TwoDimensional Spatial and Temporal Monitoring of Soil Water Content in Maize Field Using Electrical Resistivity Tomography

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1. Introduction

Soil water content in actual crop field shows heterogeneous distribution that depends on crop and soil characteristics (Wesenbeeck 1988). 2-D (two dimensional) Electrical Resistivity Tomography (ERT) can estimate subsurface cross sectional soil water content distribution under field crops (Dider Michot et al., 2003). However, Soil resistivity is affected by pore-water EC and Porosity as well as Soil water content (Archie., 1942). In the crop field, there is some application of fertilizer , so soil-water EC and porosity change after that. If we measure all vegetation period using ERT, we have to measure soil-water EC in several times to understand changes that. The objective of this study is to understand how soil resistivity changes by pore-water EC changes.

2. Study site

Study site is located in the National Agricultural Research Center for Kyusyu Okinawa Region Kumamoto, Japan (Fig.1).
Area of maize field is 6ha (400×150m)
Maize plants were sowed with 0.75m rowspacing and 0.30m intrarow spacing (Photo.1).
There was no irrigation for maize plant during the vegetative period.
Average annual temperature in this area is 15.5℃ for 1971-2000.

Photo.1 Maize field

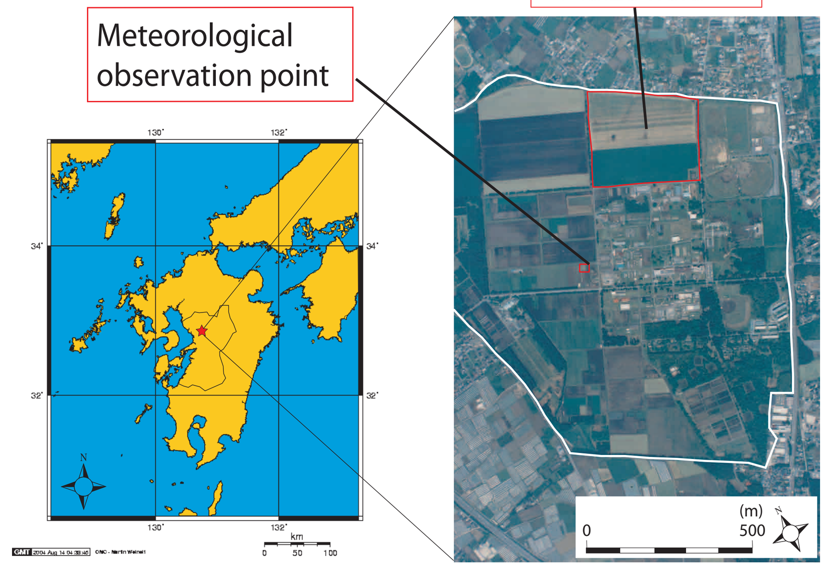


Fig.1 Location of the study site

4. Observation & vegetation period

We conducted various measurement in maize vegetation period and through the year for four years (2007-2010) (Table.1).

Vegitation Type	Vegetation period
Maize	2007(5/17-8/29)
Maize	2008(5/12-8/20)
Maize	2009(5/15-8/31)
Maize	2010(5/15-8/25)
Measurement Type	**Observation period**
ERT	2007(8/10-8/28)
ERT	2008(6/1-7/27)
ERT	2009(5/27-8/28)
Soil water	2009(15times in row)
Soil water	2010(6times in row and interrow)
Water content	every 30 minutes through the year
Soil temperature	every 30 minutes through the year
Length and LAI	once a fortnight in vegitative period

Table.1 Ocservation & Vegetation summary for 2007-2010.

