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FIELD EVALUATION OF TRACTOR MOUNTED SOIL SENSOR FOR MEASUREMENT OF ELECTRICAL CONDUCTIVITY AND SOIL INSERTION / COMPACTION FORCE

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Abstract: Soil properties like electrical conductivity and soil compaction due to its correlation with other soil properties like soil texture, water content, cat ion exchange capacity (*CEC*), drainage conditions, organic-matter level, depth to clay pans, salinity, and subsoil characteristics that affect crop growth and its productivity were found to be important properties of soil. To observe the effect of electrical conductivity and insertion force, a tractor operated soil sensor (Make Veris Technology, USA) was used for measurement of electrical conductivity and insertion force (compaction) of soil in the field. Tractor mounted soil sensor probe was having a soil *EC* contacts and a load cell to measure the electrical conductivity and insertion force, respectively by pushing the probe into the soil. Experiments were conducted at two fields of departmental research farm of Farm Machinery and Power Engineering, Punjab Agricultural University, Ludhiana. In field no. 1, the average electrical conductivity measured by tractor mounted soil sensor varied from 8.5 to 9.6 $mS \cdot m^{-1}$ having coefficient of variance 26.8% at soil moisture content of 26% (wb). In field no.2, the average electrical conductivity measured by tractor mounted soil sensor varied from 15.75 to 23.28 $mS \cdot m^{-1}$ with CV 12.1%. For Lab measurement of soil *EC*, coefficient of variance (CV) was found to be 10.9 % with average *EC* value of 20.62 $mS \cdot m^{-1}$. Overall insertion force for field no 1 was 1953.44 kPa at 0.2 m depth which suddenly increased up to 2864.06 kPa when depth was increased to 0.4 m which is 46% more than at 0.2 m depth.

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Overall insertion force for field no 2 was 8085.71 kPa observed at 0.2 m depth which increased up to 9704.96 kPa when depth was increased to 0.6 m which was 20% more as compared to insertion force at 0.2 m soil depth.

Key words*: tractor mounted soil sensor, soil electrical conductivity, insertion force, soil compaction*

INTRODUCTION

Green revolution changed Indian agriculture scenario and Punjab had major contribution in this revolution. Use of fertilizers, pesticides, insecticides, high yielding, semi-dwarf and short duration varieties, and advanced machines helped in agriculture growth. Rice-wheat cropping system became popular in Punjab. But due to continuous high usage of fertilizers, pesticides, heavy machinery and cropping pattern, lot of soil properties are affected. Further, declining water table, compaction of soil, and increase in salinity of soil are some other problems faced by farmers due to long and excessive usage of chemicals, machinery and water [1] [2] [3]. In Punjab, puddling is done before transplanting the rice seedlings resulting in creation of hard pan in soil. This hard pan is not broken with normal cultivation due to which water logging takes place in low areas in succeeding wheat crop, thereby decreasing its yield. Excessive and prolonged usage of rotary ploughs especially with L-blade for many years caused compaction of soil and formation of hard pan in the top soil which affect the crop growth and production.
Different soil properties like soil electrical conductivity, soil pH, soil temperature due to its effect on biological process like seed germination, seeding emergence and growth, root development, nutrient and water uptake porosity, and soil strength or compaction affect the crop growth considerably [4]. Out of these properties, soil electrical conductivity due to its correlation with other soil properties like soil texture, water content, cation exchange capacity (*CEC*), drainage conditions, organic-matter level, depth to clay pans, salinity, and subsoil characteristics that affect crop productivity and soil strength due to influence by soil water content, texture and structure are important soil properties [5]. Soil electrical conductivity (*EC*) is a measurement that correlates with other soil properties like *EC* is commonly expressed in milli-siemens per meter ($mS \cdot m^{-1}$). In Punjab, North Eastern undulating sub region is having *EC* 0.14-0.80 $dS \cdot m^{-1}$, Piedmont alluvial plain is having *EC* 0.15-0.80 $dS \cdot m^{-1}$, Central alluvial plain is having *EC* 0.14-1.60 $dS \cdot m^{-1}$ and South west alluvial plain is having *EC* 1.6-1.8 $dS \cdot m^{-1}$ (Kumar et. al. 2008). Soil compaction or strength property also influences the crop growth and its yield. If soil compaction/strength is less than 1 MPa (10.2 $kg \cdot cm^{-2}$) it indicates that roots grow through soil without difficulty and soil physical quality is good. If soil strength is between 1-3 MPa it indicates that root growth may become restricted and soil physical quality is moderate. If soil strength is greater than 3 MPa it indicates that root growth is retarded except through cracks and old root channels and soil physical quality is poor.

