

PC Based Soil Electrical Conductivity Sensor

*A Thesis
report*

*submitted towards the partial fulfillment of the
requirements of the degree of*

Master of Engineering

in

Electronics Instrumentation and Control Engineering

submitted by

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DECLARATION

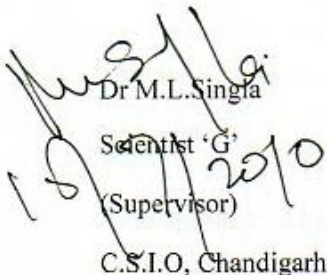
I hereby declare that the report entitled "PC Based Soil Electrical Conductivity Sensor" is an authentic record of my own work carried out as requirements for the award of degree of M.E. (Electronic Instrumentation & Control) at Thapar University, Patiala, under the guidance of Dr M.L.Singla (Scientist G), Mr. Babankumar S.Bansod (Scientist C) and Mr. M.D.Singh (Assistant Professor, EIED) during January to July 2010.


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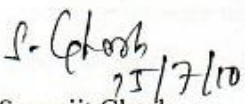
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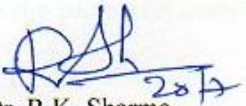
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ABSTRACT

The goal of this work is to study the correlation between apparent soil electrical conductivity (EC_a) with soil salinity and urea concentration in a agriculture field. Soil apparent conductivity establishing the spatial variability of combination of physic-chemical properties of soil and there is no optimum array method to give us more reliable and useful result, independent of soil characteristic so mapping of study area with Wenner array and Dipole-Dipole array give us different geoelectrical models of subsurface. Wenner array have high vertical resolution and Dipole-Dipole have high lateral resolution so comparative study with both the method give us more better understanding of soil apparent conductivity with soil salinity and nutrient. A PC based system is developed for this purpose which can work stand alone with the sensor. Using PCA and PLS analysis we can analyze the relation between soil salinity and nutrient with soil apparent conductivity.

ORGANISATION OF THESIS

Chapter-1 It includes the introduction of the thesis, soil properties and soil types.

Chapter-2 It contains different type of soil sensor available for soil properties measurement.

Chapter-3 Soil resistivity measurement method and their working principle.

Chapter-4 Result and Discussion has been described in this chapter.

Chapter-5 Thesis has been concluded with future scope in this chapter.

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LIST OF ABBREVIATION

1. CEC	Cation Exchange Capacity
2. EC	Soil Electrical Conductivity;
3. EC _a	Apparent soil Electrical Conductivity
4. EM	Electromagnetic Induction
5. ER	Electrical Resistivity
6. GPS	Global Positioning System
7. TDR	Time Domain Reflectometry
8. FDR	Frequency Domain Reflectometry
9. PCA	Principle component analysis
10. PLR	Partial Least Square

LITERATURE SURVEY

Soil electrical conductivity measurement taken as a standard since late 19th century for determination of soil layers, effective sounding depths for HVDC grounding electrode design and many other applications. Research papers are available on soil conductivity measurement since starting of 20 century. Paper related to the soil electrical measurement had been studied from various peer reviewed journals and conferences. A brief survey is given here in order of their publishing year.

R. L. SMITH-ROSE, December (1933) [1], studied that the mode of propagation of electrical energy through a non-conducting medium having assigned values of dielectric constant and permeability, the velocity of propagation being calculate able in terms of these quantities. Probably that the simplest method of ascertaining the conductivity of a material is to measure the current which flows under the application of a given voltage. When we apply a direct current is applied to a specimen of soil in this manner, the effects obtained are complicated by the occurrence of polarization phenomena giving rise to reverse electromotive forces and these effects arise from the fact that the conduction is partly electrolytic in nature owing to the moisture content of the soil. For this reason measurements of soil conductivity obtained by the application of direct current are not likely to yield reliable results suitable for use in connection with alternating currents .

C. J. Blattner (1982) [2], according to the principle of the four point method for uniform soil outer electrode is use to apply current to the developed a potential difference between two inner electrode . The same methodology is used by Herein to develop the potential difference between the potential probes in two layer soil conditions. It is useful in demonstrating possible limitations of the four point test in two layer soil conditions. In homogeneous earth 70.50%of the total current flows above a plane 3S deep and 29.5% flows below. And, 90.5% of the total current will flow above the plane that is 10S deep where S is inter electrode spacing . It can be seen from this current distribution that the rule of thumb which states average resistivity is measured for a depth equal to probe spacing is only approximate. In the case of two layer earth, if the bottom layer's resistivity is lowest, more current will flow deeper. Conversely, if the top layer has the lowest resistivity less current will flow deep.

Hans R. Seedher, J.K. Arora (1992) [3], according to Wenner method, four electrodes are must be driven into the surface of the earth in a straight line at equal spacing. Current I is circulated between the outer pair of electrodes and voltage V is measured across the inner pair. The depth of burial of electrodes is kept small as compared to the spacing between them, the ratio should be of at least 1:10 so that they can be regarded as points. Measurements are made by increasing the electrode spacing in steps wise, from small values to the largest practical spacing, and along several radials. The arrangement should be in such a manner that electrically equivalent to measurement of voltage V between two points .As the surface of the earth due to two point current sources I and $-I$ at the surface of the earth. The ratio R obtained by dividing V by I is called mutual resistance.

F. P. Dawalibix (1998) [4],state that there are two commonly used measurement arrangements, Wenner and Schlumberger are modeled and analyzed at different frequencies and for different soil structures from these study quantifies that the coupling between current and potential leads for typical separation distances between the leads for uniform and multilayer soils. It all so show that high operating frequencies or small separation distances between leads result in high inductive coupling levels, as expected and when the resistivity of a uniform soils or the bottom layer resistivity of a multilayer soil is low, the measurement error caused by the inductive coupling is large. One way of minimized the coupling effect is to work at DC or very low frequencies. The inductive coupling can be reduced by increasing the separation distance between the current and potential leads and in Wenner method, the signal to inductive coupling ratio is larger than Schlumberger method.

Carlos Portela (1999) [5], state that when very high electric fields, that originate significant soil ionization, soil electromagnetic behavior is essentially linear, but with electric conductivity, σ , and electric permittivity, strongly frequency dependent. The magnetic permeability μ is, in general, almost equal to vacuum magnetic permeability. For slow variation of electromagnetic entities, it may occur an hysteresis type behavior. For direct current or very slow variations of electromagnetic entities, it may be humidity migration phenomena, including electro osmosis and effects of tempera-heterogeneity that cannot be dealt with only by means of local soil parameters.

Thomas Flaschke, Hans-Rolf Trankler (1999) [6], state that every material(soil) is characterized by its dielectric properties and to be able to interpret the impact of binding water, or its dielectric spectrum, it is important to understand those dielectric properties, which can be described by a complex representation of the dielectric constant, the complex electrical permittivity. The dielectric constant of typical soil mineralogical materials ranges from about 2 to 14, and while the dielectric constant of water is approximately 81, the dielectric constant of soil is a potentially sensitive indicator of soil water content. The reorientation of polar molecules, such as water, in an electric field takes some time. With increasing frequency, the permanent dipoles become to slow to follow the fast alternating electric field. At these higher frequencies ϵ will fall to much lower values. The frequency at which ϵ has decreased to half its lower frequency value is called the relaxation frequency and at this frequency the dielectric loss ϵ has its maximum. For the case of free water with the relaxation frequency is 17 GHz soil-bound water ϵ varies between about 2 and 81 with a relaxation frequency of less than 1GHz, depending on the binding forces and the soil parameters.

F. H. Slaoui (2001) [7], state that conductivity of the soil can be vary from season to another and the depth of each layer is usually unknown which cause a serious difficulty for determining the soil electrical conductivity of soil .In the case where soil parameters are known, using classical methods in order to determine grounding resistance still takes extensive analysis and computation efforts.

Rhett Herman(2001) [8], state that the when the current flow to the subsurface material contains an upper region with higher resistivity than the resistivity of the region below and the current encounters the region of lesser resistivity, the equipotential surfaces are further apart, and the current will alter its course through the lower material accordingly. If the distance between the current electrodes is the same, then the total resistance the current encounters will be less. The total measured resistivity will be similarly lower, and the current will flow more easily between the electrodes and these alteration of the current flow between the electrodes is the basis for discerning both the presence of the boundary between the two layers as well as a value for the resistivity of the material in the lower layer .When the spacing between the current electrodes is much less than the

depth of the boundary between the two layers, most of the current will not encounter the region of lower resistivity and these means that the total resistivity measured at the surface will be mostly due to the material that lies above the boundary. When the current electrodes are placed further apart, the current penetrates more and more into the region of lower resistivity, and the total resistivity begins to decrease from its initial value that it has when the electrodes are close together. When the spacing between the current electrodes is much greater than the depth of the boundary, most of the current will spend most of its journey in the region of lower resistivity. The overall resistivity measured at the surface will be mostly due to the material in the lower layer.

Yaqing Liu, (2003) [9], present that when high voltages and currents always produce ionization in the soil around the grounding systems, which is an extremely complicated non-linear process and has not been fully understandable and in order to model the transient behavior of grounding system. The widely used model of soil ionization assumes that the soil ionization is uniform around the conductor and the resistivity of this ionization region decreases to the same value as that of the grounding conductor (almost zero) instantaneously. Before the ionization occurs, the voltage across the sample and the current going through the sample have almost the same wave shape and reach the maximum almost at the same time. Once the significant soil ionization has started, the current peak is always delayed compared with that of the voltage and their wave shapes are not similar any more. That is because the soil behaves as non-linear impedance during ionization. But, if the current only could create very small ionization region, the wave shape of the current and voltage could not have very big difference. On the other hand, the critical electric field intensity of the soil ionization has statistical behavior so, the average value of the electric field intensity on the surface of the inner electrode just before the significant soil ionization occurs is chosen as the critical electric field intensity for that particular sand sample.

Audun Korsæth (2005)[10],state that there are three methods have been used to determine EC_a in soil measurements of electrical resistivity (ER) using the Wenner array, measurements of electrical conductance with time domain reflectometry (TDR), and with non-invasive electromagnetic induction (EM). As the former is well suited for precision

agriculture applications, because the volume of measurements is large, thus reducing the local-scale variability. According to the Wenner array method depth of penetration and volume of measurements can be easily adjusted by changing the spacing between the electrodes, but the invasive nature of the resistivity measurements requires good contact between the soil and the four electrodes, and is thus less reliable in dry and stony soils. As the Exchangeable Ca^{2+} , K^+ , Mg^{2+} , Na^+ , exchangeable H^+ was determined by titration (NaOH) and CEC calculated as the sum of the five cations EC_a is primarily a function of soil texture, CEC and moisture content ignition loss appeared to be even more positively related with EC_a than was soil texture.

D.L. Corwin (2005) [11], present that the field-scale application of apparent soil electrical conductivity (EC_a) to agriculture has its origin in the measurement of soil salinity, which is an arid-zone problem associated with irrigated agricultural land and with areas having shallow water tables. Apparent soil electrical conductivity is influenced by a combination of physico-chemical properties including soluble salts, clay content and mineralogy, soil water content, bulk density, organic matter, and soil temperature consequently, measurements of EC_a have been used at field scales to map the spatial variation of several edaphic properties soil salinity, clay content or depth to clay-rich layers, soil water content, the depth of flood deposited sands, and organic matter. In addition to EC_a has been used at field scales to determine a variety of anthropogenic properties leaching fraction, irrigation and drainage patterns, and compaction patterns due to farm machinery. It may be that early agricultural use as a means of measuring soil salinity, the agricultural application of EC_a has evolved into a widely accepted means of establishing the spatial variability of several soil physico-chemical properties that influence the EC_a measurement. As the apparent soil electrical conductivity is a quick, reliable, easy-to-take soil measurement that often, but not always relates to crop yield. For these reasons, the measurement of EC_a is among the most frequently used tools in precision agriculture research for the spatio-temporal characterization of edaphic and anthropogenic properties that influence crop yield.

R. D. Southey(2005) [12], state that the expected sounding depths for a homogeneous (uniform) soil have been studied and for different electrode configurations. The ratio of the expected sounding depth (Z_e) over the distance between the two current probes (L) Z_e/L is 0.173 for the Wenner method and 0.192 for the Schlumberger method. This indicates that the expected sounding depth of the Schlumberger method is about 10% greater than that of the Wenner method. As we know that expected sounding depths are determined by integrating a sensitivity function with depth and it also indicates roughly how deep one can measure with an electrode array. In other words we can say that the soil resistivity above the expected depth has the same effect on the measured potential as the soil resistivity below the expected depth. Wenner method obtain deep soil resistivity in a more reliable manner when there are pockets of soil of various resistivity located throughout the area under study.

George E. Brown Jr (2005) [13] , represent that the first application of EC_a in agriculture was for the measurement of soil salinity conducted by Rhoades and colleagues in the 1970's at the USDA-ARS Salinity Laboratory in Riverside. Soil salinity refers to the presence of major dissolved inorganic solutes in the soil aqueous phase, which consist of soluble and readily dissolvable salts including charged species (e.g., Na^+ , K^+ , Mg^{+2} , Ca^{+2} , Cl^- , HCO_3^- , NO_3^- , SO_4^{-2} and CO_3^{-2}) non-ionic solutes, and ions that combine to form ion pairs. The predominant mechanism causing the accumulation of salt in irrigated agricultural soils is loss of water through evapotranspiration, leaving ever-increasing concentrations of salts in the remaining water. Effects of soil salinity are manifested in loss of stand, reduced plant growth, reduced yields, and in severe cases, crop failure. Salinity limits water uptake by plants by reducing the osmotic potential making it more difficult for the plant to extract water. Salinity may also cause specific-ion toxicity or upset the nutritional balance of plants. In addition, the salt composition of the soil water influences the composition of cations on the exchange complex of soil particles, which influences soil permeability.

M.C. McCutcheon(2006) [14],present that soil texture is the most important factor affecting crop growth and an understanding of its spatial distribution is essential to precision farming and the practical utility of EC_a to map texture, however, remains elusive because of the complex interactions between EC_a and soil physical and chemical properties of sand through research it is clearly shows soil water content and concentration, clay content and mineralogy, temperature, cation exchange capacity (CEC), and organic matter content are among the dominating soil properties affecting EC_a for example for in the fields that containing high concentration of salts, EC_a measurements effectively portray both the nature and the main cause of EC_a variability. In contrast, EC_a in non-saline fields depicts spatial variability without clearly identifying the dominant cause of variability.

Shozo Sekioka, (2006) [15], study that the soil resistance decreases as injected current increases and these phenomenon is caused by soil ionization around a grounding electrode. There are two approaches to calculate the nonlinear grounding resistance considering the soil ionization has been investigated. The first one considers resistivity and dimension of the soil ionization zone. The other one is determined from an empirical relation of the voltage–current curve. Bellaschi study that effective radius and length, which depend on the injected current of a driven rod to estimate the current dependence of the grounding resistance. The ionized zone with low resistivity grows with the increase of the injected current. Assuming that the zone resistivity is zero Bellaschi’s model is convenient to estimate the current-dependent grounding resistance. However, the zone resistivity does not suddenly become zero. Liew and Darveniza proposed a dynamic grounding resistance model, which considers the zone resistivity and the hysteresis effect in the case of zone resistivity in their model is a function of time and current density. It state that the calculated results using the Liew-Darveniza model agree satisfactorily with experimental results. However, the physical meaning and derivation of the model are not mentioned sufficiently.

N. Mohamad Nor (2006) [16], present numerous tests have been conducted to suggest that the measured nonlinear conduction and breakdown phenomena are a consequence of soil ionization. This mechanism was often described as being due to field enhancement in voids enclosed within the soil. When Snowden et al measured a relative dielectric

constant of wet soil with an ac parallel plate test, it was found that for sand with 4% of water content, the relative dielectric constant can be as high as 1000 at 50 Hz and is highly dependent on frequency

Torleif Dahlin and Bing Zhou(2006) [17], state that the signal-to-noise ratio also varies with the relative position of the potential electrodes, being highest close to a current electrode and lowest at the centre of the layout and this is based on normalizing the inverse of the geometry factor against that of the Wenner array, which has the highest signal-to-noise ratio of the commonly used arrays, in order to make it independent of the size of the layout. For case where the dipole-dipole array has a slightly larger depth penetration for the larger n-factors. The dipole-dipole array gave resistivity in the lower parts of the inverted models that deviated significantly from those obtained using the Wenner . As we know that the sensitivity for the longest electrode layouts is focused towards the ends of the dipole-dipole electrode array giving a low relative sensitivity at depth in the lower central part of the model.

E.N. Athanasiou (2007)[18],state that mapping of the study area with more than one array types, which have different theoretical and practical merits and demerits, can give different geoelectrical models for example, Wenner and Wenner– Schlumberger arrays appear to have high vertical resolution, while dipole–dipole and pole–dipole arrays have high lateral resolution. And electrical resistivity tomography (ERT) has been extensively used in geophysical investigations .As compared to conventional measuring modes ERT prospecting can be successfully used in areas with complex geology, as it provides information in both lateral and vertical directions and defines in a qualitative manner the shape and depth of the subsurface targets. The resistivity acquisition instruments are used in order to carry out field measurements.

Muhammad Arshad,J.M Cheema (2007) [19], present that ERM solves the problems of groundwater in the alluvium formation aquifer as an inexpensive and useful method. Some uses of this method in groundwater are to determination of depth, thickness and boundary of an aquifer, determination of interface saline water and fresh water porosity

of aquifer, hydraulic conductivity of aquifer, transmissivity of aquifer, specific yield of aquifer, contamination of groundwater. As the Contamination usually reduces the electrical resistivity of pure water due to increase of the ion concentration. However, when resistivity methods are used, limitation can be expected if ground inhomogenities and anisotropy are presented. The apparent resistivity curves indicate that there were three sub-surface layers in the study area.

Summary: According to Wenner array method the depth of penetration and volume of measurement can be easily adjust by changing the spacing between inter electrode spacing. The measurement of soil apparent conductivity using direct current cause polarization effect and to minimized the polarization effect AC current should be apply. When current is apply electrode 70.5% of total current is flow above a plane $3S$ deep and 29.5% of total current is flow below a plane $10S$ where S is inter electrode spacing. So average resistivity is measured for a depth equal to inter electrode spacing. In Wenner array method the depth of penetration of electrode be at least 1:10 so that it can be regard as point charge. The soil ionization zone increase with the injected current. During measurement of soil EC_a inductive coupling causes error in measurement so to minimized the inductive coupling between inter electrode one should have to used low frequency. For homogeneous soil apparent electrical conductivity is independent of inter electrode spacing but in case of inhomogeneous soil if upper layer of soil is highly conductive then lower layer then most of current will flow through upper layer .Wenner array has high vertical resolution and Dipole-Dipole array has lateral resolution.

