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Paddy Field Zone Characterization using Apparent Electrical Conductivity for Rice Precision Farming

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ABSTRACT

Careful consideration of the likely management operation or agrichemical input(s) to be employed is needed for site-specific management or precision farming in order to determine the procedure of how to divide a field into different management zones. The purpose of this study was to describe the characteristics of the physical and chemical properties of the humid tropic paddy soils after zoning using apparent electrical conductivity. With some management operations, grid-soil sampling and mapping of nutrients may be the most appropriate option. Soil apparent Electrical Conductivity (EC_a) delineated management zones could be a reliable indicator of yield potential and a useful basis to evaluate the probable for site specific management. This study was conducted in the Tanjung Karang Rice Irrigation Scheme located on a flat coastal plain in the district of Kuala Selangor and Sabak Bernam, Malaysia for 3 seasons namely, seasons 1/2003, 2/2003 and 1/2004. One block called Block C was selected where it contains 118 lots with 1.2 ha size for each lot and a total area is about 142 ha. Soil EC_a was collected using VerisEC 3100 and soil samples were collected for their chemicals and physicals analysis. Mean comparisons were conducted using Statistical Analysis System 8e (SAS) to determine soil properties within EC_a zones. The results showed that zone 1 of shallow EC_a had significantly lower soil Electrical Conductivity (EC), Calcium (Ca), Potassium (K) and Iron (Fe), but significantly higher fine sand and sand contents. Zone 1 of deep EC_a had significantly lower Magnesium (Mg), Sodium (Na) and total cation. This low Na may be due to deep soil profile reaching the parent material of marine clay (marine alluvial), where, it used to be a former water route. Higher fine sand and sand in zone 1 were found for all the seasons. The results suggested that field-scale EC_a survey could delimit distinct zones of soil condition among which soil nutrient levels differ, providing an effective basis for soil sampling on a zone basis. It will help farmers to identify their farm for variable rate application.

Key words: Paddy, site specific management, soil nutrient, parent material, variable rate application

INTRODUCTION

The key concept of site-specific management is to identify and manage spatially coherent regions within an area. In order to attain maximum efficiency of crop inputs, these regions or management zones should represent a homogenous combination of potential yield-limiting factors

(Mondal and Tewari, 2007). For site-specific management, careful consideration of the likely management operation or agrichemical input(s) to be employed is needed in order to determine the procedure of how to divide a field into different management zones. With some management operations, grid-soil sampling and mapping of nutrients may be the most appropriate option. Other management considerations warrant sampling by differences in soil type or elevation. When a field has little history of fertilization and manuring, availability of immobile nutrients may be related to soil mapping unit. In zone delineation, if the appropriate zones for a given operation or input is misidentified, uniform field management may be better option. However, if management zones are determined, each zone should represent a unique combination of potential yield-limiting factors which can improve the site-specific management prescription (Ferguson and Hergert, 2007). Unfortunately, the evaluation of management zones is seldom done because most fields, once landscape and soil properties are measured and mapped, also receive some type of site-specific management. This variability management may make it difficult to determine whether or not the correct or appropriate management zones have been identified (Kitchen *et al.*, 1998). Fridgen (2000) has also expressed that determination of sub-field areas is difficult due to the complex combination of factors that may affect crop yield.

However, several numbers of procedures have been used to delineate within-field management zones for site-specific management. One approach uses relatively stable soil properties such as apparent soil Electrical Conductivity (EC_a) and/or landscape features in conjunction with soil-landscape models to estimate patterns of soil variability. Topographic attributes and landscape position data have been widely used to map within-field areas of high and low productivity based on water availability (Jones *et al.*, 1989; Jaynes *et al.*, 1995). Sudduth *et al.* (1998) found that within field variation in soil properties could be explained with soil conductivity measurements. They found a significant relationship between soil conductivity and topsoil depth and Fraisse *et al.* (1999) added to this work by using soil EC for zone delineation. Both of these works concentrated on using soil EC_a to characterize local spatial variability. These reports were also supported by Johnson *et al.* (2001) that the zone management on the basis of EC_a mapping provided a useful framework for soil sampling to reflect spatial heterogeneity and could potentially be applied to assess temporal impacts of management on soil condition.

According to Li *et al.* (2007), soil EC_a delineated management zones could be a reliable indicator of cotton yield potential and a useful basis to evaluate the probable for site specific management in the saline region. The relationship between soil EC_a and several crop yields has been reported and quantified by others (Kitchen and Sudduth, 1996; Fleming *et al.*, 1998). Therefore, the purpose of this study is to describe soil physical and chemical properties after zoning using apparent electrical conductivity for humid tropic paddy soils.

MATERIALS AND METHODS

Study area

Location and topography: This study was conducted in the Tanjung Karang Rice Irrigation Scheme at 2003-2004. The scheme area is located on a flat coastal plain in the Integrated Agricultural Development Area (IADA-Barat Laut Selangor). It is in the district of Kuala Selangor and Sabak Bernam, Malaysia on latitude 3°35" N and longitude 101°05" E, which covers an area of about 20,000 ha extending over the length of 40 km along the coast with a width of 5 km on average (Fig. 1a-d). The main irrigation and drainage canals run parallel to the coast. The scheme is composed of eight compartments. One of them is Sawah Sempadan compartment, with a total

