Implications Of Soil Resistivity Measurements Using The Electrical Resistivity Method: A Case Study Of A Maize Farm Under Different Soil Preparation Modes At KNUST Agricultural Research Station, Kumasi

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Abstract: Continuous vertical electrical sounding (CVES) technique was used to investigate the soil moisture content of a maize farm at the Kwame Nkrumah University of Science and Technology (KNUST) Agricultural Research Station (ARS), Kumasi, Ghana. The soils of the maize farm were categorized into four different land preparation modes; ploughed-harrowed, ploughed, hoed and no-till plot. Time-lapse measurements with CVES was carried out using the multi-electrode Wenner array to investigate soil moisture variation with the help of the ABEM Terrameter SAS 4000 resistivity meter. The results showed a heterogeneous distribution of soil moisture content both spatially and temporally. Most of the water available for plants' uptake was within a depth of 0.20 – 0.40 m which coincided with the root zones of the maize crops. In addition, the no-till plot was found to conserve more moisture during dry weather conditions than the rest of the plots. The research shows that CVES technique is applicable in monitoring shallow soil water content in the field and the results obtained could be used to optimize irrigation scheduling and to assess the potential for variable-rate irrigation.

Index Terms: 2D and 3D electrical resistivity tomography (ERT), ABEM Lund imaging system, apparent resistivity, continuous vertical electrical sounding (CVES), soil moisture content

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1 INTRODUCTION

Knowledge of soil moisture content distribution is important in several disciplines such as climate science, hydrology, meterology and most importantly, agriculture [1]. In the case of agriculture, management practices and environmental factors such as temperature, moisture content, and solar radiation influences crop growth. Highest crop yield can only be achieved under optimum moisture conditions during the growing season whilst a drop in the moisture content at any of the growth stages will result in poor yield. Moreover, information obtained from the distribution of soil water content in unsaturated zone is important for variety of investigations such as climate research, flood prevention, matter transport into the subsurface or decomposition and transformation processes in the soil. Graham et al. [2] indicated that, the information obtained from the monitoring of soil moisture content is critical for increasing crop yields, achieving high irrigation efficiencies, planning irrigation scheduling, and minimizing lost of yield due to waterlogging and salinization. Such water content monitoring is also vital for addressing issues of water quality which is important for managing the environment impacts of irrigated agriculture and for protecting functional ecosystems. For some time now, geophysical methods have been widely applied to soil science. The basic principle in non-destructive geophysical methods is to gather data in the medium under investigation without destroying the subsurface. Electrical resistivity prospecting is one of the most attractive geophysical methods for soil water determination in agricultural fields as compared to classical soil science measurements and observations which perturb the soil by drilling and sampling. In this way, temporal and spatial soil water content variability in the field can be monitored and quantified without altering the soil structure or destroying the vegetative cover. Electrical resistivity measurements also provide a good means for detail studies of vertical water movement in the unsaturated soil zone and therefore should help to assess the boundary conditions for infiltration modeling [3]. For continuous vertical electrical sounding (CVES) of the electrical resistivity method, artificial current is injected into the subsurface through current electrodes and the resulting potential is measured across two potential electrodes. Potential differences patterns provide information on the form of subsurface heterogeneities such as water content in the soil which influences their electrical properties [4]. It also incorporates sounding and profiling techniques to give information on both the lateral and vertical extent of the subsurface with better resolution. Over the past years, the electrical resistivity method has been employed by some researchers to investigate soil moisture content. Rings et al. [5] used electrical resistivity tomography to quantify the water content of a dike model. The ERT method successfully quantifies the water content in the dike to be about 34%.

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Bottraud et al. [6] observed different patterns of water distribution related to variations in grape vine in a homogeneous sandy soil. The authors established a qualitative description of water transfer using the relative variation of apparent resistivity, during forty-five (45) days monitoring periods. Jackson et al. [7] identified anomalies in a roadside embankment following repeated measurement of resistivity over 18 months period, incorporating several wet and dry seasons. Samouëlan et al. [8] monitored artificial cracks as they deepened and observed an increasing apparent resistivity anomaly over time. This pattern was related to climatology variation affecting groundwater table, precipitation and temperature. Binley et al. [9] also found a good correlation between the net rainfall and the change of the electrical resistivity in the depth of 0 – 0.80 m. Further works using the electrical resistivity method to investigate soil moisture content can be obtained from [10], [11], [12], [13] among many others. Based on the above, it is evident that the electrical resistivity method can be employed in investigating soil water content at various scales. However, as pointed out by [11], few studies actually reported the application of electrical resistivity in soil-plant system and none aimed at quantifying water uptake by the plants. It therefore calls for more research into the area which this project sought to achieve at the end. This paper investigated the soil water content of maize farm in the Agricultural Research Station (ARS) at Anwomaso, Kumasi, Ghana using continuous vertical sounding technique. It sought to explore the potential of using the electrical resistivity method with specially design electrodes in monitoring the spatial and temporal variability of soil moisture content in Agriculture.

2 MATERIALS and Methods

2.1 Description of study site

The site for this research work is located at Kwame Nkrumah University of Science and Technology (KNUST) Agricultural Research Station (ARS), Anwomaso, Kumasi. It is about 10 km from the main University campus and has a total land area of about 555 (ha). The station shares its boundaries with Amwomaso, Domiabra, Kwamo, Fumesua and Bebre settlements (Fig. 1). The main area where the monitoring of the water content was done is a maize farm located at latitude 6˚41’ 838” N and longitude 1˚31’533” W. This area is within the Kumasi metropolis and hence, geologically, it composed of basically granitoid undifferentiated rocks (Fig. 1). This granitoid complex [14] dominates much of the basin area and contains large roof pendants of metasedimentary schists. This massive intrusive complex is basin-type granitoid, which ranges in composition from intermediate (granodiorite/tonallite) to more felsic (granite) phases. In addition, the Kumasi Metropolis falls under the Forest Belts and the major soil type is the Forest Ochrosol with an annual rainfall of about 1500 – 2000 mm range [15]. They consist principally of weathering products of metamorphosed and basic intrusive rocks, principally, granites, phyllites, quartzites, sandstones and epidiorites, greenstones, basalt and Upper Birimian phyllites. They study site is highly dominated by sandy-loam soil which is very suitably for plants growth.

