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Article

Use of Two Dimensional Electrical Resistivity Tomography to Identify Soil Water Dynamics and the Effective Plant Root Zone

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The identification of effective root zone would clarify dynamics of plant available water and soil water balance. Using the relationship between soil properties and electrical resistivity (ER) the purpose of this research is to identify soil zone affected by a plant root activity using electrical resistivity tomography (ERT) technique. Four plastic containers were prepared for two different soil textures (clay and sandy loam) and one container for each texture was selected for planting four corn seedlings (*Zea mays* L.) and the others were prepared for the blank. For ERT monitoring, we prepared 0.8 m plastic sticks with 17 electrodes installed with 5 cm space. The Ministing (AGI Inc., Texas) instrument for electrical resistivity measurement and semi-auto converter of electrode arrangement were set up for dipole-dipole array. During 2 months of the corns growing, ERT monitoring was made 3 to 4 days after the irrigation practice. Despite of the same amount water supplied into soils, two textures showed very different apparent resistivity values due to different clay content. The apparent electrical resistivity is consistently lower in clay loam comparing to sandy loam soil implying that plant root does not significantly alter the overall trend of resistivity. When plant root system, however, is active both soils with plants showed 2-7 times higher electrical resistivity and higher coefficient variation than soils without plant, implying the effect of root system on the resistivity, in which may caused by . This result suggests plant root activities regulating the soil water dynamics mainly control the variation of electrical resistivity over soil textural difference. Therefore the identification of water uptake zone would highly be correlated to plant root activities, thus ERT will be feasible approach to identify spatial characteristics of a plant root activity.

Key words: Effective root zone, Electrical resistivity tomography, Root water uptake, Spatial distribution, Soil water

Introduction

Adequate agricultural water supply would be a key factor for a sustainable water resource management. Soil water dynamics at the agricultural field is regulated primarily not only by climate or vegetation cover type but also available water fraction in effective root depth. The identification of root depth and its activities would help us to clarify plant available water capacity and to develop appropriate soil water balance model, supporting sustainable irrigation water supply strategies. However, the fact that intensive agricultural practice continuously changes the spatial-temporal properties of soil requires precise monitoring techniques during the cropping periods.

Recently, geophysical exploration techniques have received a great attention due to their non destructive character when collecting data from underground and now have been widely applied to many relevant fields including soil science recently. Especially, electrical resistivity techniques among them are considered promising tool for study of spatial and temporal variation of soil properties including geometrical characteristics of particles and pores, soil water content, salinity, or temperature due to its strong correlation (Samouëlian et al., 2005; Yoon et al., 2011). (from Hadzick et al 2011): Bernabe-Ubertosi et al. (2009) showed an

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excellent relationship among resistivity, water content, and pore water salinity in a 3 m deep profile of saline clay marsh soil. Brunet et al. (2010) monitored the soil water deficit in a shaley sandy soil with extremely homogeneous profile texture distribution, and obtained excellent correspondence between ERT derived and TDR measured soil water contents. Turesson (2006) used a relationship between ERT data and water content from 10 m deep sandy layer.

One of the most import factors to develop the proper irrigation scheduling is to identify the effective root depth of crops due to its relationship to water usage and spatial characteristics of soil water dynamics. Rooting depth infers the soil depth containing plant available water for the plant. Since plants do not evenly absorb water from the entire root zone, the effective root zone which is the space supplying most of water to plant root system should be the part of the actual root zone and is commonly referred as effective rooting depth due to the difficulty of identifying the spatial characteristics of plant root system. This effective root zone is affected by many factors such as crop itself or soil properties. Many methods are available to determine spatial-temporal water dynamics in the zone which are governed by water uptake by plant root system. However, most of them are destructive and unavailable for a continuous monitoring or spatial characterization. The ERT technique which is recently applied to soil science could be an alternative. Difficulties such as clay content as well as other soil properties affecting apparent soil electrical resistivity, however, may act as confounding factors in its relationship to soil water content and plant root system (Jayawickreme et al., 2008; Schwartz et al., 2008, Basso et al., 2010; Jayawickreme et al., 2010). Only few studies available on the use of ERT to investigate the plant root system which are also conducted under the limited condition may not be enough to fully extend our knowledge on the development of plant root zone and its activities.