Hence, it is important to measure the soil properties to reduce their influence on crop yield. In India, soil electrical conductivity (*EC*) is mostly measured by laboratory analysis. To determine *EC* in laboratory, the soil solution is placed between two electrodes of constant geometry and distance of separation [6]. Laboratory process is laborious and large number of samples has to be taken for single field analysis which is a time consuming process. Machinery available in advanced countries to measure *EC* like soil *EC* mapper (Veris 3100) is bulky and costly. Indian farmers also do not have any access to this kind of equipment. Similarly, the measurement of soil strength with cone penetrometer and manual penetrometers is laborious process by manually pushing the cone into the soil media and recording individual reading obtained at specified intervals and maintains a constant penetration rate during cone pushing into the soil. Thus, to overcome the difficulty in the measurement of Electrical Conductivity (*EC*) and strength of soil, a tractor mounted *EC* mapper along with soil strength measurement can help farmers to collect more information in lesser time about their field so that they can manage their fields effectively.

By using the tractor operated *EC* mapper along with soil strength measurement, *EC* of soil can be directly measured in field which in turn can save a lot of time and resources of farmers. The effect of agricultural machinery usage and rice-wheat cropping pattern on soil compaction can be analyzed. Farmers can determine hard pan in their field and can perform suitable action to break hard pan, which will help in decreasing water logging problem. Hence, considering the above mentioned points, the present study is undertaken with the objectives to evaluate the existing soil sensor for measurement of electrical conductivity and compaction of soil and to compare the system for measurement of conductivity with laboratory method.

MATERIAL AND METHODS

This part deals with the various materials used and methods applied for conducting the experiments like measurement of soil *EC* and compaction in the field, measurement of soil *EC* in the laboratory.

Measurement of soil *EC* and soil compaction in the field

Tractor operated soil sensor. Tractor operated soil sensor (Make Veris Technology) shown in Fig. 1, was used for measurement of electrical conductivity and insertion force (compaction) of the soil in the field and Fig. 2 shows the line diagram of soil sensor.

Figure 1. Real and field view of tractor mounted probe type soil sensor

Soil Sensor is mounted on the tractor with the hydraulic system through the hydraulic lines to activate the system and electrical supply is given to the machine through the battery of the tractor. It should be insured that all the connections must be connected properly; no leakage of hydraulic oil should be there at the connecting points. When hydraulic hoses and power supply wires connected properly, the data logger of machine is connected to the laptop by USB port.

Data of soil *EC* and insertion force is geo-referenced through a GPS connected with the soil sensor and depth is recorded for each measurement in centimeter increments. It goes up to 100 cm depth. The rack-and-pinion hydraulic side-shift provides lateral motion, and the extended cylinder moves the probe forward or backward—all controlled manually, through accessible lever controls. The heavy-duty probe is constructed of 1" (2.54 cm) diameter probe rod.

