Kanto-Tosan Agricultural Experiment Station – Japan Institute for Agricultural Mechanization (ASME and ASAE, 1990; Gill and Berg, 1968); University of California at Davis in USA; University of Hohenheim in Germany; IMAG of Wageningen in Netherlands (Yahya *et al*., 2007); Urmia University of Iran (Mardani *etal.*, 2010); and The Federal University of Technology, Akure (FUTA), Nigeria (Manuwa and Ajisafe, 2010; Manuwa and Ademosun, 2007; Manuwa, 2002)

Stationary soil bin with movable tools generally use two types of carriage supports, i.e., those with: (1) Two horizontal rafts mounted along one side of the soil bin and separated in the vertical plane in which the rails provide the support for the cantilevered carriages (Siemens, 1963); and (2) One rail on each side of the soil bin (Luth, 1974) with the test tool mounted on a tool carriage which moves back and forth on the rails.

Stationary soil bin facilities generally include a second carriage with equipment for reconditioning the test section prior to each test. The components of the second carriage normally include a tilling unit for loosening the soil, a blade for levelling, and a roller to compact the soil (Durant *etal.*, 1980).

Most soil bin test systems used the concepts of overalllength, working length, andeffective length ofthesoilbin to define a useful dataset for analyses. “Overall length” refers to the length measured from one end to another endof the entire soil bin structure. “Working length” refers to thetotal travelling distance of the test tool; and the “effective length”isthe distance overwhich atesttoolismoving atconstant speed. The analyses are then based on the draught and otherdata takenatconstanttool speed, i.e., which defines effective length (Mahadi, 2005).

The need for the design and experimentation with soil bin facility in the case of the dynamism in the soil-tool plough continuum canbe effectively accomplished only if the complex interaction between the soil and the machine/tool is clearly understood (Al-Janobi and Eldin, 1997). In this regard, Gebresenbet *et al.* (1997b) showed that only a few researchers and farmers have been involved in innovation efforts in animal traction technology in Ethiopia with an inadequate grasp of the context of the problems faced by many small farmers. Gebregziabher *et al*. (2006) reported that previous research on animal drawn tillage tools relied on experience, culture, and trial and error.

Although there is no information on any research dealing with the link between *maresha* plough and soil bin experimentation in particular, there is also little research on animal drawn implements other than those on *maresha* plough, i.e. no research of a sort particularly tailored to systematically handle the link between *maresha* plough and soil bin experimentation exists.

Gebresenbet (1995) used a soil bin to measure the forces acting on a curved tool, and attempted to develop empirical prediction models of draught. Loukanov *et al.* (2005) experimented with animal-drawn mouldboard plough to investigate effect of enamel coating on specific draught. Aikins and Kilgour (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. Theabove research was undertaken in indoor facilities with imported (disturbed) soil, which neglect the real-life situation where the plough interacts with the soil in its natural configuration and its spatial variability.

It appears that there is no reported research on *maresha* plough using an outdoor soil bin with soils in their natural structural condition.This necessitates the need for developing and designing field soil bin facility which enables the study of the dynamicsofthe interaction between the natural structure of the soil and *maresha* plough, the prime object of interest of this paper.

## 3. Materials and Methods

### 3.1 Description of the Facility

Tooldraught is known to vary withthetool'sdesign parameters, and operational conditions including tillage speed and depth, and soil conditions. In this work, the overall length of the facility was 20 m, the lengthof the entire soil bin structure. In order to easily locate the starting and ending points of experiments, pits were excavated at both ends of each row to have a working length of 16m (deducting the dimension of the front and rear pits). The effective length was the distance over which a test tool moved without hindrance. This differed from one experiment to another based on the field conditions discovered including the existence of largestones and rocks.

The major components of the developed testing device, as shown in Fig.1,were track rails, tool carriage, drive system, instrumentation and data acquisition. The developed setup madeit possible to have online measurement of draught, tillage speed,and tillage depth.

### 3.2 Moving Carriage Assembly: rails and carriage

#### 3.2.1 Rails

Six 10m rails were used to form four rail lines for three similar row rail-tracks in which eachrow had 1.435m wide. The rails were mounted on treated wooden sleepers (Fig. 2).Considering the position of wooden sleepers, the net working width was 1.36m,which allowed the carriage with its tool, instrumentation and data logging system, to easily move on parallel rails.Since the fieldswere not horizontal, they rails had located so as to prevent the carriage from accelerating due to gravity.

Material handling, for transportation within a field, mounting/installation and dismantling of rails was done manually by means of grippers. Three grippers were enough to transport 10 m of rail usingsix persons.

### 3.2.2 Carriage

Siemensand Weber(1964)suggestedthatasoil bin carriageshouldberigidenoughtowithstandweightof testtoolsandtheforcesproducedbythetools. The design of a straight soil bin facility should ensure that carriagemotionismaintainedina straightpath. Forthisreason, Stafford (1979)ran thecarriage onanoverhead rail. Godwin *etal.*(1980) usedasteelangleastheguiderail, sothat therigid wheels rolled on the steel angle instead ofona flat surface ofarail. OnwualuandWatts(1989)employeda setoffourrigid wheels, running alongtherails onthevertical plane ofthesidewalls.In order to preventa carriage from tilting, another setofrigid wheels running along the bottom surface of anI-beam railwasused.

In this work, the developed testing device hadtwo carriage sub-units assembled together with an intermediate member, a steel frame (Fig. 3). As a result, the complete carriage had eight rollers to ensure a sturdy construction for having straight motion and avoid flipping, toppling and tilting. The carriage (Fig. 4)wasa single unit with apayload of 100,000 N, a roller diameterof 250mm, a wheelbase of 540mm, a height abovethe running surface of 310mm and masswithoutbrake of 220kg.

A tillage tool and sensors were anchored to the front sub-unit of the carriage using steel frame;whilstthe data logger and the batterywere positioned at the back sub unit of carriage. The steel frame was not only an intermediate member for both carriage sub-units, but it also served as an anchoring attachment to the sensors used including a load cell,a linear variable displacement transducer (LVDT), and an optical sensor - encoder(See Fig.5 for details).