3. Methods

Electrical resistivity tomography

3-1. Field observation of ERT

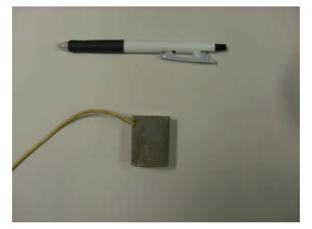


Photo.2 Electrode

Photo.3 Control equipment

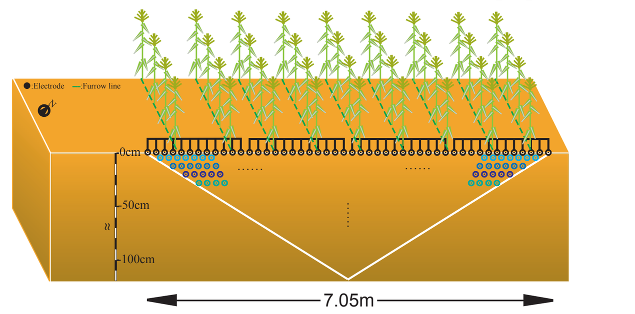


Fig.2 Image of electrical resistivity tomography

Wenner electrode array with 0.15m electrode spacing and 48 electrode (Fig.2 and Photo.2). Measurement was conducted everyday at nearly 6 a.m. when interrow and row soil temperture are about the same (Horton et al., 1984) using control equipment(Photo.3).

3-2. Theory of ERT

The value of the electrical resistivity ρ of a medium is measured with a Wenner electrode array (Fig.3) with an inter-electrode distance a, is

$$\rho = 2\pi a \frac{V}{I} = 2\pi a R$$

I: intensity of current between electrodes
V:potential difference between two- electrodes

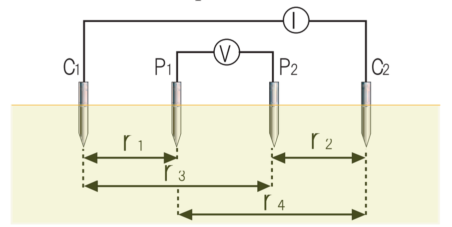


Fig.3 Schematic figure of a Wenner electrode array measurement

Volumetric water content has relation with resistivity of soil water (see Fig.4).

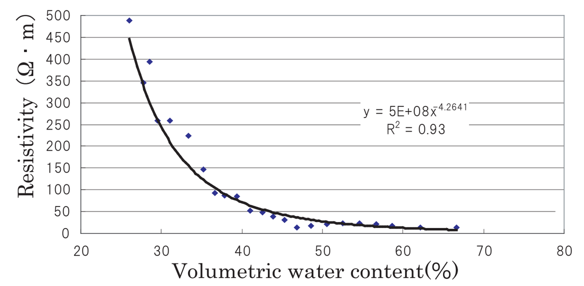


Fig.4 Volumetric water content vs soil resistivity

3-3. Removal the effect of soil temperture to soil resistivity

Soil resistivity is changed by soil temperture as well as soil water content. We corrected all soil resistivity measurements to a reference temperature of 25℃. The correction rule, adopted for a range of temperatures from 15℃ to 35℃, is a 2% per ℃ linear increase of the electrical conductivity of the soil with temperature(Cambell et al., 1948) as the following relationship.

$$\frac{1}{\rho_T} = \sigma_T = \sigma_{25^\circ C}\left[1 + 0.02\left(T - 25^\circ C\right)\right]$$

ρ_T : soil electrical resistivity at the temperature T(in Celsius degree)

σ_T $\sigma_{25^\circ C}$:soil electrical conductivity at the temperature each T and 25℃

3-4. Soil temperature observation and estimation

Soil temperature was measured by thermocouple (Copper-Constantan) from surface to 0.32m every 0.04m at 30-minute intervals through the year. Soil temperture under 0.32m, we estimated using following equation, (Fig. 5,6)

$$T(z,t) = T_A + A\exp\left(\frac{z}{d}\right)\sin\left(\omega t + \phi + \frac{z}{d}\right)$$

z : depth
ω : angular frequency
Φ : phase constant

A : amplitude of surface fluctuation
t : time
d:damping depth
T_A:annual average temperture

$$\lim_{z \to -\infty} T(z,t) = T_A \qquad d = \sqrt{\frac{2K_T}{\omega}}$$

K_T:thrmal diffusivity

Apparent thermal diffusivity(K_T) of the soil is determined using two depth (0.28m, 0.32m) annual max-min soil temperture difference(ΔT)(Horton,2002) .

