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MACHINERY FOR TESTING SOIL-CUTTING TOOLS AND TRACTION EQUIPMENT – A REVIEW

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Abstract:

Soil-mechanics and its applications have been an influencing aspect in the design, improvement, and optimization of the soil-engaging machinery. Soil-machine interaction which is considered to be one of the most significant fields of study in the branch of soil-mechanics helps in critically analyzing the complex behavior of various tillage-tools, traction equipment and machines with the soil. Previous research on different kinds of soils was performed in the fields with the assistance of full-scale or commercial implements. The results obtained were not uniform due to broad dissimilarity in soil types, conditions of the fields and the continuously changing environment. This led the way to the invention of a soil-bin which allows the attainment of uniform soil conditions as required for the research or study purpose. Soil-bin test facility is a facility for testing different types of tillage tools and traction equipment. It generally consists of a soil-bin in which the soil to be tested is placed, moving carriage with a tool holder and an additional carriage for soil-processing, drive system along with DAQ system where controlled experiments can be carried out by controlling the required operating parameters and also the experiments can be continuously observed and monitored. The testing of tools and traction equipment in a soil-bin provides an insight of the operating mechanism so that proper design, development, and optimization of the tools can be done to increase the total efficiency of the process. The literature highlights some important engineering aspects of soil-machine interaction along with the constructional features of some of the soil-bin test facilities implemented for carrying out soil-machine interaction research. The paper also highlights some recent trends and ongoing studies in soil-bins, focusing on the important parameters of the soil and machinery which has been influencing the performance of the overall system.

Keywords: Soil-mechanics, soil-machine interaction soil-bin, optimization, efficiency.

1. INTRODUCTION

Soil, by far, is the most essential ingredient of all life forms on our planet, which helps in maintaining the ecological balance. India is an agricultural country as 50 % of the total population is dependent on it as the source of their livelihood. In the Indian economy, agriculture is the most important sector contributing about 17-18 % to Gross Domestic Product (GDP) as per 2018. Not only these, but it also employs 50 to 60 % of the country's workforce. India is considered to be a country of vast dimensions accompanied by geological conditions, climate, vegetation, etc. Therefore, in India, there are broad categories of soil groups. In agriculture, one of the important processes is tillage. Tillage can be defined in simple terms as the mechanical operation of land to make it favorable for crop and plant growth. It is performed with the help of tillage tools or devices such as the mouldboard plow, chisel plow, disc harrow, etc. that are used for applying forces to the soil to cut, invert, pulverize or move the soil. Thus, the main objective of tillage is to enhance the physical properties of soil. Soil is a complex material as it contains solid, water and air blended whose property depends upon the relative proportion of these constituents. In addition to this, various types of soil are classified according to the percentage of sand, silt, and clay in a given volume. Therefore, the behavior of soil with various tools and machines should be understood thoroughly to initiate a soil-tool interaction study. The study of improvement of soil-engaging machinery for soil cultivation and traction began without the support of any logical information about how this machinery would interact with the soil which resulted in various inadequacies as the condition of operation and source of power for tools and machines both were different (Ani et al., 2018). Previous studies on different types of soils were performed in the fields with help of full scale or commercial implements. The results obtained due to these studies were meaningless as there was an extensive variety of soil types and field conditions and also there were minimum chances of getting a similar soil type at a similar condition (Al-Janobi & Eldin, 1997). Such difficulties were overcome with the help of a soil bin facility where controlled experiments can be carried out by controlling all the required operating parameters such as the speed and depth and also the experiments can be continuously observed and monitored.

The soil-machine interaction can be studied by either analytical or mathematical models to refine the design of tools (Mak, 2012). FEM or FEA as a numerical method is now being extensively used to evaluate the soil-machine interaction problems (Bentaher, 2013). Soil-bins are used for testing various types of tillage tools such mouldboard plow, chisel plow, etc. as well as for testing traction equipment like tires or wheels thereby providing an understanding of the operating method and also the design and development of traction equipment and plowing tools on different types of soils under continuously changing environments. The analyses have provided better knowledge of the soil cutting or failure patterns, having variable designs and sizes of plowing tools under varied soil and machine, forces necessary to weaken the soil, power requirements of plowing tool carriers (Ani et al., 2018). The investigation has been carried out hypothetically in soil-bins or fields with regards to mechanics or by trial methods (Ani et al., 2018). Before the experimentation in soil bins, both the soil and parameters of the testing device are set according to the need of study. Thus, the studies provide a new pathway for the proper design and improvement of various tillage and traction tools and also optimization of these tools.