Using the relationship between soil properties with plant roots and the corresponding electrical resistivity, the purpose of this research is to identify the feasibility of ERT as a nondestructive tool for the monitoring of a plant root zone development and spatial variability of soil water dynamics under the controlled environment.

Materials and Methods

Preparation of soil containers with plants Our experiments were conducted during 2 months from March 1 to May 10, 2012 at the greenhouse located in the Experimental Stations of National Academy of Agricultural Science at Suwon (Republic of Korea). Soils used in this experiment were collected from top soil of an adjacent experimental field with different texture of soil in the Station which was constructed in 2005. Four plastic container of 0.9 m (length) × 0.6 m (width) x 0.35 m (height) size were prepared for cropping corns on two different soil textures of soil. Two containers (Container 1 and 2) were filled with a sandy loam soil and the others (Container 3 and 4) with a clay loam. In order to confirm textural difference, texture analysis using the hydrometer method was performed (Table 1).

Corn seedlings were transplanted to one container from each texture (Container 2 and 4) on March 5, 2012, thus the others (Container 1 and 3) remained to represent the blank condition. Except for the seedling area, entire soil surfaces of all containers were covered by a plastic film to minimize water loss due to the evaporation. Four corn seedlings were planted with 40 cm inner row and 30 cm inter row spacing. Since the planting corn seedling, the exactly same amount of water was supplied to two different texture of soil

Table 1. Summary of basic physical and chemical properties of soils used before planting and fertilizer application.

Soil		Textural composition			Initial WC	EC	OM	pH	CEC	NO_3-N	NH_4-N	Avail. P_2O_5
		sand	silt	clay								
		---------%--------			%	dS m^{-1}	g kg^{-1}	(1:5)	$cmol_c$ kg^{-1}	---------- mg kg^{-1} --------		
Container 1	Sandy loam	55	35	10	11	0.30	8	6.9	8.79	9.3	2.5	210
Container 2		55	35	10	13	0.26	8	6.8	8.61	8.8	2.4	206
Container 3	Clay loam	30	42	28	12	0.30	16	7.2	13.59	10.9	2.7	145
Container 4		30	41	29	10	0.25	15	7.2	13.10	9.7	3.3	136

despite of the difference of plant available water for the comparison of ERT behavior. However, water kept accumulated up to near saturated level in the container without plants because there was not any source of water loss or usage. Thus, no more water supply was made on the blank soils after the mid of April (45 days after the transplant). Fertilizers were applied to all containers when planting corn seedlings including compost manure, then, one month after the planting we applied again compost manure to all soils. Water supply and fertilizer application were made by a hand sprayer to avoid soil surface sealing by impact and achieve a uniform water distribution on the surface.

Electrical resistivity measurement system setup To obtain one measurement of electrical resistivity four electrodes were required. Two electrodes inject the electric current and others measure the potential differences. By linearly arraying many of electrodes, it is possible to construct 2 dimensional image of underlying section using the inversion technique. Different methods available such as Wener or Dipole-Dipole array depending on how to increase the distance between current and potential electrodes realize different characteristics of electrical resistivity field. Details can be found in Kim et al. (2001), Samouëlin et al. (2005) and Yoon et al. (2011). Among available techniques we chose a dipole-dipole array due to the instrumental limitation but this array also has unique advantages comparing to others such as offering a fine resolution image or better identifying vertically oriented structure. According to the general principle of electrical resistivity measurement, the electric potentials measured on the soil surface can be converted into a 2D section of apparent electrical resistivity (ρ) by

$$\rho = K\frac{\Delta V}{I} \qquad (1)$$

where ρ is apparent electrical resistivity (Ωm), K is geometrical coefficient, ΔV is difference in electrical potential (V), and I is current (A).

As increasing the distance between current source of electrodes and the electric potential electrodes, the measured location moves to deeper soil. Therefore, space between the electrodes refers the resolution of a resulted image. The measured apparent electrical resistivity should be processed by the inverse modeling practice which can be done by DIPROfWin software (Heesong Geotech, Seoul) in order to convert into a true soil electrical resistivity.