There are many methods used for soil resistivity measurement but there is no optimum method which gives us always valid and useful results, independent of soil characteristics. The methods used for soil resistivity measurement are Wenner array, Schlumberger array, pole dipole, dipole dipole, driven rod. The problem with the driven rod method is it has high contact resistance between soil and electrode, resistivity measurement through this method is not that much accurate and it is a costly method that's why the driven rod method is not used. The problem with the pole dipole method is field measurements are repeated twice in a normal and reversed directions (or recording in opposite directions) relative to the position of the current pole. However, due to the asymmetry of the pole-dipole array, it is quite often difficult to determine exactly the location of the anomalous structures. The problem with the Schlumberger method is it has a low signal to noise ratio, computation is also difficult as compared to the Wenner array method and it has low vertical resolution as compared to the Wenner array method. Whereas resistivity measurement using the Wenner array method is very easy and not difficult for calculation, signal to noise ratio is also high and it provides better results for small inter electrode spacing. In case of the dipole dipole method it provides better signal noise ratio, better resistivity measurement accuracy in soil subsurface area. To solve this problem we measure the soil apparent electrical conductivity with two well known methods: Wenner and Dipole Dipole, which have different geoelectrical models of investigation. The mapping of the study area with more than one array, which has different theoretical and practical merits and demerits. So combined data sets coming from Wenner and dipole dipole arrays allow us to produce superior results because the Wenner array appears to have high vertical resolution while the dipole dipole array has high lateral resolution.

The LabVIEW software and DAQ system based soil sensor measurement system is designed and developed in this thesis work which is not done yet before. The relation and comparative study of variation of soil apparent conductivity with soil salinity and the variation of soil apparent conductivity with urea concentration using Wenner and dipole dipole arrays is

carried out in this thesis work. labVIEW based soil sensor to measure soil apparent conductivity using DAQ NI PXI 4132 source and measurement unit and automatic data logging system to get real time and real world data. The sensor has remote sense capability which provided us facility to minimize the contact resistance between soil and electrode.

1.1 Soil properties:

Soils contain clay minerals and organic matter as a result of weathering and the addition of organic debris soils act as buffer zone between atmosphere and ground water, and provides plants a steady supply of nutrients. Soils have this sportive property because of electrical charges and large surface area of the clay minerals and humus. Because of their structure and chemical composition, the clay minerals and humus usually bear a negative charge. The charge is pH independent from the surfaces of the clay minerals and from acidic groups in humus, protons dissociate. This dissociation of protons gives a negative charge which is pH dependent. Hydrous oxides of iron and aluminium present in clay become positively charged at low pH by adsorption of protons.

1.2 Exchangeable cations And cation exchange capacity:

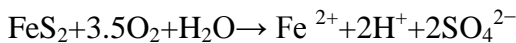
The negative charge of humus and part of the negative charge of clay minerals varies with pH. The capacity of the soils to hold exchangeable cations therefore also depends on the pH. There are many standard methods for the determination of cation exchange capacity (CEC) of the soil. In one of the method CEC is measured at the soil pH by displacing the exchangeable cations with a solution of potassium chloride, which is unbuffered. All the displaced cations are determined (by flame atomic absorption spectroscopy) and the summation is the cation exchange capacity, now known as the effective cation exchange capacity (ECEC). CEC is useful to in characterizing the soils in which most of the negative charge is pH dependent.

1.3 Acid - base ion exchange reaction in soils:

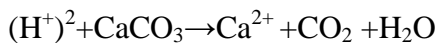
Essential trace metals are made available to plants as nutrients by the exchange of cations which is the important function of soils. Humus shows a very high cation exchange capacity. Trace metal nutrients are provided by the cation exchange in soil. The metal ions are taken up by the roots while H^+ is exchanged for the metal ions.



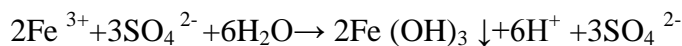
Soil acts as a buffer and resists change in pH. The buffer capacity of the soil depends on its type.



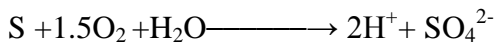
Most common plants grow best in soil with near neutral pH. Acid soils can be improved by the addition of lime.



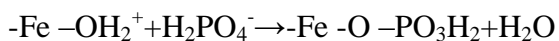
The soil may turn alkaline in the presence of basic salts such as Na_2CO_3 in drought-prone where there is less rain fall. Alkaline soils can be improved by the addition of aluminium sulphate or ferric sulphate.

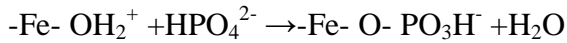


Sulphur also can be used to acidify the alkaline soils, since it is oxidised to sulphuric acid in the presence of bacteria present in the soil.



1.4 Anion retention: At low pH positive charges are developed on the surfaces of hydrated oxides of iron and aluminium as discussed previously and to a less extent on 1:1 clay minerals. Under these conditions Cl^- , NO_3^- and other anions are adsorbed and undergo exchange with each other. It can be explained as due to the formation of surface complex between anion and a metal, usually Fe or Al, in a hydrated oxide or clay mineral.





These reactions increase the negative charge on the surface. Silicate, sulphate and probably fulvic acid are adsorbed similarly to phosphate. Sulphate however forms a weaker complex than phosphate. Under field conditions the release of phosphate may depend partly on the generation of organic acids or OH⁻ by microorganisms.

1.5 Soil types and identification

When designing a soil sensor, we should have knowledge about different type soil to get most accurate results.

1.5.1 Soil texture

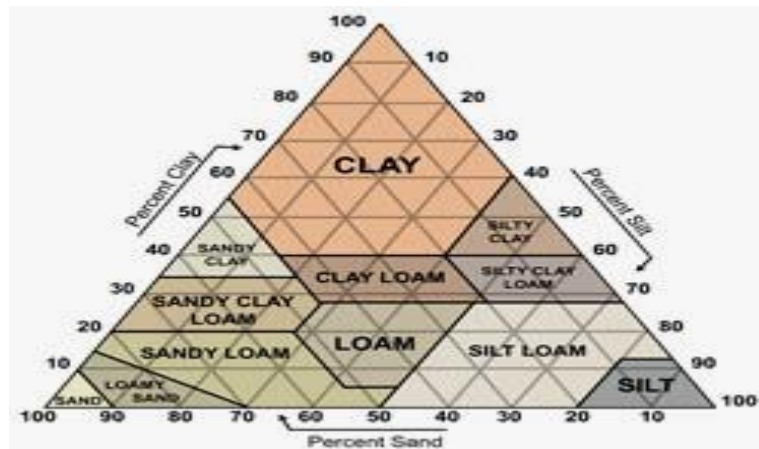


Fig 1.1, Soil texture triangle.

Most surface soils fall into five general textural classes. Each class name indicates the size of the mineral particles that are dominant in the soil. Intermediate texture soils are called loams. The sizes of these particles fall into the following sizes:

Sand is the coarsest (0.06 - 2 mm), silt is intermediate (0.002 - 0.06 mm) and clay is the finest (<0.002 mm). Soil texture refers to the relative proportion of sand, silt and clay size particles in a sample of soil. Clay size particles are the smallest being less than 0.002 mm in size. Silt is a medium size particle falling between 0.002 and 0.05 mm in size. The largest particle is sand with diameters between 0.05 mm for fine sand to 2.0 mm. Soil texture triangle are used to classify the texture class. The sides of the soil texture triangle are scaled for the

percentages of sand, silt, and clay. Clay percentages on the left side of the triangle are read from left to right across the triangle (dashed lines). The percentage of sand increases from right to left along the base of the triangle. Sand is on lower right towards the upper left portion of the triangle. The intersection of the three sizes on the triangle gives the texture class. For instance, if you have a soil with 20% clay, 60% silt, and 20% sand it falls in the "silt loam" class.

1.6 Soil horizons and sensor depth

Sensor depth of investigation of soil layer is depends on the interest of the user. Farmers will be interested in root zone depth while soil scientists may be interested in the soil horizons. The size distribution of primary mineral particles, called soil texture, has a strong influence on the properties of a soil. Particles larger than 2 mm in diameter are considered inert. The texture of soils is usually expressed in terms of the percentages of sand, silt, and clay and 12 textural classes have been defined. Each class, named to identify the size separate or separates having the dominant impact on properties, includes a range in size distribution that is consistent with a rather narrow range in soil behavior. The loam textural class contains soils whose properties are controlled equally by clay, silt and sand separates. Such soils tend to exhibit good balance between large and small pores; thus, movement of water, air and roots is easy and water retention is adequate. Soil texture, a stable and an easily determined soil characteristic, can be estimated by feeling and manipulating a moist sample, or it can be determined accurately by laboratory analysis.

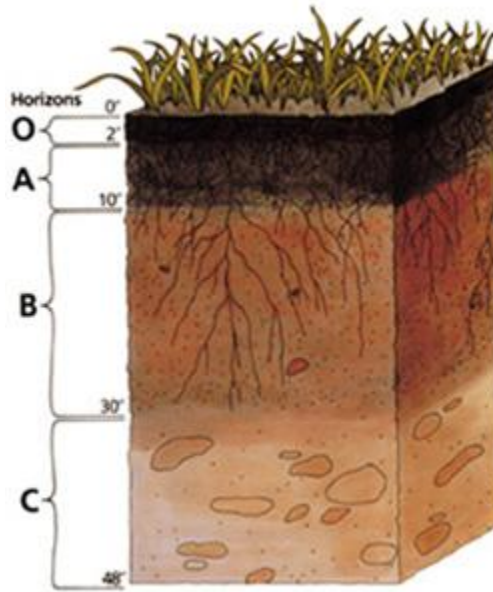


Fig 1.2, Soil horizons

The usefulness of soil sensor in each horizon is because different horizons have different hydrological properties. Some horizons will have high hydraulic conductivities and thus have greater and more rapid fluctuations in soil moisture. Some horizons will have greater bulk densities with lower effective porosities and thus have lower saturation values. Some horizons will have clay films that will retain water at field capacity longer than other soil horizons. Knowledge of the soil horizons in combination with an accurate soil sensor will allow the user to construct a more complete picture of the movement of water in the soil. The horizons that exist near the surface can be 6 to 40 cm in thickness. In general case, with increasing depth, the clay content increases, the organic matter decreases and the base saturation increases. Soil horizons can be identified by color, texture, structure, pH and the visible appearance of clay films.

1.7 Soil horizon names:

O: Decaying plants on or near surface

A: Top Soil, Organic Rich

B: Subsoil, Most Diverse Horizon and the Horizon with the most sub classifications

C: Weathered/aged parent material

1.8 Soil orders and taxonomy

There are thousands of types of soil around the world, they can all be classified under 12 major orders.

(a) Alfisols: Alfisols are found in in semiarid to moist areas. They formed under forest or mixed vegetative cover and are productive for most crops.

(b) Andisols: Andisols tend to be highly productive soils. They are common in cool areas with moderate to high precipitation, especially those areas associated with volcanic materials.

(c) Aridisols: Aridisols are soils that are too dry for the growth of mesophytic plants. They often accumulate gypsum, salt, calcium carbonate, and other materials that are easily leached from soil in more humid environments. Aridisols are common in the world's deserts.

(d) Entisols: Entisols occur in areas of recently deposited parent materials or in areas where erosion or deposition rates are faster than the rate of soil development; such as dunes, steep slopes and flood planes.

(e) Gelisols: Gelisols are soils that have permafrost near the soil surface, have evidence of frost churning, or ice segregation. These are common in the higher latitudes or high elevations.

(f) Histosols: Histosols have a high content of organic matter and no permafrost. Most are saturated year round, but a few are freely drained. They are commonly called bogs, moors, peats or mucks.

(g) Inceptisols: Inceptisols are soils of semiarid to humid environments that generally exhibit only moderate degrees of soil weathering and development. These occur in a wide variety of climates.

(h) Mollisols: Mollisols are soils that have a dark colored surface horizon relatively high in content of organic matter. The soils are base rich throughout and therefore are quite fertile.

(i) Oxisols: Oxisols are highly weathered soils of tropical.

(j)Spodosols: Spodosols formed from weathering processes that strip organic matter combined with aluminum from the surface layer and deposit them in the subsoil. These tend to be acid and infertile.

(k)Ultisols: Ultisols are soils in humid areas. They are typically acid soils in which most nutrients are concentrated in the upper few inches. They have a moderately low capacity to retain additions of lime and fertilizer.

(l)Vertisols: Vertisols have a high content of expanding clay minerals. They undergo pronounced changes in volume with changes in moisture. Because they swell when wet, vertisols transmit water very slowly and have undergone little leeching. They tend to be fairly high in natural fertility.

1.9 Water, air and particles in soil: Large quantities of water are required for the production of most plant materials. It is the basic transport medium for carrying essential plant nutrients from solid soil particles into plant roots and to the farthest reaches of the plant's leaf structure. The availability of nutrient solutes in water depends on concentration gradients. Water present in larger spaces in soil is relatively more available to plants and readily drains away. But water held in smaller pores or between the unit layers of clay particles is held more strongly. When the soil is water logged (water-saturated) it undergoes drastic change in physical, chemical and biological properties. Oxygen in such soil is rapidly used up by the respiration of microorganisms that degrade soil organic matter. Thus excess water in such soils is detrimental to plant growth, since it does not contain the air required for most plant roots. Most useful crops with the exception of rice cannot grow on water logged soils.

1.10 Micro and macro-nutrients in soil:

Plants require both macro nutrients and micro nutrients for their growth. The essential micronutrients for plants required are boron, chlorine, sodium, copper, iron, manganese, zinc, vanadium and molybdenum. They are required at trace levels and if present at higher levels, have a toxic effect. Most of these serve as components of essential enzymes. Some of these such as chlorine, manganese, iron, zinc and vanadium are likely to take part in photosynthesis. The essential macronutrients required for the plants are carbon, hydrogen,

oxygen, nitrogen, phosphorous, sulphur, potassium, calcium and magnesium. The atmosphere and water are the sources of carbon, hydrogen and oxygen. Nitrogen may be obtained by some plants, directly from atmosphere, through nitrogen fixing bacteria. The other essential macronutrients are obtained from the soil. Nitrogen, phosphorus and potassium (NPK) are commonly added to soil as fertilizers. Calcium deficiency in soil is due to calcium uptake by plants, and leaching by carbonic acid in acidic soils, and competitions with high levels of sodium, potassium and magnesium in alkaline soils. Calcium-deficient soils are generally treated with lime (liming) to provide the required calcium supply for plants. Magnesium is made available to plants through ion- exchanging organic matter or clays. Magnesium deficiency in soil is caused by high levels of calcium, sodium or potassium, sulphur in the form of assimilable SO_4^{2-} is taken up by the plants.

1.11 Nitrogen phosphorous and potassium in soil:

Management of N and P cannot be accomplished without the cognizance of the transformations of the nutrients that occur in nature, represented conveniently by Nitrogen and Phosphorous cycles. In agricultural systems, these transformations largely occur in the soil and are a function of complex interactions between the atmosphere, soil particles, soil bacteria, plant and animal life, and soil water. The nitrogen content in the soil is mostly organic in nature (90%) resulting from the decay of dead plants and animals, plant residues; and faeces, urine of animals, etc .It is hydrolysed to NH_4^+ , which can be oxidised to NO_3^- the action of bacteria in the soil.

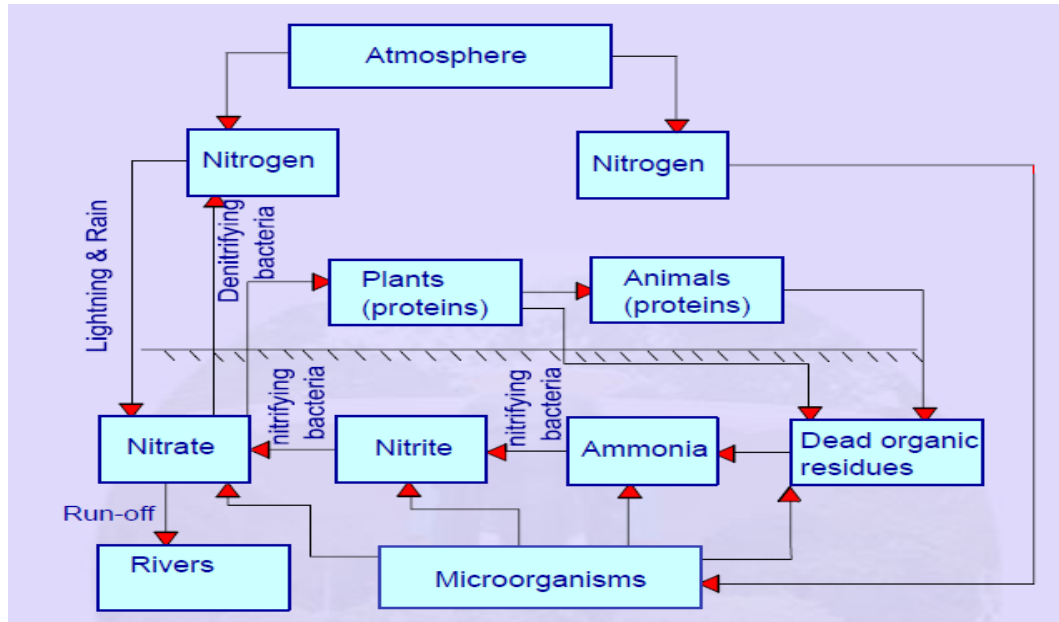


Fig 1.3, Nitrogen sinks and pathways in soil

Nitrogen bound to soil humus is responsible for maintaining soil fertility. It serves as reservoir for the nitrogen required by plants. An additional advantage of its property is that its rate of release of nitrogen to plants roughly parallels plant growth. Plants use NO_3^- from soil in general. When nitrogen is applied to soils as NH_4^+ (fertilizer), nitrifying bacteria converts it into NO_3^- for use by plants.

1.12 Phosphorous: The phosphate species by the plants are H_2PO_4^- and HPO_4^{2-} which exist at the soil pH. Orthophosphate is most available to plants at pH values near neutrality. In acidic soils, the orthophosphate ions are either precipitated by cations, like Al^{3+} , Fe^{3+} , etc.

1.13 Potassium: Potassium is one of the three major fertilizer elements required by plants. In general potassium status of soils is satisfactory only when enough potassium is added to compensate for the potassium removed in the crops. In areas where crops have been grown for many years without the addition of adequate potassium containing fertilizers, yield gradually decrease as the potassium from between the illite layers is slowly removed. If potassium fertilizer is then added, the increase in yield is not as great as might be expected. This is because the potassium returns to the illite structure rather than remaining immediately available for plant growth.

1.14 Saline soils and their remediation: Rainwater always contains small concentrations of many elements and when it percolates freely through a well drained soil, some of these dissolved ionic species are retained at various depths by interaction with soil particles. At the same time weathering and leaching can cause dissolution of elements from the soil. The composition of water in the soil pore is therefore determined by a combination of removal and dissolution reactions. In regions of heavy rain fall therefore, the drainage water usually contains only a very small concentration of ionic species and there is no significant accumulation of salts in any part of the soil profile. On the other hand in regions where there is limited precipitation and high rates of evaporation, the downward movement of water may be insufficient to leach out all the salts that accumulate near the soil surface. Salt-affected soils are therefore common in arid and semi-arid regions of the world. The percolation of rainfall over extended period of time, salinity related problems arise. The possibility of soils accumulating salt is enhanced, when the input irrigation water itself contains relatively high concentrations of salts. Soil salinity is usually confirmed by measuring the electrical conductivity of the saturated the soil. The sodium hazard from the dissolved salts is expressed as the sodium absorption ratio (SAR) where $SAR = [Na / (Ca + Mg)]$, with concentrations in millimoles per liter. The high concentration of accumulated salts in soil leads to several environmentally significant consequences. The large clay minerals present in the fine-grained soils become dispersed into individual particles and remain as separate units. The problem becomes acute for sodic and sodic-saline soils, where in the large (hydrated) monovalent sodium ion contributes most to dispersion of the clay minerals, resulting in losing its structure and thus becomes highly impervious to the movement of water.