## 3.3 Drive System

Most soil bins operate with a driving power source either from an electricmotor (Siemens and Weber, 1964), or ahydraulicmotorandpump - hydrostatic transmission (Durant *et al.,* 1980, and Godwin*et al*., 1980).

Traditional tillage in Ethiopia uses a pair of oxen to pull the implement, the*maresha*. Because of mass inertia of the carriage, a greater force was necessary to trigger initial movement, i.e., the setup was heavy to be pulled by a pair of oxen. Hence, a two-wheel (walking) tractor (1 kW, Model DF, Changzhou Dongfeng Agricultural Machinery Group Co., LTD – DFAM, with CHANGCHAI engine, China) was used, to provideenough power to conduct the experiments. The two-wheel tractor had a wider wheelbase than the working width of the testing device. For this reason, a steel cable (for minimum elasticity) was used to connect the two-wheel tractor and carriage.

## 3.4 Instrumentation and Data Acquisition System

The instrumentation and data acquisition system was designed and configured to incorporate three sensors: load cell, linear variable displacement transducer (LVDT), and optical sensor - encoder.

### 3.4.1 Draught

A force transducer (shear beam load cell from Celtron SQB-5tSS, The Netherlands)was used in the developed testing system. The load cell has a maximum load of 500 kg, and a sensitivity of 2.99mV$V^{-1}$ (Gebregziabher, 2005; Mouazen *et al*., 2007). The load cell has three holes and was attached as intermediate member to a locationbetween the plough shank and steel frame (Fig. 6). To avoid interference of soil with the measurement, the load cell was positioned above the soil surface instead of being directly located behind the ploughshare. The measuring point with load cell differed from the point where concentrated load, assumed equivalent to the sum of distributed load (of the soil resistance), acted on *maresha*.The design allowed for free contact of load cell with shank of plough;thecontact point was where the draughtwas transferred.The free contact allowedfor force transfer without coupling effect, which cannot be avoided with a solid connection. Also, in order to ensureproper measurement, theconnectionof the *maresha* plough with the frame needed to be pinned to allow forces to be absorbed by the frame, with rotating end on 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 implement through the soil

Calibration was undertaken based on the following assumption and dimensions:

- The location of area of centroid of *maresha* plough coincided with the centroid of the distributed load area – soil resistance. The measured concentrated load at point '***b***' was equivalent to the sum of distributed load (of the soil resistance) on the plough surface.
- The vertical projected distance in metres from the area of centroid of *maresha* plough (point **'*b*'**) to the weld connection point of ploughshare and plough shank **'*a*'** was designated by 'C. Let the length in metres between point **'*a*'** and '***b***' be $L_{ab}$, and the rake angle in degrees be **'*α*'**.

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

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

Static force analysis made direct use of static equilibrium equations for an analytical solution using schematic and free body diagram (Fig. 7). Then, at static force equilibrium, the force and moment equations are given by Eqs.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 Eqs. (2) and (3), the force measured by load cell, $F_{Load\ Cell}$, is given by Eq.(4) is.

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

To minimise noise in the data, hardware and digital filters were used. The selection of hardware filter was based on experimentation with resistors by positioning jumpers on DBK 43A(8-channel strain gauge module). Experiments showed the standard filter with a frequency of 13.3Hz lowered most of the noise.The digital filter processed the incoming load cell data; a low pass filter at 135 Hz gavethe best results. The load cell and the data acquisition systemswerecalibrated.

### 3.4.2 Tillage Speed and Depth Measurement

The measurement system included a freely moving wheel gauge (depth wheel). It was made of steelwithgripping shapes at its periphery to minimise slip.Alinkage with a crank and follower,anchored to the steel frame and carriage, allowedthe wheel to move up and down easily.

As shown in Fig. 8, the wheel gauge had a shaft/spindle, and its linkage was mounted on this spindle by means of ball bearings. The LVDT(BS 75A, Dimed Electronic Engineering, Belgium) was directly assembled at one end to the spindle for tillage depth measurement. At the other end, a disc (a circular plate having drilled holes at equal arc lengths at its periphery) was assembled and fitted with aencoder (EE-SPX303N, Omron, Belgium) tocalibrated measure tillage speed (Fig. 9).

The LVDT was mounted on spindle of wheel gaugeto measure tillage depth (Fig. 8&9). The attachment design was based on the working principle of the LVDT and safety. One end was directly connected to the spindle of the wheel gauge, and the other, to the carriage having a plate with a slot to accommodate lateral movement of endpin of the LVDT for safety. The endpinwas a positioning pin and served as a reference for the moving wheel.

The LVDT was a position-sensing device that provided an AC output voltage proportional to the displacement of its core passing through its windings. The LVDT provided linear output for small displacements where the core remained within the primary coils. The exact distance was a function of the geometry of the LVDT.

During the experiment, the wheel gauge moved up and down easily; and the stroke length of the LVDT increased or decreased as a function of the depth. The output signal of LVDT, then, was sent to the data acquisition unit. The measurement was calibrated to read zero when the tip of the ploughshare was standing still on the ground.

### 3.4.3 Data logger: Data Acquisition System

The data acquisition hardware (IOtech, OH, USA)was placed in a frame mounted on the carriage together with external 12V battery power source. The hardware included: DBK43A (8-channel strain gauge module); Daqbook/2000E (ethernet 16 bit, 200 kHz data acquisition system; including DaqView software); DBK203 (Screw terminal adapter board in rugged metal enclosure for Daqboard 2000 series; P/P2/P3, analogue and digital I/O expansion ports); DBK34A (uninterruptible power supply for DC powered systems), and CA-37-3T (expansion cable from Daqbook to DBK modules). Thesoftware program DASYLab 8.0.1 (National Instruments, Ireland)was used for data presentation and storing. The DASYLab uses icon-based module and flowchart; the job of communicating with the hardware was taken care of by a driver.The incoming signals (mV) from the load cells and volts (V) from the LVDT, and the pulses from encoder were rescaled to give kg, m, and m $s^{-1}$, respectively. The data were read, interpreted, scaled, averaged, displayed and stored on the laptop.