In this paper, an overview of soil-machine interaction along with literature of various soil-bin testing facilities, method of force measurement in tillage studies has been presented. The paper discusses some important features highlighting the need for soil-bin and some key engineering aspects of soil-machine interaction which will prove essential in carrying out a soil-machine interaction study.

2. ASPECTS OF SOIL-MACHINE INTERACTION STUDIES

Nowadays, terra-mechanics is the term used to describe the relationship of soil with machinery. It is the study of properties of soil and the interaction of terrain (mostly soil) with the tool or machine. The goal is to examine how various tools and machines affect the soil. It includes two types of studies which are as follows: (a) traction studies (soil's relationship with the tractive elements, e.g. tire or track) and (b) tillage studies (soil's relationship with the tools, e.g. tools like chisel plow, moldboard plow or planting tools, etc.) (Ani et al., 2014). Traction is the capacity of the automobile's tire or supplementary tractive element to create an adequate driving force to cancel out all sorts of opposing forces and henceforth maintain the automobile in continuous motion along the path of the force (Yong et al., 1984). In terra-mechanics, the tractive performance of agricultural wheels is an important characteristic consisting of five dimensionless parameters namely travel reduction ratio (TRR) also known as slip, pull by weight ratio or net traction ratio (NTR), gross traction ratio (GTR), motion resistance ratio (MTR) and tractive efficiency (Sedara, 2019). It is evaluated with the help of a wheel-tester or a tractor but owing to the uneven nature of the soil and environmental situations in the farm, the results are not consistent and are often considered as unreliable. In tillage operations, the soil structure is mainly affected by various types of forces and location of the action. Thus, the goal of analyzing technicalities of tillage or traction equipment is to offer a way for relating the soil's reaction to various forces. Such detailed analysis would prove crucial in predicting the nature of the soil and also help in controlling the process either with the new design of tools or through optimization of the tools being used. It has been reported that the mechanical behavior of the soil has a fundamental role in the suitable design and choice of tools to attain desired soil conditions (Rajaram & Erbach, 1998). For assessing the changing nature of the soils under different tools, failure patterns are considered to be a significant aspect. There are various kinds of soil failure patterns which include chip fracture, collapse, bending, flow, etc. (Rajaram & Gee-Clough, 1988). These patterns might differ from soil and tool parameters (Makanga et al., 1996). Analyses of soil failure patterns could help in understanding the reaction of the soils with different types of tools and implements (Ani et al., 2014).

3. RECENT TRENDS IN SOIL-MACHINE INTERACTION STUDIES

The most important goal in the soil-machine interaction is to predict the reaction forces so that the equipment in use could be optimized thereby reducing the effect of draught force and energy consumption. From the past few years, the examination of the off-road machinery which is used for various purposes like agriculture, construction, military, desert resource, and earth-moving equipment such as bulldozers, scrapers, etc. has been a challenging task. During the motion of the vehicle, the efficiency and trafficability of the vehicle are greatly affected by the interaction of the tire and the granular particles of the soil. In addition to this, a parameter of the tire, which is the slip ratio, also affects the driving tendency of the vehicle (Zhao & Zang, 2017). The tire should be selected according to the type of road with a reasonable slip. For these, a thorough knowledge of soil-tire interaction is needed so that matching of the parameters and also the design and optimization of the parameters could be done. In tillage also, for optimizing the overall tilling operation, it is important to select proper equipment by considering the field conditions. The development of the soil-engaging machinery in agriculture is dependent largely on field experimentations and trial and error methods (Chi & Kushwaha, 1991). To improve the energy-efficiency, the need for optimization of the tillage tools and traction equipment becomes important which is possible by modeling the soil-machine interaction accurately thereby eliminating the need for costly field tests and reducing the prototype development time and its verification (Shumulevich et al. 2007).