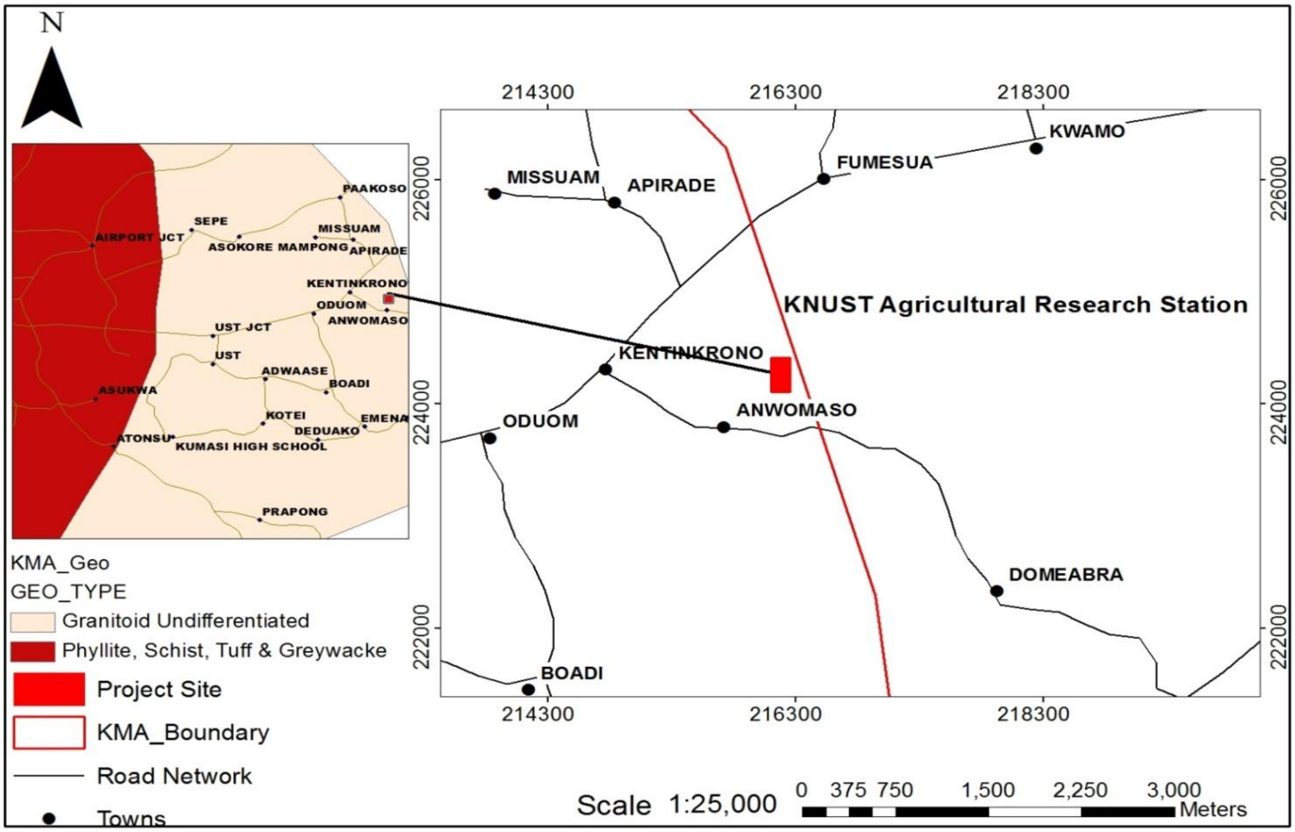

Fig. 1: *Geological map of study area*

2.2 Land Preparation

The site was divided into four plots based on different land preparation modes which includes Ploughed-Harrowed, Ploughed, Hoed and No-till (Fig. 1). In addition, each of these were subdivided into four parts based on the land treatment such as no fertilizer, ½ poultry manure + ½ NPK, 100% poultry manure and 100% NPK respectively. Four profiles were then laid on each of the plot with the subdivision "no fertilizer' for the measurement. The length of each profile was 8 m but the inter-profile separation was variable due to 'no fertilizer' location (Fig. 2).