### 3.5 Experimental Details

Three rake angles of $8^o$, $15^o$, and $24^o$ were considered representing, primary, secondary and tertiary tillage process, respectively, in Ethiopia. Experimental runs were undertakenat two plough planes:(1) at surface, and (2) at the depth of 200mm - by excavating a strip of soil having width of 400 mm.

## 4. Results and Discussions

The online data was measured as a function of time. Examination of the collected data set required conversion of all parameters into a common platform. To this end, all data were transformed, plotted, and analysed by means of a program developed using Matlab toolbox (R2009b, from The MathWork, Inc., Natick, MA, USA). From the data set and observations, it was seen that some experimental runs operated well but some encountered difficulties. The experiments undertaken with rake angle of $8^o$- at surface, and with rake angles - $8^o$ and $24^o$ performed at second plough plane were considered representing smooth experimental run and experimental runs encountered difficulties, respectively, for elaborating insights observed.

## 4.1 Insights Observed from Experiments

### Observation 1: Smooth Experimental Run

The dataset from experimental run with rake angle of $8^o$ at surfacewas transformed and plotted as a function of tool travel distance as shown in Fig.11.From the visible force curveno indication of overload was observed and the draught measured was within the capacity of designed instrumentation and measurement system.With this soil condition, variability in soil resistance (Mouazen and Ramon, 2006) could be mapped with travel distance. Furthermore, at these soil conditions (with no stones present),the interaction between soil and *maresha* could be understood. Hence, a tillage tool design could be studied and optimised for optimal tillage performance e.g., maximum soil loosening for minimum draught requirement.

### Observation 2: Experimental Runs Encountered Difficulties

Experimental runswith rake angle of $8^o$, at second plough plane,plotted as a function of distance and time, areshown inFigs. 12 and 13, respectively. The plot is divided described as follows in 6 sections and a point (labelled by the letters "A to G"):

i. *Section 'A' - Zero tillage speed, with minimal force*: When the plough encountered big stones, the carriage moved back and forth, and the operator exerted impulsive force.

ii. *Section 'B' - Low speed with no overload but higher forces*: This showed the presence of high soil resistance, in which the plough could still penetrate the soil without stoppage. Under such soil cutting conditions, the force increased and the signal started oscillating. In the movie as well as on the speed graph, oscillations were observed whenever the carriage moved back and forth. When force signal oscillated, it meant that the speed was low and with only small variations.

iii. *Section 'C' - Zero force with non-zero speed:* When large stones were encountered while tillage was in progress, the obstacle (stone) was taken out and the tool moved forward in void space till it faced subsequent soil or stone. That was similar to how a farmer tilling with a traditional plough would do, i.e., the operator would lift the handle when the plough encountered largestones, and would move forward a few centimetres without soil-tool engagement. Then he would push down the tool re-engaging it with the soil for subsequent tillage.

iv. *Section 'D and F' - Zero force and zero speed:* The plough could not move forward because of stone and no oscillation of carriage was observed.

v. *Section 'E' - Low speed and low force:*This was observed when the tractor encountered obstacle and cannot progress forward smoothly, while the soil-tool engagement was normal.

vi. *Point 'G' - Recorded data set*: Because of stones and rocks, the experiment could not progress up to 16m - the experimental line distance, and stopped at about 14.5m distance(Fig. 13).

Experimental run with rake angle of 24$^o$, at second plough plane,showedoverloads and stops (Fig. 14) as the plough encountered big stoneand rocks (Fig. 15). The plot is dividedin 6 sections (*labelled by the letters "a to f"*), and described as follows in terms of draught, overload, zero forces, and zero speed measurements:

i. Section *'a'* showed a normal trend in soil resistance, starting from zero and as tillage progressed, increased with distance, before slowing down.

ii. Section *'b'* showed overload due to interaction of tillage tool and big stone/rocks. Between the overloads, the plot showed low forces, this resulted from the cyclical movement of the carriage.

iii. Section *'c'* was similar to section '*a*' in that the soil-tool interaction and thetrend in measurement progressed smoothly, i.e., with no overload andstops.

iv. Section'*d'*was also similar to section '*b*'; it was characterised by overloads and cyclical movement of the carriage.

v. Section *'e'* included overload, stoppage, and speed without force. Thespeed without force attributed to the travel of plough in space withoutinteracting with soil/stone/rock. That was because, when the plough encountered big stone, the stone was taken out manually and the tool moved forward in a void space till it faced subsequent soil or stone.

vi. Section*'f'*indicated tillage tool encountering big stones, and the measurement process was halted at a distance of about 11m.

Experimental runs that encountered difficulties showed that outdoor experiments with the soil should avoid fields with the presence of large stones as these would prevent the main purpose of understanding the interaction between soil and *maresha*. However, the presence of stones has theadvantage ofallowing the study of tool rigidness against breakage or abrasion.

## 5. Conclusions

An *in-situ* soil bin facility described in this paper was designed and installed to carry out soil-*maresha* plough interaction studies. This study mainly focused on field observations from smooth experimental runs, experimental runs that encountered difficulties, and laying the foundation for future research.

Analysis of data collected from the experimental runs, supported with video recording,revealed the following observations:

- *Smooth run*: The draught measured,with no overload measurement caused by stones, was within the capacity of the designed instrumentation and measurement system. At that soil condition, the interaction between soil-*maresha* could be understood, and variability in soil resistance could be mapped across the travel distance. Furthermore, at these soil conditions where no stones were present, tillage tool design could be studied and optimized for optimal tillage performance e.g. maximum soil loosening for minimum draught requirement.
- *Overload*: This was attributed to a situation where the tillage tool encountered big stone/rocks leading to measurement beyond the capacity of the

instrumentation and measurement system. This indicated the need to increase the load cell capacity or avoid soil with big stones. These experimental conditions were not suitable to refine the tillage tool design for optimal soil loosening performance at reduced traction requirement.

- *Cyclic contact:* This was attributed to the cyclic movement of the carriage whenthe tool encountered big stones.
- *Stoppage - zero force and zero speed*: This was attributed to the difficulty facing atillage run because of big stones, which brought the measurement processto a halt, i.e., the plough could not move forward because of stone andwith no oscillation of carriage.
- *Speed without force*: After removing the stone impeding tillage, the tool was then moved forward in a void space until it encountered another soil or stone. This was similar to how a farmer tilling with a traditional plough would do when the tool faced with a huge stone, i.e., the operator would lift the handle and would move forward a few centimetres without soil-tool engagement. Then, he would push down the tool, re-engaging it with the soil for subsequent tillage.