In this context, some of the numerical approaches like the FEM and DEM have been extensively used for studying the soil-machine interaction. FEM was developed in the late 1960s which was then considered to be a strong tool for investigating the soil-tool interaction. FEM was devised from the necessity for explaining analysis problems related to the complex elastic nature of structures. It uses a model to define the association between stress and strain within the soil. It was developed in the late 1960s and was used for modeling tillage using blades, sweeps, and bent leg plow as well as optimizing the design parameters to reduce the tool wear and protect the soil against erosion. DEM was used for modeling granulated materials and to study their mechanical behavior for solving the problem of motion associated with each discrete element (Cundall &

Strack, 1979). The most important feature of the DEM is that it allows the assumption of constant velocity and acceleration over a given time step which can be applied for solving non-linear interaction. For successful implementation of the DEM, it is necessary to select proper values for the input parameters for the contact models and also appropriate time step size has to be selected given that the velocity, acceleration, and forces remain constant over the time step (Mak et al., 2012). Prior consideration of these factors helps in analyzing the effect of various tool geometries on the draft force as well as the various deformation zones associated with the soil (Tamas et al., 2018). Thus, a thorough knowledge of FEM and DEM can successfully be applied to optimize the geometric parameters of tools and implements and eliminate the requirement of expensive field tests. An added advantage is that both these approaches can also serve as a tool for validation of results with real field conditions.

3.1. Past And Current Studies In Soil-Bins

The main purpose of soil-bins is to evaluate the draft force which can be defined in simple terms as the pull force generated by the motion of the tool or implement in the soil. Estimation of draft and power requirement is very crucial in tillage to match the necessary machinery and implement with the field conditions thereby limiting the use of fuel consumption. In the past, there has been a considerable amount of research regarding the effects of implement depth, speed, the rake angle of implement (angle made by the implement with the horizontal in the traveling direction) and soil compaction on the draught. Out of this, depth has been considered to be the most influential factor which increases the draught as it is increased thereby resulting in higher specific draught (Draught per soil's cross-sectional area operated by the implement). (Rahman & Chen, 2001) had concluded that it was the depth that was the more influencing factor causing more soil to disturb thereby resulting in higher draft force. The studies reported that a large number of compressive forces are generated that resulted in higher draft force. In addition to the compressive forces, soil cohesion also increases which results in higher draft force (Armin, 2014).

(Abdolmaleki et al., 2015) in their work carried out soil-tire interaction study which showed an increase in the rolling resistance when there was an increase in the normal load and sideslip angle and it reduced when the angular velocity was increased at higher cone index values. The type of tool used also had a considerable effect on the draft force. Sweep type tools have large surface width and a thus large area of contact which causes more soil volume to get disturbed thereby resulting in higher draft force. (Deshpande & Shirwal, 2017) in their work observed the variation of depth on the draft with the help of a sweep type tool and found out that the graphical results of draft and depth were linear up to a certain point, and then it considerably reduced. The authors reported that it was because after a certain depth, the soil disturbance was less and the furrow formed was narrower. (Okoko et al., 2018) have analyzed the influence of speed and depth on the draft with three different types of implements and calculated the draft force at two depths of 10 and 30 cm and it was observed that there was an overall increase of 4-6 % in the average draft force with the variation of depth from 10 to 30 cm and speed from 0.74 to 2.6 m/s. Another important parameter that affects the draft force is the rake angle. (Al-Neama, 2019) in their work reported an upsurge in the compressive force due to the increase in rake angle. (Ale & Ewetumo, 2019) experimented in sandy loam soil with a moldboard plow for analyzing the behavior of different speeds (5, 10, 15 and 20 km/hr) on draught and soil disturbance. The graphical results showed the highest mean value of draught at 15 km/hr and graph of speed versus the soil disturbance was also polynomial. Thus, the invention of soil-bins which has led to the development of soil-bin testing facilities so far has proved to be an important means for carrying out soil-tool as well as soil-tire interaction studies. Thus, to lessen the intensity of higher draft force, all the important parameters viz. tool shape, tool width, rake angle, and operating depth should be selected after thorough consideration.