We prepared 0.8 m plastic sticks having 17 holes for electrodes installation with 5 cm interval (Fig. 1a). The Ministing (AGI Inc., Texas) instrument was used for an electrical resistivity measurement. This instrument is only available for a single measurement by 4 electrodes

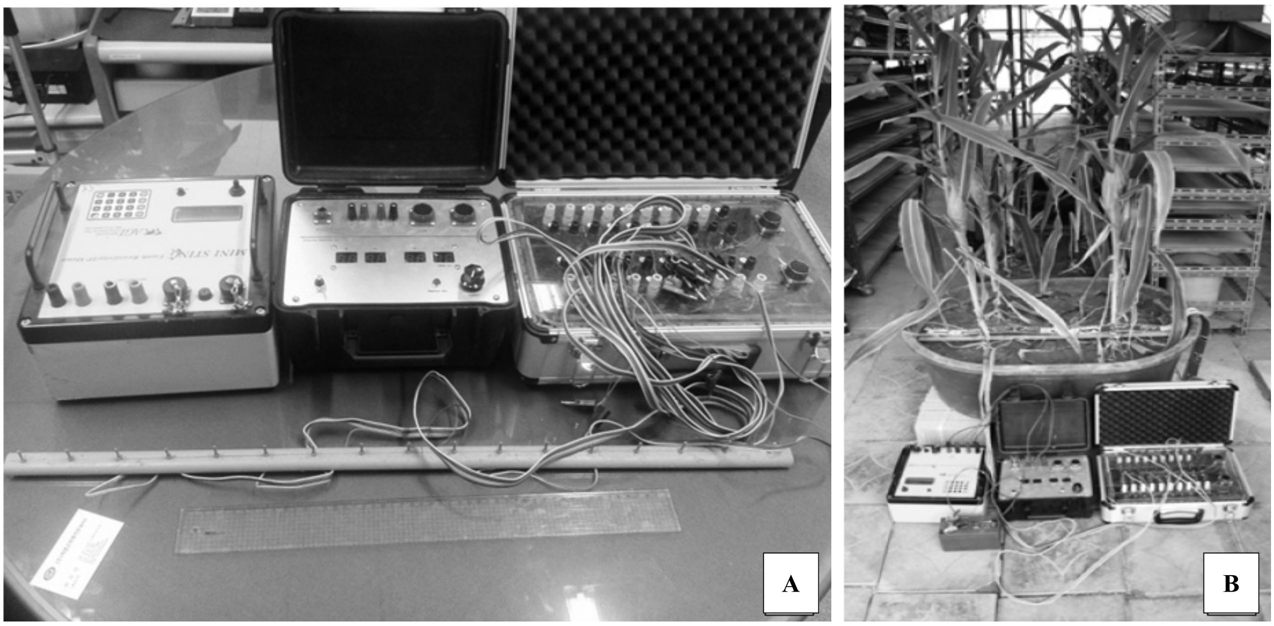

Fig. 1. A) The experimental setup to measure electrical resistivity tomography and B) The electrical resistivity measurement system installed on 4 containers with and without corns at the experimental site.