1.5 Soil pH: Soil pH is probably the most commonly measured soil chemical property and is also one of the more informative. Like the temperature of the human body, soil pH implies certain characteristics that might be associated with a soil. Since pH (the negative log of the hydrogen ion activity in solution) is an inverse, or negative, function, soil pH decreases as hydrogen ion, or acidity, increases in soil solution. A soil pH of 7 is considered neutral. Soil pH values greater than 7 signify alkaline conditions, whereas those with values less than

7 indicate acidic conditions. Soil pH typically ranges from 4 to 8.5, but can be as low as 2 in materials associated with pyrite oxidation and acid mine drainage.

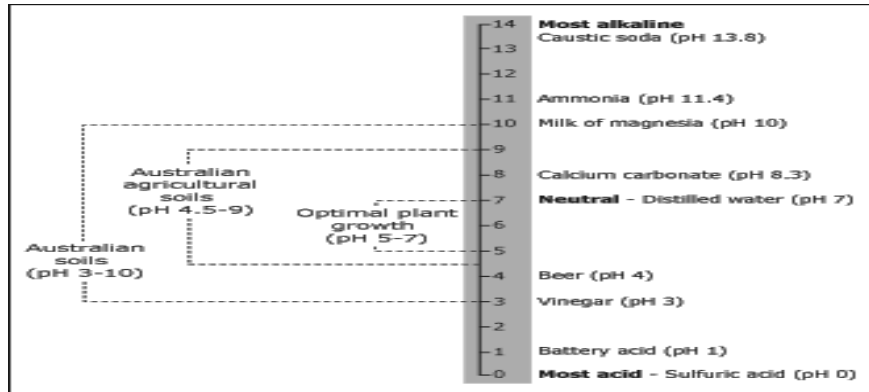


Fig1.4, pH scale, Australian soils, agriculture, plant growth and some common products

2.1 Electrical conductivity of soil:

Electrical conductivity is a measure of a material's ability to conduct an electric current. Conductivity is the reciprocal (inverse) of electrical resistivity. Electrical conductivity is commonly represented by the Greek letter σ , but κ or γ are also occasionally used. Conductivity is the reciprocal (inverse) of electrical resistivity, ρ

Electrical conductivity is commonly expressed in SI units of millisiemens per meter (mS/m) i.e. if the electrical conductance between opposite faces of a 1-metre cube of material is 1 siemens then the material's electrical conductivity is 1 siemens per meter. Soil EC measurements may also be reported in units of decisiemens per meter (dS/m), which is equal to the reading in mS/m divided by 100.

2.1.1 Apparent conductivity:

When we measure the conductivity of soil we measure the apparent conductivity of soil. The difference between conductivity and apparent conductivity is that conductivity is an intrinsic property of a microscopic volume of material, such as density. Apparent conductivity is a volume average of a heterogeneous half-space that attempt to represent a real-world heterogeneous earth by an imaginary homogeneous half-space, except that the averaging is not arithmetic but dependent on each instrument and how it is used.

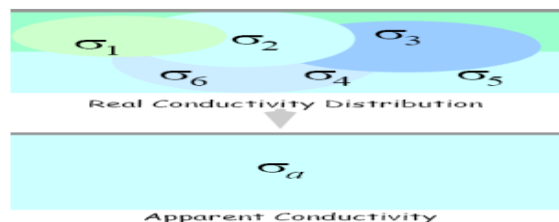


Fig 2.1, Relation between apparent conductivity and real conductivity distribution

Concept of apparent conductivity is representing a heterogeneous earth as a homogeneous earth having a single conductivity.

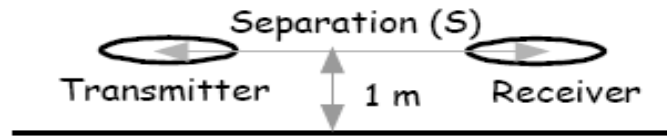


Fig 2.2, Basic model to measure Apparent Conductivity of Soil (EM Method)

2.2 Soil parameter measurement:

Different methods for the measurement of Soil parameter, we can use the different principles

2.2.1 Electrical and electromagnetic sensor:

Electrical and electromagnetic sensors use electric circuits to measure the capability of soil particles to conduct or accumulate electrical charge. When using these sensors, the soil becomes part of an electromagnetic circuit and the changing local conditions immediately affect the signal recorded by a data logger. Several such sensors have become commercially available. For example, one way to estimate soil electrical conductivity (EC) is by electromagnetic induction using Geonics Limited EM38 meter. The transmitting coil induces a magnetic field that varies in strength with soil depth. The magnetic field strength/depth can be altered to measure different depths of the soil to a maximum of 1.5 meters (about 5 ft.). A receiving coil measures the primary and secondary “induced” currents in the soil and relates the two to the soil electrical conductivity. Another instrument for mapping soil EC, the Veris® ECSurveyor™, measures EC more directly (galvanic contact resistivity method). It uses a set of coulter electrodes to send and receive electrical signals through the soil, indicating the EC for several different depths (always starting at the surface). Alternatively, several researchers have used capacitor-type soil sensors to study dielectric properties of the soil. It appears that both conductive and capacitive soil properties which can be measured on-the-go are affected by several agronomic soil characteristics, including soil type (mainly soil texture), soil salinity, moisture, and other characteristics. Capacitor-type sensors have been useful in determining volumetric moisture content in combination with the mechanical sensors described later.

2.2.2 **Optical and radiometric sensors:**

Optical and radiometric sensors use light reflectance or another electromagnetic wave signal (ground penetrating radar) to characterize soil. Optical sensors can simulate the human eye when looking at soil as well as measure near infrared, mid-infrared, or polarized light reflectance. Vehicle-based optical sensors use the same principle as remote sensing. Cost, timing, cloud coverage, and heavy plant residue cover are major issues limiting the use of bare soil imagery from these platforms. Close-range, subsurface, vehicle-based optical sensors have the potential to be used on-the-go in a way similar to electrical and electromagnetic sensors. They also have the ability to provide more information about individual data points since reflectance can be easily measured in more than one portion of the spectrum at a time. Several investigators have worked on the development of optical sensors to predict clay, organic matter, water content, and cation exchange capacity. In addition, several researchers have correlated soil reflectance with soil chemical properties soil NO₃ or phosphorus (P) content and pH. Some researchers are utilizing ground-penetrating radars (GPR) to investigate wave movement through the soil. Changes in wave reflections may indicate changes in soil density or restricting soil layers. Ground penetrating radar has great potential for geophysics, in general, and agriculture, in particular, especially to support water management. There is no widely used commercial optical or radiometric sensor developed for precision agriculture at this time.

2.2.3 **Mechanical sensors:**

Mechanical sensors can be used to estimate soil mechanical resistance (often related to compaction). These sensors use a mechanism that penetrates or cuts through the soil, and records the force measured by strain gages or load cells. Several investigators have developed prototypes that show the feasibility of continuous mapping of soil mechanical resistance, however, none of these devices is commercially available. The vertical blade instrumented with an array of strain gages was designed to detect spatial and depth variability of soil mechanical resistance within a soil profile between 5 and 30 cm (2 to 12

in). Simultaneously, a capacitor-type sensor detects spatial variability in soil moisture when two sets of photodiodes and light-emitting diodes protected with a sapphire window are used to determine soil reflectance in blue and red portions of the spectrum. This system is expected to help delineate field areas with potential compaction, excessive moisture and/or low organic matter level.

2.2.4 Acoustic and pneumatic sensors:

Acoustic and pneumatic sensors serve as alternatives to mechanical sensors when studying the interaction between the soil and an agricultural implement. Acoustic sensors have been investigated for determining soil texture and/or bulk density by measuring the change in noise level due to the interaction of a tool with the soil particles. Pneumatic sensors were used to measure soil air permeability. The pressure required to force a given volume of air into the soil at a fixed depth was compared to several soil properties, such as soil structure and compaction. At this time, the relationship between sensor output and the physical state of soil is poorly understood and additional research is needed.

2.2.5 Electrochemical sensors:

Electrochemical sensors can provide the most important type of information needed for precision agriculture soil nutrient availability and pH. When soil samples are sent to a soil-testing laboratory, a set of recommended laboratory procedures is performed. These procedures involve sample preparation and measurement. Some measurements are conducted using an ion-selective electrode (ISE), or an ion selective field effect transistor (ISFET). These electrodes detect the activity of specific ions (NO_3 , K, or H in the case of pH).

2.2.6 Electrical and electromagnetic sensors

There are two types of EC sensors currently used to measure soil EC in the field

1. Contact method
2. Non- Contact method
3. Spectral Reflectance Method

2.2.6. a Contact method

This type of sensor uses coulter electrodes to make contact with the soil and to measure the electrical conductivity. In this approach, two to three pairs of coulter electrodes are mounted on a toolbar; one pair provides electrical current into the soil (transmitting electrodes) while the other coulter electrodes (receiving electrodes) measure the voltage drop between them. Soil EC_a information is recorded in a data logger along with location information. A global positioning system (GPS) provides the location information to the data logger. The contact sensor is most popular for precision farming applications because large areas can be mapped quickly and it is least susceptible to outside electrical interference. The disadvantage of this system is that it is bulkier than non-contact sensors, and cannot be used in small experimental plots and some small fields

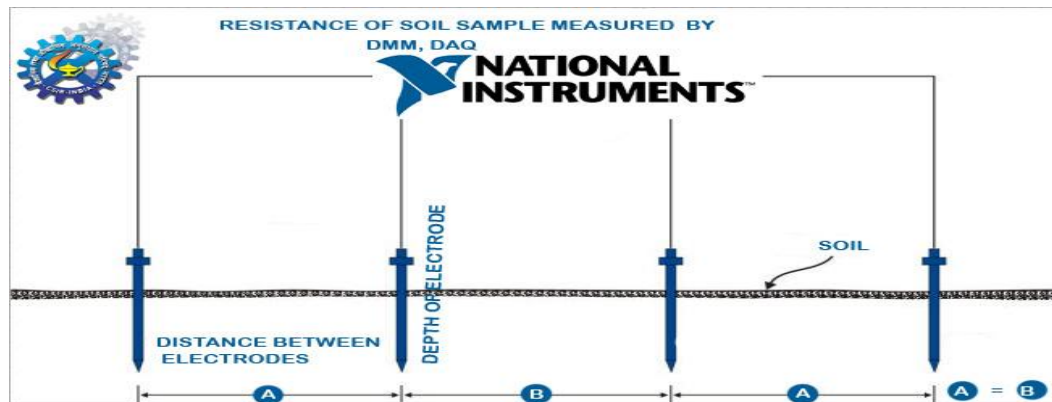


Fig 2.3, LabVIEW Based Virtual model of 4-Probe Method

2.2.6. b System design approach of contact type sensor

1. Development of four probe sensor response for various design dimensions and variations, fabrication etc. The soil conductivity mapping sensor will have two arrays to investigate soil at depths, up to 0-30 cm.
2. Excitation variations of electronics, tuning of sensor response, signal

conditioning , optimized electronics designing Interfacing with processing cards

3. Data generation
4. Data logging
5. Software developments
6. Interfacing to human m/c interfaces and external world

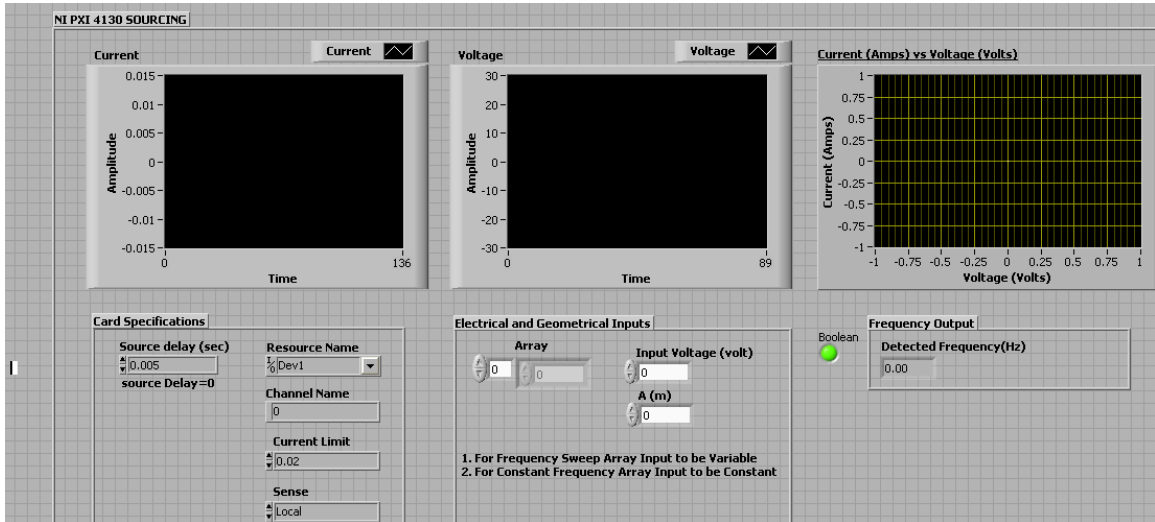


Fig 2.4, front panel of sourcing part of labVIEW base soil sensor

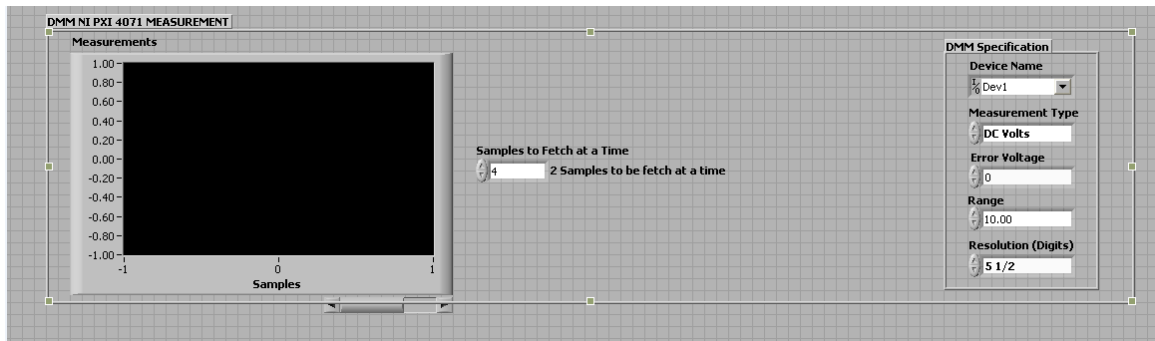


Fig 2.5, front panel of sensing part of labVIEW base soil sensor

2.2.6.c Analog architecture of the PXI

In a dual control loop where voltage and current work together through the power amplifier stage, the PXI-4132 can operate in either constant voltage mode or constant current mode. In constant voltage mode, the PXI-4132 acts as a precision voltage source, and, regardless of the load, the voltage across the output terminals is held constant at the programmed value up to the programmed current limit. In constant current mode, the PXI-

4132 acts as a precision current source, and, regardless of the output voltage, the current through the load is held constant at the programmed value up to the programmed voltage.

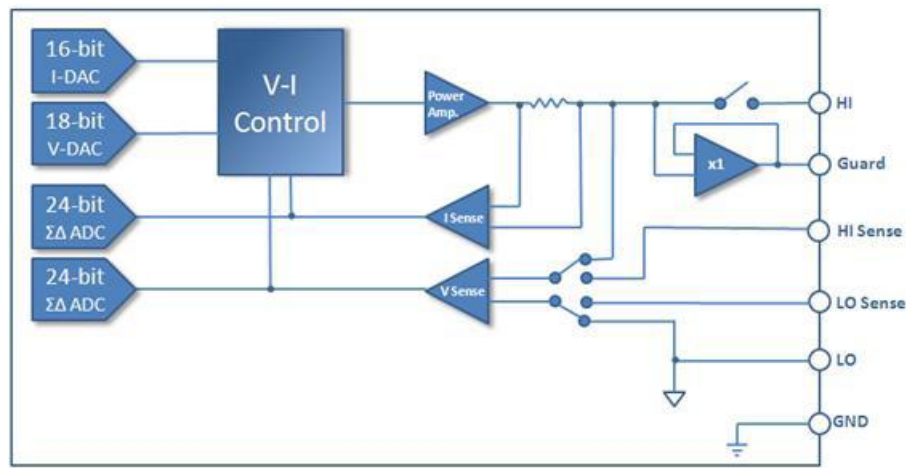


Fig 2.6, Block Diagram of PXI-4132 Precision SMU Analog Front End

A measurement circuit on the PXI-4132 can simultaneously read the voltage and current values present at the output terminals. These measurements are performed by two analog-to-digital converters (ADCs) that are synchronized at all times. To use sense terminals when remote sense is enabled (constant voltage mode only) to compensate for current-resistance loss drops due to cables and switches. The PXI-4132 also features Guard terminals on the output connector. Guard terminals is use to implement guarding techniques in cabling and test fixtures.

2.2.6.d Optimizing measurement speed and resolution of PXI:

The PXI-4132 uses integrating ADCs for sampling voltage and current [19]. The PXI-4132 measurement circuitry operates in one of the three active states:

- Signal conversion — During signal conversion, the PXI-4132 samples the input signal for the programmed aperture time of the device.
- Zero conversion — When auto zero is enabled, the PXI-4132 samples with the signal disconnected and uses that to compensate for internal offsets. Zero conversion has the same aperture as the signal conversion.
- Settling time — During settling time, the analog circuitry of the device settles before the next measurement state occurs.

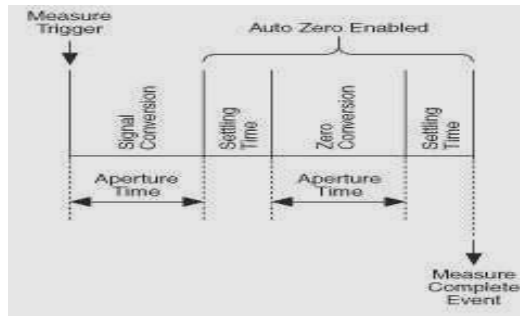
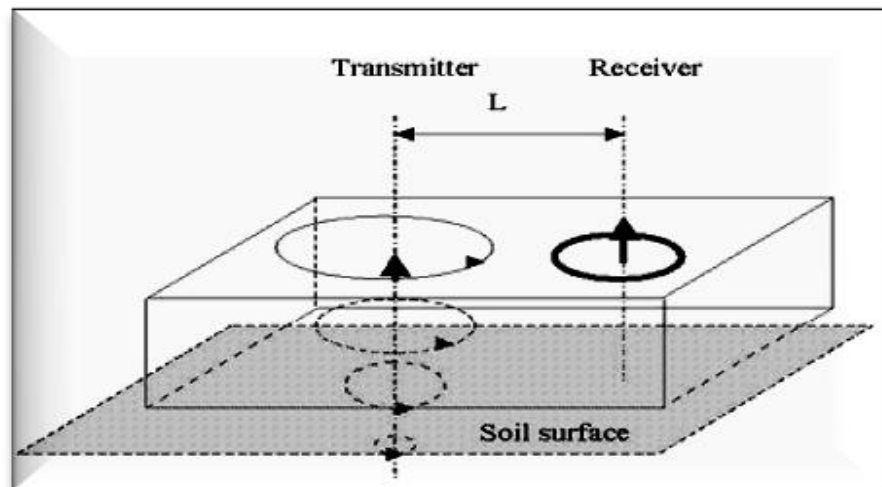


Fig 2.7, PXI-4132 Precision SMU Measurement Cycle

2.2.6.e Non-Contact Method

This type of EC sensor works on the principle of Electromagnetic Induction (EMI). EMI does not contact the soil surface directly.