4. SOIL-BIN TESTING FACILITIES

Soil-bin test facility includes a soil-bin that is fixed on the ground, mobile transporter consisting of soil engaging tool, power source and the drive system, soil processing equipment to prepare and pre-condition the soil before experimentation, instrumentation, and data acquisition systems for measurements in real-time, displaying the variables of the soil, and a lifting system for winching of heavy components (Ani et al., 2018). It is equipped with various transducers for measuring parameters like horizontal force, vertical force, depth, etc. Indoor soil-bins offer a clear view to conduct tests by isolating certain parameters and reduce experimental inconsistency and improved control of machine and soil parameters (Rosa & Wulfsohn, 2008). Soil-bins, based on their design, are classified as (a) mobile soil-bins (straight or circular) where the tools are stationary and the bin is in motion and (b) stationary soil-bins where the bin is stationery and tools are movable. The circular or round soil-bin is meant for operating the tool continuously. The straight, movable soil-bin consisting of a soil container, moves on a track. Fig. 1 represents a schematic of a soil bin testing facility with its primary components like the soil container, moving carriage, chain-sprocket system, motor, rail, and rail support. The demerits of these types of soil-bin were that it required large space for the tool travel and also a high amount of force to move the soil container past the tool (Durant et al. 1980). The majority of soil-bins used for experimental purposes are straight and stationary. One of the oldest soil testing facilities by the National Soil Dynamics Laboratory (NSDL) has been shown in figure 2. A tire-testing facility is as shown in figure 3. Table-1 presents some soil-bin test facilities having unique designs and constructional features.

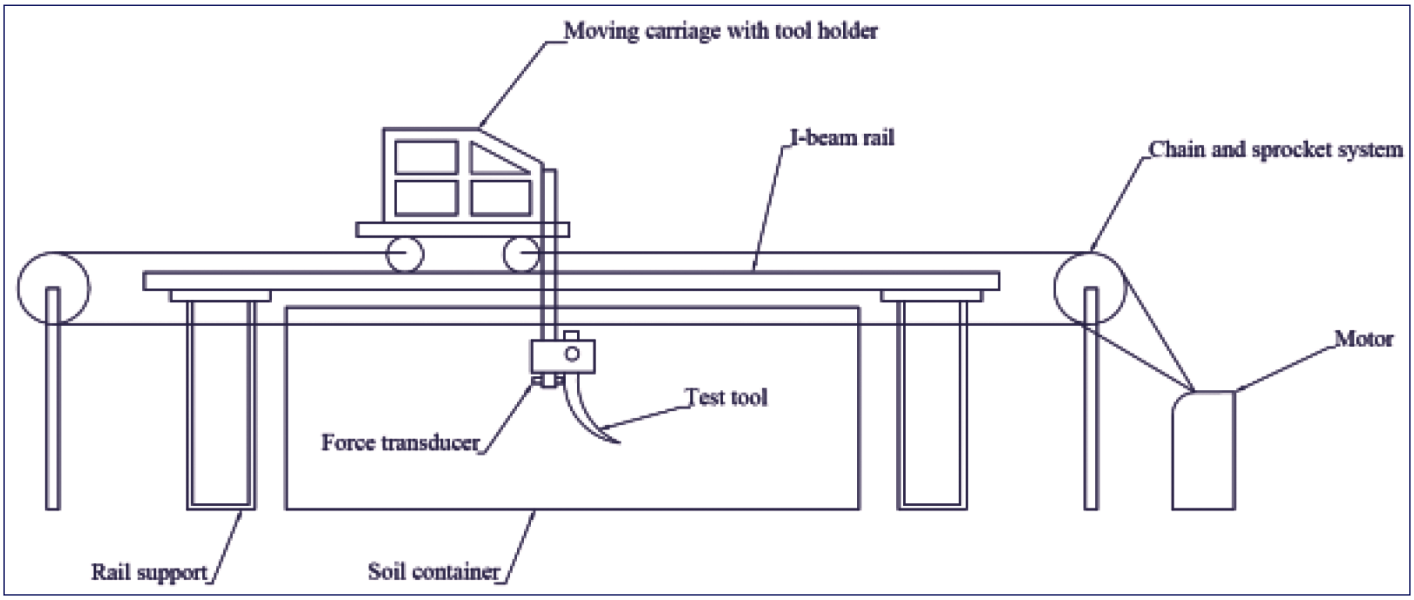

Figure 1. Schematic of soil bin testing facility (Source: Author)

Figure 2. The national soil dynamics laboratory (1935)