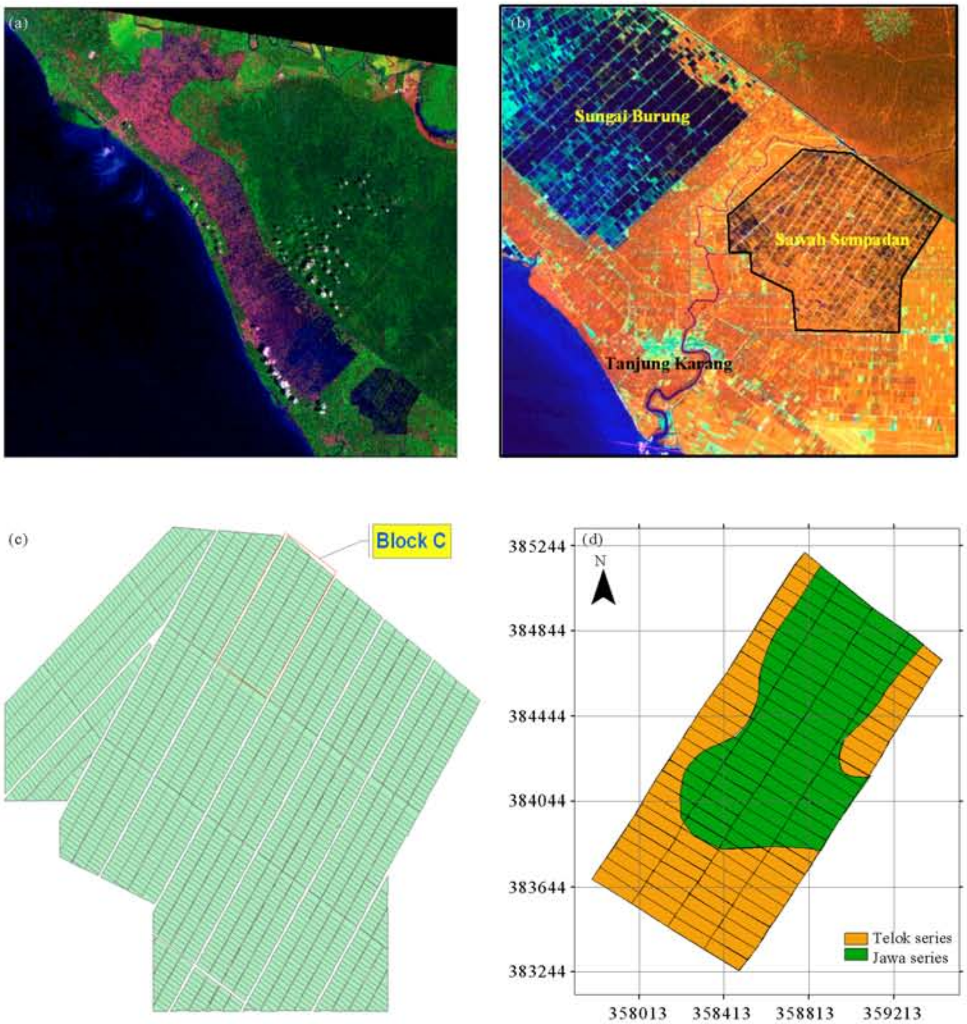


Fig. 1: Sawah Sempadan Compartment and Block C (a) Satellite image for Tanjong Karang rice irrigation scheme, (b) Satellite image for Sawah Sempadan rice irrigation compartment, (c) Block C at Sawah Sempadan rice irrigation compartment and (d) Soil series map of block C, Sawah Sempadan (DOA, 2000)

area of 2,300 ha., divided into 24 blocks namely Blocks A to X. Block C was chosen as the study area. The block contains 118 plots, 1.2 ha each with a total area of about 142 ha and is located at the upstream of the irrigation scheme canal adjacent to the Tanjung Karang swamp forest.

Soil characteristics: Tanjung Karang area is mainly composed of mineral and organic soils. The soils of the Tanjung Karang Irrigation Project area are classified into fifteen soil series. These are Kranji, Banjar, Sedu, Jawa, Sempadan, Karang, Telok, Selangor, Bernam, Bakau, Serong, Brown Clay, Briah, Organic Clay and Unclassified series. Kranji, Banjar and Karang are developed on the marine alluvium along the coast and riverine alluvium along the Bernam River. Brown Clay, Briah and Organic Clay are transition soils between the mineral soils and the peat soils in the swamp.

They are composed of brown clays derived from brackish water deposits and organic clays and muck which originated from peat soil. Within Block C however, there are only two major soil series namely, Telok Series (Typic Sulfaquept) and Jawa Series (Fine, Mixed isohyperthermic Sulfic Tropaquept) as can be shown in Fig. 1d.

Duration of field work: The EC_a data acquisition and soil sampling were done for three continuous seasons. The first season (Season 1) soil samples were collected on 2nd to 20th June 2003 coinciding with after harvest of the off-season for 2003 and, the second season (Season 2) samples were collected on 16th December 2003 to 3rd January 2004 coinciding with after harvest of the main season for 2003. The third season (Season 3) samples were collected on 9th to 18th June 2004 (off-season 2004).