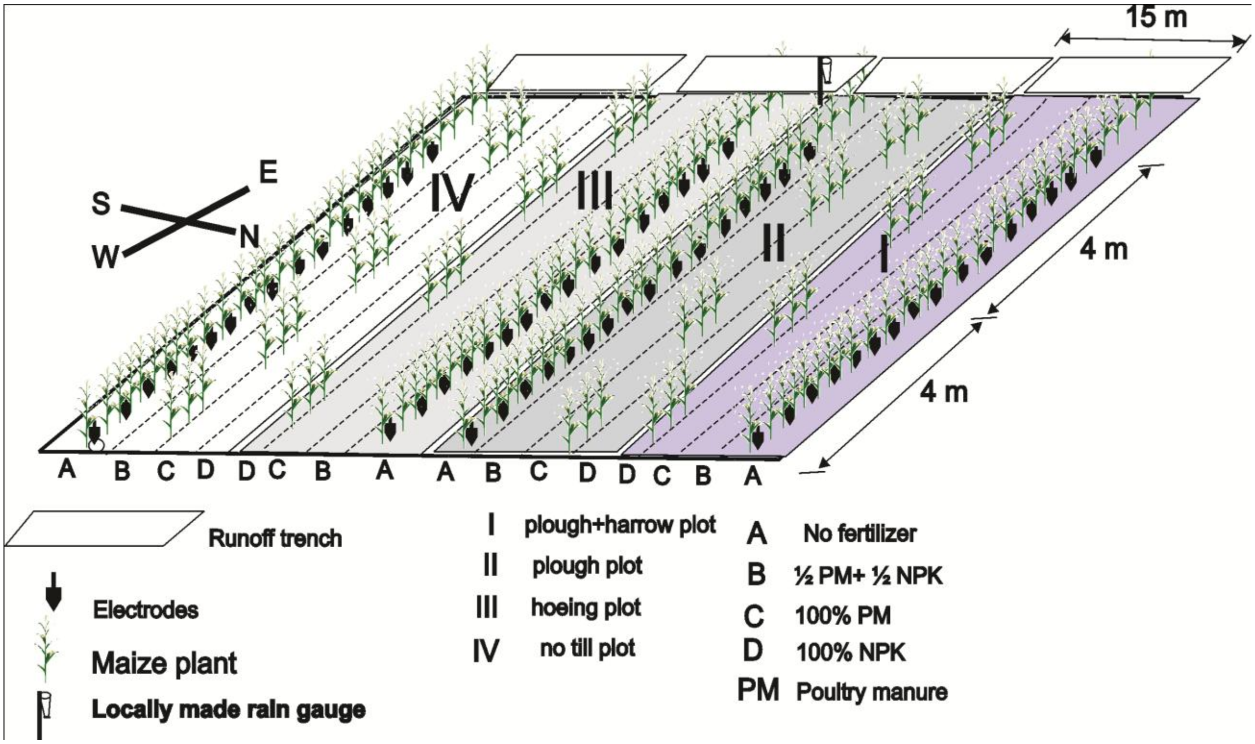

Fig. 2: *Layout of survey profiles at the project site*

2.3 Data Acquisition

The equipment used for data collection was ABEM LUND Imaging System which includes the Terrameter SAS4000, electrode selector, car battery, steel electrodes, tape measure, cable joints, cable jumpers, hammer and the pegs (Fig. 3). For the nature of this work, these steel electrodes were not suitable since they have to be left at the mercy of rainfall and thieves during the three month period. To overcome this challenge, 400 improvised electrodes (Fig. 3) were made for this project. They were made of copper wires and supported with wood. The copper wires served as the conducting medium for the current as well as the potentials and the wood helped to support the wires in the ground. In collecting the data, the WEN32SX Wenner array protocol was used, 41 of the improvised electrodes were connected to two 40 m long multi-core cables with electrode separation of 0.2 m. These electrodes were driven gently into the ground close to the maize plants with the help of a small hammer. Each of the electrodes was then numbered according to its take-out with a permanent marker pen. This made the connection of the jumpers very fast and helped avoid skipping of electrodes. The cables were laid and the jumpers connected from the copper part of the electrodes to their respective cable take-outs. All the electrode take-outs were connected in the WEN32SX protocol. Each electrode position was uniquely identified at a take-out on the cable which helped in identifying the required current and potential pairs during the measurement at various data levels [16]. The resistivity meter automatically switched the electrodes to serve as current or potential pairs to build up a pseudo-section (Fig. 4). The ABEM terrameter, the electrode selector ES 10-64C and the 12 V car battery were then connected between cables 1 and 2 of the set-up. The electrode resistance test was run first before the measurements to ensure that all the 41 electrodes were connected and conducting. When measurement for the first profile was completed, the terrameter, the electrode selector ES 10-64C, the 12 V car battery and jumpers were then moved quickly to the second profile. The procedure described for the first set of measurements was repeated to acquire the data for all the four profiles. In order to allow comparison of the temporal changes in soil moisture content, the electrodes on each profile in the farm were maintained at the same position and measurements were taken using the same protocols on 24 hrs interval throughout the survey period of two months (10th June, 2013 to 16th August, 2013).

Fig. 3: *(a) Electrodes (b) Cable-jumper- electrodes connection (c) Set-up of system for CVES measurements.*

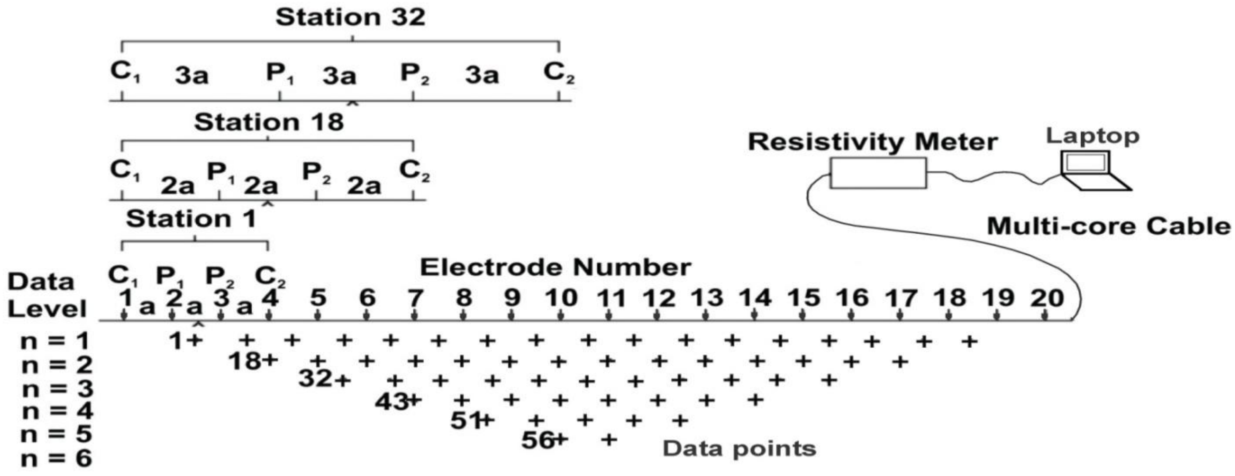

Fig. 4. *Sketch of the electrodes for the 2D electrical resistivity survey and sequence of measurements for building the pseudo-section [17]*

2.4 Data Processing

The data for the 2D resistivity was processed with the RES2DINV software. Here, our main purpose was to convert the apparent resistivity measured in the field to true resistivity so as to see the resistivity variations as a result of soil moisture content. The data was first filtered to remove bad data points which were easily viewed as they stand out since the values were displayed in the form of profiles for each data level. The L1-norm (robust) inversion technique was employed to allow the modeling of relatively sharp changes in resistivity because the inversion algorithm aims to minimize the absolute value of data misfit [18]. The Gauss-Newton method was used in calculating the resistivity matrix for all the iterations. To get optimum results, the Inversion/Model refinement was used which allowed us to choose models with widths of half electrode spacing. In addition to the inversion routine, the user defied logarithmic contour interval was applied to all the four profile lines in order to have even contour values and spacing for easier comparison of the profiles lines. The final 2D models were then enhanced using Golden Software Surfer and CorelDraw. Time-lapse inversion was also carried out using RES2DINV software to transform the apparent resistivity pseudo-section into a model of the subsurface resistivity distribution as described in section above. Here the each data file was sorted by running a shell script on Linux terminal to compare two files from the same profile but with different time-lapse. This was necessary since data from the resistivity survey are mostly confronted with missing data points from some electrodes. The output from the script indicates the position of missing data which was manually corrected. Also, the editing ensured that all the data files from the same profile were of equal length and with same coordinates. After sorting of the data, another shell script was compiled to merge the individual files into a single file for time-lapse inversion processing. This made it flexible to merge any desired number of files for processing. The merged files were then saved into new names for inversion with the RES2DINV software. L1-norm (robust) inversion techniques, Gauss – Newton method, inversion/model refinement and user defined logarithmic contour interval were all carried out to produce 2D models.