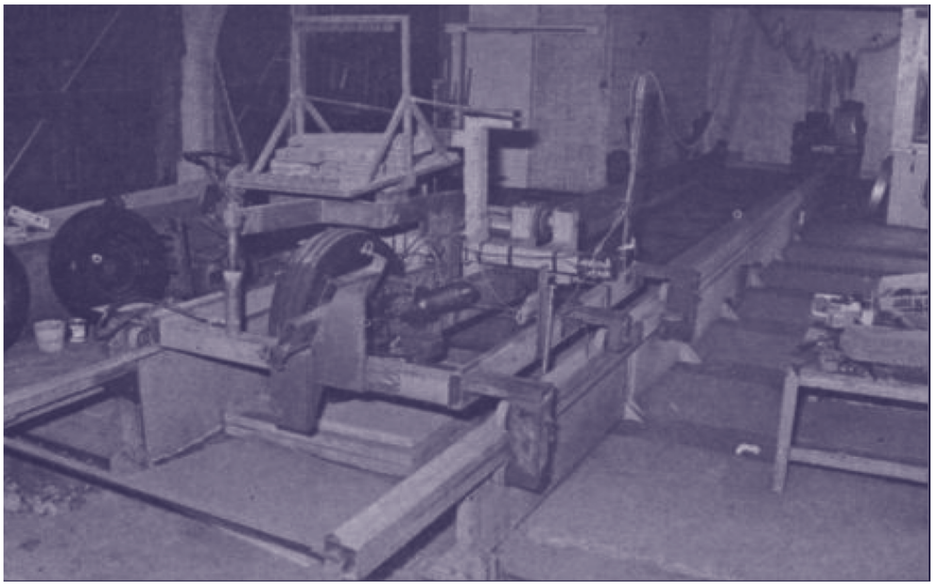

Figure 3. Tire-testing facility (Godwin et al. 1980)able 1 - Important features of various soil-bin test facilities.

Author	Year	Soil bin design	Moving carriage assembly	Drive system	Special features
Godwin et al.	1980	An adjustable bin of 5 m to 13 lengths, 0.5 m depth and 0.8 m to 2.0 m width.	Test equipment and wheels were attached to a carriage running on two side walls.	Tractor with a rated capacity of 30 kW.	The control mechanism consisted of solenoid controlled pneumatic cylinders. Symmetrical or even implements were mounted on the carriage via an (EORT) while Non-symmetrical or uneven implements were attached to a dynamometer suspension system.
Durant et al.	1980	Stationary bin with dimensions 10 x 0.91 x 0.38 m.	A tool carriage consisted of a dynamometer on which the tool was mounted.	The hydrostatic transmission system, cable-sheave system, and servo controls.	Instrumentation for recording the outputs of the dynamometer consisted of six bridge amplifiers along with a six-channel oscilloscope. Safety features having limit switches were attached to the carriage to limit the dynamometer movement and shock-absorber to control the carriage travel.
Al-Janobi & Eldin	1997	Movable soil-bin having dimensions 4500 x 500 x 250 mm.	The carriage unit was maintained by twin rails, one on either side of the bin.	A 7.5 HP d.c shunt motor positioned at the end of the bin.	An EORT was employed for measuring the forces and also moment in the vertical plane on the tines and blades. The carriage motion was controlled with the aid of two limit switches provided at the ends of the soil bin.
Kawase et al.	2006	A system consisting of a soil-bin, a tire tester, a soil conditioning device and a traction load device. The bin had an effective inner dimension of 3015 x 480 x 605 mm.	There were twin rails located on top placed on either side for mounting the tester and soil conditioning device.	Soil mixing and compaction device or MCD had a tiller (FG201: 1.1 kW) located on the front side and a roller driven by a motor (Kyowa KMP: 0.4 kW) on its rear side. The tester was driven with the help of an electric motor.	The tester had strain gauges mounted on the drive shaft for torque measurement. A linear potentiometer was used for measuring the tire sinkage. An EORT was installed between the linear guide and the drive unit for drawbar pulls measurement.
Rosa & Wulfsohn	2007	An instrumented soil-bin of 10 x 1.76 x 0.4 m.	The mainframe of the monorail comprised of an extended beam supported by transverse arm beams.	A variable displacement piston pump is driven by a 30kW electric motor.	A hydraulic circuit was used for accelerating and decelerating the carriage for limited periods. DAQ system consisted of a tool holder with six load cells and interfaced with a PC that was used for measuring the forces. An optical encoder linked to the shaft of the chain-sprocket system was used for measuring the tool speed.
Yahya et al.	2007	A tire testing facility having a soil container of 6.4 x 0.6 x 0.8 m.	The motion of the carriage was accomplished with the help of rails on which the tire to be tested was mounted.	A 3-phase motor of 7.5 kW working at 1500 rpm and a reducing gearbox with a chain and drive system. A 3-phase motor having a rated capacity of 0.75 kW working at 1500 rpm for tire driving unit.	A Tai-pan gasoline soil compactor of 3.75 kW weighing 100 kg equipped with a vibration plate was used for getting the desired soil density.