EC_a data acquisition and map generation: The Veris 3100 Sensor Cart was pulled across each field behind a tractor in a series of parallel transects spaced about 15 m apart. The plot width was 60 m and the length was 200 m. The instrument was calibrated, as per manufacturer instructions, prior to data collection for each field by checking its resistance of lesser than 2 ohm using ohmmeter. The Veris 3100 has three pairs of coulter-electrodes to determine soil EC_a. The coulters penetrate the soil surface into a depth of 6 cm. One pair of electrodes emits an electrical current into the soil, while the other two pairs detect decreases in the emitted current due to its transmission through soil (resistance). The depth of measurement is based upon the spacing of the coulter-electrodes. The center pair, situated closest to the emitting (reference) coulter-electrodes, integrates resistance between depths of 0 and 30 cm (shallow), while the outside pair integrates between 0 and 90 cm (deep). Output from the Veris data logger was the conversion of resistance conductivity (1/resistance = conductivity). A Differential Global Positioning System (DGPS) Trimble AgGPS132 (Trimble Navigation Ltd., Sunnyvale, CA) with submeter accuracy was used to geo-reference EC_a measurements. This differential correction process was done automatically on real time basis by using available beacon station at Lumut (4° 15.075" N and 100° 39.638"E), Perak (transmission frequency was 298.00 kHz). The Veris data logger recorded latitude, longitude and shallow and deep EC_a data (mS m^{-1}) at 1 sec interval in an ASCII text format. The EC logger was available to log only when DGPS signal was received. The location of latitude and longitude (WGS84) were then converted to Malaysian Rectified Skew Orthomorphic (RSO) using GPS Pathfinder Office 2.90.

The EC_a data in ASCII format was then transferred through a diskette to an available Geospatial and GIS software such as GS+ version 5.1 and ArcGIS 8.3 with Spatial Analyst extension in order to generate an EC_a map by Kriging technique. The GS+ was used to generate variogram and the best model was selected for use in spatial interpolation (kriging).

Soil sampling, lab analysis and map generation: The samples were taken at two points within a plot. The locations were recorded by GPS (Trimble GeoExplorer3). The post processing technique was done in order to increase the accuracy level from meter accuracy to sub-meter accuracy (centimeter level) by comparing the base station data which was collected from the Department of Survey, Jabatan Ukur dan Pemetaan Malaysia (JUPEM) and Malaysian Palm Oil Board (MPOB) at Bangi. The post processing data correction was performed on GPS Pathfinder Office 2.90. The soil samples were collected within the root zone depth (0 to 30 cm) on both sides of mid-drain with the distance of 10 m apart from it. At each sampling point, two types of soil samples were collected.

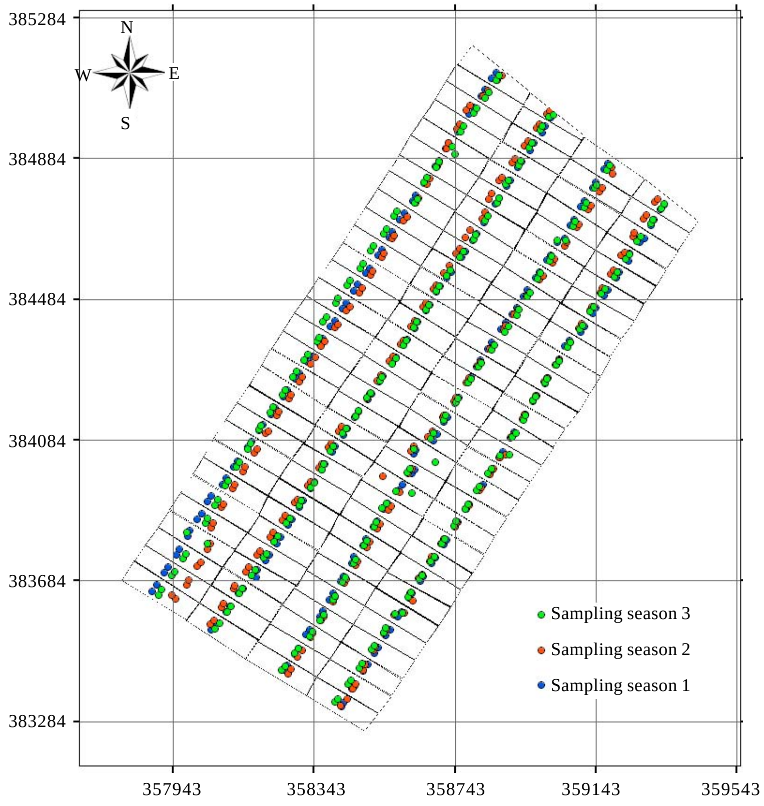


Fig. 2: Typical map of the soil chemical and physical sampling points in block C for three seasons

One was undisturbed sample, collected by core sampling (size of about 70×40 mm) and another was disturbed sample collected by using an auger. The total number of soil samples was 236 (2 points for 118 plots). The EC_a values were also recorded manually at every sampling point by inserting the sensor probe at static condition. Soil sampling positions for all three seasons are shown in Fig. 2. The sampling points for the three seasons were roughly determined as the same point as in the previous season. The distribution of the sampling point is considered as uniform density (Davis, 2002). The core samples were weighed quickly in order to avoid the evaporation of its moisture, whereas the disturbed samples were air-dried. Disturbed samples after air drying were ground in mortar and then sieved through a 2 mm sieve. These samples were then brought to soil laboratory for physical and chemical analysis. Soil chemical and physical analysis were conducted at the Soil Science Laboratory, Soil Fertility Division, Department of Agriculture, Malaysia. Soil moisture content and dry bulk density determinations were conducted at the Institute of Advanced Technology (ITMA), Universiti Putra Malaysia.