$$d = \frac{z_1 - z_2}{\ln\left[\Delta T_{(z1)} / \Delta T_{(z2)}\right]}$$

$$K_T = \frac{\omega d^2}{2}$$

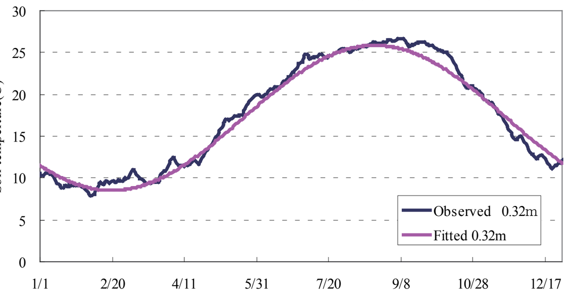


Fig.5 Observed and fitted soil temperture at 0.32m depth

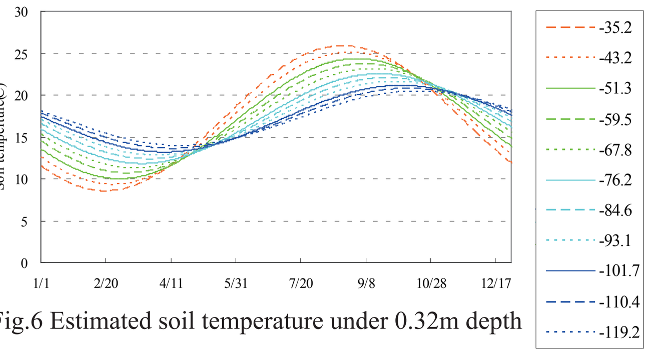


Fig.6 Estimated soil temperature under 0.32m depth

3-5. Growing status of maize plants

Length and LAI were measured once a fortnight. Length of maize was mesured by averageing for 12 individual plants. LAI was measured directly by averaging for 3 individual plants using LAI-3050 (Photo.4).

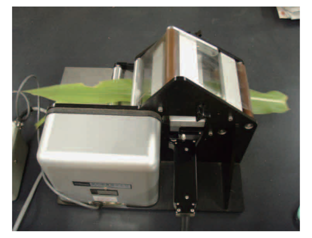


Photo.4 LAI-3050

3-6. Volumetric water content by Time domain reflectometry (TDR)

Volumetric water content was mesured accuratly using TDR(Fig.7) at 30-minute intervals through the year.
TDR were installed at four depths (0.05, 0.15, 0.25, 0.35m).

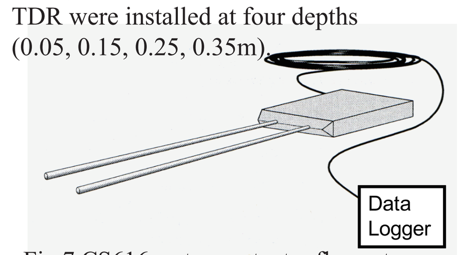


Fig.7 CS616 water content reflecmeter

3-7. Soil water sampling

Soil water was sampled at four depths(0.1, 0,2 0.4, 0.7m) with suction lysimeter (photo.5) in 2009 year, and centrifugation method(pF 4.2) from soil sample in 2010 year

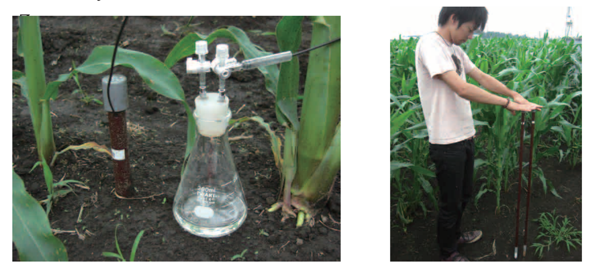


Photo.5 Suction lysimeter

3-8. EC measurement

All water samples were measured by using HORIBA CONDUCTIVITY METER B-173 (Photo.6).