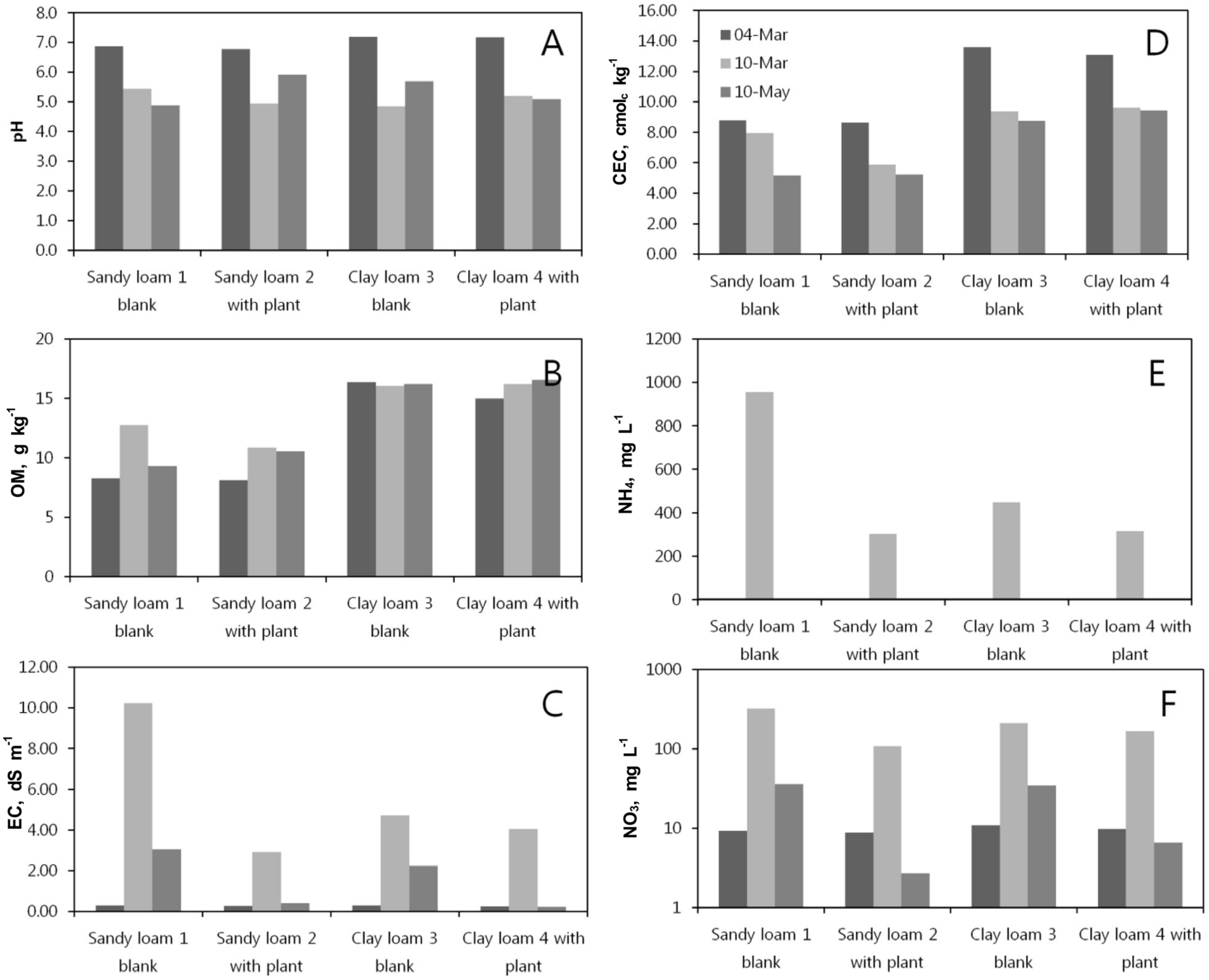

Fig. 2. Trends of various nutrients and chemical components: before planting and fertilizer application (March 4, 2012), right after planting and fertilizer application (March 10, 2012), and the end of experimental period (May 10, 2012).

array, thus in order to facilitate the measurement we used the semi-auto converter of electrodes arrangement which was developed by C&H Inc (Seoul, Korea). Additionally we construct the connector plate to connect all electrodes once to semi-auto converter, then to the Ministing device to avoid repeating new set-up of the arrangement for each time of measurement. During two months of corn growing, ERT monitoring was made three times on 3-4 days after the irrigation (Fig. 1b).

Soil physical, chemical and hydraulic properties In order to measure soil water content, EC, and temperature we prepared 15 holes to insert 5 TE water probe (Decagon Inc.) on the side section of each plastic container, covering three depths ranged between 0 and 0.1 m, 0.1 and 0.2 m, and 0.2 and 0.3 m, respectively, for top, middle, and bottom. For soil textural composition, nutrients, EC, CEC, and pH, we collected bulk soil samples three times on before and right after the fertilizer application and also the end of experiment period.

Results and Discussion

The converted true resistivity image indicated higher electrical resistivity area and also spatial variability roots with time compared to soils without plant (Figure 3). This result may infer the effect of root zone development induced by plant roots growth and associated activities. At the initial periods of corn growing (plant age up to 15 days) sandy loam soils did not present any significant features of corn root emergence at the top soils although soils without plant (Container 1 and 3) showed obvious different spatial trend of