Soil physical and chemical properties analysis: The undisturbed (core) samples were used in determining the moisture content in the field condition and dry bulk density. The air dried samples were used for soil particle size analysis (texture). The standard gravimetric method by oven-dry at the temperature of 105°C (Gardner, 1986) was used to determine moisture content. Soil bulk density was defined by the standard core method (Blake and Hartge, 1986). The pipette method was used in determining soil particles size distribution (PSD). This method has been adapted from Day (1965) and Green (1981). Percentages of sand (>50 μm), silt (2-50 μm) and clay (<2 μm) were determined and used to identify the textural class from the textural triangle. This standard soil textural triangle was devised by the United State Department of Agriculture (USDA)

Soil total N was determined using the Kjeldahl digestion procedure described by Bremner and Mulvaney (1982). Available P was determined by the Bray II method (Bray and Kurtz, 1945). Exchangeable K, Mg, Ca, Na, Al, Fe and Cation Exchange Capacity (CEC) were determined by neutral ammonium acetate extraction method (Schollenberger and Simon, 1945). Total S was determined by heating with magnesium nitrate and precipitated as barium sulphate adopted form Chaudry and Cornfield (1966). Total cation was the summation of soil K, Na, Mg and Ca. Base Saturation (BS) was calculated as the percentage of total cation (K, Na, Mg and Ca) per CEC. Exchangeable Sodium Percentage (ESP) was calculated as exchangeable Na per CEC, above were defined as follows:

$$BS = (\text{Total exch cation}/CEC)\times 100 \tag{1}$$

$$ESP = (Na_{exch}/CEC)\times 100 \tag{2}$$

The standard method for determining the soil pH in water (ratio 1:2.5) was adopted using pH meter (Herdershot *et al.*, 1993). The EC meter was used to measure soil EC in water at ratio 1:5 (Rhoades, 1982). The titrimetric dicromate redox method (wet oxidation method) adopted from Schollengberger (1927) with the modification method introduced by Walkey and Black (1934) was used in this study.

Classical statistical analysis for EC_a and soil data: The basic statistical analysis, such as mean, Coefficient of Variance (CV), minimum value, maximum value and standard deviation were described in order to understand the basic features of the soil EC_a and soil properties. The number of classes was defined based on five manageable zones. The EC_a map was delineated into several classes by using ArcGIS 8.3 software. Then, the actual area for each class was estimated and the transition line was identified. Values within a class were derived using ArcGIS 8.3 by zonal statistical method.

The Statistical Package for Social Science (SPSS) for Windows version Release 10.0.5 (27 Nov 1999) and the Statistical Analysis System 8e (SAS) were used for determining basic statistical descriptions. The matrix correlation of EC_a and soil properties was determined by Pearson's 2-tailed technique in order to check out the relationship of each particular soil property on average soil EC_a. The significance of the relationships was determined between classes by Duncan's Multiple Range Test by PROC GLM in SAS.

Geostatistics analysis for EC_a: Geostatistical analysis of soil EC_a, physical and chemical properties are presented according to their semivariograms. A semivariogram shows autocorrelation as a function of distance (semivariance versus separation distance) and, when plotted represents spatial variability (Cohen *et al.*, 1990). In order to compare the spatial correlation of different semivariograms, one can use the ratio of the nugget to the sill after having fit a model to each semivariogram (Balasundram *et al.*, 2007). Low ratios indicate strong spatial dependence and vice versa (Henebry, 1993). This ratio, however was used to define three classes of spatial dependence for the measured soil variables (Cambardella *et al.*, 1994), (1) when the ratio was <0.25, the measured variable was considered strongly spatially dependent, (2) between 0.25 and 0.75, the soil variable was considered moderately spatially dependent and (3) if the ratio was >0.75, or the slope of the semivariogram was about 0, the variable was considered random or nonspatially correlated (pure nugget). Therefore, the recommended model of higher R^2, low Reduced Sums of Squares (RSS) and high C/(Co + C) was then chosen to be used for spatial autocorrelation process.

Mapping of soil EC_a: Spatial variability maps were generated using kriging technique in ArcGIS 8.3. Initially, the required values of variogram, such as sill, nugget and partial sill were derived from GS+ for Windows. The technique of Smart Quantile was used to classify the zone. It identifies break points by looking for groupings and patterns inherent in the data. It is a compromise method between equal interval and quantile, with unequal-sized intervals, such as quantile that generally get a bit wider at the extremes, but not so much as with the quantile method, so there is also a decreasing number of values in the extreme classes (ESRI, 2001).

RESULTS AND DISCUSSION

Apparent soil electrical conductivity: The total data points were 93,884 and 85,811 for shallow and deep EC_a, respectively. The spacing of the sampling points was about 1 m when the tractor moved at a speed of about 10 to 15 km h^{-1}. Information from these data points collected by the EC_a sensor indicated that within a large field scale of about 145 ha, the soil information could be collected intensively. The coefficient of variation values (CV) indicats that shallow $EC_{a,}$ varied more than deep one in season 1 while it is inverse in season 2 and 3 (Table 1). The average deep EC_a shows significantly higher value than the average of shallow Ec_a in all three seasons. High mean deep EC_a is probably due to effect of soil parent materials at the deeper depth. It is confirmed by Aimrun *et al.* (2002), the average lab EC at the greater depth was higher than that at the topsoil lab EC for Sawah Sempadan paddy soils, because the soil of the study area was formed from marine clay as their parent material.

Chemical properties: Table 2 shows that available P varied the most as compared to other soil chemical properties in season 1 while soil total N had the most variability in seasons 2 and 3. It

Table 1: Descriptive statistics for three seasons EC_a data

		Min	Max	Mean*	SD	
Parameters	Count No.	------------	------------ (mS m^{-1})	------------	------------	CV (%)
Season 1						
Shallow EC_a^{+}	93884	0.20	357.60	28.71^{Ac}	13.84	48.21
Deep EC_a^{++}	85811	0.20	211.10	72.53^{Bc}	33.54	46.24
Season 2						
Shallow EC_a	65618	0.10	494.70	32.17^{Aa}	13.94	43.33
Deep EC_a	65667	0.10	1059.00	92.59^{Ba}	41.77	45.11
Season 3						
Shallow EC_a	63578	0.40	291.00	31.46^{Ab}	11.69	37.16
Deep EC_a	63571	0.30	813.00	80.44^{Bb}	30.81	38.30