The experiment and the resulting analyses gave some insights regarding soil-*maresha*interactions and patterns, and indicated that further research should consider field experiments with few or no stones - by undertaking prior pit tests.

When necessary to have controlled operating parameter, i.e., for instance speed, this work recommends to gear portable winch as a drive means into the developed system.

In conclusion, the developed soil bin setup canbe used as a platform for experimenting different geometries of tillage tools to get information on how geometry and working conditions affect draught and power requirements for soil manipulations under actual field soil conditions, and examine if there is an optimum geometry for minimum draught and to see if this optimum draught force varied with variable soil conditions and tillage parameters.  .

Though designed for experimentation on tillage tools, the facility could, with minor alterations, also be used for studies involving soil-wheel interaction (traction).

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**Figure Captions**

Fig. 1 *In-situ* and mobile soil bin test system with three rail-tracks

Fig. 2 Rail-line assembly with connector plates, and wooden sleepers

Fig. 3 Carriage with tillage tool and data acquisition system: (a) Left close shot, and (b) Right close shot

Fig. 4 Rail and carriage assembly

Fig. 5 Schematic: carriage, tool, instrumentation and data logger.

Fig. 6 Assembly of load cell with plough shank and steel frame, and encoder with disc and wheel gauge.

Fig. 7 Load cell assembly and forces: (a) Schematic of load cell assembly and acting forces, and (b) Projected free body diagram (A-B).

Fig. 8 An optical sensor – encoder and linear variable displacement transducer (LVDT), and *maresha* plough assembly

Fig. 9 Assembly of linear variable displacement transducer (LVDT) and optical sensor (Encoder) on wheel gauge

Fig. 10 Wheel with disc and encoder assembly for tillage tool travel speed measurement

Fig. 11 Variation of draught - F, tillage speed - V, and tillage depth – D with tool travel distance.

Fig. 12 Variation of force F and speed V with tool travel distance

Fig. 13 Not used in final version

Fig. 14 Plot with experimental difficulty: Force - F, Speed - V, Tillage depth - D

Fig. 15 Rock and big stones found underneath the surface which had put halt to some experiments