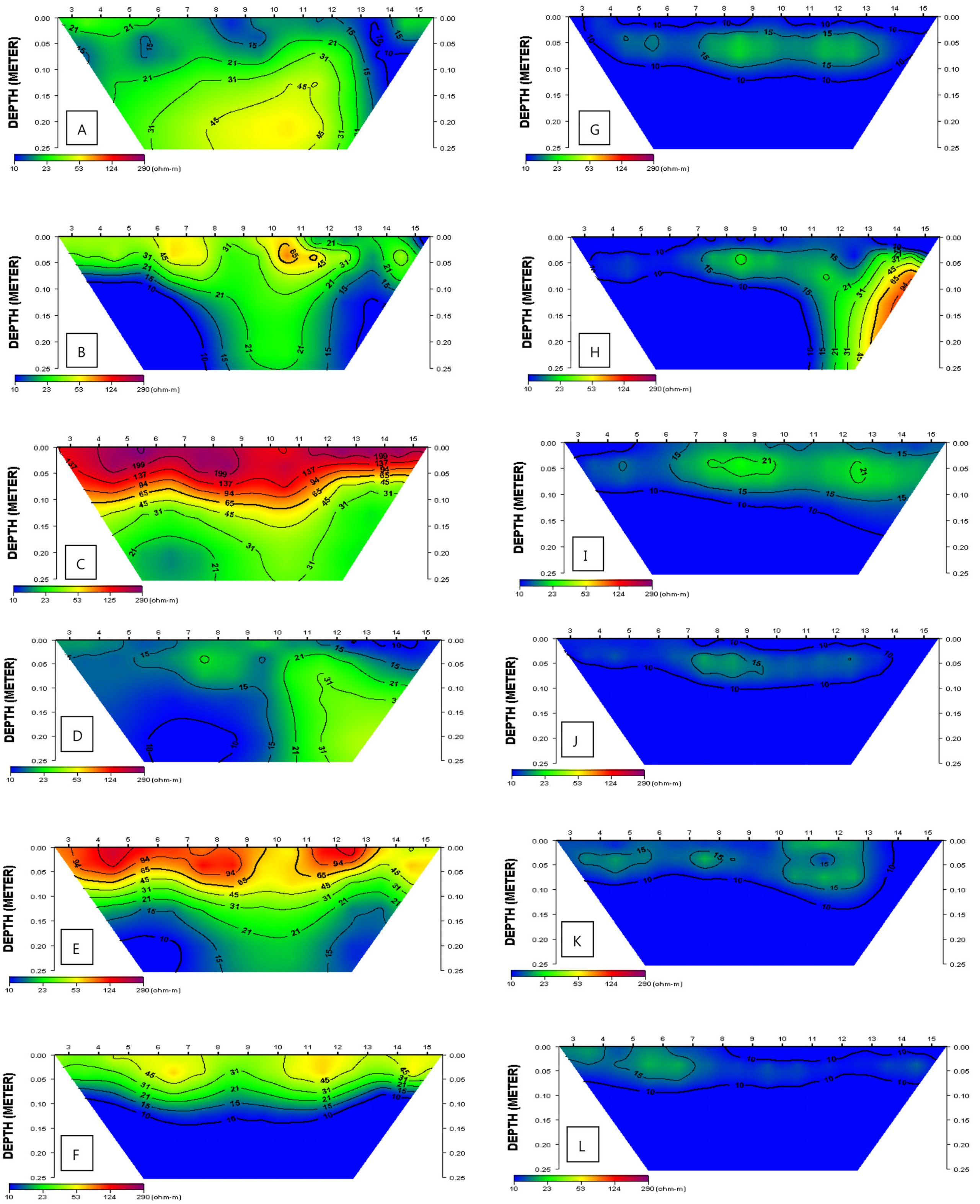

Fig. 3. The interpreted true resistivity images derived from dipole-dipole method: left side figures on soils with plants (A − F) and right side figures on the corresponding soils without plant (G − L). Upper six figures (A − C and G − I) left side are sandy loam and others (D − F and J − L) are clay loam. The first row of each soil image (A and G for sandy loam, and D and J for clay loam) were measured on March 26, 2012 and the second (B and H for sandy loam, and E and K for clay loam) and the third row (C and I for sandy loam, and F and L for clay loam) were measured on April 10 and May 10, respectively.

Table 2. Electrical resistivity measurement schedule and the cumulative amount of water supply.

Date	Plant age	Cumulative amount of irrigation
	-- days --	m^3
March 23	18	0.010
April 26	52	0.028
May 10	66	0.043

Table 3. Comparisons of average apparent electrical resistivity values measured on May 10, 2010 for different depths of soils.