3 Results and Discussions

Fig. 5 - 12 showed resistivity models and their percentage changes which were obtained from the four different plots in the maize farm. It was assumed that, during the period of the survey there were no changes in lithology and all variations within the soil were as a result soil water content changes. In addition, rainfall played a significant role in the soil water content variations in the plots. The range of resistivity values obtained were between 40 – 600 Ωm which is within that of sandy-loam soil class [19]. Generally, all four plots (ploughed-harrowed, ploughed, hoed and no-till) showed a heterogeneous depletion of soil water content by the maize crops and this was indicated by the low/high electrical resistivity variations at the surface. Very low resistivity zones apparently due to saturated clay were present in all the plots and served as the storage zone of moisture. The top soil (vadose zone) in all cases experienced much evaporation during prolonged dryness and also hosted majority of the maize roots during the vegetative stage. Moreover, it was also clear that, areas where the maize crops were planted showed presence of soil water extraction by the plants characterized by high resistive values. In the ploughed-harrowed plot (Fig. 5), there was heterogeneous distribution of moisture within the subsurface which could be ascribed to the leveling and disaggregation carried out during the land preparation mode. Also, the top layer easily gave off much water (poor retention ability) although there is enough moisture below 0.30 m of the soil. From the resistivity model, this top surface was characterized by resistivity values of about 200 Ωm and above while the lower section recorded below 200 Ωm. As compared to the other plots, this land was considered to have high infiltration rate due to the loosed soil within the top layer. This high permeability of the soil was ascribed to the loose soil on its surface which resulted from ploughing and harrowing as well as enhanced activities of earthworms [20]. However, temporally, the ploughed-harrowed plot was susceptible to high rate of evaporation of moisture at the surface as shown in Fig. 5c which was recorded after five days without rainfall. These changes in resistivities between the models measured on 10/06/13 to 17/06/13 are well displayed in the percentage models in Fig. 6. Here after 48 hrs with a little precipitation, negative percentage change in resistivity values were recorded at the top layer (Fig. 6a). This indicated that moisture has been gained. After 7 days, with five (5) days of no rainfall, high percentage changes in soil moisture of about 50% - 150% were recorded on the surface (Fig. 6b) indicating loss of soil moisture. This was attributed its high rate of evaporation, as well as infiltration into deeper sections and finally extraction of water by the plants among other factors. Comparatively, it recorded the highest resistivity values of about 566 Ωm within the surface during this period (Fig. 5c).

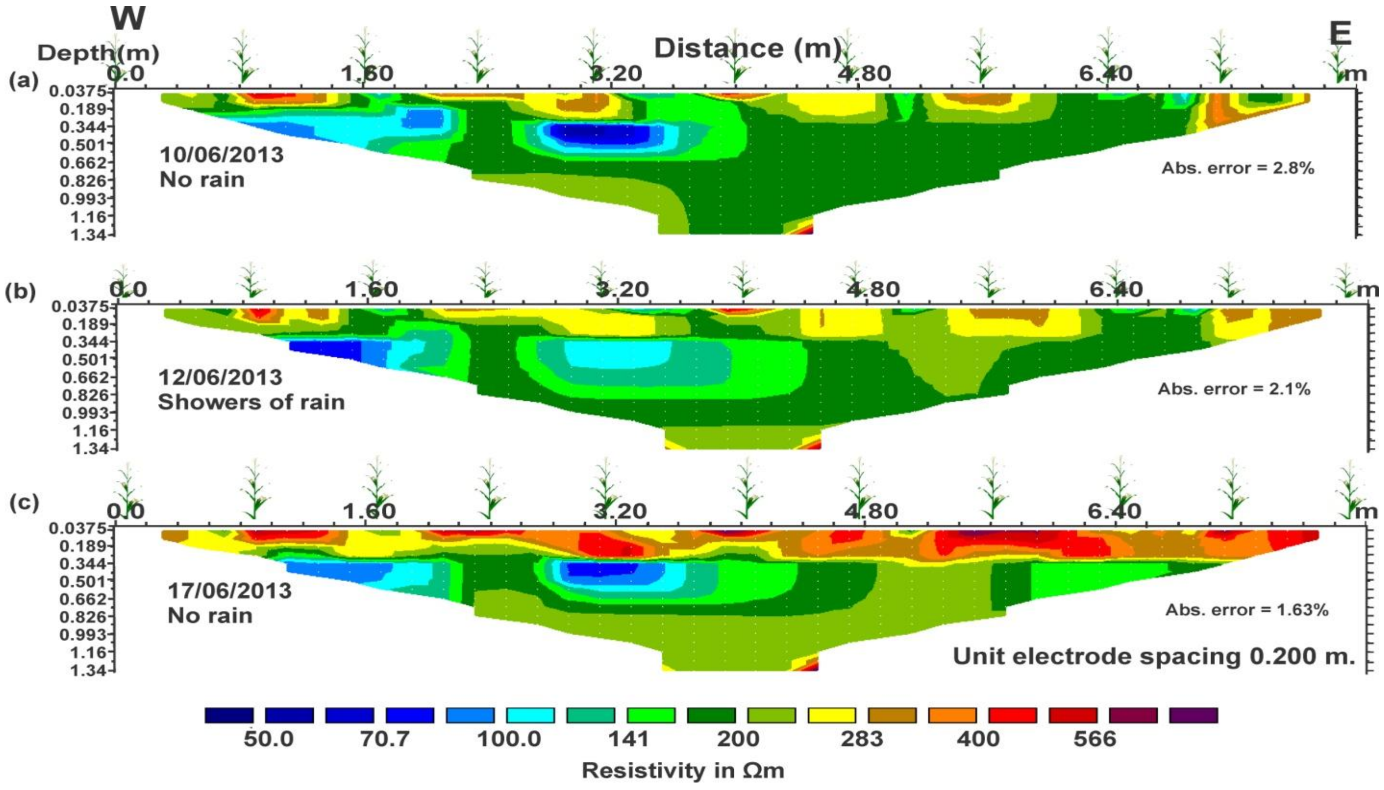

Fig. 5: *Ploughed-harrowed plot resistivity models (a) 10/06/13 (b) 12/06/13 (c) 17/06/13*