Photo.6 HORIBA CONDUCTIVITY METER B-173

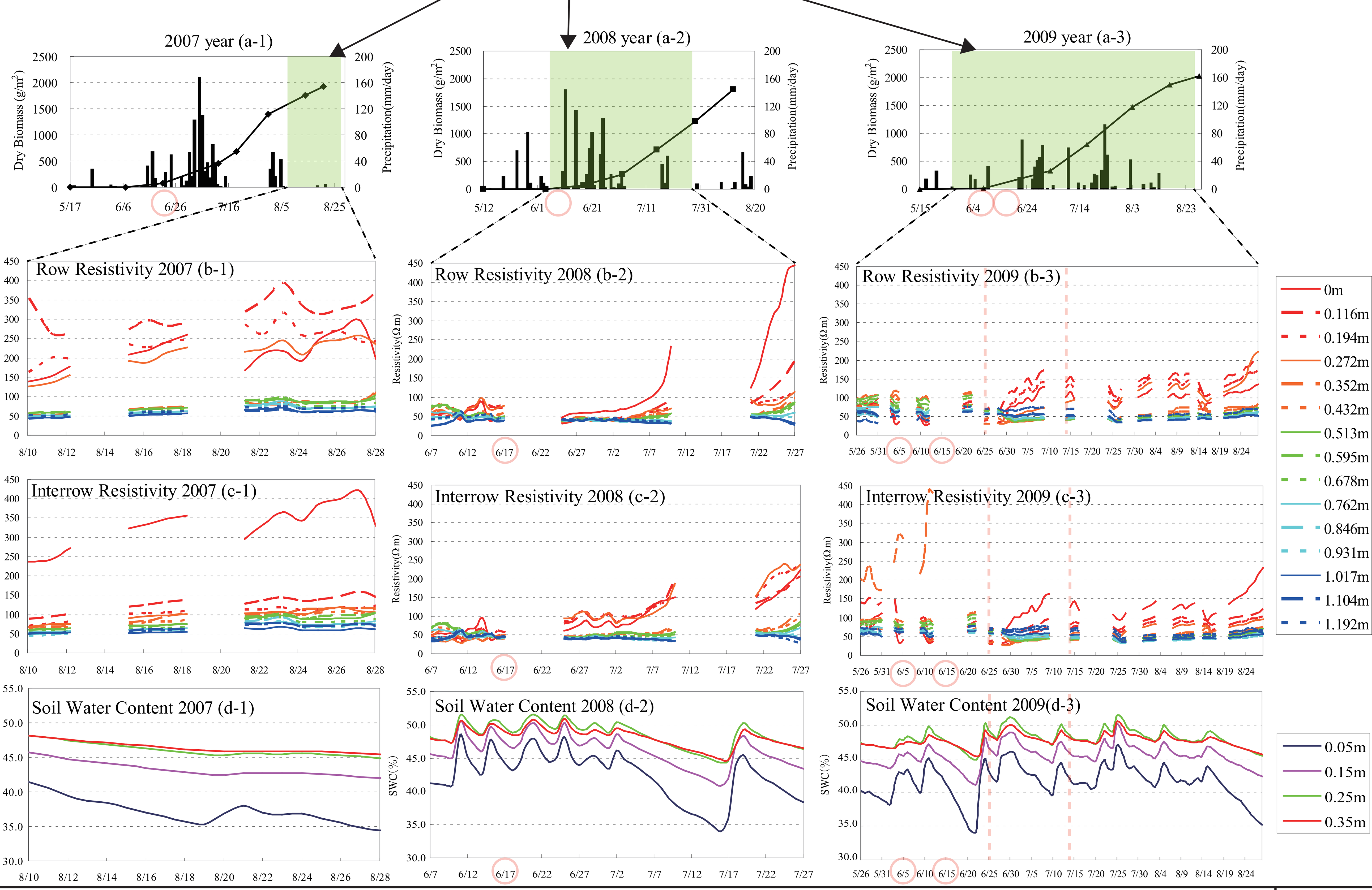
5.Results

Fig.8 Growing status of maize & Precipitation each year(a-1,2,3)
Fig.9 Soil Electrical Resistivity at row each year(b-1,2,3)
Fig.10 Soil Electrical Resistivity at interrow each year(c-1,2,3)
Fig.11 Soil water content at interrow each year(d-1,2,3)