Depth	Sandy loam						Clay loam					
	ρ			WC			ρ			WC		
	Average	Std.	CV	Average	Std.	CV	Average	Std.	CV	Average	Std.	CV
m	------Ωm------		--%--	----------------%----------------			------Ωm------		--%--	---------------%---------------		
						With plants C						
0-0.05	170.6	34.1	20.0	0.17	0.02	11.3	39.9	7.1	17.8	0.16	0.04	24.5
0.05-0.10	135.1	45.7	33.8				34.5	5.6	16.2			
0.10-0.15	105.3	44.4	42.1	0.15	0.05	31.0	26.0	6.6	25.6	0.19	0.01	6.0
0.15-0.20	78.2	31.0	39.6				20.9	6.6	31.5			
0.20-0.25	62.5	16.0	25.7	0.09	0.02	27.7	16.0	6.3	39.4	0.19	0.05	29.0
						Without plants (blank)						
0-0.05	16.2	1.7	10.2	0.22	0.05	23.0	11.4	3.2	27.9	0.19	0.02	12.4
0.05-0.10	18.0	1.6	8.9				11.9	2.0	16.6			
0.10-0.15	17.9	2.1	11.6	0.19	0.01	3.9	11.1	1.8	15.8	0.23	0.01	4.4
0.15-0.20	16.4	1.9	11.4				9.2	3.5	37.6			
0.20-0.25	15.1	1.6	10.4	0.19	0.01	3.8	7.8	3.1	40.2	0.27	0.02	8.1

electrical resistivity from soils with plant (Fig. 3A and 3D). This infers early period of corn root activity only affect spatial characteristics of soil water distribution, considering that both soils with or without plant received the same of amount of water and nutrients. The similar trend was also found in Clay loam soils (Fig 1D and J), conforming the effect of plant root activities on soil water spatial distribution despite of textural difference. This trend of difference between soils with and without plant became obvious as corns grew in Sandy loam soils, especially (Fig. 1C). The distinct features of high electrical resistivity area were built up from soil surface to 10 cm depth in case of Sandy loam and 7 cm in Clay loam soils (Fig. 1C and Fig. 1F). It is considered plant root development has played an important role in regulating resistivity field by combination of root system itself blocking electric current and absorbing soil water around them, resulting in an increase of electrical resistivity. Clay loam probably provide unfavorable environmental in development of root system comparing to Sandy loam soils, causing sallow development of active root zone. When comparing with soils of different texture, Clay loam soils had lower electrical resistivity than sandy loam no matter that corns were planted or not. It is well known that the tendency of resistivity change due to clay content decreases the resistivity with increasing clay content although there is difference response depending on clay types. The electrical charges on the clay surface resulted in greater electrical conductivity due to the magnitude of the specific surface (Fukue et al., 1999; Samouelian et al., 2005) and it is particularly true when clay particles are coated on the surface of sand grain in soil, leading to greater continuity for electric current flow by clay bridge (Lamout et al., 1994; Samouelian et al., 2005). Root uptake in clay loam would be slower than that in sandy loam causing higher water content and lower electrical resistivity (Fig. 1C for Container 1 and Table 3), but the planted zone located around electrode #6 and #12 clearly distinguished from around area (Fig.

1F) despite of relatively high soil water content. This result may suggest plant root activities regulating soil moisture mainly cause the variation of electrical resistivity comparing to soil textural difference. Soils with plant roots presented 2 to 10 times higher apparent resistivity values implying the resistivity increase would also be induced by plant roots (Table 3). In clay loam soil, however, coefficient variation of top soil up to 10 cm showed higher values in soils without plant, requiring further analysis on actual root development, but it is considered that plant roots concentrated on top soil due to difficulties to penetrate into deeper soil. Nevertheless, spatial heterogeneity induced by plant root growth and activity were confirmed by higher coefficient of variance (CV) of soil water content measure by different depth. Especially, higher CV of the resistivity has been found between 10 and 20 cm depths of both soils may infer the root activities would be a major factor of spatial heterogeneity.

Conclusion

Planted soil showed distinct pattern of spatial heterogeneities of the electrical resistivity built up by plant root activities altering hydraulic and physical properties within the effect root zone. Our results confirm that electrical resistivity tomography technique could facilitate the characterization of the effective root zone without any disturbance of soil. Contrary to classic measurement techniques disturbing soil, electrical resistivity is non-invasive offering continuously spatial-temporal measurements along various scales. Soil water dynamics and the associated soil zone which are important in the management of water resources can effectively be controlled by a continuous monitoring of soil properties by the electrical resistivity technique without altering the soil structure. It further enables us to improve our understanding of the soil processes functioning in varying fields with varying conditions.

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