Fir 2.8, Non- Contact method of measuring Soil EC.

The instrument is composed of a transmitter and a receiver coil usually installed at opposite ends of a non-conductive bar located at opposite ends of the instrument.

2.2.7 Spectral Reflectance Method:

This type of sensor works on the principle of Reflectance of light from the soil. There is no involvement of the field generation (as in the case of non contact type method) or supply of current to the soil to measure the potential difference (as in the case of contact type sensor). This instrumentation consists of a source of light, detector and related circuitry to study the amount of light reflected by the soil sample which is related to the properties of soil

CHAPTER 3

SOIL RESISTIVITY MEASUREMENT METHOD

3.1 Soil Resistivity Measurement: The basic principles and the purpose of electrical resistivity surveys are to determine the resistivity distribution of the sounding soil volume. Electric currents are supplied to the soil and the resulting potential differences are measured. Potential difference patterns provide information on the form of subsurface heterogeneities and of their electrical properties of soil. The greater the electrical contrast between the soil matrix and heterogeneity, the easier is the detection. Electrical resistivity of the soil can be considered as a proxy for the variability of soil physical properties. The current flow line distributions depend on the medium under investigation. For a simple body, the resistivity $\rho(\Omega\text{m})$ is defined as $\rho=R(S/L)$ where R being the electrical resistance (Ω), L the length of the cylinder (m) and S is its cross-sectional area (m^2). The electrical resistance of the cylindrical body $R(\Omega)$, is defined by the Ohm's law as $R=V/I$. with V being the potential (V) and I is the current (A). Electrical characteristic is also commonly described by the conductivity value $\sigma(\text{Sm}^{-1})$, equal to the reciprocal of the soil resistivity so $\sigma=1/\rho$. In a homogeneous and isotropic half-space, electrical equipotentials are hemispherical when the current electrodes are located at the soil surface. The current density $J(\text{A}/\text{m}^2)$ has then to be calculated for all the radial directions with $J=(I/2\pi r^2)$, where $2\pi r^2$ is the surface of a hemispherical sphere of radius r . The potential V can then be expressed as follows:

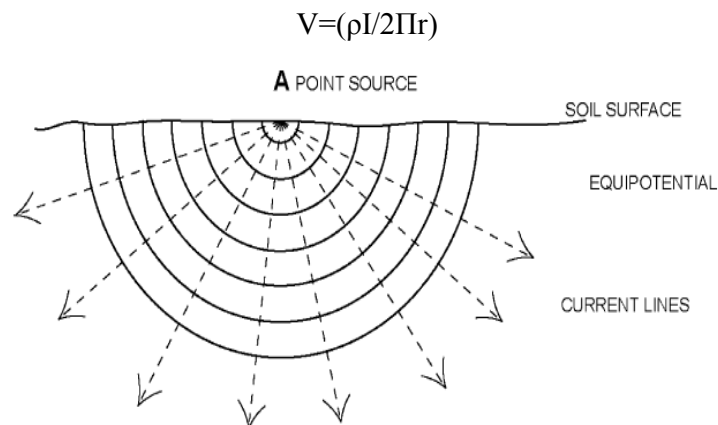


Fig 3.1, Distribution of the current flow in a homogeneous soil.

Measurement of electrical resistivity usually requires four electrodes: two electrodes called A and B that are used to inject the current (“current electrodes”), and two other electrodes called M and N that are used to record the resulting potential difference (“potential electrodes”). The potential difference ΔV measured between the electrodes M and N is given by the equation.

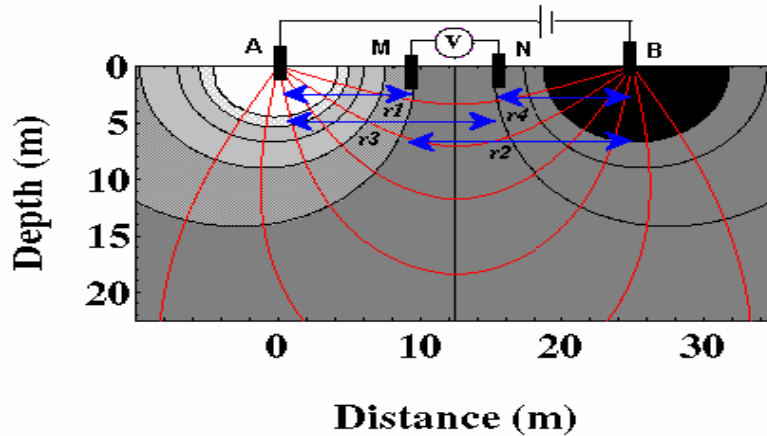


Fig 3.2, Field variations due to flow of current [Reference 20]

$$\Delta V = (\rho I / 2\pi) [(1/AM) - (1/BM) - (1/AN) + (1/BN)]$$

3.2 Introduction to Wenner Array Method

soil resistivity measurement arrangement based on the Wenner method. The generator causes a current to flow in the current probe leads. Although alternating current is used, at any given instant, the two current probes discharge currents $+I$ and $-I$, respectively. The potential difference ΔV between the two potential probes can be measured through the voltmeter which is connected to the potential probes via the potential leads. The apparent resistance $R = \Delta V / I$ is then obtained. Approximating the current electrodes by small hemispheres, the soil resistivity ρ can be computed using $\rho = 2\pi a R$. Where “a” is inter electrode spacing.

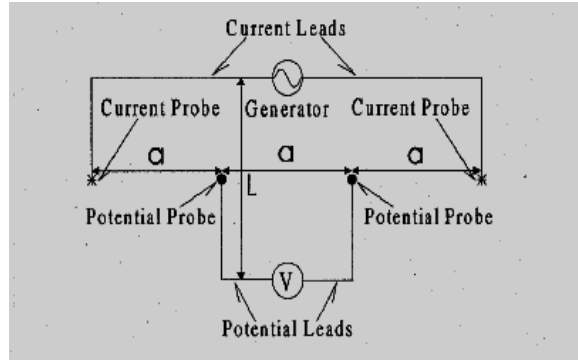


Fig 3.3, Soil Resistivity Measurement Set-Up Based on Wenner Method

In uniform earth the apparent resistivity is same as soil resistivity and it is independent of electrode spacing. In case of nonhomogeneous soil the depth of penetration of current into the earth changes with the change in the electrode spacing. The principle of the four point method for two layer soil as shown in fig 3.3 where the top layer resistivity ρ_1 is shown as hemispherical shells around the current probes 1 and for the purposes of this analysis the top layer thickness h is limited to the probe spacing S or less ($h < S$). Because of the current flowing into the ground at 1, a potential is developed at 3 which is a function of ρ_1 and ρ_2 . The potential at point "a", in soil resistivity ρ_1 at a distance h from point 1 is,

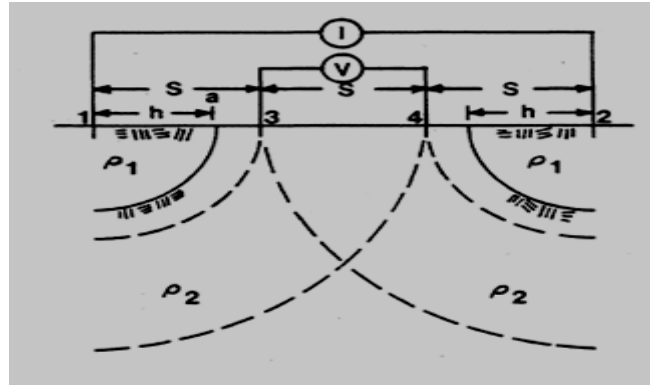


Fig 3.4, Resistivity measurement for two layers [Reference 3]

$$V_{a1} = I\rho_1 / (2\pi h) \quad \dots\dots(1)$$

Where

V_{a1} = potential at distance h (volts)

ρ_1 = soil resistivity of top layer (ohm-meters)

h = thickness of top layer ρ_1

The potential difference between points 3 and "a" in soil resistivity ρ_2 can be expressed as:

$$V_{3'1} - V_{a'1} = (I\rho_2/2\pi S) - (I\rho_2/2\pi h) \quad \dots\dots(2)$$

Where

$V_{3'1} - V_{a'1}$ = potential difference between points 3 and "a" (volts)

ρ_2 = soil resistivity of lower soil layer (ohm-meters)

S = probe spacing (meters)

h = thickness of top layer ρ_1

The potential at point 3 due to the current flowing into the ground at 1 can be expressed

$$V_{31} = V_{a1} + (V_{3'1} - V_{a'1}) = I\rho_1 / (2\pi h) + [(I\rho_2/2\pi S) - (I\rho_2/2\pi h)] \quad \dots\dots(3)$$

A potential is also developed at 3 due to the current flowing from the ground at 2 from Fig 3.4. Use of the same methodology yields the following expression for

$$V_{32} = -I\rho_1/(2\pi h) - [(I\rho_2/4\pi S) - (I\rho_2/2\pi h)] \quad \dots\dots(4)$$

From equation (3) and (4) we get

$$V_3 = V_{31} + V_{32} = I\rho_2/4\pi S \quad \dots\dots (5)$$

Similarly, the potential developed function of the current flowing in 1 and from the earth at 2.

$$V_4 = -I\rho_2/4\pi S \quad \dots\dots(6)$$

The potential difference between potential probes 3 and 4 is

$$V = V_3 - V_4 = I\rho_2/4\pi S + I\rho_2/4\pi S = I\rho_2/2\pi S \text{ [from equation (5) and (6)]}$$

The "measured resistance"

$$R_w = V/I = \rho_2/2\pi S$$

The "measured soil resistivity", ρ_w is

$$\rho_w = 2\pi SR_w = 2\pi S R = 2\pi S \left[\frac{\rho_2}{2\pi S} \right] = \rho_2$$

The above analysis is based on the condition $h \leq S$. For the condition where the top layer thickness is greater than S , but less than $2S$ ($S < h < 2S$) the same methodology indicates a transition in measured values from ρ_2 to ρ_1 . For the condition where h is equal to or greater than $2S$ ($h > 2S$), the measured values reflect only ρ shows the anticipated four point soil resistivity measurements for a two layer soil condition where the top layer ρ_1 is greater than $\rho_2 = 1000$ ohm-meters with a thickness $h = 1.829$ meters (6 feet). The anticipated four point soil resistivity measurement, ρ_w is shown as a function of several values of ρ_2 . Four point soil resistivity measurements for a two layer soil condition where the top layer ρ_1 is less than ρ_2 and $\rho_1 = 100$ ohm-meters with a thickness $h = 1.829$ meters (6 feet). The anticipated four point measurement, ρ_w , is shown as a function of several values of ρ_2 . The four electrodes 1, 2, 3 and 4 are placed on the surface of the earth in a straight line with a distance S between two adjacent electrodes. Let current I enter the earth at electrode 1 and leave at electrode 2.

Assume that the earth is of uniform resistivity, ρ . Because of current flowing into ground from 1 and out of ground from 2, the potential at 3 is:

$$V_3 = I\rho/2\pi[(1/S)-(1/2S)] \dots\dots\dots(7)$$

And the potential at 4:

$$V_4 = I \rho/2\pi [(1/2S)-(1/S)] \dots\dots\dots (8)$$

Subtracting equation (7) from equation (8), the potential difference between 3 and 4 is.

$$V = I \rho/2\pi S$$

$$(V/I) = R = \rho/2\pi S \dots\dots\dots (9)$$

$$\rho = 2\pi SR \dots\dots\dots(10)$$

3.3 Earth current penetration: Wenner test determines its resistivity from current flow in a much different volume of earth. For the Wenner Method, current penetration into homogeneous earth can be realized by integrating the current density formula along the plane midway between the current probes from $Z = 0$ to $Z = Z_1$ and laterally from $Y = -\infty$ to $Y = +\infty$.

$$I_1 = \int_0^{Z_1} \int_{-\infty}^{+\infty} \sigma(Y, Z) dY dZ$$

$$\sigma = (3S/2)(I/\Pi) / [Y^2 + Z^2 + 9S^2/4]^{3/2}$$

The current flow (I_1) above the Z_1 plane will be determined by:

$$I_1 = (2/\pi) I \arctan(2Z_1/3S)$$

Where: "S" is the probe spacing, 3S is the distance between current probes and I is the total current flowing between current probes.

Thus, in homogeneous earth 70.50% of the total current flows above a plane 3S deep and 29.5% flows below. And, 90.5% of the total current will flow above the plane that is 10 S deep. It can be seen from this current distribution that the rule of thumb which states average resistivity is measured for a depth equal to probe spacing is only approximate. In fact for two layer earths, if the bottom layer's resistivity is lowest, more current will flow deeper. Conversely, if the top layer has the lowest resistivity less current will flow deep

3.4 Measurement on soil with alternating current

The conductivity and dielectric constant were both found are dependent upon the moisture content of the soil, except when it was within the normal range for the site under consideration. The effect of frequency on conductivity was more marked for dry than for moist soil, and in the latter case there was a small although definite rise in the conductivity at the highest frequencies. The dielectric constant decreased with increase of frequency towards a limiting value for moist soil, whereas for dry soil the variation of dielectric constant with frequency was very small. From measurements made on samples of different types of soil it

was found that the temperature coefficient of the conductivity at 20°C was about 2 to 3 per cent per deg C, whereas the effect of temperature on the dielectric constant was negligible

3.5 Dependence of electrical properties on moisture content

The electrical properties of soil and their variation with frequency depend upon the moisture content of the specimen under examination. For example illustrates set of conductivity measurements made at a frequency of 1200 kilocycles per sec. on samples and field soil from four different sites within the .It is seen that the conductivity of the dry soil is of the order of 105 e.s.u. (9 mega ohms per cm cube), while at a moisture content of between 12 and 26 per cent the conductivity approaches a limiting value of between (9000 to 4500 ohms per cm cube).The corresponding values of dielectric constant are shown in Fig.3.5, from which it is seen that the value is 3 or 4 for the dry soil, rising to 30 or 40 for the very moist soil. It is worthy of note that the limiting values to which the curves in Fig 3.5, approach, are for moisture contents.

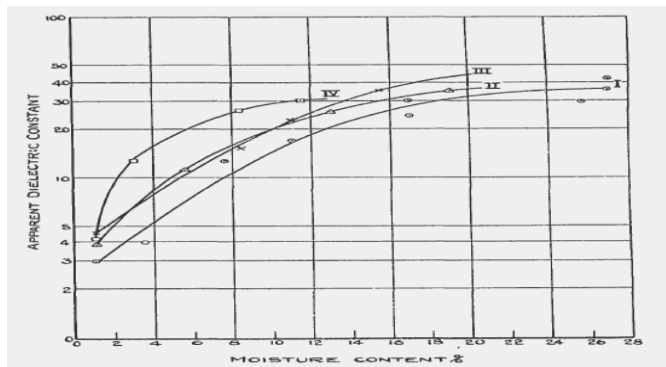


Fig 3.5, Relation between apparent dielectric constant and moisture content

3.6 Effect of temperature on soil Constants.

Frequency at 50 Hz measured the conductivity of the soil at temperatures between -15° C. and + 20° C. With a view to ascertaining the corresponding values at radio frequencies was subjected to a temperature variation from - 3° to + 30° C, while the electrical measurements were made at a frequency of 1200KHz then the variation of conductivity with temperature is in Fig.3.6.

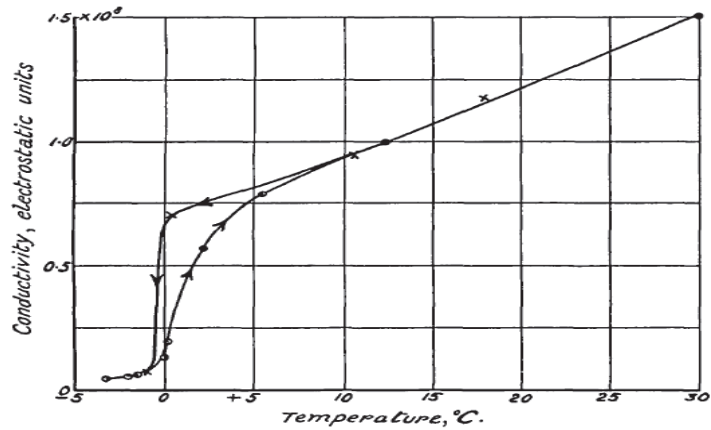


Fig 3.6, Variance of conductivity with temperature

3.7 Penetration of electric waves into ground:

From knowledge of the electrical properties of the ground it is now possible to calculate the rate of attenuation of the current flowing at any depth as a result of an electrical disturbance produced at the surface. If the amplitude of the current flowing at the surface be I_0 at a frequency corresponding to the wavelength λ

Then the amplitude of the current flowing at a depth x is I_x ,

$$\text{Where, } I_x/I_0 = e^{-(2\pi x/\lambda)\alpha}$$

$$\text{and } \alpha^2 = \sigma/f \sqrt{[(k^2 f^2 / 4\sigma^2 + 1) - (k/2)]}$$

In cases where $(kf/2\sigma) \ll 1$, the formula for α reduced to

$$\alpha = \sqrt{[(\sigma/f) - (k/2)]}$$

With the aid of this formula the relation between current and depth were calculated.

3.8 Dipole-Dipole array method

The dipole-dipole array is most convenient in the field, especially for large spacings. All the other arrays require significant lengths of wire to connect the power supply and voltmeter to their respective electrodes and these wires must be moved for every change in spacing as the

array is either expanded for a sounding or moved along a line. The convention for the dipole-dipole array the current and voltage spacing is the same, a , and the spacing between them is an integer multiple of ' a ' as shown in Fig 3.7.