$^{+}$Shallow EC_a measured the average EC_a from the soil surface to the depth of 30 cm. $^{++}$Deep EC_a measured the average EC_a from the soil surface to the depth of 90 cm. *Means with the same capital letters and followed by the different small letters are significant at $\alpha = 0.05$ level by DMRT

Table 2: Soil chemical properties for three studied seasons

Soil chemical properties	Unit	Min.			Max.			Mean*			SD			CV (%)		
		S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3
pH		4.0000	4.1000	4.5000	6.1000	6.300	6.0000	4.8100^{b}	4.8800^{a}	4.9200^{a}	0.3600	0.3300	0.1900	7.44	6.76	3.86
EC	dS m^{-1}	0.0800	0.0100	0.0500	0.9400	0.730	0.2000	0.1910^{a}	0.1627^{b}	0.1055^{c}	0.1000	0.1000	0.0300	51.73	62.50	27.27
OM	%	3.2700	2.7900	3.0600	32.2300	26.260	63.6600	9.4000^{ab}	8.8700^{b}	10.3400^{a}	3.6500	3.5200	7.5700	38.84	39.68	73.21
OC		1.8900	1.6200	1.7800	18.6900	15.230	36.9200	5.4500^{ab}	5.1500^{b}	6.0000^{a}	2.1200	2.0400	4.3900	38.84	39.61	73.17
Total S		0.0760	0.0140	0.0020	0.2320	0.138	0.2602	0.1209^{a}	0.0512^{b}	0.0529^{b}	0.0231	0.0201	0.0297	19.07	39.26	56.14
Total N		0.0880	0.0400	0.0042	0.7660	2.436	10.5000	0.3898^{a}	0.5181^{a}	0.4414^{a}	0.1438	0.3541	1.3508	36.90	68.35	306.03
P	ppm	10.0000	15.1900	1.6700	418.0000	106.500	26.8900	55.8900^{a}	35.3100^{b}	10.2900^{c}	78.2900	16.6700	4.1500	140.09	47.21	40.33
CEC	$cmol_c\ kg^{-1}$	7.3000	9.6000	7.9500	49.0000	40.500	28.4500	17.2900^{b}	17.8500^{b}	19.7400^{a}	5.2100	4.9300	4.6100	30.14	24.97	25.83
Ca		2.5600	1.5600	1.3500	14.4600	17.200	9.7200	7.2400^{a}	6.6000^{b}	3.9100^{c}	2.3100	2.3300	1.8700	31.93	35.30	47.83
Mg		0.3600	1.0400	0.6600	9.8400	13.300	6.0500	3.2800^{b}	4.7200^{a}	2.0100^{c}	1.6300	2.4000	0.9200	49.81	50.85	45.77
K		0.0900	0.0200	0.1100	0.7000	1.150	0.8400	0.3300^{b}	0.5700^{a}	0.3200^{b}	0.0900	0.2600	0.1500	28.56	45.61	46.88
Na		0.1200	0.1700	0.1700	1.3300	0.720	1.0500	0.3900^{b}	0.3500^{c}	0.4400^{a}	0.1700	0.0900	0.1800	44.75	25.71	40.91
Al		0.0400	0.0100	0.0900	5.6100	9.070	7.9700	2.2100^{c}	2.5400^{b}	2.9500^{a}	1.2600	1.4300	1.4600	56.85	56.30	49.49
Fe		0.0300	0.0300	0.1200	1.6000	0.730	0.9700	0.3400^{b}	0.3200^{b}	0.4100^{a}	0.1800	0.1100	0.1500	53.64	34.38	36.59
Total cation (Ca Mg K Na)		3.3700	3.6300	2.4600	23.0800	23.460	14.0700	11.2200^{b}	12.2400^{a}	6.6600^{c}	3.5000	3.3100	2.3900	31.19	27.04	35.89
BS	%	32.1900	26.5000	16.7700	100.4800	99.830	94.4300	66.5400^{a}	64.2900^{a}	38.8200^{b}	17.2100	18.5800	14.4500	25.87	28.90	37.22
ESP		0.6500	0.8700	0.8500	5.9900	3.520	6.1600	2.3200^{b}	1.8200^{c}	2.6200^{a}	0.9100	0.4900	1.2500	39.09	26.92	47.71

*Means within a row followed by the same letters are not significant at $\alpha = 0.05$ level by DMRT. S: Season

should be noted that the least variability was seen in soil pH in all three seasons. However, these classical statistics could not show the location of where it varied (location of high and low). The mean pH value showed that it was categorized as acidic soil and it needed to rise up to neutral level by liming. Ganawa *et al.* (2003) showed that this study area had higher variation of total N, while available P was almost similar. Throughout the study period, it indicated that the pH was observed to have low spatial variation. Low soil pH variation indicated that it was almost homogeneous for the entire study area while high variation as available P indicated more heterogeneous. Furthermore, Sun *et al.* (2003) reported that soil available P shows the highest CV, while soil pH the lowest. Other researches also documented a lower variance of soil pH compared to other soil chemical properties (Aimrun *et al.*, 2007; Yost *et al.*, 1982; Tsegaye and Hill, 1998). Because pH values are on log scale of proton concentration in soil solution, there would be a much higher variability if soil acidity is expressed in terms of proton concentration directly (Sun *et al.*, 2003).