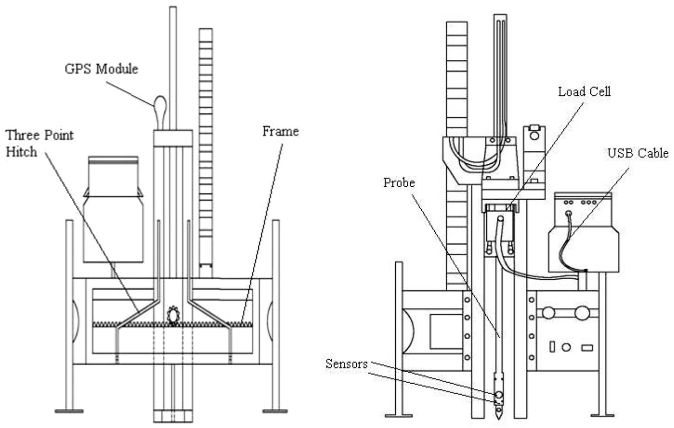

Figure 2. Front and rear view of tractor mounted soil sensor

Measurement of soil EC. Tractor mounted soil sensor is having a probe which can be inserted into the soil through tractor hydraulic system. At the bottom of the probe there is a cone-tip with soil *EC* contacts for collecting dipole *EC* data as shown in Fig. 3. Soil *EC* data along with its geo-referenced location was directly coming to laptop attached with it.

Figure 3. EC contacts on the probe of soil sensor

Measurement of soil compaction. Tractor mounted soil sensor probe is also having a load cell to measure the insertion force required to push the probe into the soil. Data of insertion force or compaction of the soil along with its geo-referenced location is saved.

Data Logging. Before collection of data using sensor, check the indication or light of *EC* port, depth port and GPS system turned green, which ensure that the laptop is properly connected to the machine and machine is ready to operate. The probe of the machine was lowered manually by operating the lever. When the probe just touches the soil, the log button in the software was clicked which starts the data logging. The depth control should be operated continuously without any interruption. Probe measures the electrical conductivity up to 100 cm depth. When the lever was stopped operating, the software stops taking readings by saving data automatically into the computer as an excel sheet format. The data was transferred to the computer using surfer 7.0 software and Arc-GIS 8.3 with spatial and 3D analyst extension.

Calibration of soil sensor EC in the laboratory. In this method the *EC* is measured by *EC* meter installed in the soil testing laboratory of the university. For measuring the soil *EC* in the laboratory, Soil samples were collected from all the marked points in the selected fields. The samples were taken up to the average depth of the probe. Approximately 200g of soil samples were collected and completely dried for further preparation of soil samples. The soil solution was prepared by having 20g of soil and adding 40 ml of water making soil volume ratio as 1:2. For mixing the soil and water properly, solution was stirred with the help of glass rod. Soil solution was ready to measure the *EC* data after keeping it for 24 hrs at room temperature.

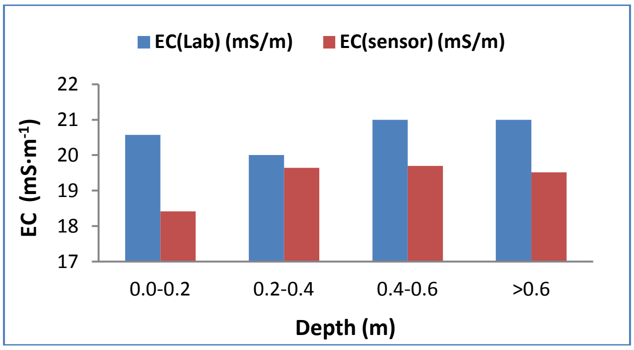

Figure 4. Electrical conductivity measured in lab and with tractor mounted sensor at different soil depths

To measure the soil *EC* in laboratory, the electrode was dipped into the prepared soil solution and *EC* of the samples was determined which was shown on the digital *EC* meter. The unit of *EC* is $mS \cdot m^{-1}$. Industrial conductivity probes often employ an inductive method having advantage of fluid not wetting the electrical parts of the sensor. Here, two inductively coupled coils were used. One was the driving coil produced a magnetic field with accurate voltage supply. The other formed a secondary coil of a transformer. The liquid passing through a channel in the sensor formed one turn in the secondary winding of the transformer. The induced current was the output of the sensor.

Conductivity electrode was placed into a standard solution of 0.005 *M KCl*. Electrode was agitated using up and down movement to create proper electrode contact with solution. After agitation, the meter should read 0.72 ± 0.04 mmho·cm^{-1} (0.72 ± 0.04 dS·m^{-1}). Agitate the probe again and re-read the standard solution. Both the first and second readings should be the same value if the probe is in good contact with the solution. Otherwise adjust it for *EC* value 0.72 mmho·cm^{-1}. For accurate measurement of soil *EC* data, Electrode was washed with pure water.