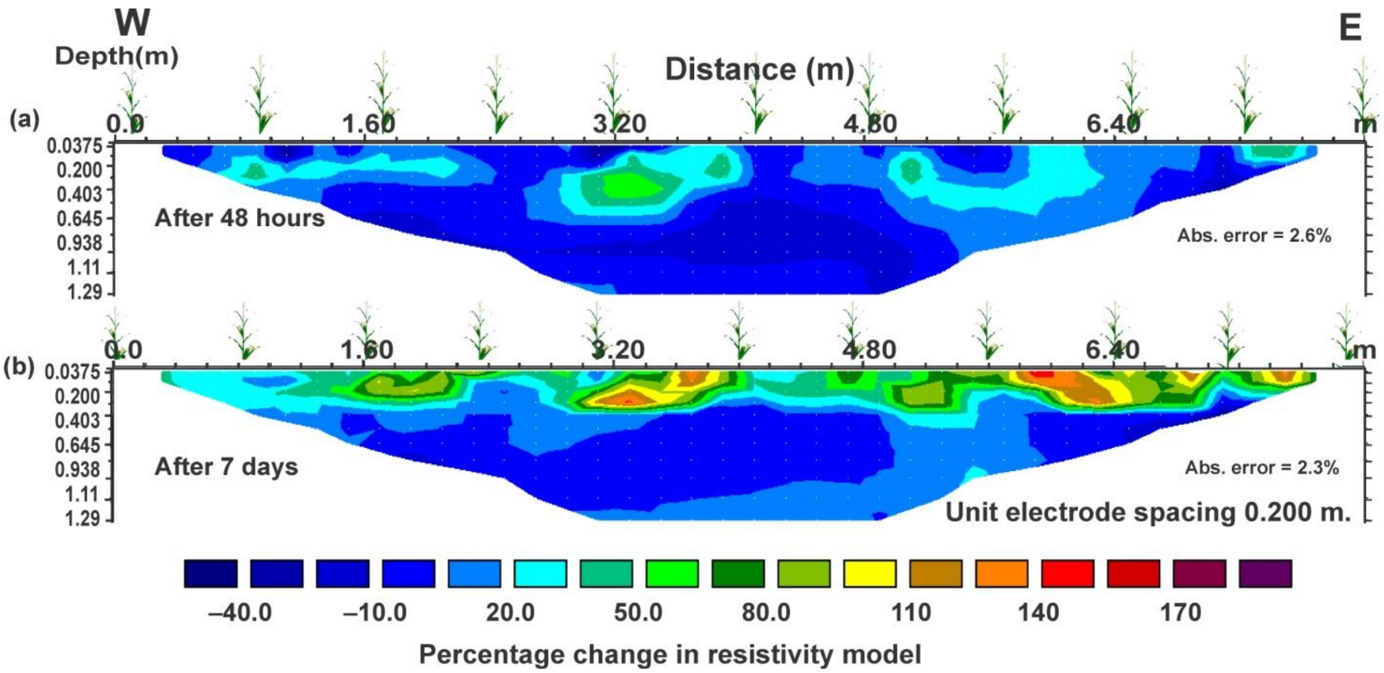

Fig. 6: *Ploughed-harrowed plot percentage change in resistivity models (a) 12/06/13 (b) 17/06/13*

For that of ploughed only plot (Fig. 7), variations of soil water content on the topmost layer was not as uniform as that of the ploughed-harrowed plot. There was retention of water as well as good infiltration within the top surface up to a depth of about 0.40 m. As shown in the models (Fig. 7), the top layer displayed resistivity values of about 100 to 283 Ωm while a very resistive zone of 283 Ωm is located at 0.50 m depth which stretches to 3 m wide on the plot. In the absence of rainfall, the ploughed plot looses moisture at the top surface and beneath (Fig. 7c). These changes in resistivity values were between 0 – 20% after 7 days with five days without rainfall. As compared to the other plots, the bottom had poor storage capability of soil moisture content because of the high resistive zone located beneath with resistivity of about 400 Ωm (Fig. 13b). This plot is therefore not suitable for deep rooted plants but can support maize production.

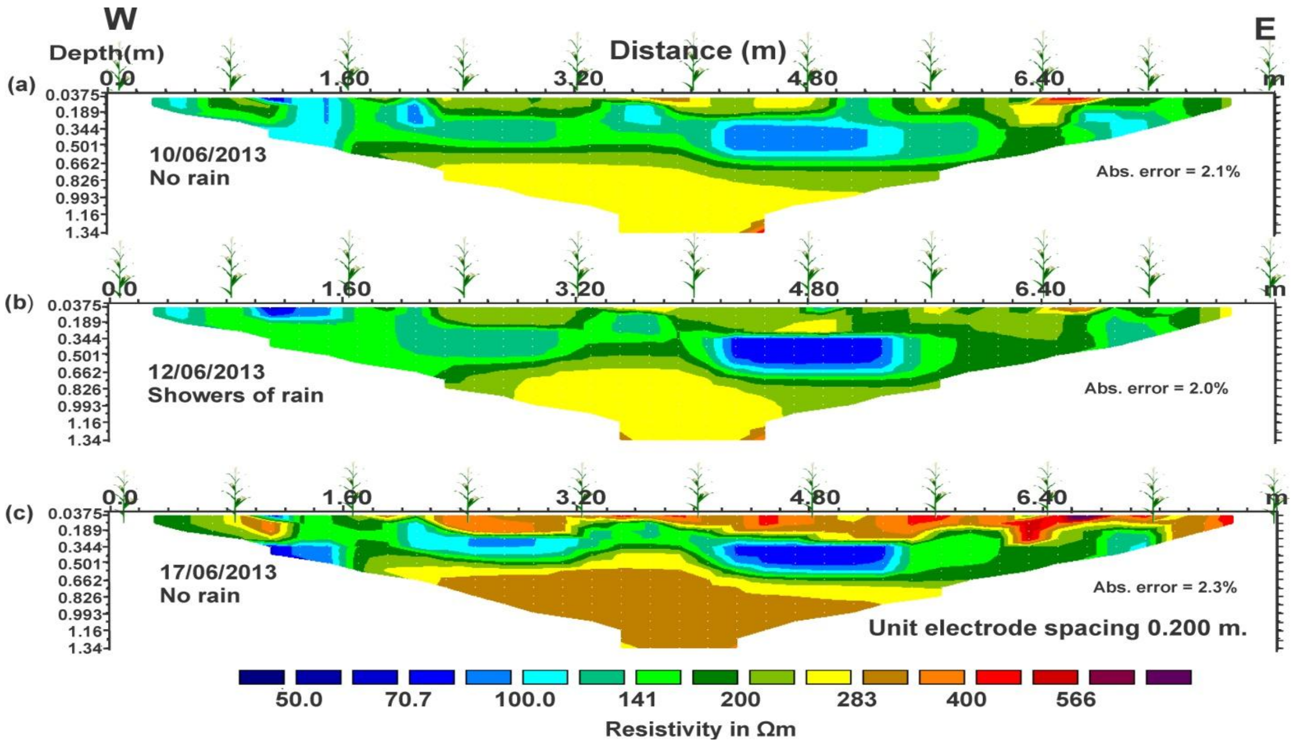

Fig. 7: *Ploughed plot resistivity models (a) 10/06/13 (b) 12/06/13 (c) 17/06/13*