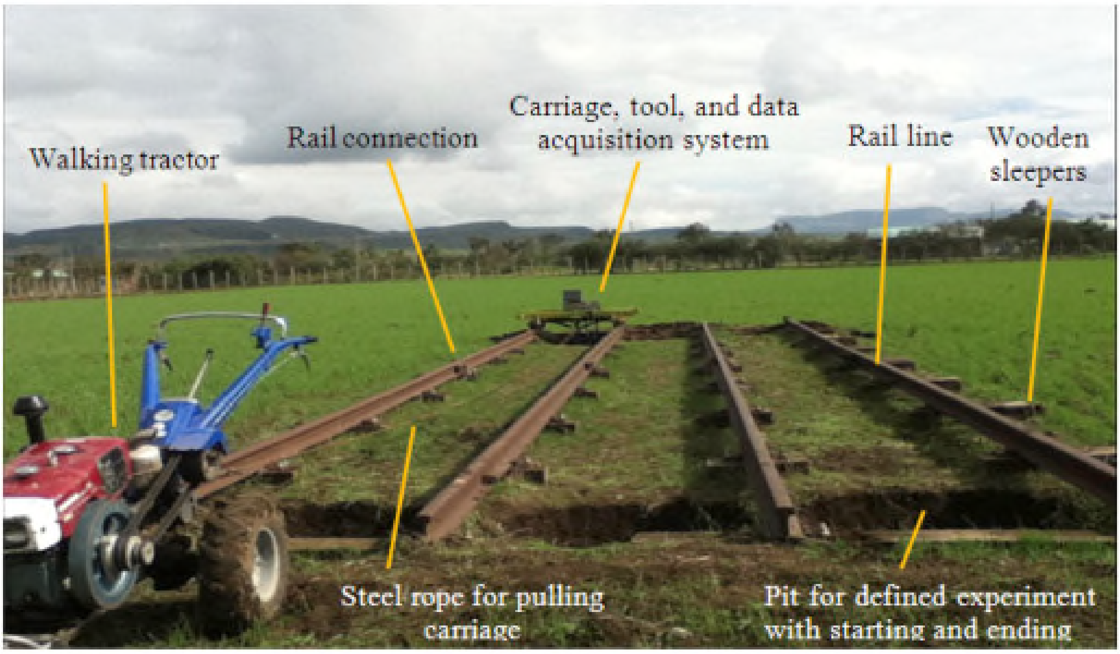



Fig. 1 *In-situ* and mobile soil bin test system with three rail-tracks


Fig. 2 Rail-line assembly with connector plates, and wooden sleepers

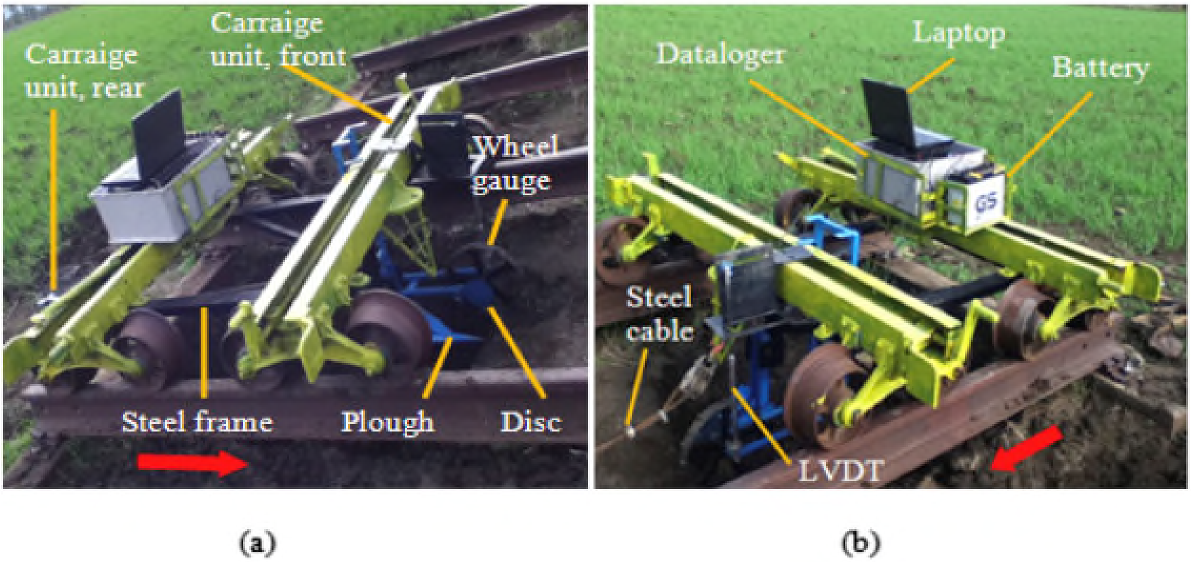



Fig. 3 Carriage with tillage tool and data acquisition system: (a) Left close-up, and (b) Right close-up

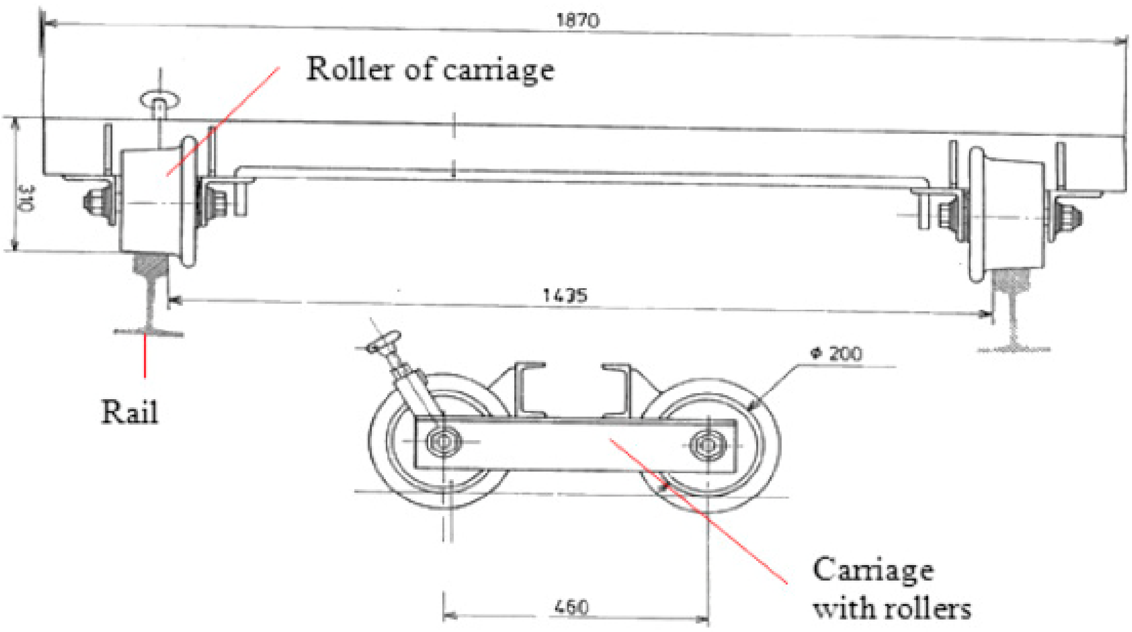



Fig. 4 Rail and carriage assembly

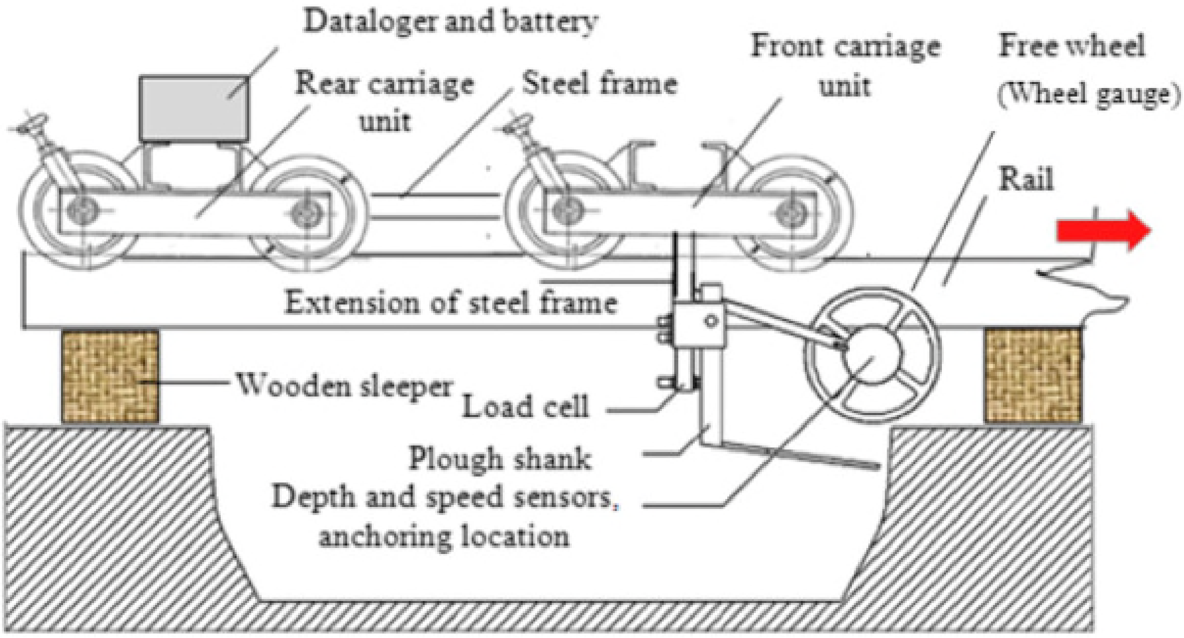



Fig. 5 Schematic: carriage, tool, instrumentation and data logger.