Duncan's Multiple Range Test (DMRT) grouped soil chemical properties according to their seasons over the period of this study. Soil pH was not significantly different after season 1. The EC, available P and Ca significantly decreased, while Al significantly increased with seasons 1 to 3. Total N did not significantly increase with season. It did not change within the period of this study, where Duncan's test considered there was non significant difference in seasons 1, 2 and 3 at $\alpha = 0.05$ level. This consistency of total N throughout the study period may be due to the consistent application and uptake rates, eventually it remained the same balance in the soil. The study showed the temporal variability of soil chemical properties as indicated by significant difference level tested by DMRT. The concentrations of these soil chemical properties changed over time (temporal variability) and affected by several factors such as rainfall, application rate, plant uptake rate, leaching rate, run off rate and so on.

Physical properties: Table 3 presents statistical analysis of soil properties. Comparison of CV for dry bulk density and moisture content indicates higher variation in soil moisture content in all

Table 3: Soil physical properties for three studied seasons

Soil chemical properties	Unit	Min.			Max.			Mean*			SD			CV (%)		
		S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3
Dry bulk density	g cm^{-3}	0.64	0.83	0.19	1.71	1.85	1.37	1.20^b	1.24^a	0.95^c	0.17	0.20	0.15	14.17	15.90	15.79
Moisture	%	23.50	29.93	27.46	103.95	99.71	96.23	55.12^b	69.66^a	54.51^b	14.19	15.90	12.69	25.74	22.83	23.28
Clay (<2 µm)		20.80	2.90	18.30	64.90	55.40	93.30	39.46^b	35.48^c	44.68^a	8.33	9.43	10.58	21.11	26.58	23.68
Silt (2-50 µm)		10.20	24.90	0.00	54.40	82.70	54.00	36.51^b	38.21^a	35.73^b	7.48	7.51	8.18	20.49	19.67	22.89
Fine Sand (50-500 µm)		2.20	2.40	2.30	48.20	50.90	44.70	23.47^a	25.33^a	19.11^b	11.86	12.29	11.38	50.53	48.53	59.55
Coarse sand (>500 µm)		0.10	0.10	0.10	2.10	27.80	5.10	0.52^b	0.99^a	0.48^b	0.39	2.59	0.54	75.00	261.37	112.50
Sand (>50 µm)		2.50	2.80	2.60	48.80	55.10	45.20	23.99^b	26.32^a	19.59^c	11.93	12.55	11.43	49.73	47.69	58.35

*Means within a row followed by the same letters are not significant at α = 0.05 level by DMRT. S = Season

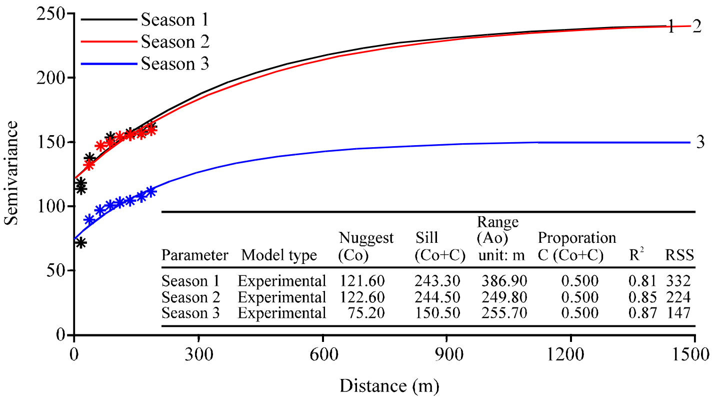
three seasons. This means moisture content varied more than dry bulk density which indicates samples may contain high straw residues and adsorb more water.

The CV for clay, silt, fine sand, coarse sand and sand in three seasons were compared. It indicates that higher variation was seen in coarse sand whereas least variation was seen in silt for all three seasons. As reported by Aimrun *et al.* (2002), clay content for Sawah Sempadan paddy field was about 43.88%, silt was 47.75% and sand was 8.20%. The CV for the three seasons indicated that coarse sand had high variation as compared to other particles. Most of soil particle had similar CV values for three seasons, except coarse sand where seasons 2 and 3 had higher variation as compared to season 1.

The dominant textures that were found for the three seasons in the present study, was clay loam and clay. According to Aimrun *et al.* (2002), random soil samplings (408 samples) for the compartment were found to be 4 textures viz; clay, clay loam, silty clay and silty clay loam. These textures were commonly found in other lowland paddy field, where clay particle plays an important role in creating hardpan layer for water retention and percolation prevention. The prevention of excessive percolation of the hardpan layer is necessary for efficient rice production (Brady, 1980). The difference of soil texture found for three seasons may be due to the disturbance during the land preparation and the sampling was done at surface layer of 0 to 20 cm, where this layer used to be disturbed by surface activities.

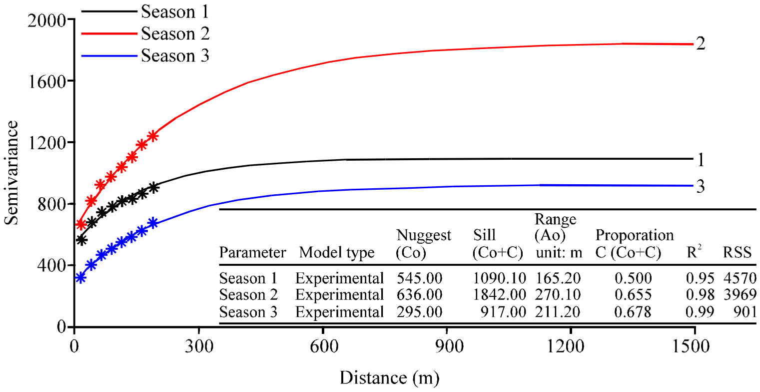
For the temporal test, dry bulk density varied with season and season 2 was significantly higher as compared to seasons 1 and 3. Moisture content for season 2 cultivation of the year was significantly lower values as compared to season 2, where the sampling was done in December. There was no significant difference between seasons 1 and 3. This means the moisture content of the same cultivation period was similar for the seasons. Most of the mean value of soil particle size was significantly different from one season to the other seasons. Clay and sand were significant different for the three seasons. Season 2 had the lowest clay and the highest sand. In season 3, clay had the highest content and significantly lowest in sand content. Season 1 and 3 had no significant difference in silt and coarse sand contents. Fine sand showed that there was no significant difference for seasons 1 and 2, but season 3 was significantly low (Table 3).

