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[F] PhD Extended Abstract Form *(Please select the Calibri 10 typeface)*

FULL PhD THESIS TITLE: DEVELOPMENT OF SENSOR-BASED INTEGRATED SYSTEM FOR MEASURING SOIL COMPACTION AND ELECTRICAL CONDUCTIVITY OF SOIL

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Extended Abstract

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1. INTRODUCTION

With the current advancement in precision agriculture, spatial variation of soil compaction and electrical conductivity of soil has been the center of attention by many researchers in their research. Sudduth et al (2004) developed a hydraulically actuated probe having an electrical conductivity sensor at the tip to measure soil compaction and electrical conductivity simultaneously. In recent years, many integrated soil sensor systems have been developed for measuring soil compaction and electrical conductivity for three-dimensional mapping and are mainly based on soil strength sensors, water content sensors, and conductivity sensors. It has been acknowledged that the recommended methods of using a hand penetrometer (with high accuracy) require more time and intense effort for direct measurement of a huge amount of soil compaction in field conditions, which is labour-challenging and uneconomical for field mapping on large scale. Determination of indirect methods of measurement along with their geographical coordinates has therefore become a more pleasing substitute (Gaultney 1989). Similarly, measurement of electrical conductivity by laboratory process or by an indirect method is also laborious and time consuming, especially when large samples are to be analysed. Very limited research has been done on such technologies that can establish a reliable, faster, and demonstrate cost-effective soil compaction monitoring system simultaneously with EC measuring systems in geotechnical site investigations (Grisso et al 2009). However, equipments are available in advanced countries to measure real-time data of the electrical conductivity by grid mapping like Veris 3100 which is bulky and costly but Indian farmers do not have access to such costly types of equipment. Therefore, the development of such a tractor-operated real-time sensor for simultaneous measurement of electrical conductivity and soil compaction to directly acquire the data in the agricultural field is necessary to save time and resources for the farmer.

Keeping all the factors in view, the present study entitled "Development of Sensor based Integrated System for Measuring Soil Compaction and Electrical Conductivity of Soil" was conducted with the following objectives

1. To study different parameters for the selection of real-time soil sensors based upon the local soil conditions.
2. To develop the prototype for tractor operated soil sensor to measure soil compaction and electrical conductivity.
3. To evaluate the developed prototype under different tillage conditions.

2. REVIEW OF LITERATURE

The major objective of precision agriculture technologies is site-specific management strategies for various agricultural inputs to increase profit from the crops, improve quality of product and protect the environment from degradation. In the present era, the biggest limitation for the adoption of such technologies is the inability to obtain soil attributes and their characteristics inexpensively and rapidly. It has been also reported that errors in the measurements of the developed soils sensors depend upon several parameters such as the type of soil sensor and its driving mechanism. To minimise such errors various researchers have proposed and adopted numerous methods for the development of the cone penetrometer combined with electrical conductivity measuring sensors that provide quick and very accurate measurements. After reviewing the literature on cone penetrometers and Ec sensors, the following key findings were summarised which could be taken into consideration for the development of tractor-mounted, hydraulically operated soil sensors:

1) Soil compaction & EC both adversely affect to the soil environment due to use of heavy machines and fertilizers.
2) Collection of soil samples for measuring the compaction and EC of soil is most labour and time-consuming work.