Green color indicates ERT measurement period

Red circle( ) indicates application of fertilizer

Red bar ( ) indicates day for comparison in Fig.12



5-1. Temporal change of soil electrical change in vegitative period in 2007-2009 year

There was enough precipitation for Maize grew as the usual year (Fig.8 a-1,2,3)
ERT measurement was conducted in maize vegetative period for 2007-2009.
All ERT measurement was conducted at nearly 6 a.m. (see section 3-1).
All ERT data was corrected with soil temperature to a reference soil temperature of 25℃ (see section 3-3,4).

After July, soil water content decrease means soil electrical resistivity increase row and interrow point (see Fig.9 b-1,2,3 Fig.10 c-1,2,3 Fig.11 d-1,2,3). Particularly in 2007, row point soil electrical resistivity increases until 0.27m depth, on the other hand interrow point soil electrical resistivity increases only surface (see Fig.9 b-1, Fig.10 c-1).

But in June, shallow soil electrical resistivity is almost same or lower than deep soil electrical resistivity even though shallow soil water content is lower than deep soil water content (see Fig.10 c-2,3 Fig.11 d-2,3).

June 25, 2009 and July 14, 2009 have almost same soil water content by TDR measurement (see Fig.11 d-3), soil electrical resistivity distribution is obviously different up to 200-300Ω• m (Fig.12 e-3).

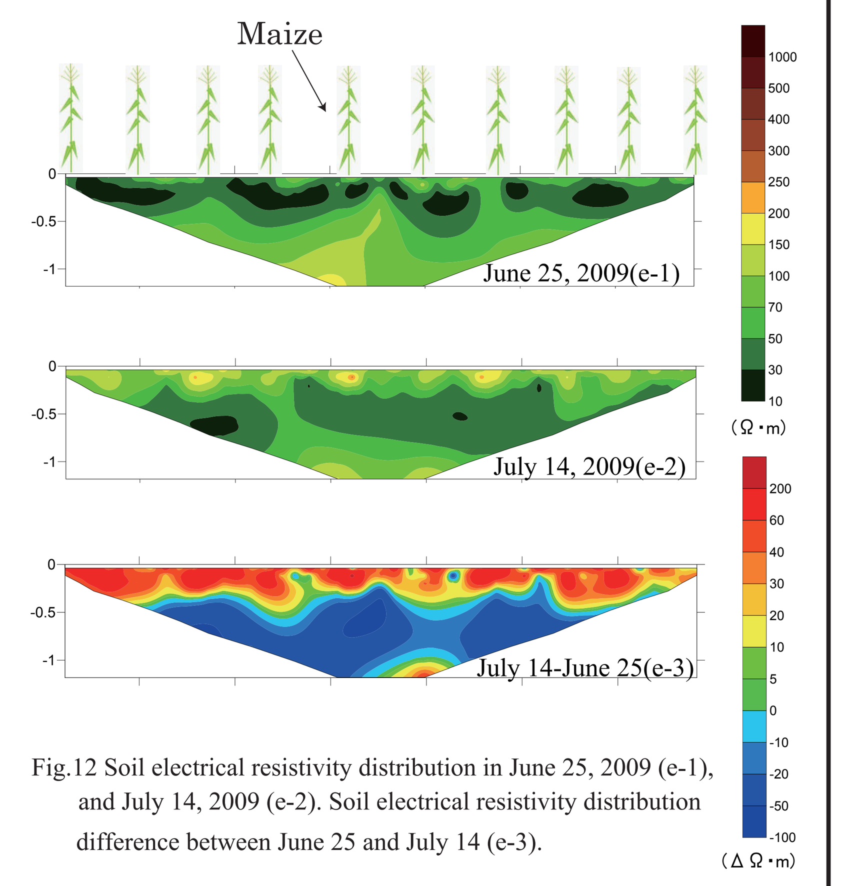


Fig.12 Soil electrical resistivity distribution in June 25, 2009 (e-1), and July 14, 2009 (e-2). Soil electrical resistivity distribution difference between June 25 and July 14 (e-3).