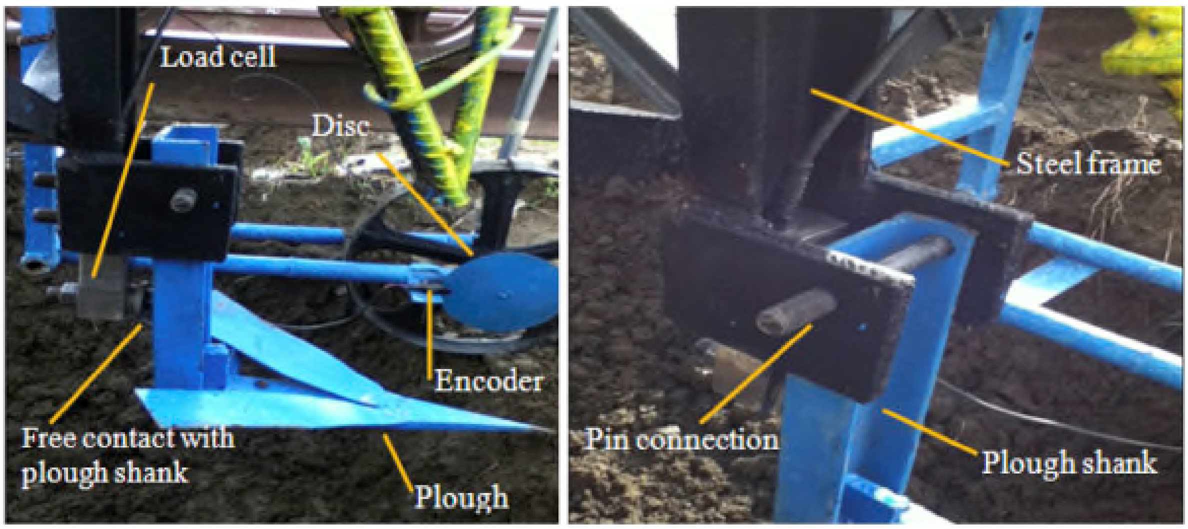
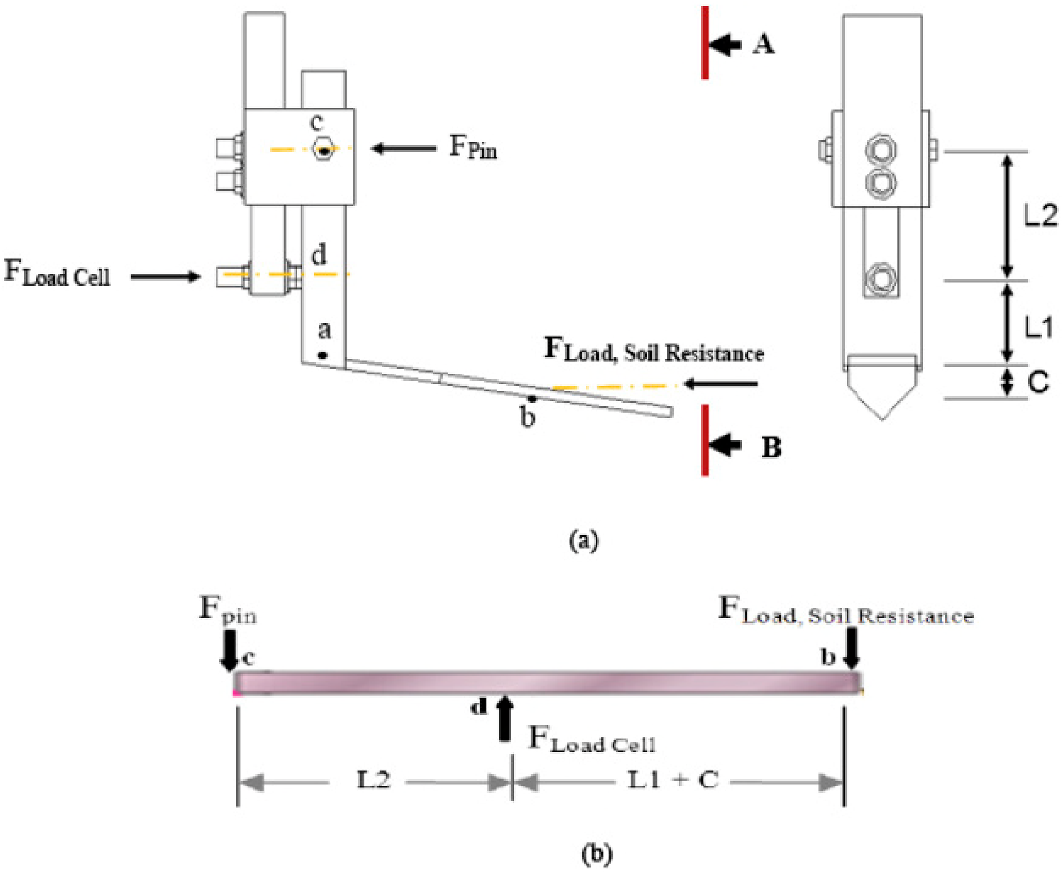



Fig. 6 Assembly of load cell with plough shank and steel frame, and encoder with disc and wheel gauge.