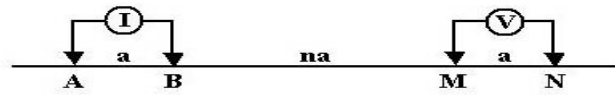


Fig 3.7, Dipole Dipole array

The apparent resistivity is given by:

$$\rho_A = \frac{V}{I} \frac{\pi a n (n+1)(n+2)}{}$$

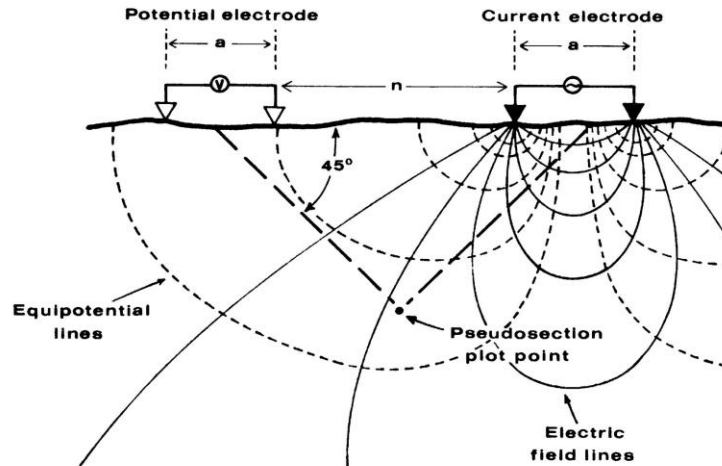


Fig 3.8, Electrical field of Dipole-Dipole array method

The Wenner configuration to characterize soil electrical conductivity it shows that the depth of penetration of sounding depends on the approximately current electrode separation in addition to the electrical properties of the medium. For dipole-dipole arrays, this depth depends on the value of ' na ' as shown in Fig 3.8. In general, there is no single optimum array which can always give valid and useful results, independent of the target characteristics. Geoelectrical models produced by the inversion of different arrays over the same structure can be different. In order to use all available information and produce a potentially more reliable geoelectrical model of the earth we can combined inversion of the most commonly used arrays (dipole-dipole, Wenner) is examined. The mapping of the study area with more

than one array types, which have different theoretical and practical merits and demerits, can give different geoelectrical models. For example, Wenner arrays appear to have high vertical resolution, while dipole–dipole arrays have high lateral resolution .The combined data sets coming from different configurations carry more information than the individual data sets.

3.9 Joint inversion of Wenner and Dipole–Dipole

It has been shown that the dipole–dipole and Wenner data presented different features; due to the length of the spread used in the deployments, the dipole–dipole gave good lateral resolution but low penetration, in spite of the larger value of n while the Wenner array, carried out by performing vertical soundings, defined the soil in depth but with low lateral resolution of the shallow layers. To improve the overall final electrical model, we can tested the joint inversion of both sets of data. When we analyzed the depth of penetration for each set separately, we found that using the Wenner configuration the depth of investigation was high while for dipole–dipole less than Wenner . Although the dipole–dipole configuration gives very good shallow lateral resolution it does not have high depth penetration, at least with the spacing required to resolve and characterize the shallow structure. For the joint Wenner and dipole–dipole joint inversion reaches a greater depth of investigation. The joint inversion of Wenner and dipole–dipole data gives a model with deeper penetration than both dipole–dipole and Wenner alone, and also gives better shallow lateral resolution than Wenner alone.

CHAPTER 4

RESULTS AND DISCUSSION

Initially we design a soil electrical conductivity sensor to measure the soil apparent electrical conductivity EC_a . The basic method we are used to measure the apparent electrical conductivity using Wenner array and Dipole Dipole array and we are trying to do comparative study between these two well known methods. First of all we we made a correlation between salt salinity and electrical conductivity through experiments. We dissolve different amount of salt to five litter distil water and pour into surface of one meter square area and after one day we performed experiments on that field.

4.1 Data sheet for Wenner array method

Measurement of electrical conductivity variation with different amount of salt in a particular inter electrode spacing using Wenner method.

Inter electrode spacing (mts)	I/P Current (A)	Freq (Hz)	O/P Voltage (Volt)	Resistance (Ohm)	Resistivity (Ohm-m)	Salt Con. (gm/L)/m ²	Conductivity (S/m)
0.1	0.0199	9.9	0.4981	24.9228	15.6594	100	0.063859
0.1	0.0199	9.9	0.3580	17.9123	11.25466	200	0.088852
0.1	0.0199	9.9	0.3183	15.9256	10.00635	300	0.099937
0.1	0.0199	9.9	0.2519	12.6051	7.920073	400	0.126261
0.1	0.0199	9.9	0.2236	11.1904	7.031163	500	0.142224
0.1	0.0199	9.9	0.2004	10.0305	6.302375	600	0.15867
0.1	0.0199	9.9	0.1320	6.60892	4.152507	700	0.240818
0.2	0.0199	9.9	0.3701	18.5199	23.27281	100	0.042969
0.2	0.0199	9.9	0.3358	16.8028	21.11512	200	0.047359
0.2	0.0199	9.9	0.2788	13.9520	17.53271	300	0.057036
0.2	0.0199	9.9	0.2739	13.7041	17.22115	400	0.058068
0.2	0.0199	9.9	0.2581	12.9156	16.23029	500	0.061613
0.2	0.0199	9.9	0.2315	11.5835	14.55627	600	0.068699
0.2	0.0199	9.9	0.2027	10.1411	12.74375	700	0.07847
0.3	0.0199	9.9	0.7155	35.7977	67.47722	100	0.01482

Inter electrode spacing (mts)	I/P Current (A)	Freq (Hz)	O/P Voltage (Volt)	Resistance (Ohm)	Resistivity (Ohm-m)	Salt Con. (gm/L)/m ²	Conductivity (S/m)
0.3	0.0199	9.9	0.3305	16.5401	31.17751	200	0.032074
0.3	0.0199	9.9	0.2520	12.6095	23.76847	300	0.042073
0.3	0.0199	9.9	0.2472	12.3694	23.31588	400	0.042889
0.3	0.0199	9.9	0.2414	12.0825	22.77498	500	0.043908
0.3	0.0199	9.9	0.2299	11.5027	21.68223	600	0.046121
0.3	0.0199	9.9	0.2099	10.5038	19.7992	700	0.050507

4.2 Variation of Electrical conductivity with different amount of salt concentration using Wenner array method

4.2.1 Measurement of EC_a using Wenner array method at 0.1m spacing

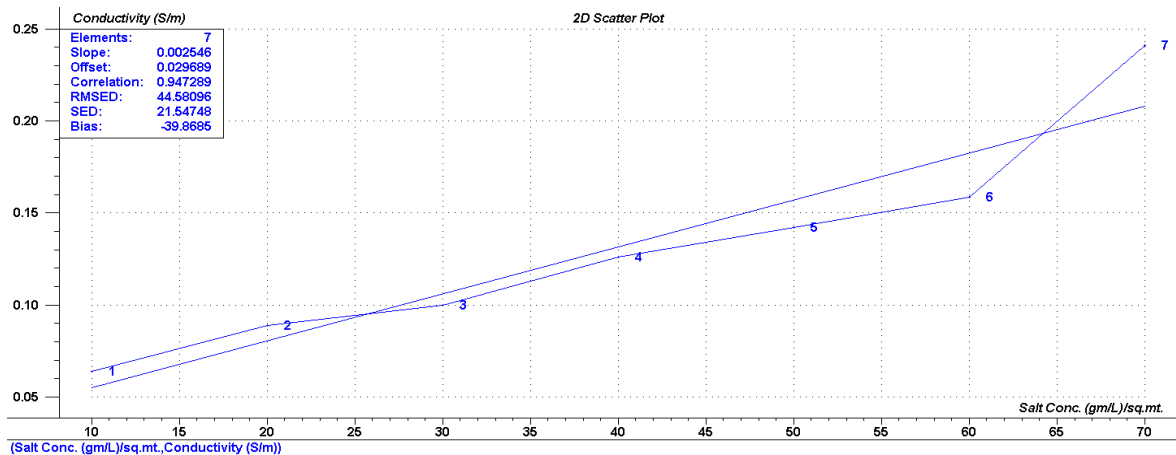


Fig 4.1, Variation of soil EC_a with different salt concentration at 0.1m spacing using Wenner array

From the above Fig 4.1 we see that at 0.1 m inter electrode spacing as salt concentration increase soil electrical conductivity also increases. For linear curve correlation value should be 1 but in Fig 4.1 correlation value is 0.9473 which is nearly equal to one.

4.2.2 Measurement of EC_a using Wenner array method at 0.2 m spacing

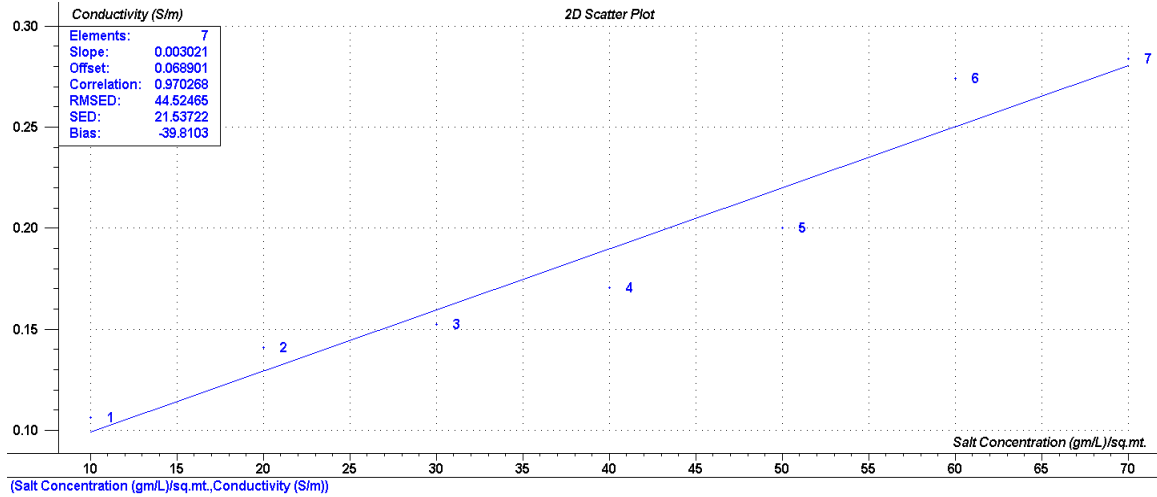


Fig 4.2 Variation of soil EC_a with different salt concentration at 0.2 m spacing using Wenner array.

From the above Fig 4.2, we see that at 0.2 m inter electrode spacing as salt concentration increases soil electrical conductivity also increases. For linear curve correlation value should be 1 but in Fig 4.2 correlation value is 0.9702 which is nearly equal to one.

4.2.3 Measurement of EC_a using Wenner array method at 0.3 m inter electrode spacing

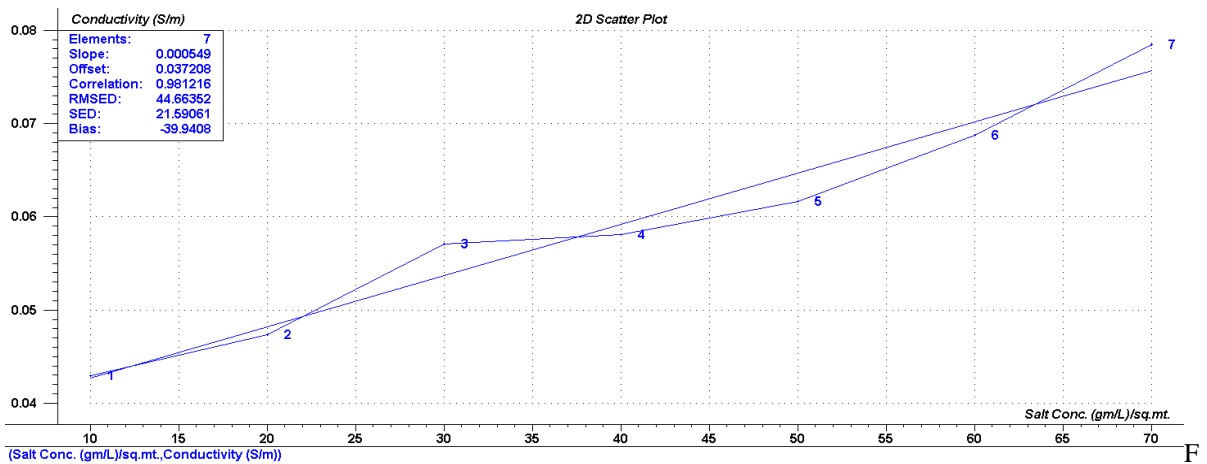


Fig 4.3, Variation of soil EC_a with different salt concentration at 0.3 m spacing using Wenner array

From the above Fig 4.3 we see that at 0.3 m inter electrode spacing as salt concentration increases soil electrical conductivity also increases. For linear curve correlation value should be 1 but in Fig 4.3 correlation value is 0.981216 which is nearly equal to one.

4.3. PLS analyses

In PLS method the number of original variables is reduced to latent variables or latent structures or principle components or factors. The regression is done between the X-variables or predictors and Y-variables or responses. For example if X-variables salt concentration and concentration square is two factors, factor 1 and factor 2 then the regression of X-variables and Y-variables is done for factor 1 and factor 2.

4.3.1 Scores plot

The scores plot is used to detect the pattern of the samples and the outliers in the samples. An outlier is a sample which is far from groups of samples. The outliers which do not belong to the groups of samples do not form the pattern with the group of the samples and reduce the correlation coefficient value and increase the error in the calibration equation and reduce the linearity of the relationship.

4.3.2 Loadings plot

The loading plot is used to detect the percentage of the explained variance of X-variables and Y-variables along factors. The variables which are on the same direction from the centre of the plot and close to each other are highly positively correlated and the variables which are on the opposite direction from the centre of the plot are highly negatively correlated.

4.3.3 Regression coefficients plot

The regression coefficients plot is used to detect regression coefficients of the calibration equation for the factors.

4.3.4 Predicted vs measured plot

The predicted vs. measured plot is used to detect the correlation coefficient, root mean square error of calibration RMSEC, root mean square error of prediction RMSEP, offset and slope of the regression line corresponding to calibration equation and validation of the calibration equation for the factors. The correlation coefficient should be equal to 1. The RMSEC, RMSEP, offset should be equal to 0. The slope should be equal to 1.

4.3.5 PLS Analysis for Wenner Array Method:

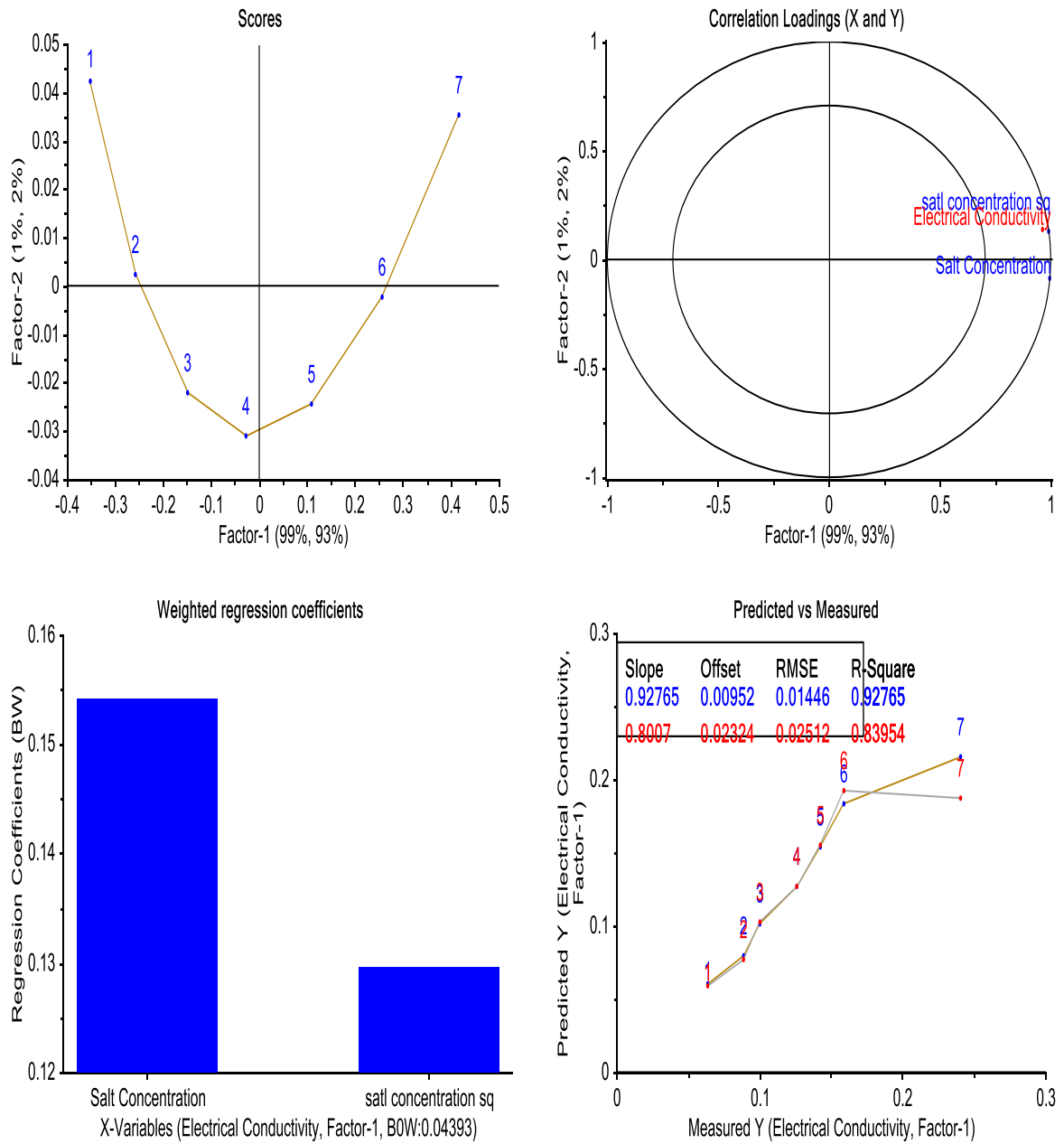


Fig 4.4, PLS analysis for factor1 (using Wenner array method) at 0.1 m inter electrode spacing where factor1 is salt concentration .