Author	Year	Soil bin design	Moving carriage assembly	Drive system	Special features
Tiwari et al.	2009	A tire traction facility comprising a soil bin of 23.5 x 1.37 x 1.50 m with angle iron posts on which the rails were mounted.	A single wheel tester consisting of a mainframe for containing numerous sizes of tires, loading bench, hoisting arms, a parallel bar linkage system connected to a pulling trolley through immovable supports	The drive system was an induction motor with a rated capacity of 7.46 kW working on 3-phase and 1500 sync rpm.	A control unit for operating the processing of the soil and tire tester direction was established along with some recording units. A ring and a torque transducer were used for measuring the pull force and the input torque.
Manuwa et al.	2011	An outdoor soil-bin facility consisting of a stationary soil bin with a length of 48.0 m, a width of 1.5 m, the height of 1.2 m.	Implement carriage was fabricated for attaching tillage or traction devices.	An MF 415 tractor with a power of 31.6 kW.	There was a leveling blade of a plane steel board having light curvature for leveling the soil. A soil compaction roller coupled with the implement carriage was used for compacting the soil in layers as desired for testing.
Abdolmaleki et al.	2015	An in-situ tire test rig consisting of a single wheel tester with its components such as the rails, carrier, three-point hitch, and a wire-rope and deadweight for providing drawbar pull to the wheel.	A support rig with dead weights attached to the single wheel tester provided the vertical load on the wheel.	Hydraulic motor and a gearbox.	S-beam load cells were incorporated for measuring the lateral and longitudinal forces acting on the tire as well as for measuring input and self-aligning torques. Two opto-counter connected to the carrier of the wheel determined the forward and angular velocity.
Gebregziabher et al.	2016	An in-situ facility having an overall length of 20 m and 1.435 m wide having six 10 m rails forming four rail lines to analyze the behavior of soil with a maresha-plow.	The carriage system consisted of two carriage units connected to a steel frame as an intermediate member.	The drive system consisted of a two-wheel walking tractor having a power of 11.18 kW was used.	The carriage was supported with eight rollers to ensure a well-balanced construction in order have a flip free, topple free and tilt free straight motion. A DAQ system incorporating three sensors viz. load cell, LVDT, and an optical encoder was mounted on the carriage with a battery source of 12 V.
Rasool & Raheman	2017	A testing facility consisting of a soil bin with a length of 15 m, a width of 1.8 m and a height of 0.6 m with two horizontal rails for supporting soil processing and guide trolley.	Track tester consisting of a mainframe and a guiding trolley with a lifting platform and transmission system.	A 3-phase electric motor with a capacity of 7.5 kW and working at 1425 rpm was used for powering the track.	Torque transducers having a capacity of 1000 N-m were incorporated for measuring the input torque to the drive wheel. Two electric strain gauges arranged in the wheat-stone bridge were used for measuring the pull force.

Author	Year	Soil bin design	Moving carriage assembly	Drive system	Special features
Mahadi et al.	2017	An indoor soil-bin facility having overall dimensions of 10 x 0.91 x 0.61 m.	The carriage was a square tube steel frame with rigid wheels at the corners of the frame which was mounted on two I-beams acting as rails. An additional frame enclosed within the mainframe was used for mounting the dynamometer and test tools.	A chain-sprocket system driven by an electric motor of 11.2 kW (15 hp) capacity at a maximum speed of 1725 rpm.	The control system consisted of a variable speed drive (VSD) for controlling the motor as well as the carriage speed. Four 3D load cells contained within two rectangular aluminum plates, having a total capacity of 22.3 kN, were employed for force measurement.
Fechete-Tutunaru et al.	2019	An indoor circular soil-bin having a depth of 900 mm.	Around the circumference of the bin with a circular trajectory of 1700-2000 mm diameter for tool movement.	A 3.2 kW motor running at 720 rpm with a combination system of a gear reducer and a VSD.	HBM spider 8 DAQ system along with force transducers for draft measurement.
Al-Neama	2019	An indoor soil bin of 28.6 x 2.5 x 1.0 m overall dimensions.	Electric-hydraulic carriage with three-point transversely movable linkages for tool attachment.	Electro-hydraulic drive train with an achievable speed and traction of 17 km/hr and 13 kN respectively.	The radar sensor mounted on the carriage for measuring the ground speed and a humidification system.