Geostatistics description for EC$_a$: The variograms of the shallow EC$_a$ for the three study seasons indicated that they were best fitted to exponential function (Fig. 3). The exponential model



Parameter	Model type	Nuggest (Co)	Sill (Co+C)	Range (Ao) unit: m	Proporation C (Co+C)	R^2	RSS
Season 1	Experimental	121.60	243.30	386.90	0.500	0.81	332
Season 2	Experimental	122.60	244.50	249.80	0.500	0.85	224
Season 3	Experimental	75.20	150.50	255.70	0.500	0.87	147

Fig. 3: Isotrophic Variograms of Shallow EC_a (mS m^{-1}). *Lag distance was set at 200 m with the uniform lag class distance interval of 25 m



Parameter	Model type	Nuggest (Co)	Sill (Co+C)	Range (Ao) unit: m	Proporation C (Co+C)	R^2	RSS
Season 1	Experimental	545.00	1090.10	165.20	0.500	0.95	4570
Season 2	Experimental	636.00	1842.00	270.10	0.655	0.98	3969
Season 3	Experimental	295.00	917.00	211.20	0.678	0.99	901

Fig. 4: Isotrophic Variograms of Deep EC_a (mS m^{-1}). *Lag distance was set at 200 m with the uniform lag class distance interval of 25 m

has never quite reached the limiting value of the sill, but approaches it asymptotically (Davis, 2002). The effective range (effective Ao) for the exponential model is defined as three times Ao. The nugget (Co) which is the error in estimation process caused by sampling intensity, positioning, chemical analysis and soil properties, for season 2 was higher than for seasons 1 and 3. Myers (1997) reported that it can be reduced further if the number of samples is increased. However, high Co for this study may be due to high variation within the minimum sampling space (Davis, 1986; 2002). Season 3 was found to have the lowest nugget (75.20 mS $m^{-1})^2$, which meant least sampling error. The Co+C represented spatially-independent variance, where the data locations were separated by a distance beyond which semivariance did not change. It showed that season 3 had the lowest sill values. Season 2 had the lowest Ao which meant shallow EC_a for season 2 was dependent within a shorter distance as compared to the other seasons. The proportion of C and Co+C (partial sill per sill) defines the best variogram model defined by GS+. This was the opposition to nugget to sill ratio. They were found to have moderate spatial dependence for all seasons. The R^2 values were high for all seasons, but RSS for season 3 was the lowest.

The best fitted variogram of the three seasons for deep EC_a was exponential model (Fig. 4). Nugget values for season 3 were the lowest and this indicates that low sampling error for season

3, but season 2 was the highest. Season 1 deep EC_a had the shortest distance of dependence (Ao = 165.20 m) as compared to seasons 2 and 3. The proportion of partial sill to sill indicated that their spatial dependences were moderate. Season 3 had the strongest spatial dependence with the highest R^2 and the lowest RSS as compared to seasons 1 and 2. The range values for shallow EC_a were dependent within larger lag distance than that for deep EC_a for all the seasons. On the other hand, any pairs of EC_a values were spatially independent when they were separated by a lag distance greater than range (Ao), i.e., 386.90 m for shallow EC_a and 165.20 m for deep EC_a in season 1. The nugget and sill values of all the seasons for deep EC_a were higher than that for shallow EC_a. This indicates that variance at zero lag distance for deep EC_a was high. The strength of spatial dependence for both shallow and deep EC_a was moderate, but deep EC_a had higher than that for shallow EC_a.

Spatial variability map: According to the DOA classification map, the areas were mostly occupied by low shallow EC_a level after kriging. It distributed to the west and middle area close to the south of the study area and it seemed to be concentrated on few plots while, moderate level scattered all over the area and mostly in the south. Based on this, it can be generalized that the top soil of 0 to 30 cm was homogeneous in EC_a values. The scatter of moderate shallow EC_a level may be due to human activities or farm practices on the top layer, i.e., fertilization, land preparation and leveling and/or the effect of parent materials at the lower layer. Deep EC_a values mostly fell into classes 3 (moderate level) and 4 (high level), with class 4 occupying a bigger area than class 3 in seasons 2 and 3. Class 5 (very high level) was not found in season 1, but in seasons 2 and 3 with very low percentage of occupied area (less than 1%). This indicates that after spatial interpolation, there were no deep EC_a values higher than 200 mS m^{-1}. However, the deep EC_a values were higher than shallow EC_a values, where most of deep EC_a were categorized as in class 4, while shallow EC_a was mostly in class 2. The map of season 3 deep EC_a showed the distribution clearly, especially for very low and low EC_a levels. They showed the pattern of the former canal routes clearly as continuous lines in the northern and central regions of the study area. The former water routes were about 45 m wide. Most of high EC_a levels were distributed in the southern and central regions. For all the three seasons, the pattern of the map followed the same shape (clear former water route in low EC_a zone and zone of high EC_a).