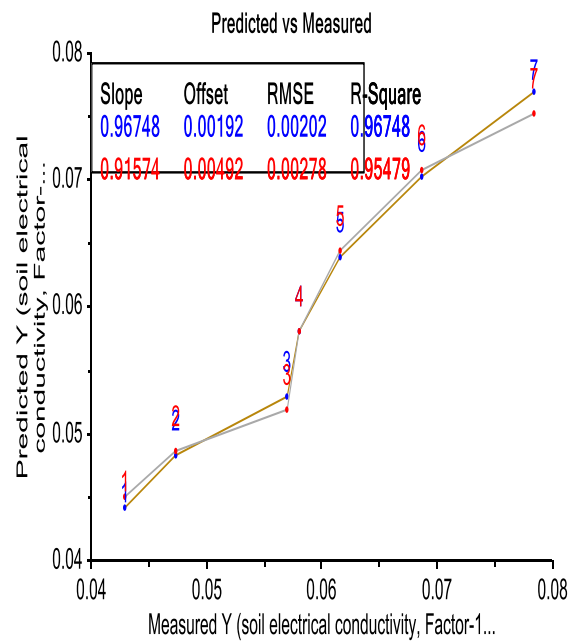
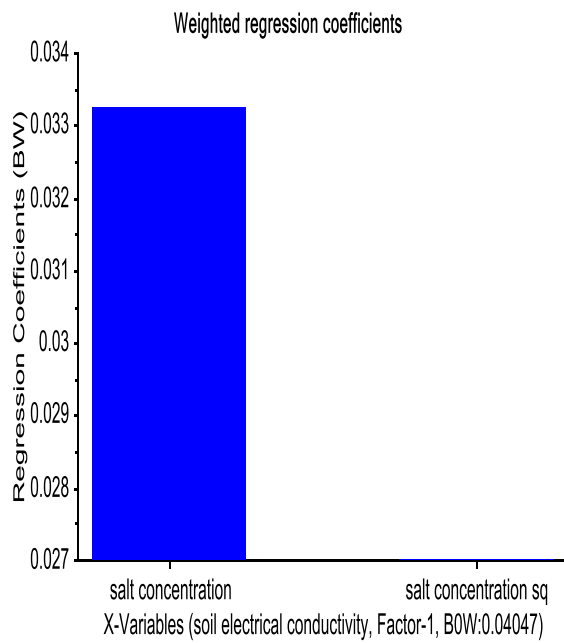
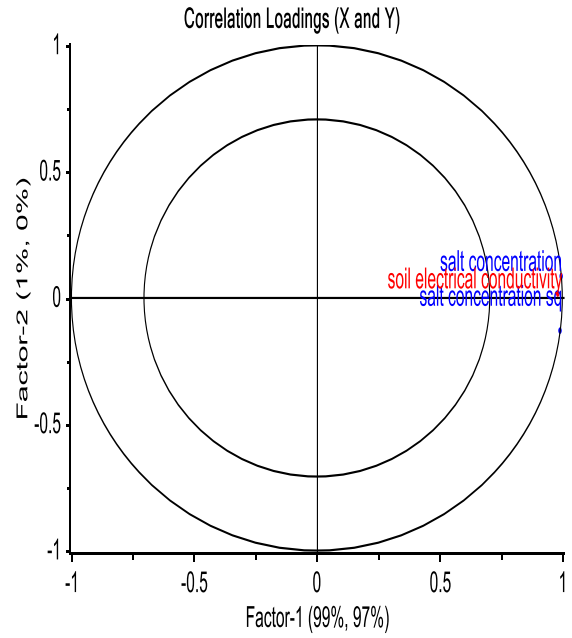
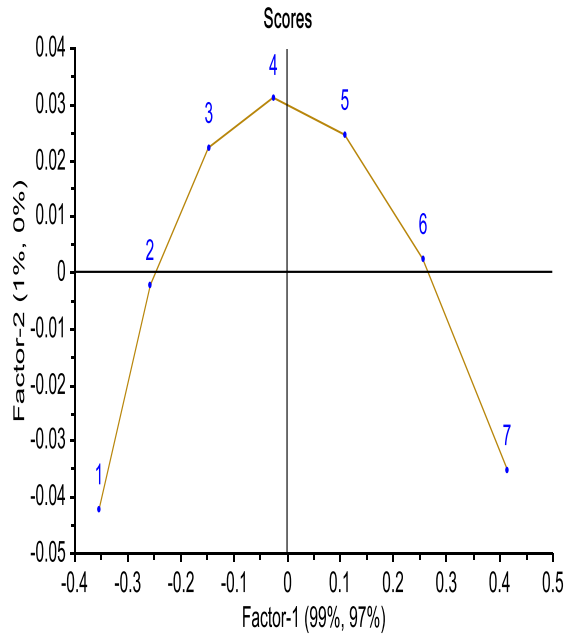


Fig 4.5, PLS analysis for Factor 1 (using Wenner array method) at 0.2 m inters electrode spacing where factor 1 is salt concentration.

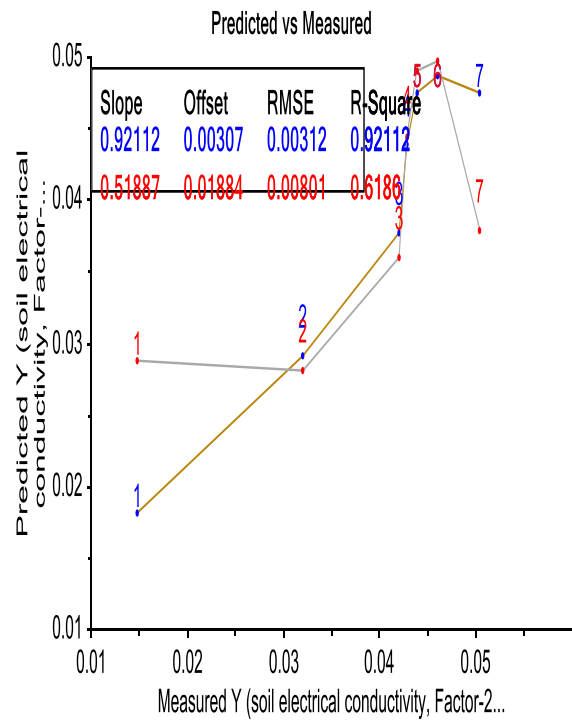
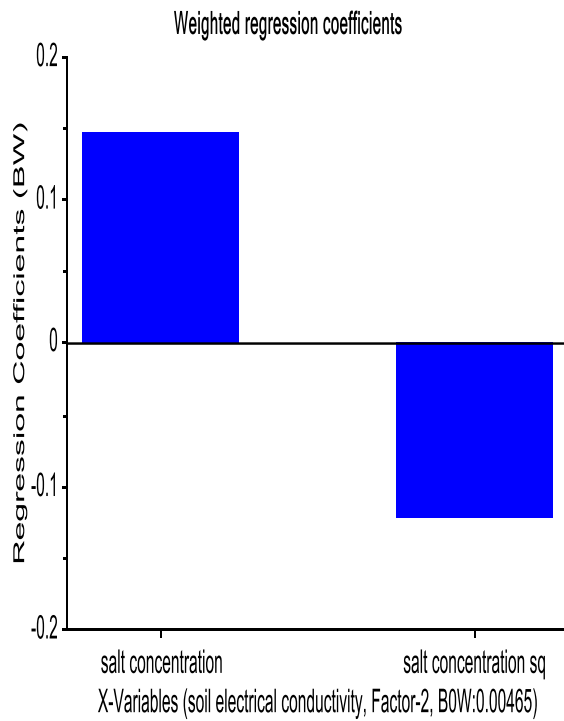
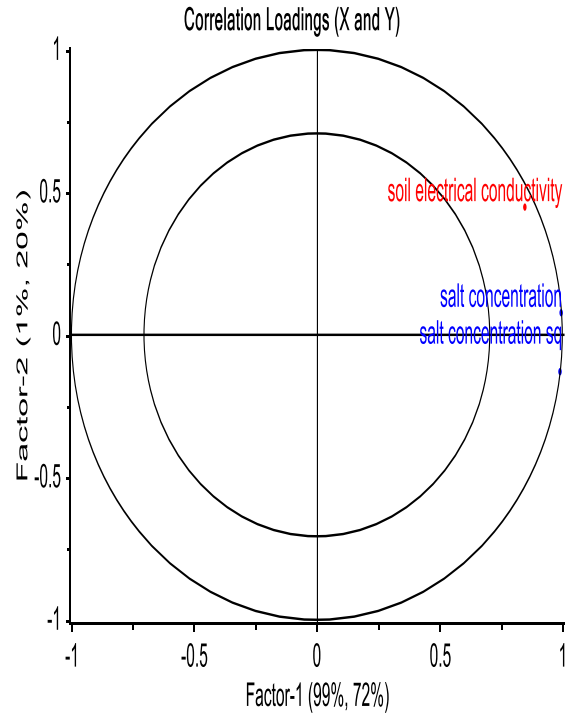
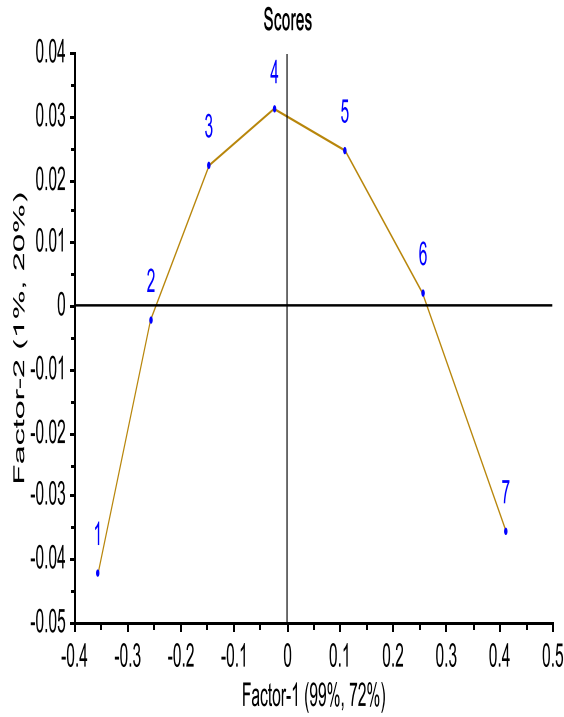


Fig 4.6, PLS analysis Factor 1(using Wenner array method) at 0.3 m inters electrode spacing where factor 2 is salt concentration square.

4.4. Data sheet of Dipole Dipole method

Inter electrode spacing A (mts)	Input Current (A)	Freq (Hz)	O/P Voltage (V)	Resistance (Ohm)	Resistivity (Ohm-m)	Salt Concentration (gm/L)/sq.mt.	Conductivity (S/m)/ m ²
0.1	0.01998	9.927	0.09965 9	4.985801	9.414189	100	0.106223
0.1	0.01998	9.964	0.07503	3.75407	7.088435	200	0.141075
0.1	0.01998	9.914	0.06937	3.470681	6.55334	300	0.152594
0.1	0.01355	9.956	0.04211	3.107411	5.867413	400	0.170433
0.1	0.01998	9.936	0.05292	2.647683	4.999355	500	0.200026
0.1	0.01998	9.912	0.03862	1.932286	3.648542	600	0.274082
0.1	0.01998	9.952	0.03731	1.86695	3.525175	700	0.283674
0.2	0.01998	9.949	0.18372	9.19246	34.71441	100	0.028806
0.2	0.01998	9.944	0.08365	4.18507	15.8045	200	0.063273
0.2	0.01998	9.939	0.05170	2.586901	9.769173	300	0.102363
0.2	0.01998	10.02	0.04853	2.428478	9.170904	400	0.109041
0.2	0.01998	9.959	0.03789	1.895909	7.159711	500	0.13967
0.2	0.01998	9.964	0.03646	1.82426	6.889135	600	0.145156
0.2	0.01998	9.987	0.03456	1.729392	6.530876	700	0.153119
0.3	0.01998	9.957	0.09068	4.537129	25.70102	100	0.038909
0.3	0.01998	9.976	0.07545	3.774811	21.38279	200	0.046767
0.3	0.01998	9.986	0.06459	3.231742	18.30653	300	0.054625
0.3	0.01998	9.952	0.06374	3.189486	18.06716	400	0.055349
0.3	0.01998	9.976	0.04156	2.07967	11.7805	500	0.084886
0.3	0.01998	9.947	0.03967	1.984805	11.24313	600	0.088943
0.3	0.01998	9.965	0.03686	1.844412	10.44786	700	0.095713

4.4.1 Measurement of EC_a using Dipole Dipole array method at 0.1m spacing

From the Fig 4.7 we see that at 0.1 m inter electrode spacing as salt concentration increases soil electrical conductivity also increases. For linear curve correlation value should be 1 but in Fig 4.10 correlation value is 0.970268 which is nearly equal to one.

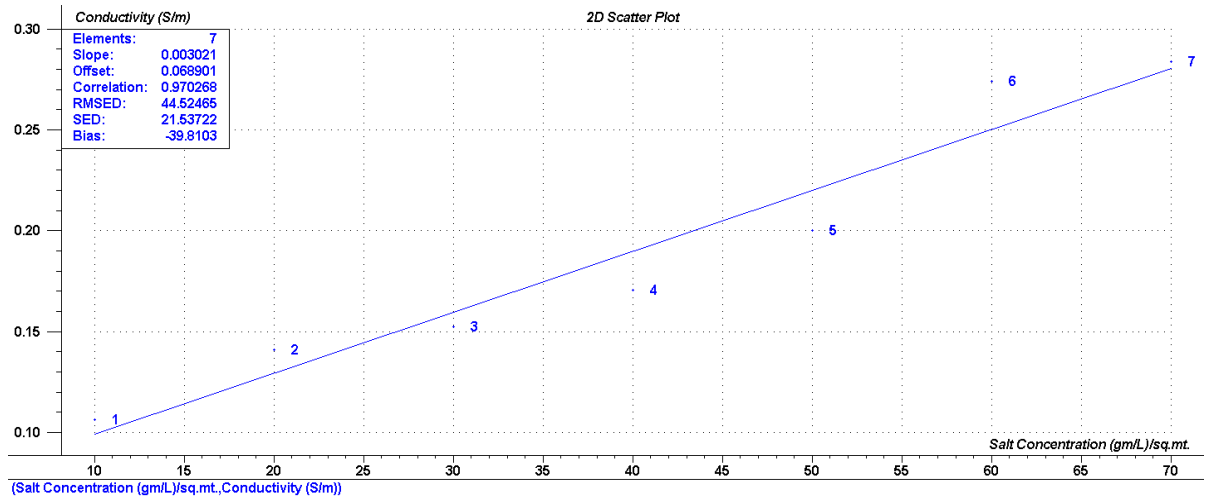


Fig 4.7, Variation of soil EC_a with different salt concentration at 0.1 m spacing using Dipole-Dipole array

4.4.2 Measurement of EC_a using Dipole Dipole array method at 0.2m spacing :

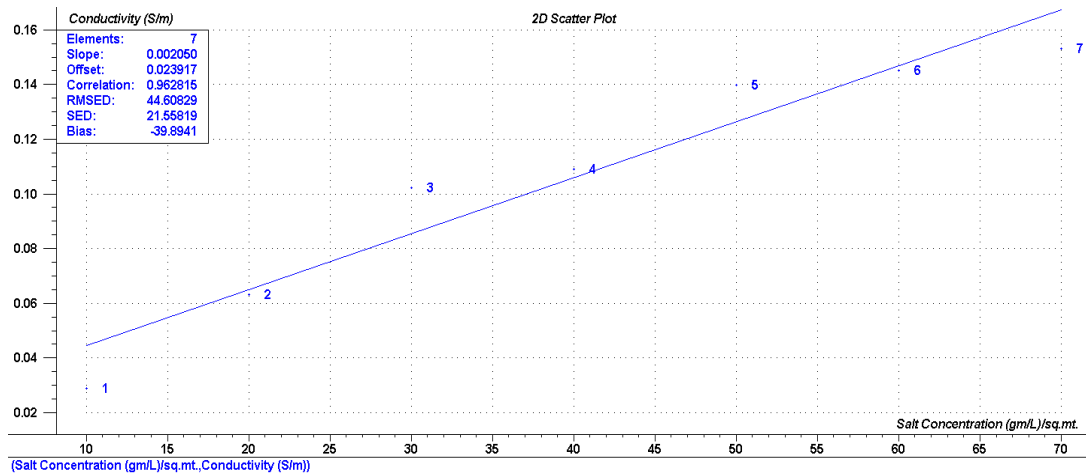


Fig 4.8, Variation of soil EC_a with different salt concentration at 0.2 m spacing using Dipole-Dipole array.

From the above Fig 4.8 we see that at 0.2 m inter electrode spacing as salt concentration soil increases electrical conductivity also increases. For linear curve correlation value should be 1 but in Fig 4.11 correlation value is 0.96281 which is nearly equal to one.

4.4.3 Measurement of EC_a using Dipole Dipole Array method at 0.3m spacing :

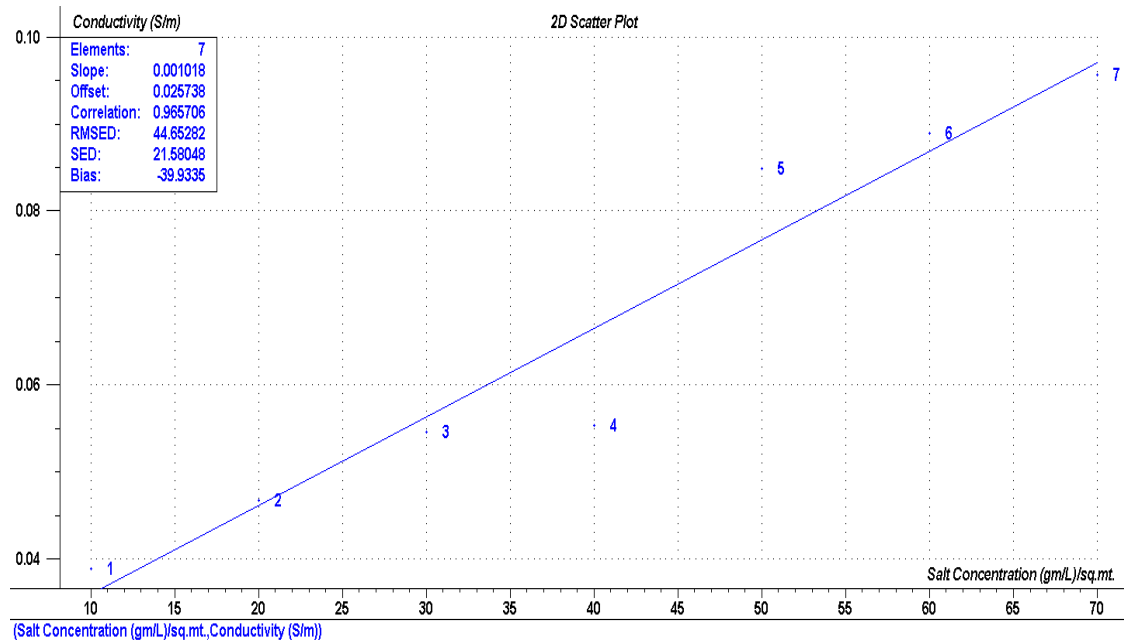


Fig 4.9, Variation of soil EC_a with different salt concentration at 0.3m spacing using Dipole-Dipole method.

From the above Fig 4.9 we see that at 0.3 m inter electrode spacing as salt concentration increases soil electrical conductivity also increases. For linear curve correlation value should be 1 but in Fig 4.12 correlation value is 0.9657 which is nearly equal to one.

4.4.4 PLS Analysis for Dipole Dipole Array:

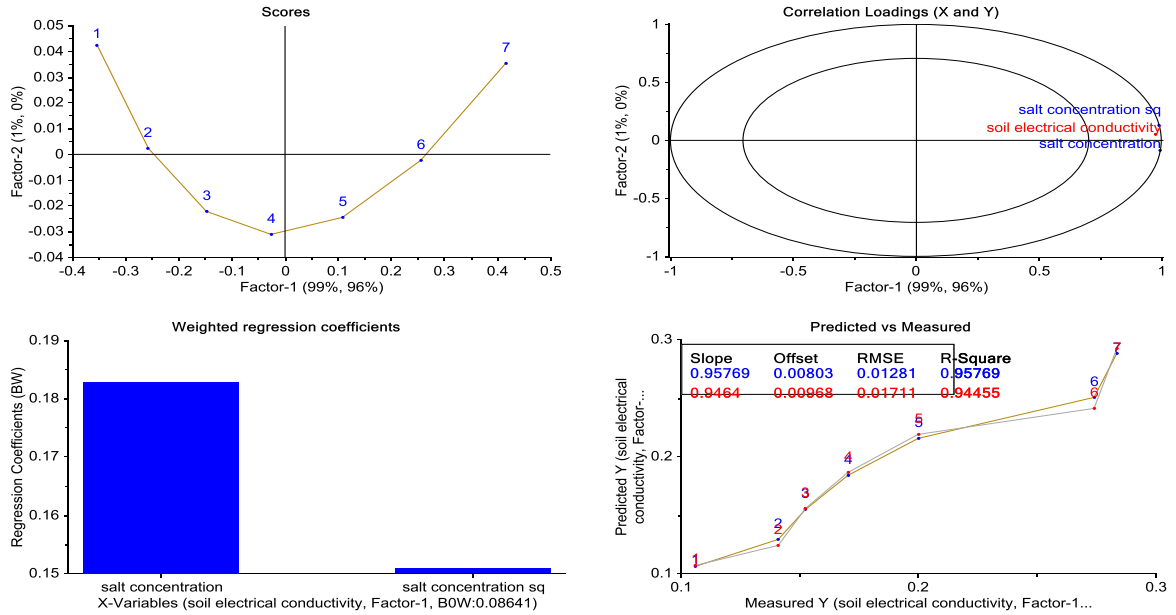


Fig 4.10, PLS analysis Factor 1 (using Dipole Dipole array method) at 0.1 m inter electrode spacing where factor 1 is salt concentration .