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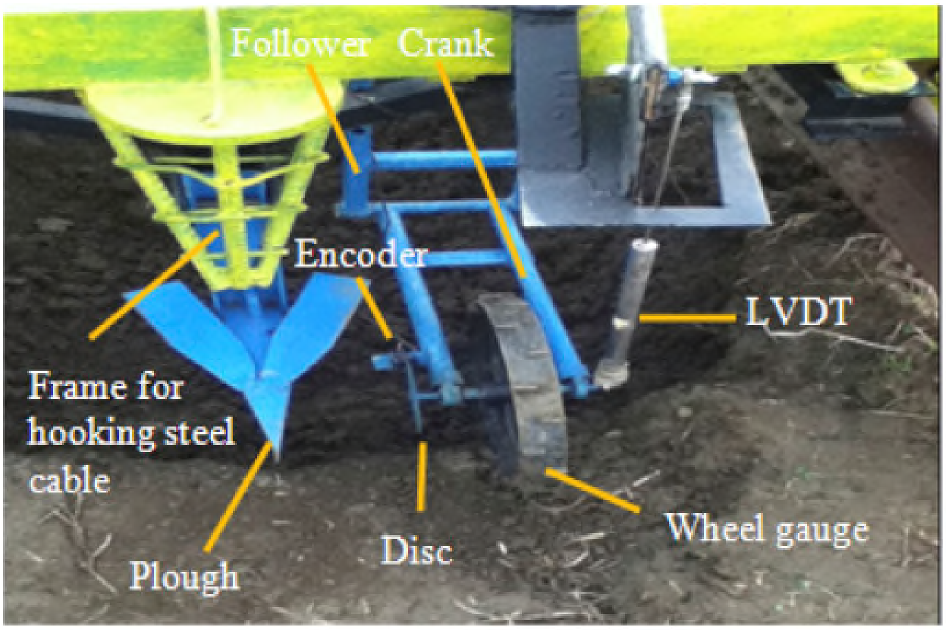


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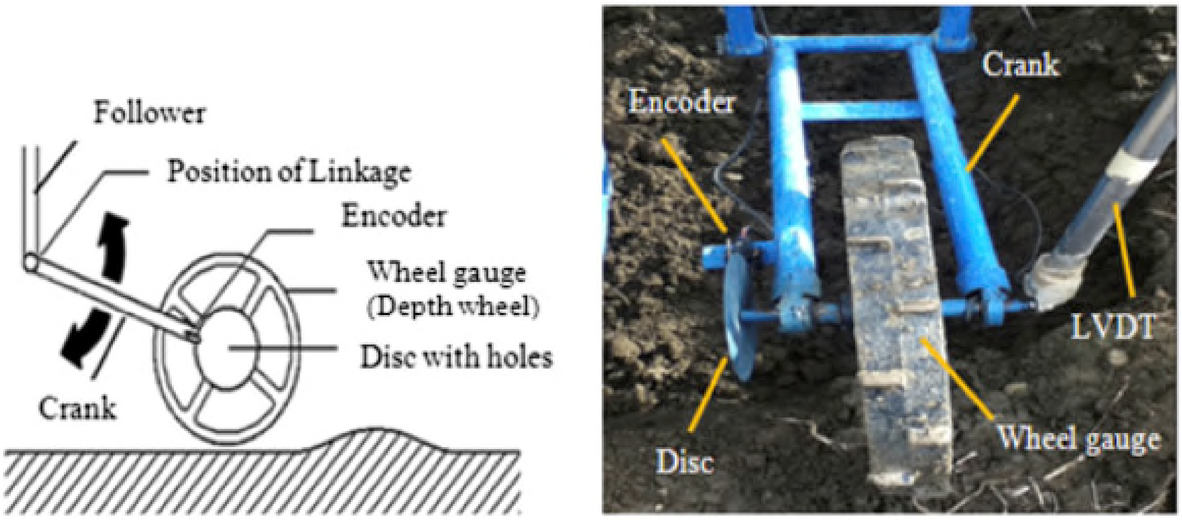


Fig. 9 Assembly of linear variable displacement transducer (LVDT) and optical sensor (Encoder) on wheel gauge

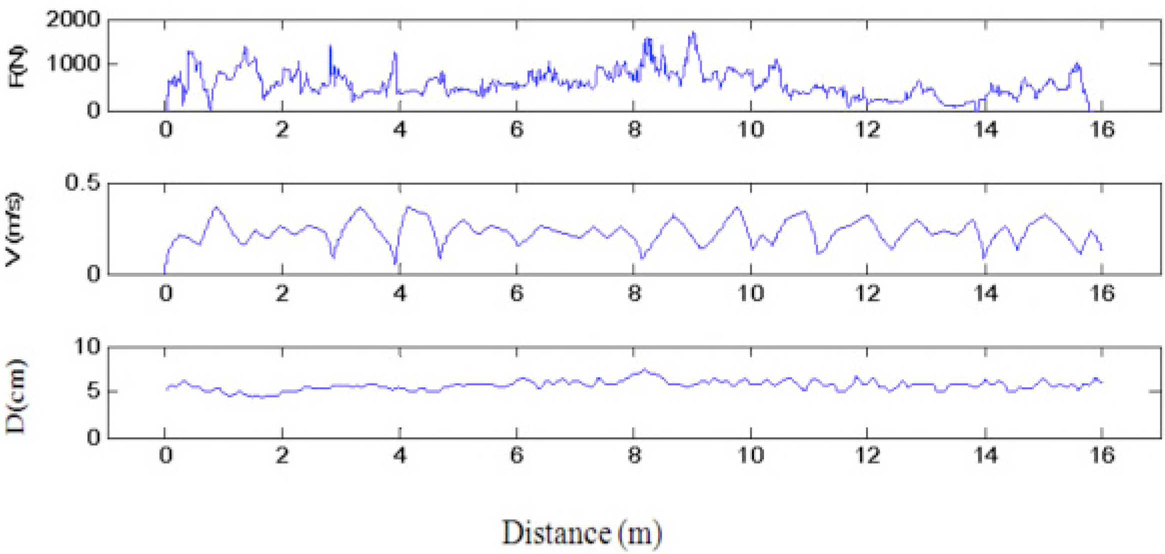


Fig. 10 Variation of force – F, tillage speed – V, and tillage depth – D with tool travel diastance