Table-1 presents some soil-bin testing facilities developed to date highlighting some of their important features.

It is evident from the table that during the years, the design and application of the soil-bin varied from tire to tool testing, incorporating the use of sophisticated machinery like sensors, transducers and DAQ systems for carrying out the research work providing an insight into the working dynamics thereby helping in analyzing and optimizing the overall tillage operation.

5. FORCE MEASUREMENT IN TILLAGE AND TRACTION STUDIES

For assessing the behavior of the soil and to track the performance of the machine, force measurement is very crucial. The determination of draft force can be accomplished with the help of dynamometers and load cells. The dynamometers are categorized into two types viz. drawbar dynamometers intended for pull or drag-type implements and the three-point hitch dynamometers intended for mounted implements. The drawbar dynamometers are again grouped into two categories viz. the frame type and the linkage type dynamometers. The most durable and widely used linkage-type dynamometer, the ring transducer, is employed for calculating the draft forces, vertical forces and also the pitch moment (Godwin, 1975). Force measurement is done with the aid of strain gauges

Table 2 - Dynamometers used for force measurement in tillage.

Author	Year	Special features	Observations
Godwin	1975	Implemented for measuring draft and vertical forces as well as pitch moment.	Strain gauges were attached to the thinner sections of the ring. The capacity of EORT for moment loading was 1260 Nm.
Chen et al.	2007	Measuring capacity for draft up to 180 kN and up to 35 kN for vertical force.	The calculated moment was 2.2 kNm on each transducer. Field tests were performed with a liquid manure injector and a draft force of 4.70 kN was recorded.
Alimardani et al.	2008	Dynamometer consisted of the mainframe, three force transducers, a satellite computer, a data logger, a power supply and a cable. Each transducer consisted of load cells and a bridge configuration of four active strain gauges.	Field tests were performed with a tractor weighing 1200 kg and having a power of 25 kW at a speed of 2.2 km/hr for a distance of 36 m and a depth of 24 cm. The draft force calculated was 4.2 kN.

mounted on the thinner sections of the ring. The octagonal ring-type force transducers are limited to only one hitch type conditions. So, to overcome this, there is another type known as the three-point hitch type dynamometers. These are frame type dynamometers in which the transducers are mounted on special frames and are located between the tractor and the implement. Some of the dynamometers used for calculating various forces are described in table 2.

5. METHOD ADOPTED FOR LITERATURE REVIEW

The sources of the literature review were identified from multiple databases. Most of the sources were retrieved from Google Scholar. For primary sources and peer-reviewed articles, broad search terms were used. Initially, I searched for articles with some key terms namely soil-bin, soil-tool interaction, sensors and transducers for soil testing. I also searched for related articles in Science Direct and Taylor & Francis Group. This search helped me to list down all the important articles and narrow down my search for more relevant articles in the domain. I tried to give more consideration to the data related to the system of soil-machine interaction machinery and their application for analyzing the interaction of soil with the tools and equipment. While analyzing the quantitative research, I tried to look for acceptable research questions that were most in line with my purpose. Finally, for the qualitative analysis, I tried to comprehend the different collection of procedures and data and verified that the research is valid.

6. IMPORTANT CONSIDERATIONS BEFORE INITIATING SOIL-MACHINE INTERACTION STUDIES

It is important to make certain considerations while setting up a soil-bin test facility. The facility should be developed according to the need of the research activity which may be short term or long term. Power sources and drive systems should not be complex rather should be selected based on the minimum requirement. Drive systems can be hydraulic, pneumatic or electric and care should be taken while frequent connection and disconnection of the supply lines. The most time-consuming operations are the soil preparation and conditioning which can be accomplished with the help of soil fitting devices like the rollers and levelers. An extra set of drives may be required for positioning the soil conditioning devices. The soil in the soil-bin should be properly mixed to produce uniform test conditions. Before transferring the soil into the soil bin, all the important properties such as moisture content, bulk density, specific gravity must be properly measured and also it is recommended to measure the desired property values throughout the length of the bin to keep a track of uniformity. For these, the concerned authority should have a better knowledge of soil mechanics and expertise in handling varieties of soil and their focus should be on specific parameters of the soil like the shear resistance, soil cohesion, compression resistance, plasticity, etc. to initiate a soil-tool interaction with minimum effort. The soil should be slightly compacted so that it can be loosened from the top surface of the bin and also mixing could be done to maximum possible depth for homogeneity. It is recommended that to compact the soil properly, the roller to be used for compacting should be equal in width to that of the bin which will compact the entire soil volume. The sidewalls of the bin are generally closed and one is unable to see the actual soil-cutting process happening inside the bin. It can be made possible with the help of a transparent tempered glass or plastic which can be installed on the sidewalls of the bin to scrutinize the soil-cutting process. The tools and equipment should be kept clean to avoid the contamination of the soil and the concerned personnel should ensure that the soils are free from contaminants which will affect the soil properties.