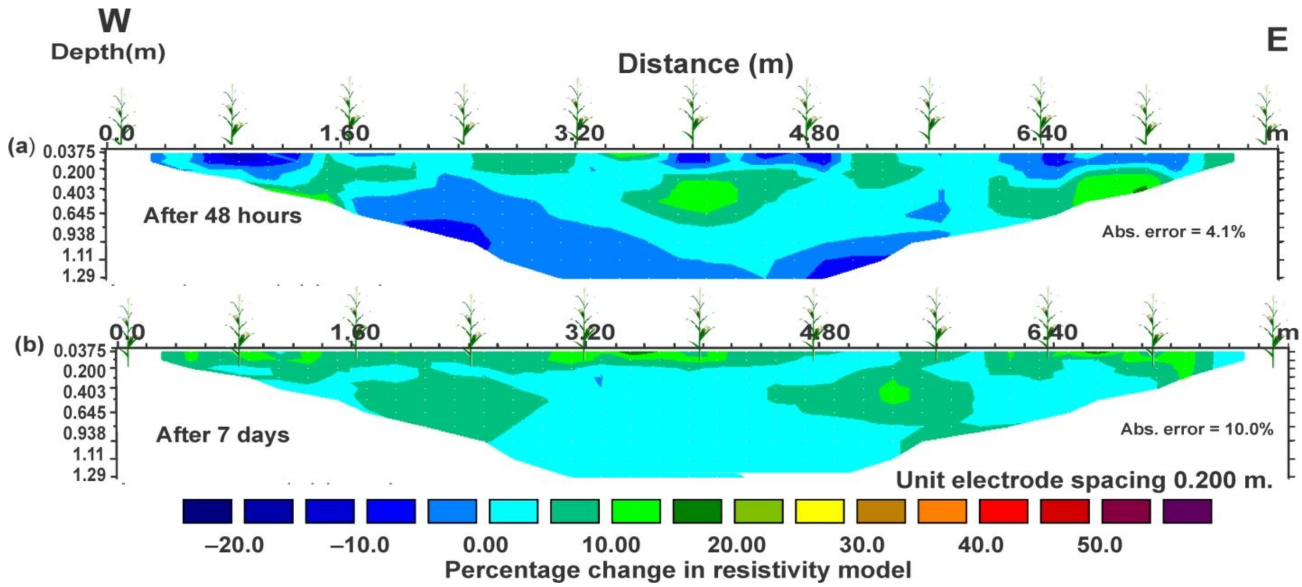

Fig. 8: *Ploughed plot percentage change in resistivity models (a) 12/06/13 (b) 17/06/13*

In the case of the hoed plot (Fig. 9), a minimal amount of soil moisture was lost at the surface as compared to that of ploughed-harrowed plot. This was because the traditional hoeing of land does not penetrate deep enough to perturb the deeper sections of the soil. It is therefore more compacted than other land preparation modes which were either ploughed or harrowed. Deeper parts of the soil (below 0.34 m) under thin land preparation indicated more moisture which was characterized by low resistivity values up to 200 Ωm (Fig. 9a – c). The temporal distribution of soil moisture revealed that this plot also had low evaporation rate as compared to the first two plots and could support maize crops during the vegetative stage. The percentage resistivity changes between the 10th to 17th June, 2013 also, confirms the retentive nature of this plot as most of the sections recorded either negative or no-change at all (Fig. 10). The hoed plot does not require daily irrigation during the dry season but at regular intervals of about three days to sustain plants water requirements.