Fig. 4 showed that the values of soil *EC* measured by lab method was observed to be more as compared to the *EC* values measured by soil sensor at 0.0-0.2 m depth of soil. This may be due to the reason that salts are more likely to accumulate and remain near the soil surface up to 10 cm of depth and the salts cannot be leached from the root zone and accumulate on the surface of the soil. The change in soil *EC* was observed in top 20 cm of depth in field no 1 having cotton as harvested crop but corresponding change was in only 10 cm of depth in field no 2 having wheat as harvested crop.

Selection of fields. For conducting the experiment, two fields were selected at departmental research farm of Farm Machinery and Power Engineering, Punjab Agricultural University, Ludhiana. Field 1 was selected after the harvesting of cotton crop and data was collected at different locations in the month of December, 2013. Field 2 was selected after the harvesting of wheat crop and data was collected at different locations in the month of May, 2014.

RESULTS AND DISCUSSION

The present study was undertaken to measure the electrical conductivity and compaction of soil by using tractor mounted soil sensor. Various results obtained from the study undertaken and their discussions are presented under this part.

Measurement of soil electrical conductivity

The trend of electrical conductivity with respect to different soil depths at different Geo-referenced locations of field 1 is represented by bar graph as shown in Fig. 5. It is observed that the average electrical conductivity measured by tractor mounted soil sensor varied from 8.5 to 9.6 mS·m^{-1} at average soil moisture content of 26% (wb) (Fig. 4). Coefficient of variance of the measured *EC* data was found to be 26.8 %. Fig. 4 shows that initially when probe of the soil sensor was inserted into the soil up to 0.2 m depth than average electrical conductivity was observed to be 8.5 mS·m^{-1} and further increased to 9.4 mS·m^{-1} at the soil depth of 0.2-0.4 mS·m^{-1}. The trend of graph was further changed as the probe inserted in to the soil at depth 0.4-0.6 m and value of electrical conductivity for that depth was decreased to 8.6 mS·m^{-1} and further increased to 9.6 mS·m^{-1} at depth more than 0.6 m. This may due to the reason that salts are more likely to accumulate and remain near the soil surface. The salts cannot be leached from the root zone and accumulated on the soil surface.

The average soil electrical conductivity of field 2 at different Geo-referenced locations measured by two methods i.e. laboratory and soil sensor is given in Table 2 and profile electrical conductivity of selected points is shown in Fig. 5. It is indicated from the table that in field 2 average electrical conductivity measured by tractor mounted soil sensor varies from 15.75 to 23.28 mS·m^{-1} and for lab measurement it varies from 17 to 23 mS·m^{-1}. For Lab measurement of soil *EC*, coefficient of variance (*CV*) was found to be 10.9% with average EC_L value of 20.62 mS·m^{-1} and for *EC* measurement with tractor mounted soil sensor; the *CV* was 12.1% with EC_S having a value of 19.11 mS·m^{-1}. The average relative error in measurement of *EC* using tractor mounted soil sensor was found to be 9.13% as compared to the lab method.

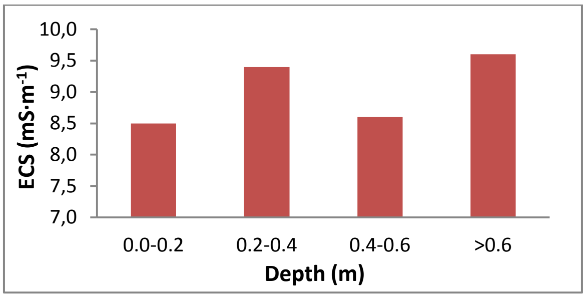

Figure 5. Electrical conductivity measured by sensor at different soil depths

Table 2. Average electrical conductivity measured by soil sensor (EC_S) and in laboratory (EC_L) of different data points with their Geo-referenced location for field 2