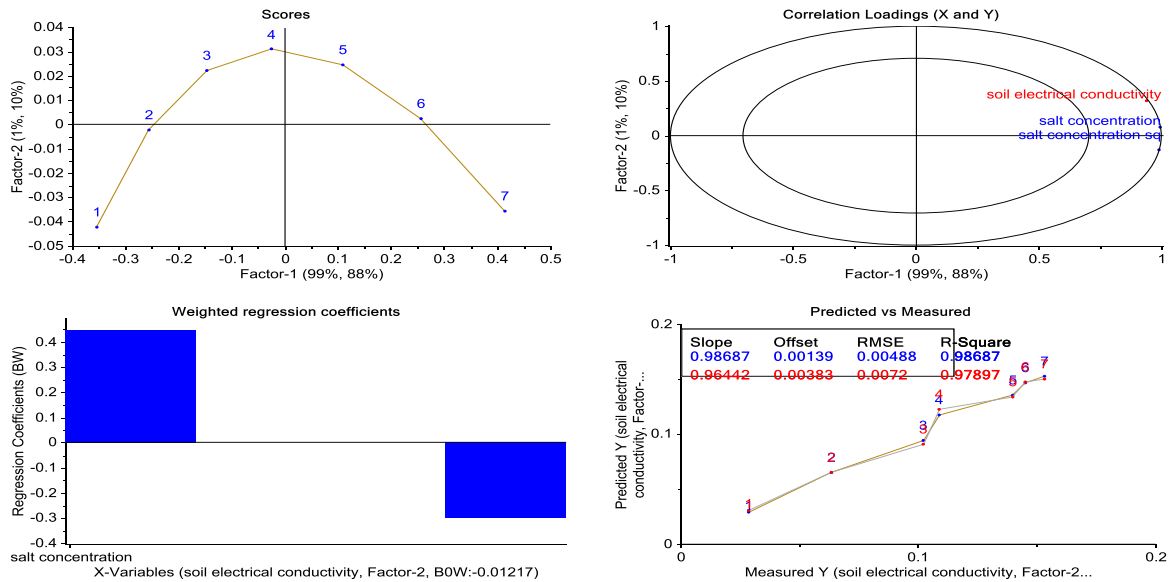


Fig 4.11, PLS analysis factor 2 (using Dipole Dipole array method) at 0.2 m inter electrode spacing where factor 2 salt concentration square.

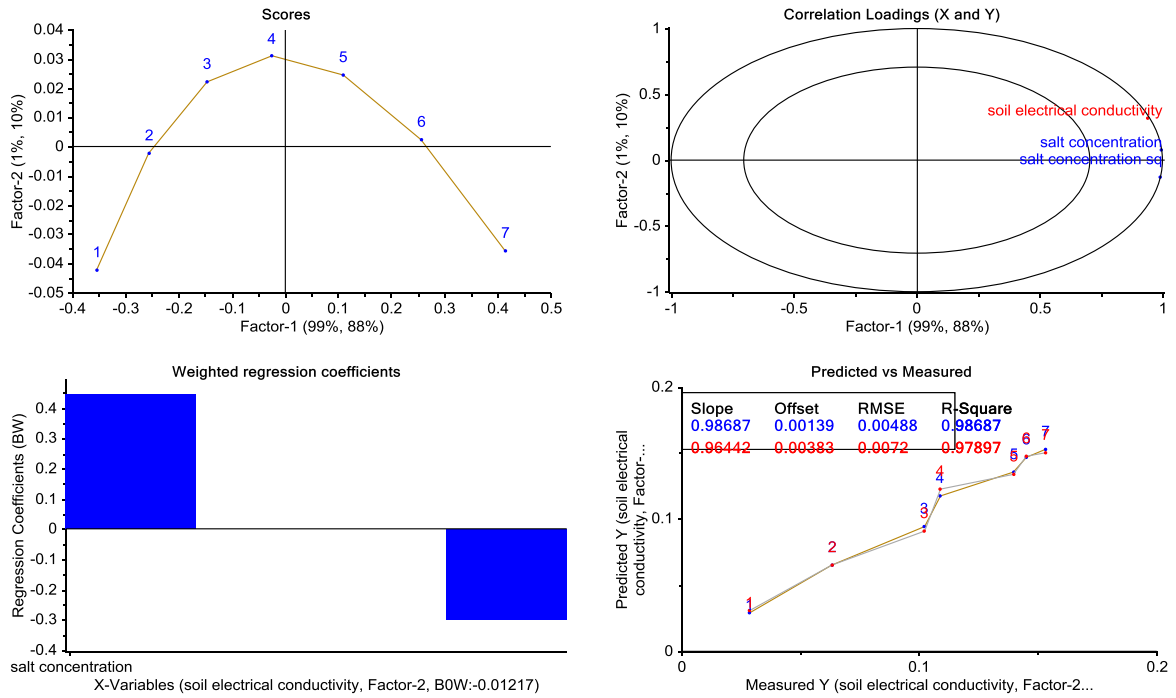


Fig 4.12, PLS analysis factor 1 (using Dipole Dipole array method) at 0.3 m inter electrode spacing where factor is salt concentration.

4.4.5 Summary of PLS Analysis for Wenner array and Dipole Dipole array

Method used	Inter electrode spacing (m)	Factor select for PLS analysis	R-square value of Predicted equation	RMSE	Calibration Equation	Value of σ for $x=1$
Wenner Array	0.1	Factor 1	0.92765	0.0144	$\sigma=1.542 e^{-1}x^2+1.296 e^{-1}x+0.04393$	1.0879
Wenner Array	0.2	Factor 1	0.96748	0.002	$\sigma=3.324 e^{-1}x^2+2.701e^{-2}x+0.04047$	1.6288
Wenner Array	0.3	Factor 2	0.92112	0.003	$\sigma=1.469e^{-1}x^2- 1.225e^{-1}x+0.00465$	1.00
Dipole-Dipole array	0.1	Factor 1	0.9559	0.02	$\sigma=1.829 e^{-1}x^2+1.508 e^{-1}x+0.08641.$	1.1314

Method used	Inter electrode spacing (m)	Factor select for PLS analysis	R-square value of Predicted equation	RMSE	Calibration Equation	Value of σ for $x=1$
Dipole-Dipole array	0.2	Factor 2	0.98687	0.0048	$\sigma=4.456 e^{-1}x^2-3.008 e^{-2}x-0.01217$.	1.22
Dipole-Dipole array	0.3	Factor 1	0.9356	0.006	$\sigma=6.163 e^{-2}x^2+5.002 e^{-2}x+0.0318$	1.5428

4.5 Variation of EC_a with different amount of urea

To measure electrical conductivity variation with different amount of urea in a particular inter electrode spacing like 0.1m,0.2m,0.3m and analysis with Wenner array soil electrical conductivity measurement method.

4.5.1 Data sheet for Wenner array method

A (mts)	Input Current (A)	Frequency (Hz)	Output Voltage	Resistance (Ohm)	Resistivity (Ohm-m)	Conductivity (S/m)	gm/mt.sq.
0.1	0.000503	9.929808	0.914275	165.9989	104.3002	0.009588	125
0.1	0.005514	9.964623	0.914275	97.2224	61.08663	0.01637	250
0.1	0.014364	9.912492	0.914275	75.04323	47.15105	0.021208	375
0.1	0.015	9.952161	0.914275	71.90093	45.17669	0.022135	500
0.1	0.014078	9.927325	0.914275	64.94387	40.80544	0.024507	625
0.1	0.004579	9.929808	0.914275	45.334	28.4842	0.035107	750
0.1	0.016776	9.949673	0.914275	40.70058	25.57293	0.039104	875
0.1	0.01491	9.942214	0.914275	32.58795	20.47561	0.048839	1000
0.2	0.007388	9.924854	0.914275	46.47393	58.40086	0.017123	125
0.2	0.012413	9.937248	0.914275	33.82416	42.50469	0.023527	250

A (mts)	Input Current (A)	Frequency (Hz)	Output Voltage	Resistance (Ohm)	Resistivity (Ohm-m)	Conductivity (S/m)	gm/mt.sq.
0.2	0.014719	9.922379	0.914275	31.43191	39.49851	0.025317	375
0.2	0.010627	9.952161	0.914275	30.23413	37.99333	0.02632	500
0.2	0.019976	9.954651	0.914275	27.14575	34.11235	0.029315	625
0.2	0.017594	9.917433	0.914275	24.39406	30.65448	0.032622	750
0.2	0.019987	9.897697	0.914275	19.50305	24.50825	0.040803	875
0.2	0.012412	9.944699	0.914275	11.64467	14.63313	0.068338	1000
0.3	0.010564	9.917433	0.914275	21.68051	40.8668	0.02447	125
0.3	0.004419	9.952161	0.092411	20.91103	39.41636	0.02537	250
0.3	0.00889	9.952161	0.914275	20.12141	37.92796	0.026366	375
0.3	0.014079	9.934767	0.914275	19.71048	37.15338	0.026915	500
0.3	0.019986	9.914962	0.914275	15.96115	30.08606	0.033238	625
0.3	0.016761	9.897697	0.914275	14.44799	27.23381	0.036719	750
0.3	0.019983	9.927331	0.914275	14.31372	26.98073	0.037063	875
0.3	0.014689	9.942214	0.914275	13.97439	26.3411	0.037963	1000

4.5.2 Measurement of EC_a using Wenner array method at 0.1m spacing :

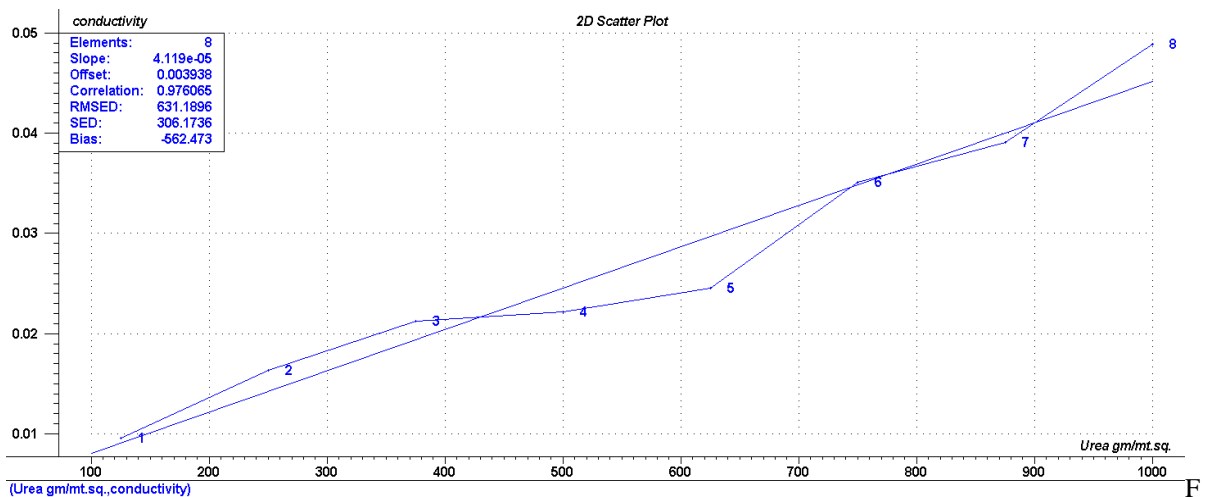


fig 4.13, Variation of soil EC_a with different urea concentration at 0.1m spacing using Wenner array method

From the above Fig 4.13 we see that at 0.1 m inter electrode spacing as urea concentration increases soil electrical conductivity also increases. For linear curve correlation value should be 1 but in Fig 4.16 correlation value is 0.9760 which is nearly equal to one.

4.5.3 Measurement of EC_a using Wenner array method at 0.2m spacing

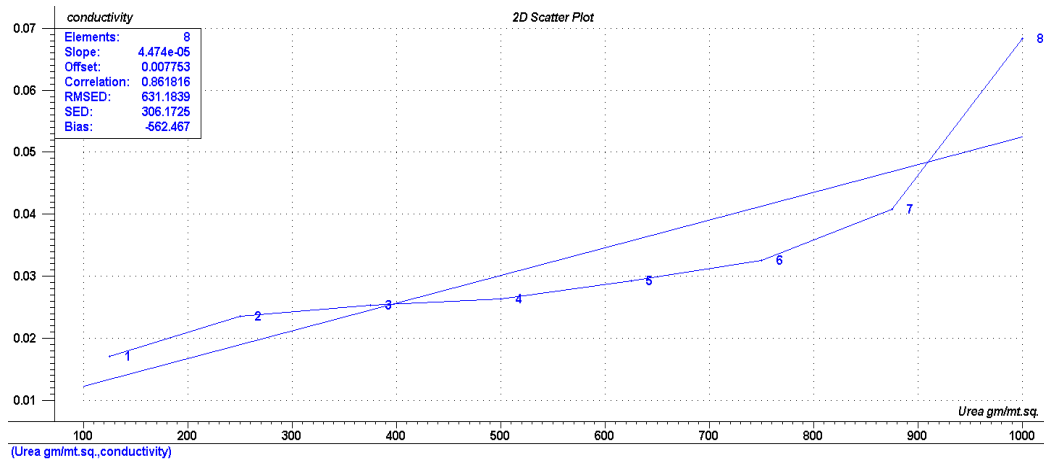


Fig 4.14, Variation of soil EC_a with different urea concentration at 0.2 m spacing using Wenner array method

From the above Fig 4.14 we see that at 0.2 m inter electrode spacing as urea concentration increases soil electrical conductivity also increases. For linear curve correlation value should be 1 but in Fig 4.17 correlation value is 0.8698.

4.5.4 Measurement of EC_a using Wenner array method at 0.3m spacing

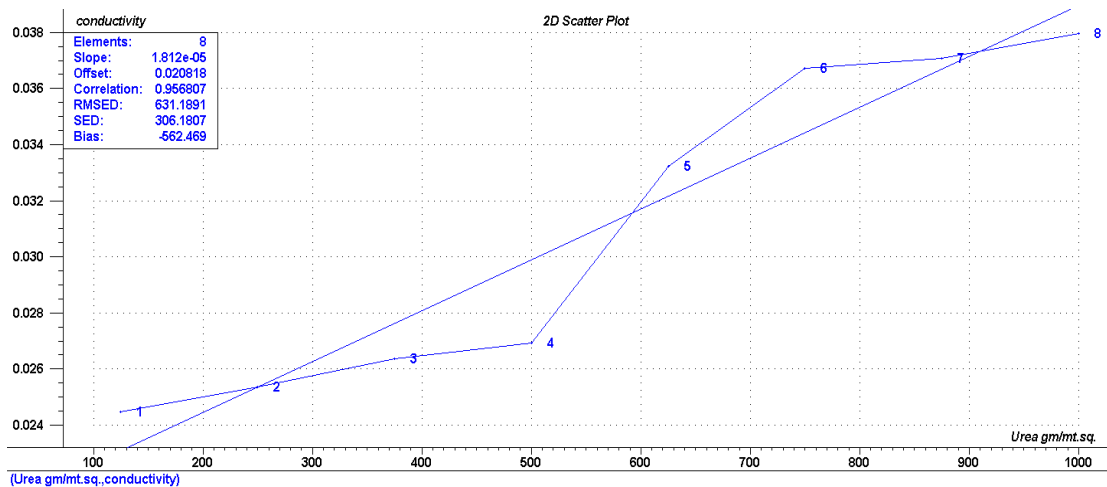


Fig 4.15 Variation of soil EC_a with different urea concentration at 0.3 m spacing using wenner array method

From the above Fig 4.15 we see that at 0.2 m inter electrode spacing as urea concentration increases soil electrical conductivity also increases. For linear curve correlation value should be 1 but in Fig 4.18 correlation value is 0.9569.

4.6 PCA analyses of electrical conductivity with different concentration of urea using wenner array

The basic method we are used to measure the apparent electrical conductivity is Wenner array and Dipole-Dipole array and we are trying to comparative study between these two well known method. First of all we want to make a relation between soil urea concentration and electrical conductivity, to conduct this experiment we mixed different amount of urea to (0.3*0.9) m² area.

4.6.1 PCA

PCA is a bilinear modeling method that provides an interpretable overview of the main information contained in a multidimensional table. It is also known as a projection method, because it takes information carried by the original variables and projects them onto a smaller number of latent variables called Principal Components (PC). Each PC explains a certain amount of the total information contained in the original data and the first PC contains the greatest source of information in the data set. Each subsequent PC contains, in order, less information than the previous one. By plotting PCs important sample and variable interrelationships can be revealed, leading to the interpretation of certain sample groupings, similarities or differences. PCA is used to describe which variables describe the differences between samples, which variables contribute most to an observed difference and which variables contribute in the same way.

4.6.2 Scores

Scores describe the data structure in terms of sample patterns, and more generally show sample differences or similarities. Each sample has a score on each PC. It reflects the sample location along that PC and is the coordinate of the sample on the PC.

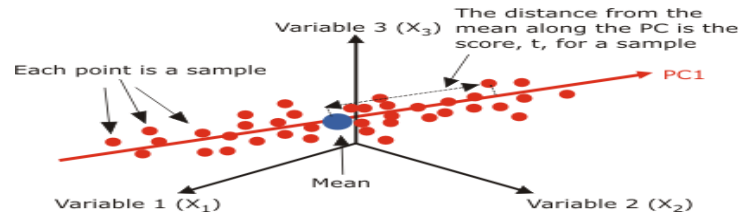


Fig 4.16 Scores plot for PCA analysis

4.6.3 Scores interpretation

The score describes the major features of the sample, relative to the variables with high loadings on the same PC. Samples with close scores along the same PC are similar (they have close values for the corresponding variables). Conversely, samples for which the scores differ greatly are quite different from each other with respect to those variables. The relative importance of each principal component is expressed in terms of how much variance of the original data it describes. The score describes the major features of the sample, relative to the variables with high loadings on the same PC. Samples with close scores along the same PC are similar.

4.6.4 Explained variance

Explained variance is the complement of residual variance, expressed as a percentage of the global variance in the data. Thus the explained variance of a variable is the fraction of the global variance of the variable taken into account by the model. Total explained variance measures how much of the original variation in the data is described by the model. It expresses the proportion of structure found in the data by the model.