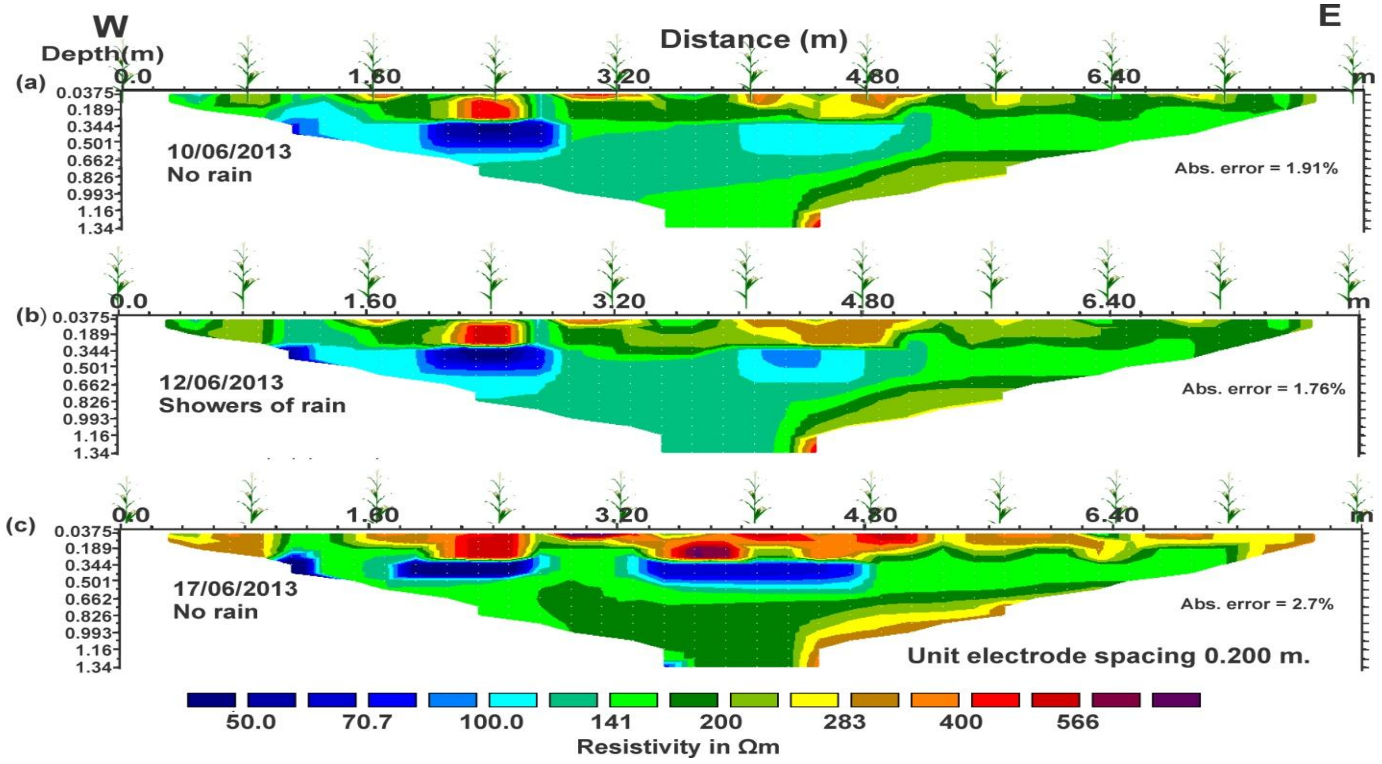

Fig. 9: *Hoed plot resistivity models (a) 10/06/13 (b) 12/06/13 (c) 17/06/13*

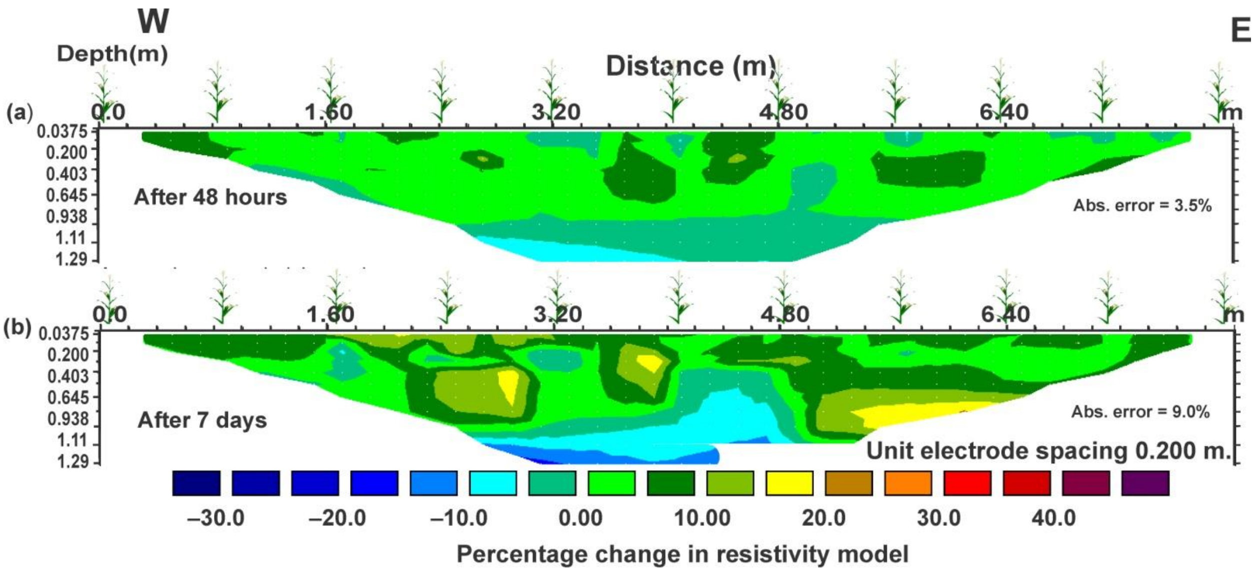

Fig. 10: *Hoed plot percentage change in resistivity models (a) 12/06/13 (b) 17/06/13*

Profile 4 located on the no-till plot (Fig. 11) showed minimal variation of soil water content within the surface as a result of the compacted nature of the soil. This caused less infiltration of water through the soil. It also maximized surface sealing and this directly reduced soil water evaporation within the surface. As shown in Fig. 11, the top zone has resistivity distribution of up to about 200 Ωm except at the 1.60 m and 3.40 m marks located on top of the saturated clay zones, which recorded resistivity values of about 200 to 300 Ωm respectively. Also, three saturated zones with very low resistivity which were maintained in the natural formation due to the absence of hoeing or ploughing served as the recharged zone for the immediate surroundings. Spatially within this plot, the eastern section showed low resistivity variations as a result of high soil moisture content. The percentage change in resistivity from the 10th June, 2013 to the 12th and 17th June, 2013 indicated negative change of about 10% within this model (Fig. 12). This actually buttressed the ability of this plot to retain enough water for plant growth even during dry weather conditions as compared to the other three plots. The no-till technology therefore conserved moisture by reducing evaporation, temperature fluctuations and runoff as was observed by Goddard et al. [21]. Temporally, the plot did not require regular water supply in the dry season since conservation was efficient. It is therefore suitable for the maize crops in both wet and dry seasons.

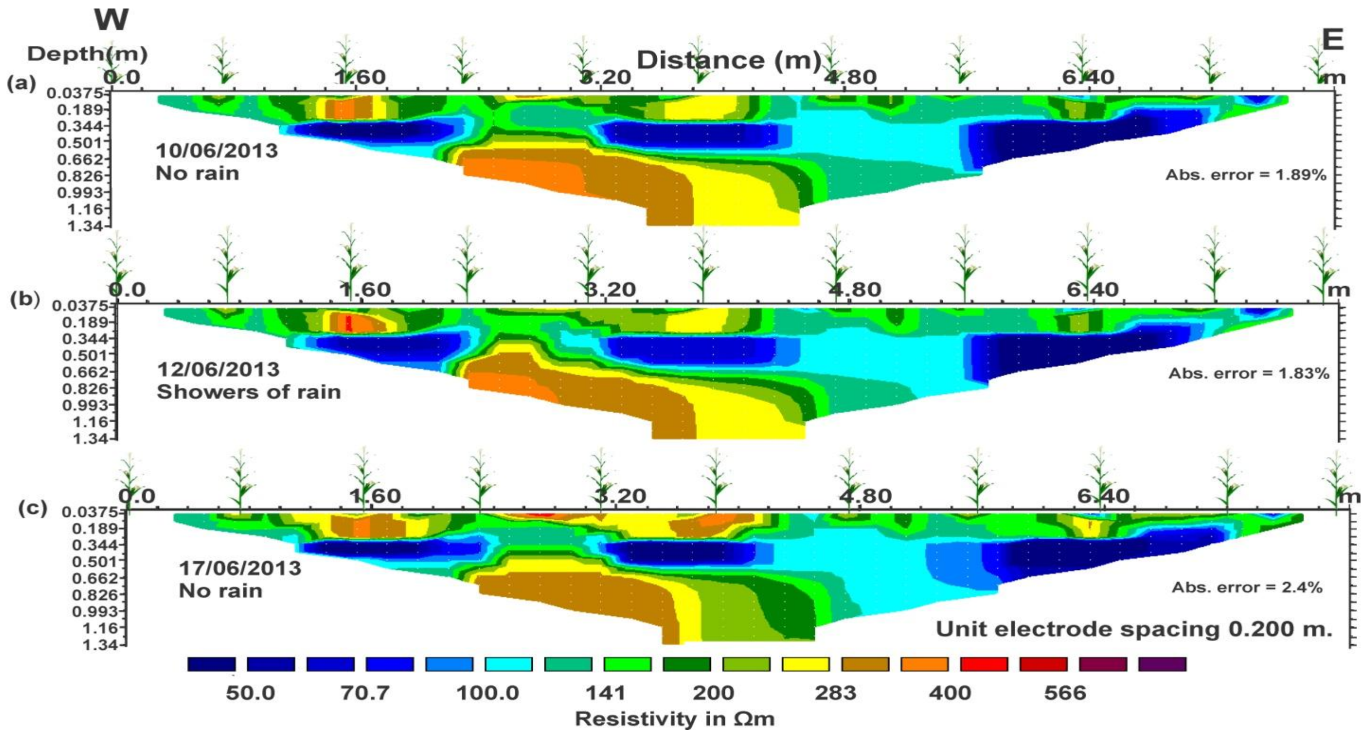

Fig. 11: *No-till plot resistivity models (a) 10/06/13 (b) 12/06/13 (c) 17/06/13*