Data points	Geo-referenced location	EC_L (mS·m^{-1})	EC_S (mS·m^{-1})	Relative error (%)
1	75.8188N-30.90999E	19	19.1	0.5
2	75.8191N-30.91001E	18	17.38	3.4
3	75.8191N-30.90989E	21	22.83	8.7
4	75.8190N-30.90988E	19	19.54	2.8
5	75.8188N-30.90988E	23	22.9	0.4
6	75.8186N-30.90986E	21	19.4	7.6
7	75.8185N-30.90983E	22	18.5	15.9
8	75.8185N-30.90968E	23	23.28	1.2
9	75.8187N-30.90968E	17	17.67	3.9
10	75.8188N-30.90969E	21	17.53	16.5
11	75.8192N-30.90957E	18	16.49	8.3
12	75.819N-30.90956E	19	15.75	17.1
13	75.8188N-30.90955E	22	18.78	14.6
14	75.8187N-30.90953E	19	17.27	9.1
15	75.8185N-30.90952E	24	21.07	12.2
16	75.8185N-30.90937E	24	18.25	23.9
Average value of EC		20.62	19.11	-
Coefficient of variance (CV)		10.9	12.1	-
Average relative error (%) between EC_S and EC_L				9.13

It's clear from the data that at some points the *EC* values sensed by soil sensor does not correlate with the values of *EC* determined from the lab analysis of soil, but at some points correlate well with each other. The reason behind it may be that in saline soil like in field no 2, the two sets of data are typically well-correlated, but in non-saline fields there is often no statistically significant correlation. Because when a soil sample is put into solution or a saturated paste, conductance through alternating layers of soil particles and along surfaces of soil particles are virtually eliminated. But conductance through salts in solution dominates the conductivity. In non-saline fields, conductance through alternating layers of soil particles, along surfaces of soil particles and conductance through continuous soil solution contribute significantly to the overall *EC* signal. In saline fields, conductance through continuous soil solution dominates the signal response in the field.

Measurement of insertion force or soil compaction

Soil insertion force (compaction) at different soil depths of selected locations in field 1 is graphical presented in Fig. 6. It is evident from the data that at all locations when probe was inserted into the soil there was gradual increase in the insertion force or soil compaction with the depth. When probe was at 60 cm depth, the change in insertion force was increased up to 50 - 100% as compared to the insertion force at the shallow depth i.e. 20 cm. But overall insertion force data for field no 1 showed that 1953.44 kPa insertion force was observed at 20 cm depth which suddenly increase up to 2864.06 kPa at 0.2-0.4 m soil depth which was 46% more than at 0.2 m soil depth. It indicates that there is a hard pan at about 30 cm below the surface which increases insertion force up to 58.5% more as compared to the insertion force at 0.2 m depth.

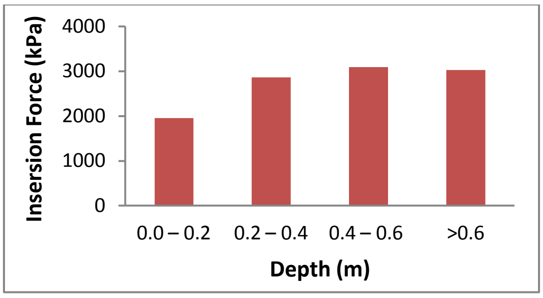

Figure 6. Insertion force (compaction) at different depths of soil in field 1

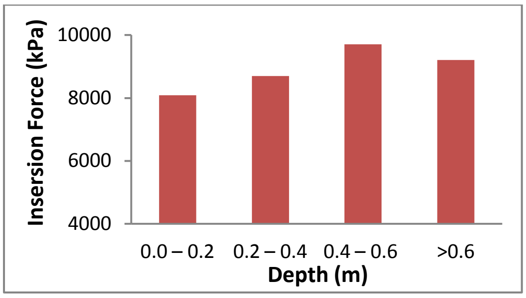

Figure 7. Insertion force (compaction) at different depths of soil in field 2

Soil insertion force (compaction) at different depths of selected location in field 2 is given in Fig. 7. It is evident from the data that at all locations when probe was inserted into the soil there was gradual increase in the insertion force or soil compaction with the depth. When probe was at 0.6 m depth, the change in insertion force was increased up to 20% as compared to the insertion force at the shallow depth i.e. 0.2 m. But overall insertion force data for field no 2 showed that 8085.71 kPa insertion force was observed up to 0.2 m depth which increased up to 9704.96 kPa at 0.6 m soil depth.