7. IMPLICATIONS OF STUDY

The literature highlights two important aspects of soil-machine interaction viz. soil-tool interaction and soil-tire interaction. The soil bin testing facilities can be grouped into two categories viz. small soil bins and large soil bins. Most of the soil-bin facilities are small having a length of 10 to 15 m and are owned by universities. Small soil-bins generally have their working components controlled by a controller and all components are arranged into a single unit. The significance of small soil-bins is that it can be developed from readily available materials thereby reducing the need for huge capital investment. From the literature, it is clear that most of the soil-bins developed are generally small-soil bins. Development of small soil-bins would provide a strong background for the establishment of a large-scale soil bin which in turn would provide a means for carrying out precise research work. Large soil-bins, on the other hand, require more space and because they are scattered widely, expertise is required to automate the whole system. To establish a large soil-bin, huge capital investment along with expertise is required to handle various complex components. Some of the authors as can be seen from table-1 had developed large scale soil-bins for full-scale testing. The significance of large soil-bins is that they allow the use of sophisticated components and also have enough space to carry out full-scale soil-machine interaction testing. Long lengths of the large soil-bins help in attaining desired speeds of the moving carriage assembly. The tests can be repeated several times and a sufficient speed of the soil-bin carriage could be achieved. A wide range of machine activities like the tillage and traction could be studied in large soil-bins.

The types of machinery used in agriculture have a key role in the advancement of agriculture and crop production. The efficient management of the farm machinery can be done by formulating the performance data from various machinery as well as tillage implements which can be used for proper selection of implements for a specific farm. It will eventually reduce the time required to carry out the operation as well as the cost, thereby conserving the fertility of the soil and reducing the adverse effects. The most important goal in tillage is to measure the forces necessary for cutting the soil. Investigation of the effect of soil with soil engaging machinery is essential for performance estimation, modeling and constructing a balanced design of plowing apparatus and traction. Studies about the different types of soils and their interaction with the tools are not possible within a short period as it may require a considerable amount of time to go to the choice of region for examination purposes. So, to carry out the examination of the soils in a considerably limited amount of time, the soil bins can be employed to carry out the testing of the tools or implements in varieties of soils. With the help of soil-bins, detailed research can be conducted if soils are cleaned of stones and other materials and the results obtained can be compared with field test plots. Soil-bins intended for laboratory purposes provide a means for the use of more sophisticated instrumentation and data acquisition for calculating various forces and moments.

8. CONCLUSION

This paper highlights the importance of machinery for analyzing the behaviors of soils with different tools and traction equipment and also reviews some of the key aspects of the science and some pre-requisites to be taken into account before initiating a soil-tool interaction. Soil-bin examination of the tillage tools helps in the development and enhancement of tillage implement. Real-time measurements are carried out with the help of a data acquisition system that receives and controls the information, measure the signals, show the data on the monitor and document the data into a storage medium in real-time. Soil-bins are intended to find out the optimum design parameters and the manner of operation. It is also possible to control some of the soil physical parameters, setting of operation variables according to need and repeating tests within short periods independent of the weather. Studies in soil-bins could also assist in the design and development of tillage tools with distinct geometries which will eventually provide a clear view of how these tools would affect the draft force if subjected to variable soil conditions. This examination of tools will help in determining the optimum geometry required for the minimum draft force. Soil-bins can be customized according to the available space, resources, and availability of personnel, varying from small to large size housed in a separate research facility. It will provide access to different varieties of soils having different physical-mechanical properties. Personnel having primary knowledge of soil dynamics will be able to interpret the results of the research more appropriately. Having an in-depth knowledge of soil-machine interaction would provide insight into the actual working condition which can be applied as a future scope in other areas such as performance evaluation and management of agricultural machinery, design, and development of traction elements for earthmoving machines and design, development and deployment of off-road vehicles for extra-terrestrial planetary exploration.

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