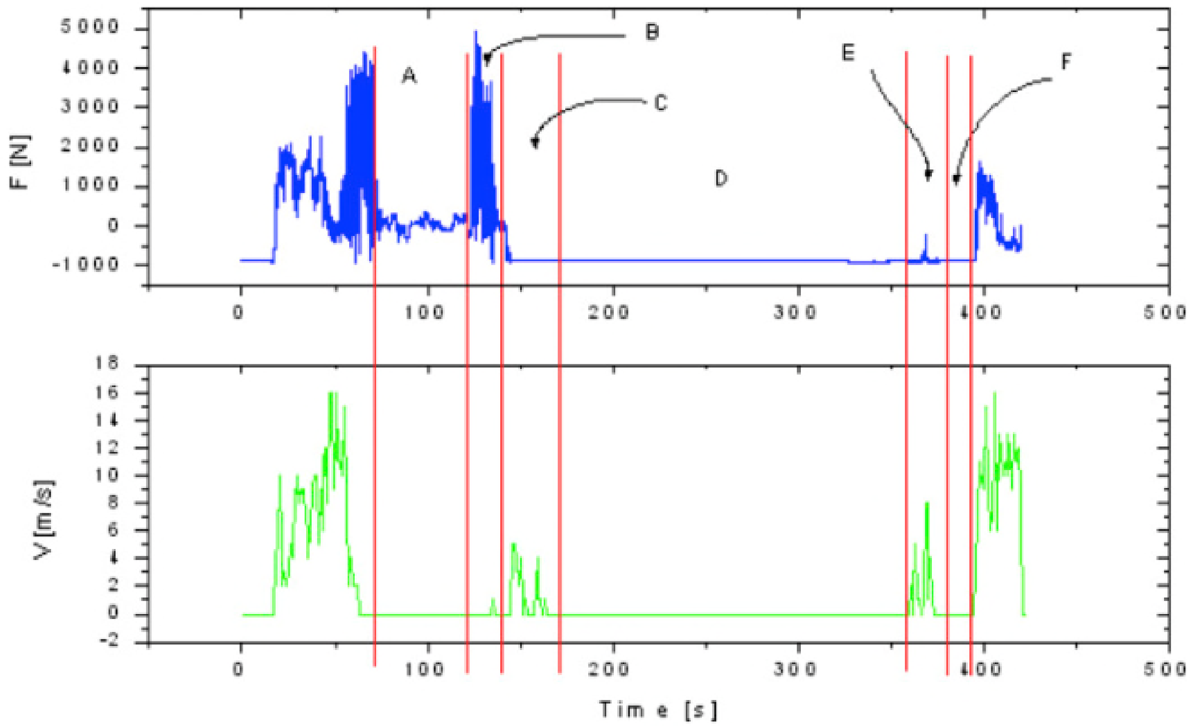



Fig. 11 Variation of draught - F, tillage speed - V, and tillage depth – D with tool travel distance.

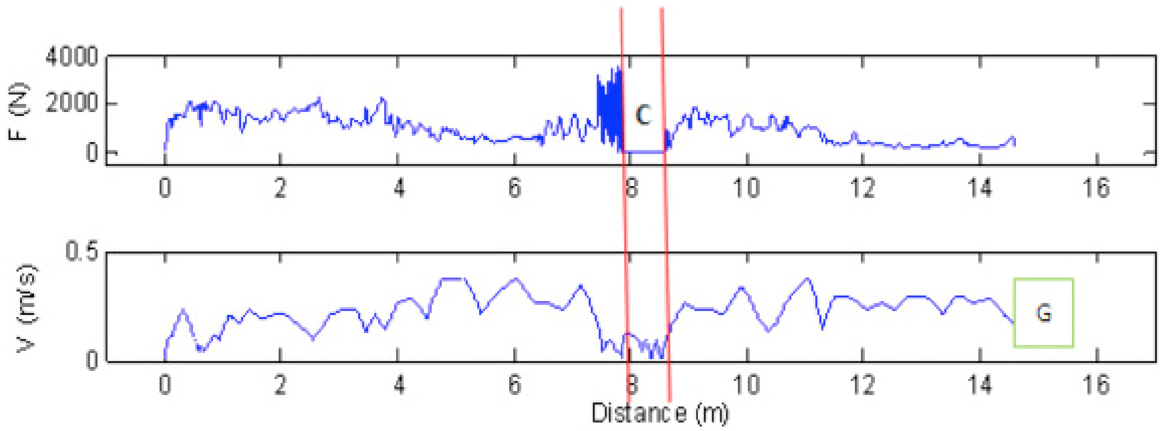
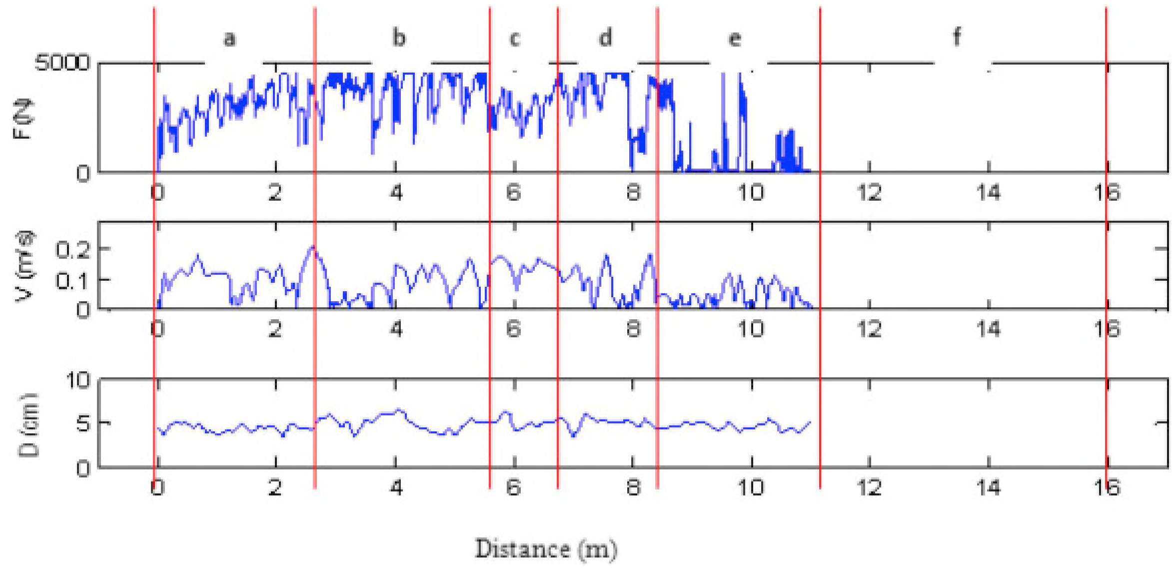



Fig. 12 Variation of force - F and tillage speed - V with tool travel distance.

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# A mobile, in-situ soil bin test facility to investigate the performance of maresha plough

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