CONCLUSIONS

The following conclusions were drawn from the conducted experiments:

- In field no. 1, the average electrical conductivity measured by tractor mounted soil sensor varied from 8.5 to 9.6 mS·m^{-1} having coefficient of variance 26.8% at soil moisture content of 26% (wb).
- In field no.2, the average electrical conductivity measured by tractor mounted soil sensor varied from 15.75 to 23.28 mS·m^{-1} with CV 12.1% and average EC_S value of 19.11 mS·m^{-1}.
- For Lab measurement of soil *EC*, coefficient of variance (CV) was found to be 10.9 % with average EC_L value of 20.62 mS·m^{-1}.
- On an average, the relative error in measurement of *EC* using tractor mounted soil sensor was found to be 9.5 % as compared to the lab method.
- Overall insertion force for field no 1 was 1953.44 kPa at 0.2 m depth which suddenly increased up to 2864.06 kPa when depth was increased to 0.4 m which is 46% more than at 0.2 m depth.
- Overall insertion force for field no 2 was 8085.71 kPa observed at 0.2 m depth which increased up to 9704.96 kPa when depth was increased to 0.6 m which was 20% more as compared to insertion force at 0.2 m soil depth.
- Hard pan occurs at 0.15-0.20 m of soil depth for a wheat harvested field and for cotton harvested field it occurred at 0.3 m soil depth.

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POLJSKA OCENA TRAKTORSKOG SENZORA ZA MERENJE ELEKTRIČNE PROVODLJIVOSTI I SILE PRODIRANJA / SABIJENOSTI ZEMLJIŠTA

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Sažetak: Elektroprovodljivost i sabijenost su izdvojene kao posebno važne karakteristike zemljišta zbog svog odnosa sa drugim njegovim svojstvima, kao što su tekstura, sadržaj vode, kapacitet razmene katjona (*CEC*), uslovi drenaže, sadržaj organske materije, dubina glinovitih slojeva, salinitet i ostale karakteristike koje utiču na porast i produktivnost useva. Za merenje efekta električne provodljivosti i sabijenosti korišćen je traktorski zemljišni sensor (Make Veris Technology, USA). Senzor ima kontakte i ćeliju za merenje elektroprovodljivosti i sile prodiranja ubadanjem sonde u zemlju. Ogledi su izođeni na dve ogledne parcele Instituta za poljoprivredne i pogonske mašine. Na parceli br. 1, srednja izmerena elektroprovodljivost iznosila je od 8.5 do 9.6 $mS \cdot m^{-1}$, sa koeficijentom varijacije od 26.8%, pri vlažnosti zemljišta od 26%. Na parceli br. 2, srednja izmerena elektroprovodljivost iznosila je od 15.75 do 23.28 $mS \cdot m^{-1}$, sa koeficijentom varijacije od 12.1%. Za laboratorijska merenja elektroprovodljivosti, koeficijent varijacije iznosio je 10.9 %, sa srednjom vrednošću od 20.62 $mS \cdot m^{-1}$. Srednja sila prodiranja na parceli br. 1 bila je 1953.44 kPa na dubini od 0.2 m, a zatim je naglo porasla na 2864.06 kPa sa povećanjem dubine na 0.4 m, što je 46% više nego na 0.2 m.

Srednja sila prodiranja na parceli br. 2 bila je 8085.71 kPa na dubini od 0.2 m, a povećala se na 9704.96 kPa sa povećanjem dubine na 0.6 m što je 20% više nego na 0.2 m.

***Ključne reči**: traktorski zemljišni sensor, električna provodljivost zemljišta, sila prodiranja, sabijenost zemljišta*

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