Fig.13 Soil water EC at Row & Interrow in 2010(f-1,2)

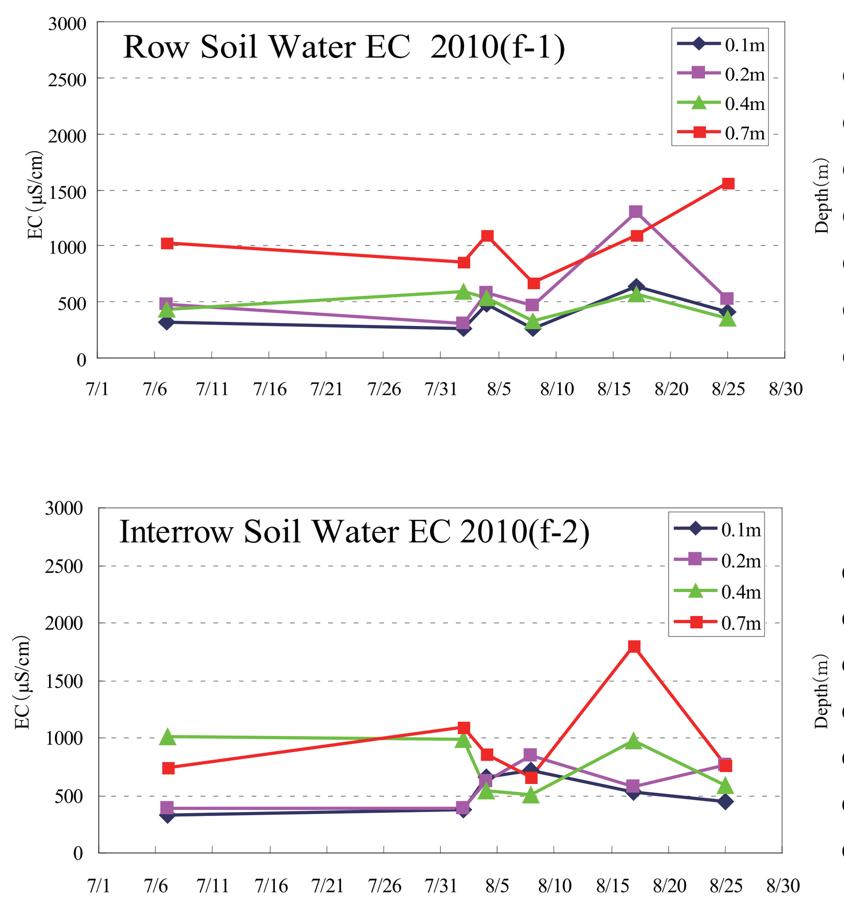


Fig.14 Soil water EC at Row & Interrow on Aug 4, 2010(g-1,2)