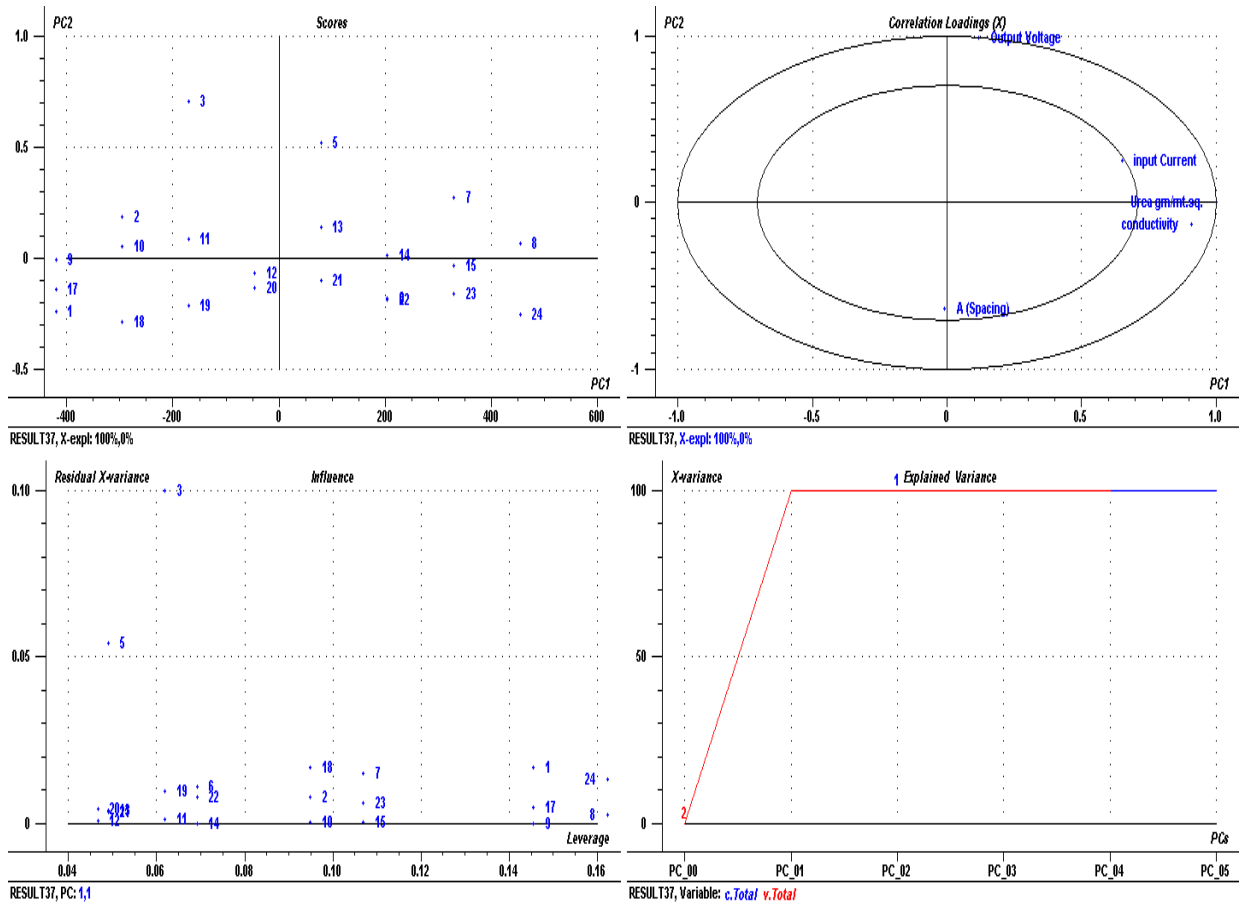


Fig 4.17 PCA Analysis of soil EC_a with different urea concentration using Wenner array method

From the PCA analysis of Fig 4.17 we can see that soil electrical conductivity is highly correlated with concentration of urea and is independent of inter electrode spacing. PC shows 100% explained variances for this analysis so original variation in the data is described by the model is 100%

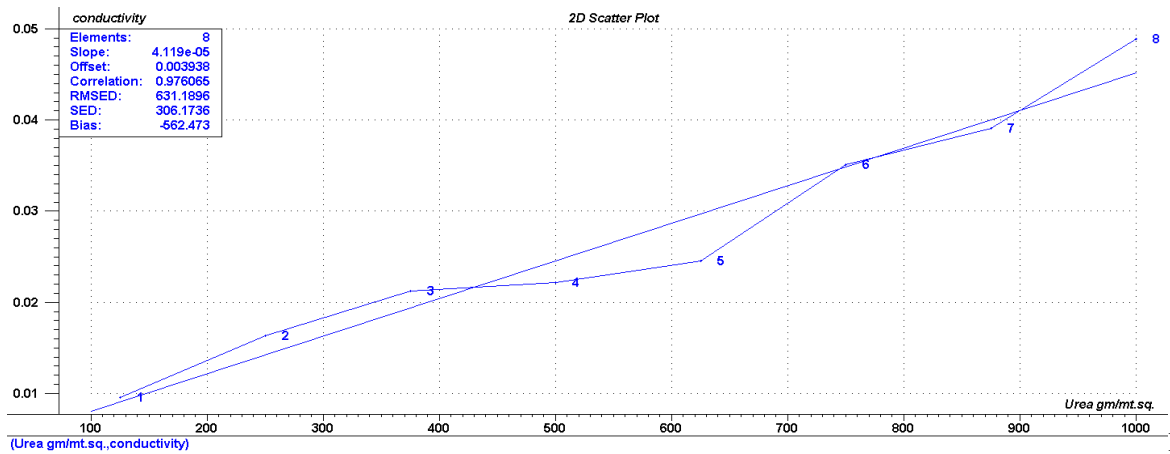
4.7 PCA analyses of EC_a with different concentration of urea using Dipole-Dipole array:

To measure electrical conductivity variation with different amount of urea in a particular inter electrode spacing like 0.1m,0.2m,0.3m and measure EC_a at different urea concentration with Dipole-Dipole soil electrical conductivity measurement method.

4.7.1 Data sheet of Dipole Dipole method

A (mts)	Input Current (A) (Hz)	Frequency (Hz)	Output Voltage	Resistance (Ohm)	Resistivity (Ohm-m)	Conductivity (S/m)	gm/mt.sq.
0.1	0.00574	9.93973	0.207617	36.14447	68.24799	0.014652	125
0.1	0.00692	9.924854	0.160733	23.21567	43.83582	0.022812	250
0.1	0.01370	9.927331	0.297668	21.71437	41.00107	0.02439	375
0.1	0.01972	9.982123	0.375706	19.04872	35.96779	0.027803	500
0.1	0.01353	9.949673	0.234688	17.34182	32.74482	0.030539	625
0.1	0.01486	9.93973	0.235011	15.81087	29.85409	0.033496	750
0.1	0.01997	9.914962	0.236799	11.85213	22.37919	0.044684	875
0.1	0.01748	9.934767	0.206149	11.7904	22.26263	0.044918	1000
0.2	0.00441	9.952161	0.092411	20.91103	78.96841	0.012663	125
0.2	0.01242	9.949673	0.172202	13.86144	52.34635	0.019104	250
0.2	0.01422	9.905089	0.174965	12.29869	46.44477	0.021531	375
0.2	0.01241	9.944699	0.144535	11.64467	43.97495	0.02274	500
0.2	0.01042	9.90016	0.119	11.41801	43.11898	0.023192	625
0.2	0.01588	9.924854	0.157654	9.926036	37.48468	0.026678	750
0.2	0.01998	9.942214	0.189393	9.476109	35.78558	0.027944	875
0.2	0.01182	9.937248	0.091602	7.749695	29.26595	0.034169	1000
0.3	0.01046	9.937248	0.099512	9.506559	53.85085	0.01857	125
0.3	0.01591	9.932287	0.137327	8.627117	48.86917	0.020463	250
0.3	0.01094	9.949673	0.094017	8.591461	48.66719	0.020548	375
0.3	0.01997	9.924854	0.168358	8.423569	47.71615	0.020957	500
0.3	0.01998	9.952161	0.159431	7.976779	45.18526	0.022131	625
0.3	0.01878	9.934767	0.13905	7.402876	41.93433	0.023847	750
0.3	0.01400	9.907555	0.098631	7.040432	39.88123	0.025074	875
0.3	0.01944	9.912492	0.128658	6.616326	37.47884	0.026682	1000

4.7.2 Measurement of EC_a using Dipole Dipole array method at 0.1m spacing

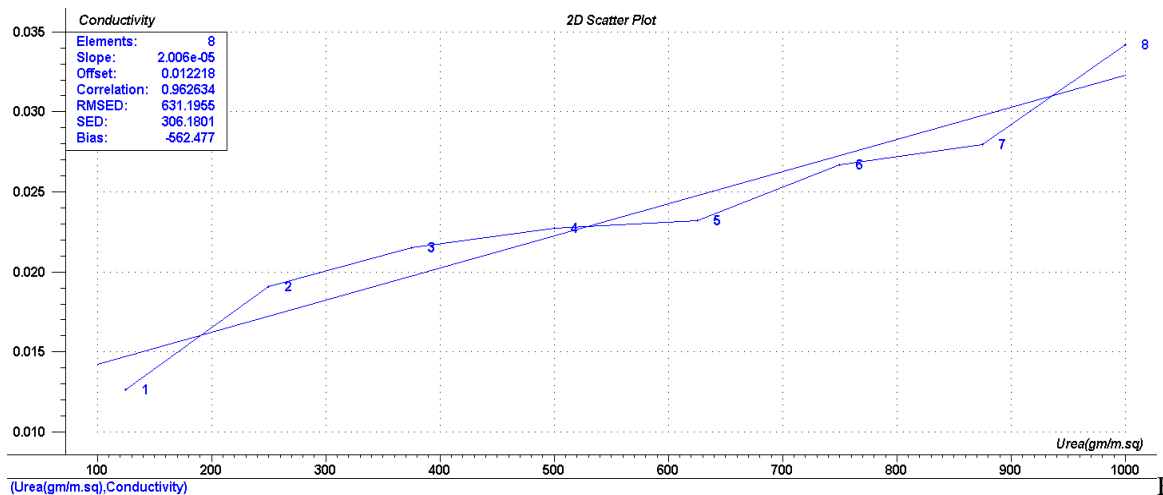


Fig

4.18 Variation of soil EC_a with different urea concentration at 0.1 m spacing using Dipole -Dipole array method

From the above Fig 4.18 we see that increases urea content soil electrical conductivity increase at 0.1 m inter electrode spacing .The correlation value is 0.9760 which is nearly equal to one and offset value 0.003.

4.7.3 Measurement of EC_a using Dipole Dipole array method at 0.2m spacing



Fig

4.19 Variation of soil EC_a with different salt concentration at 0.2 m spacing using Dipole -Dipole array.

From the Fig 4.19 we see that increases urea content soil electrical conductivity also increases at 0.2 m inter electrode spacing .The correlation value is 0.96260 which is nearly equal to one and offset value 0.0122.

4.7.4 Measurement of EC_a using Dipole Dipole array method at 0.3m spacing

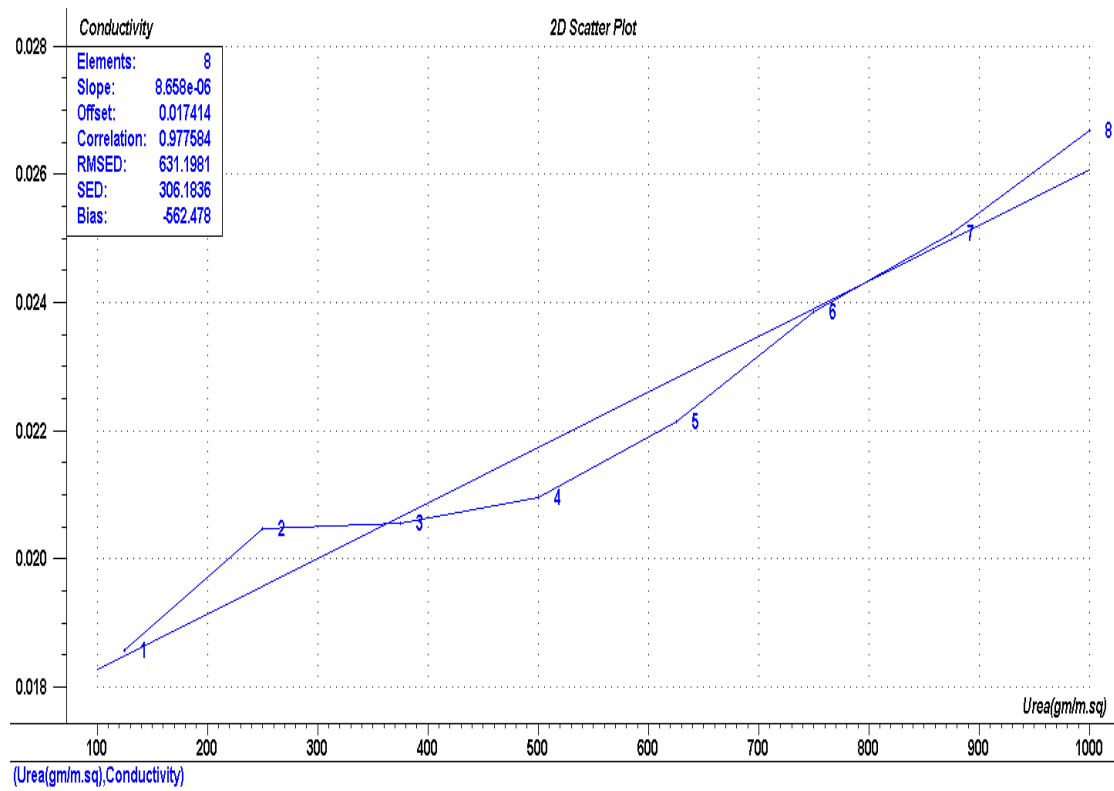


Fig 4.20 Variation of soil EC_a with different salt concentration at 0.3 m spacing using Dipole-Dipole array

From the Fig.4.20 we see that increases urea content increases soil electrical conductivity also increases at 0.3 m inter electrode spacing .The correlation value is 0.9770 which is nearly equal to one and offset value 0.0174.

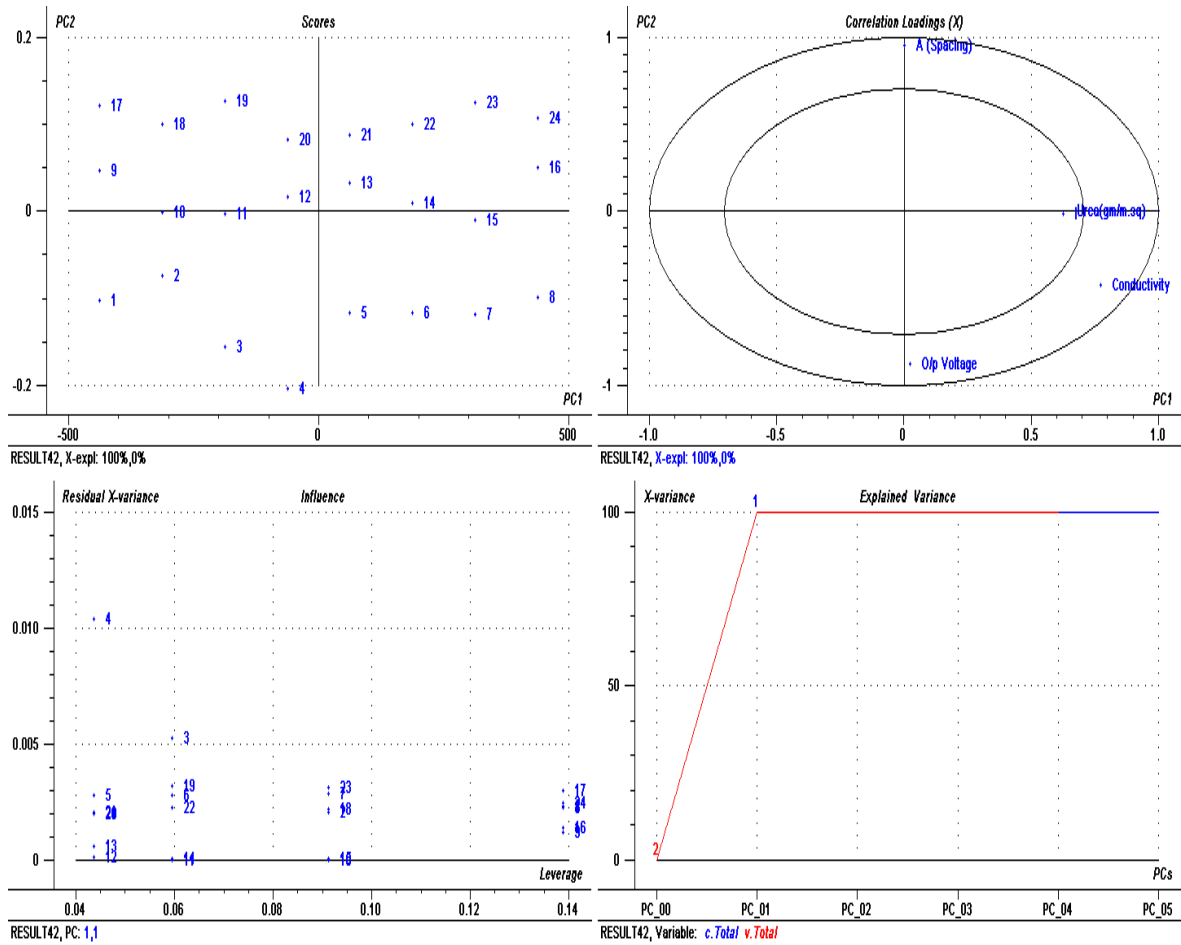


Fig 4.21 PCA Analysis of soil EC_a with different urea concentration using Wenner array method

From Fig 4.21 we can see that soil electrical conductivity is highly correlated with concentration of urea and is independent of inter electrode spacing, output voltage and inter electrode spacing. PC shows 100% explained variances for this analysis so original variation in the data is described by the model is 100%.

By plotting PCA important sample and variable interrelationship can be revealed, leading to the interpretation of certain sample grouping. The PCA analysis of EC_a with different urea concentration at different interelectrode spacing shows that there is no relation between soil electrical conductivity and interelectrode spacing. This is the properties of homogenous soil. Conductivity of soil highly correlated with urea concentration in the field and it is independent of input frequency.

CHAPTER 5

CONCLUSION & FUTURE SCOPE

In this thesis work we have discussed the development of soil sensor and analyzed the apparent electrical conductivity EC_a with respect to soil salinity and nutrient on soil. Secondly for Wenner array method it provided better vertical resolution because as the inter electrode space increases, the electrical conductivity also increases where as dipole-dipole array method provides better lateral resolution because it measures conductivity of subsurface. As the moisture percentage in soil is high at sub surface area so value of soil electrical conductivity measured by dipole dipole array higher then wenner array method .

In future, those soil properties can be found and related with spatial EC_a measurements which are influencing a crop's yield. To buildup relationship between EC_a and yield we are trying to physical understanding of the EC_a measurement and from this understanding an interpretation of its relationship to a crop's. EC_a measurements can be used to soil sampling to evaluate the spatial variation in overall quality of soil physicochemical properties that affect yield. The application of EC_a measurements to 'Precision Agriculture' will play a crucial role in future to create concept of precision agriculture and fulfilled demands for food in future.

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