3) Crop root effected when the soil compaction pressure near to 2 MPa which result in crop yield
4) Electrical conductivity represents salt concentration of soil which has adverse on reduction of yield when greater than 40 mS/m or 4 dS/m
5) Most of the frames designed for mounting sensor assembly components were linked to tractor three-point linkage system according to category 2.
6) The maximum number of hydraulically operated cone penetrometers connected to the tractor hydraulic system was designed at maximum pressure between 5 to 10 MPa.
7) The maximum soil cone index was 5.5 MPa and 7 MPa in a rare case and S-type load cell maximum up to 500 Kg capacity were widely used.
8) Most of the researchers recommended the Standard size of probe (20.27 mm dia. of the cone, 15.88 mm of shaft and Cone angle 30°) with an insertion velocity of 3 cm/s.
9) Cone or shaft dimensions changed for incorporations of other sensors such as moisture sensor, Electrical conductivity, or temperature with standard penetration velocity also predicted many accurate results.
10) Constant velocity was considered more important than the speed of insertion. Ultrasonic depth sensors and encoders were used for the recording of the depth of insertion.
11) Various types of electrical conductivity measuring soil sensors were based on the different phenomena of electromagnetic principles such as electromagnetic induction (EMI), electrical resistivity (ER), reflectometry, either time domain reflectometry (TDR), amplitude domain reflectometry (ADR), and frequency domain reflectometry (FDR).
12) Electrical resistivity can be calibrated with moisture content from various models developed according to the feasibility of the method used.
13) The four-electrode (Wenner array method) was considered best among other arrays for measuring soil resistivity because of its good efficiency, excellent vertical resolution, simple mechanism, and easy calculation.
14) Most of the grid sizes for evaluation of tractor-operated sensors under different tillage conditions were found between 2 to 8 meters in grid size to better understand spatial variability between and within the blocks.

A tractor-operated indigenous soil sensor for measuring soil compaction and electrical conductivity simultaneously is not available. Measurements of soil compaction and electrical conductivity are commonly done with the help of hand held cone penetrometer and laboratory techniques which require more time in field as well in laboratory. The development of an indigenous soil sensor for measuring electrical conductivity and soil compaction simultaneously will surely help in collecting real-time data accurately which will play a vital role in the estimation of numerous soil-related or associated problems in the present era of precision agriculture.

3. MATERIAL AND METHODS

This chapter describes the various methodology, experimental techniques, materials and methods employed during research for the development of sensor based integrated system for measuring soil compaction and electrical conductivity of soil simultaneously. Based on the reviews, pre-experiments and detailed study of the critical components of the machine of the preceding research work, analysis was carried out on selected soil and machine parameters to validate the applicability of the sensor to be developed. The maximum operating pressure, capacity of load cell and essential functional requirements were selected based on preliminary study, prior experimentations and as per availability of the machine material, sensor locally. Design and analysis were carried out at Computer Aided Design Laboratory, Department of Farm Machinery and Power Engineering, PAU, Ludhiana, and later further design modifications were validated using FEM analysis techniques for failure prediction at Mahindra Research Valley (MRV) Chennai and the electronic control unit (ECU) was developed in collaboration locally. The development of soil sensor system and experiments on field evaluation were carried out at the research farm of the Department of Farm Machinery and Power Engineering, PAU Ludhiana. The detailed procedure of experimental techniques is described as under following sub-headings:

Experiment No.1	
Study of key design parameters for development of sensor based integrated system for measuring soil compaction and electrical conductivity of soil.	1. Measurement of Soil compaction by cone penetrometer at different geographical reference point 2. Measurement of Electrical conductivity by laboratory method 3. Analysis of soil type by laboratory method

	4. Preliminary data was analysed with the help of descriptive statistics
Experiment No.2	Locally available and adaptable sensors, load cell and GPS device were identified. Hydraulically actuator system, probe and frame mechanism of the tractor operated soil sensor was developed.
Selection of sensors and development of the prototype of tractor operated integrated soil sensor for measuring soil compaction and electrical conductivity	Following components of the tractor operated soil sensor were developed 1. Frame fabrication 2. Probe and Cone 3. Selection of sensors and GPS system 4. Data acquisition system 5. Integration of sensors, GPS system with Data acquisition system 6. Hydraulic system
Experiment No.3 Evaluation of developed tractor operated soil sensor prototype in the field at different locations.	Developed prototype was evaluated in the research farms at two different locations for collecting soil compaction and electrical conductivity
Observations and parameters determined	a) Independent variables: 1. Soil Type 2. Tillage conditions 3. Soil depth 4. Grid Size b) Dependent variables: 1. Soil compaction 2. Electrical Conductivity
Statistical analysis	Randomized complete block design