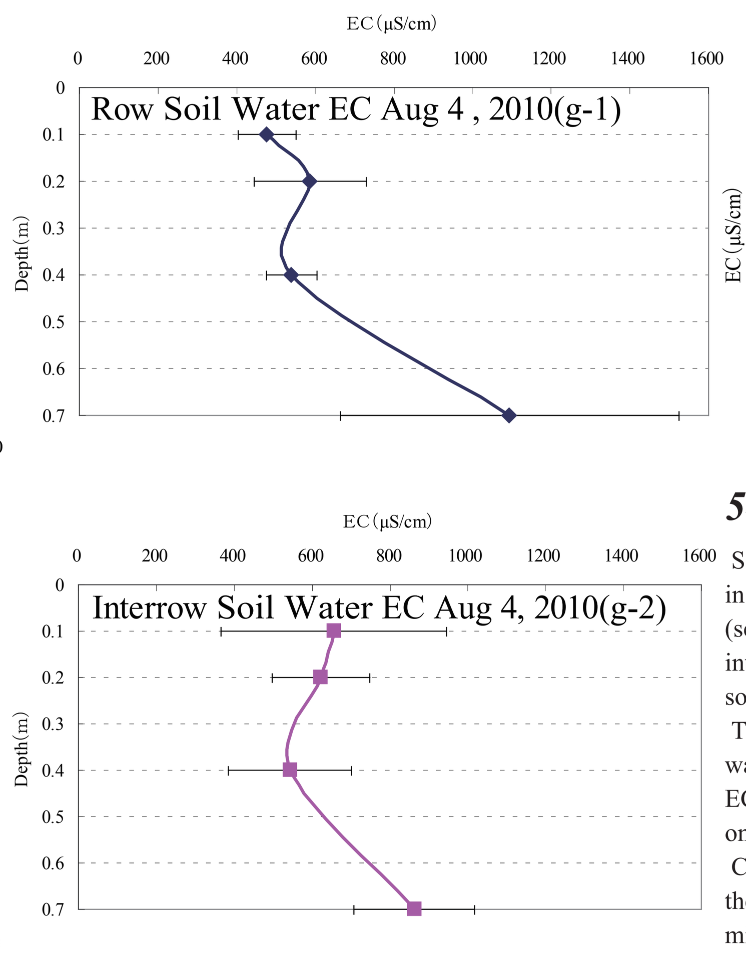
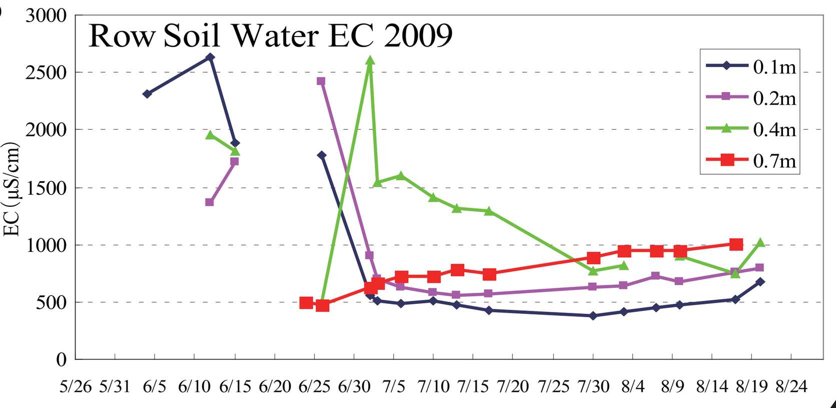


Fig.15 Soil water EC at row in 2009



5-2. Temporal change of Soil water EC in maize field

Soil water was sampled at four depths (0.1, 0.2, 0.4, 0.7m) with suction lysimeter in 2009 year, and centrifugation method (pF4.2) from soil sample in 2010 year (see section3-7). Only row point soil water was sampled in 2009, row and interrow points soil water was sampled in 2010. To understand soil water EC variability, soil water was sampled at three points at four depths in Aug 4, 2010.

There was application of fertilizer in June 5 and 15, 2009, after that shallow depth soil water EC value was higher than deep one (see Fig.15). Shallow depth soil water EC value reduced gradually and finally there is little change in EC value around 500μS/cm, on the other hand deep one increased gradually.

Compare row with interrow points, there is not so much of a difference between these points (see Fig.13 f-1,2). Soil water EC variability maximum value is ±400, minimum value is ±100 (see Fig.14 g-1,2).

6. Conclusion

Shallow depth soil water EC was higher than deep one after application of fertilizer, so shallow depth soil electrical resistivity was lower than deep one even though shallow soil water content is lower than deep soil water content.

After application of fertilizer , finally shallow depth soil water EC value remain around 500μS/cm, at that time soil electrical resistivity change means soil water content change.

When we use ERT measurement to measure soil water content in the crop field, there is large soil water EC change, so we should take soil water EC change in consider.

7. Future Study

We have not succeeded at conversion from soil electrical resistivity to soil water content, so we are going to try laboratory experiment to convert soil electrical resistivity into soil water content.

8. References

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