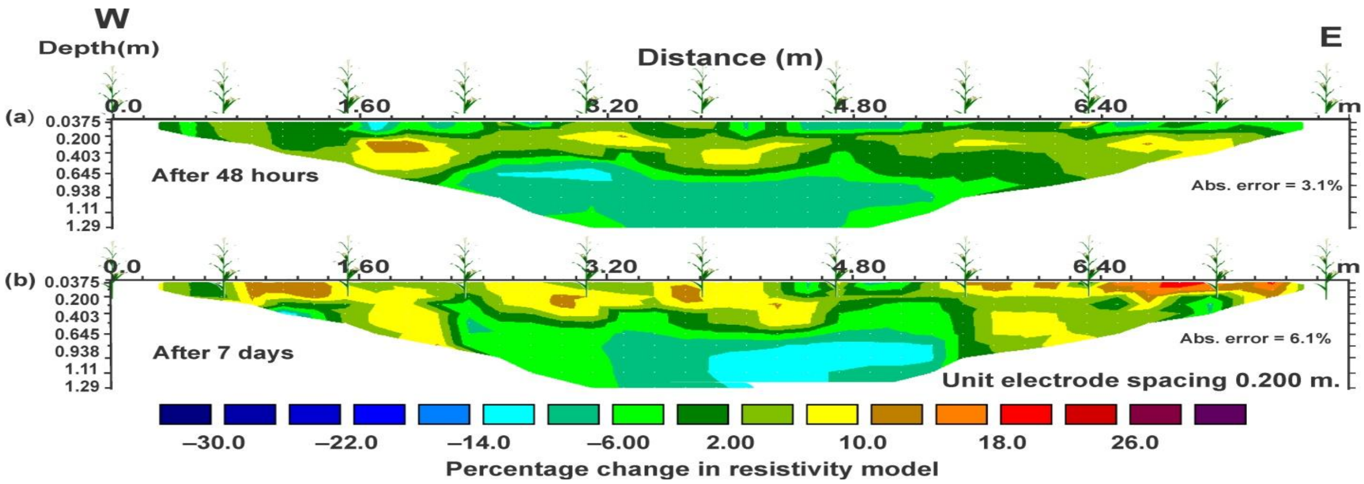

Fig. 12: *No-till plot percentage change in resistivity models (a) 12/06/13 (b) 17/06/13*

To assess these temporal and spatial distributions of soil moisture with respect to the soil preparation mode, Fig. 13 shows resistivity models that were obtained on the 16th August, 2013 for all the four plots. This was done during the dry season to assess the moisture retention capability of these plots. From fig.13a, there is a high resistivity variation on the top surface as a result of high evaporation rate of the ploughed-harrowed plot. Resistivity distributions of about 600 Ωm and above were observed on the surface. Due to its good infiltration rate, there was still quite a significant amount of soil moisture at deeper sections which were characterized by resistivity values of 300 Ωm and below. The second plot (Fig. 13b), which was only ploughed displayed similar results on the surface as that of the ploughed-harrowed plot. But this plot unlike the previous plots, had poor storage capability as a result of a very resistive zone located at deeper depths. It is therefore considered unsuitable for deeper rooted plants. For the hoed plot, evaporation was high on the surface as indicated by the resistivity distribution but with high accumulation of moisture at deeper depths (Fig. 13c). Comparatively, the hoed plot could support deep rooted plants as said earlier. The no-till plot on this day (16/08/13) still displays minimal variation of resistivity on the surface as compared to the other three plots. Moisture was heterogeneously distributed with several areas of low resistivity distribution both on the surface and at deeper depths. This indicates the moisture retention ability of this type of land preparation and makes it suitable for both shallow and deep rooted crops especially during the vegetative stage of maize.

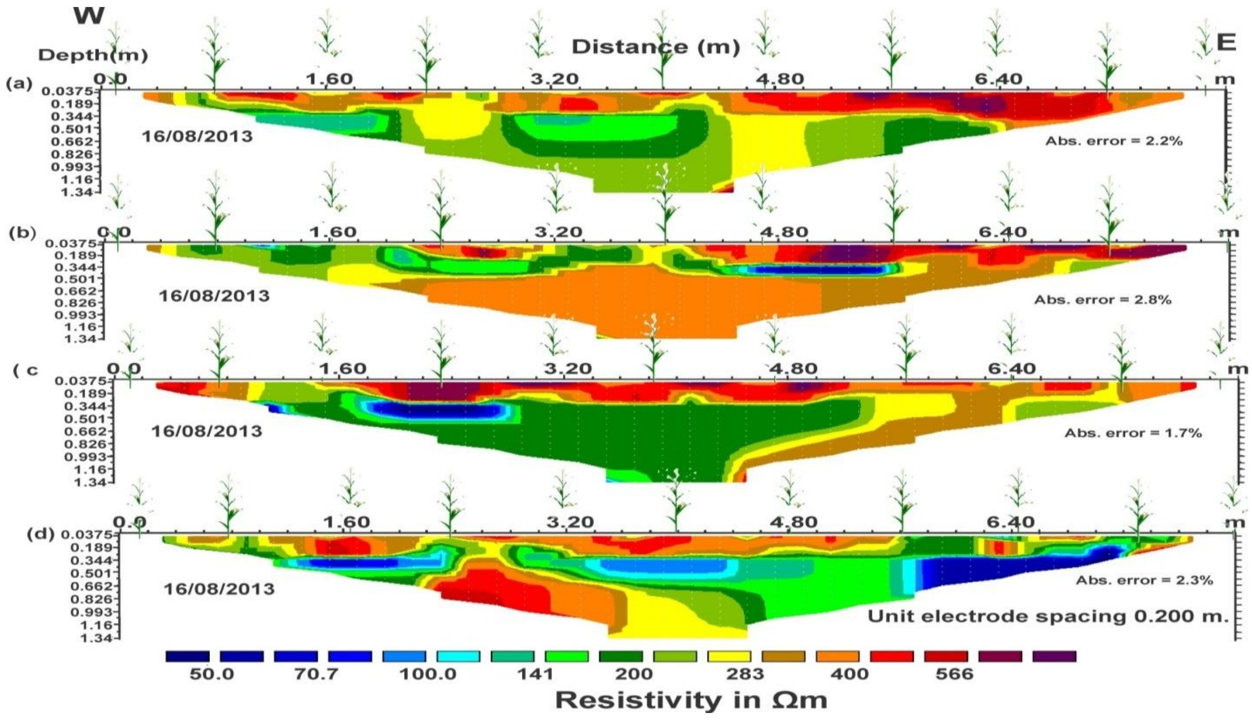

Fig. 13: *Resistivity models obtained on 16/08/13; (a) Ploughed-harrowed plot (b) Plough plot (c) Hoed plot (d) No-till plot*

4 Conclusions

- There is a heterogeneous distribution of moisture both spatially and temporary due to the nature of soil, organic matter present, evaporation, plants water uptake, infiltration into deeper depths etc in all plots with high accumulation at a depth of about 0.20 – 0.40 m coinciding with the root zone of the maize.
- The No-till plot conserved more moisture as compared to the ploughed-harrowed, ploughed and hoed plots. Hence there is the need for regular irrigation in these plots to sustain crop yield during dry weather conditions.
- Very low resistivity zones apparently due to saturated clay were present in all the plots.
- The use of the improvised electrodes made of wood and copper wire as an alternative to the steel electrodes in monitoring soil water content for agricultural purposes also proved to be very efficient.
- The application of Continuous Vertical Electrical Sounding technique was efficient in monitoring shallow soil water content in the field and results from the measurements could be used to optimize irrigation scheduling and to assess the potential for variable-rate irrigation.

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