4. RESULTS AND DISCUSSION

The tractor mounted and hydraulically operated real time sensor based integrated system for measuring soil compaction and electrical conductivity was successfully developed and evaluated in the field. The preliminary computer aided design version developed in the department was further modified and upgraded by using NX software considering its both direct modelling and parametric capabilities. The design parameters of the developed soil sensor were similar to ASAE Standard S313.3 with incorporation of soil electrical conductivity measuring sensors at the tip of the cone of the cone penetrometer. The major components of the developed cone penetrometer were frame, hydraulic cylinder, probe, ultrasonic depth sensor, global position system (GPS), control panel and data acquisition system. The Finite Element Analysis (FEA) of the critical parts as well as the whole assembly with different types of materials was done by using ANSYs software. The Structural steel was selected for construction of frame of the soil sensor due to easy availability and cost efficiency. The En8 was selected for fabrication of probe of the assembly and low carbon-based steel (EN 8 BS970 080M40) material was selected for hydraulic cylinder. The developed soil sensor was evaluated in two different types of soil at two different locations after the harvesting of wheat crop, where the paddy crop was the previous crop in rice wheat rotation and paddy residue was managed as per the treatments. The three treatments for both the location were treatment T1 (rice residue retained on the soil), treatment T2 (rice residue removed manually) and treatment T3 (rice residue incorporated). The developed soil sensor showed sensing accuracy of 95.38 and 95.06% for soil compaction measurement in comparison with manual cone-penetrometer and, 73.42 and 74.45% for soil electrical conductivity measurement in comparison with standard laboratory method in sandy loam soil (S1) and loamy soil (S2), respectively. The coefficient of correlation between the developed soil sensor and hand cone penetrometer was R2= 0.88 and R2= 0.83 for site one and two respectively. The coefficient of correlation between the developed soil sensor and laboratory was R2= 0.93 and R2= 0.89 for sandy loam soil (S1) and loamy soil (S2) respectively for electrical conductivity. The overall results of the machined concluded that it was feasible to adopt the developed soil sensor to establish the reliable, faster and cost-effective soil compaction monitoring system with EC measurements.

5. CONCLUSIONS

The tractor mounted and hydraulically operated sensor based integrated system was successfully developed for measuring soil compaction and electrical conductivity of the soil to minimise the efforts, error and time to record/collect data from the agricultural field. The solid model of the sensor based integrated system was developed in NX CAD software which has direct parametric and modelling capabilities. The design parameters and critical components of the soil sensors such as probe and cone were based on the ASAE Standard standards. However, small modification was done in the cone for the provision and placement of electrical conductivity measuring copper electrodes by length of the cone's upper head. The major components of the developed cone penetrometer were frame, hydraulic cylinder, probe, ultrasonic depth sensor, global position system, and data acquisition system. The data acquisition and control system with the help of GPS records and display three-dimensional real-time soil profile maps, which provides a quick and effective way to digitally update soil surveying and improve sample collecting efficiency. The CAD model of the developed soil sensor was analysed in ANSYS software for structural stability and failure analysis by using finite element analysis prior to manufacturing, to estimate structural deformation and critical stress/load distributions under the designed pressure and defined boundary conditions. The designed prototype of the soil sensor passed all the material selection criteria selected for the study on the basis of material availability and market price with a desired factor of safety.

The overall results of the machined concluded that it was feasible to adopt the develop soil sensor to establish a reliable, faster, cost-effective soil compaction and electrical conductivity monitoring system in geotechnical investigations. The hydraulic operated soil sensor with automatic recording system with geo reference data has the potential to give more authentic data in less time. It can be further used for site specific and variable depth control tillage management with the help of grid mapping of the whole soil profile to save energy, fuel and money. Further, it will increase the volume of sampling for a particular area with reduced human error and upgrade the quality of measuring equipment used by scientific community all over the world for measuring soil compaction (CI) and electrical conductivity (EC) of the soil. The tractor operated "on the go and stop" indigenous hydraulic operated dual soil sensor will be accessible for recording or monitoring real time data for soil compaction and electrical conductivity of soil which will play an important role in adoption of precision agricultural technologies.

Final remarks concerning benchmarks and strength points of the the Pellizzi Prize 2024

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