However, the aim of this study was to present the variability of EC_a within the study area in a local spatial variability characterization. Since the standard classification did not visualize much variability, then most of the data points fell into a single class. Thus, the classification technique of smart quantiles, which was introduced by ArcGIS software was selected. This was based on natural groupings of data values. It identifies break points by looking for groupings and patterns inherent in the data. The features are divided into classes whose boundaries are set where there are relatively big jumps in the data values. This is a compromise method between equal interval and quantile, with unequal-sized intervals, such as quantile that generally get a bit wider at the extremes, but not so much as with the quantile method, so there is also a decreasing number of values in the extreme classes. This option tries to find a balance between highlighting changes in the middle values and the extreme values (ESRI, 2001). This study had decided to zone the area into 5 manageable zones classified by smart quantile method with the adjustment of the class value to a single number based on three-season data range. They were less than 20, 20 to 30, 30 to 40, 40 to 50 and more than 50 mS m^{-1} for shallow EC_a. For deep EC_a, they were less than 40, 40 to 60, 60 to 80, 80 to 100 and more than 100 mS m^{-1}. This was to produce a consistence range over the study seasons to use as reference and simplify the comparison.

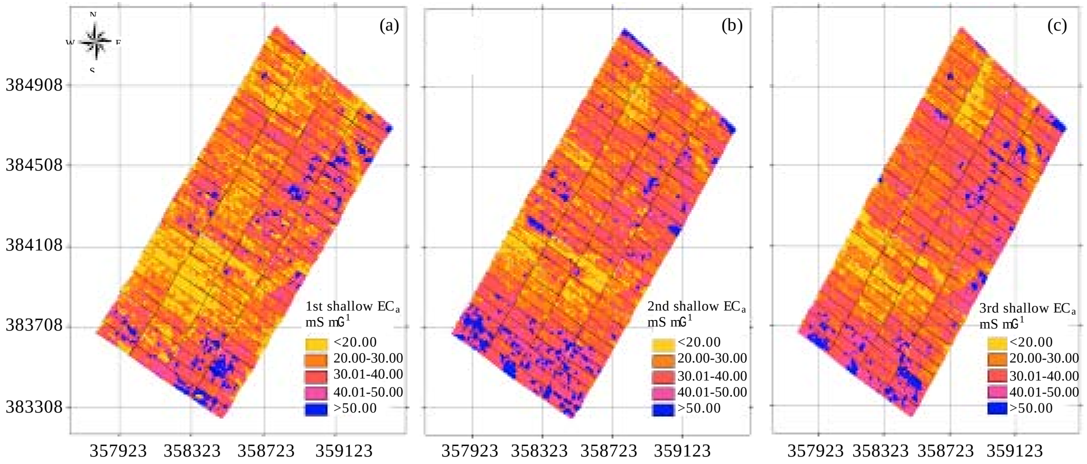


Fig. 5: Kriged map for shallow EC_a (mS m^{-1}) classified by smart quantiles (a) Season 1, (b) season 2 and (c) season 3

Table 4: Summary of kriged shallow and deep EC_a maps for three seasons classified by smart quantiles

	Count		Area (ha)		Min (dS m^{-1})		Max (dS m^{-1})		Range (dS m^{-1})		Mean*		SD	
Class	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep
Season 1														
1	7586	4176	32.56 (22.49)	17.92 (12.38)	1.68	0.89	20.00	40.00	18.32	39.11	14.92^e	26.11^e	4.02	10.59
2	12562	6375	53.92 (37.25)	27.36 (18.90)	20.00	40.00	30.00	60.00	10.00	20.00	25.04^d	50.84^d	2.82	5.75
3	8841	9035	37.95 (26.21)	38.78 (26.79)	30.00	60.00	40.00	80.00	10.00	20.00	34.48^c	70.04^c	2.86	5.73
4	3421	7469	14.68 (10.14)	32.06 (22.14)	40.00	80.00	50.00	100.00	10.00	19.99	44.07^b	89.54^b	2.79	5.75
5	1318	6673	5.66 (3.91)	28.64 (19.78)	50.00	100.00	91.17	166.02	41.16	66.02	57.49^a	113.75^a	7.17	10.25
Season 2														
1	3415	1528	14.66 (10.13)	6.56 (4.53)	2.56	15.44	20.00	40.00	17.44	24.56	16.55^e	32.04^e	2.98	6.17
2	12292	5366	52.76 (36.45)	23.03 (15.91)	20.00	40.00	30.00	59.99	10.00	19.99	25.43^d	51.28^d	2.80	5.65
3	11702	7640	50.23 (34.70)	32.79 (22.65)	30.00	60.00	40.00	80.00	10.00	19.99	34.57^c	70.05^c	2.86	5.68
4	4529	6702	19.44 (13.43)	28.77 (19.87)	40.00	80.01	50.00	100.00	9.99	19.99	44.07^b	89.50^b	2.78	5.73
5	1789	12492	7.68 (5.30)	53.62 (37.04)	50.01	100.00	112.29	278.44	62.27	178.44	57.80^a	129.33^a	8.18	22.22
Season 3														
1	3319	2007	14.25 (9.84)	8.61 (5.95)	4.94	8.50	20.00	40.00	15.06	31.50	17.16^e	31.44^e	2.35	6.67
2	12240	6350	52.54 (36.29)	27.26 (18.83)	20.00	40.01	30.00	60.00	10.00	19.99	25.49^d	50.87^d	2.81	5.71
3	12167	8924	52.22 (36.07)	38.30 (26.46)	30.00	60.01	40.00	80.00	10.00	19.99	34.51^c	70.22^c	2.81	5.64
4	4675	7729	20.07 (13.86)	33.18 (22.92)	40.00	80.00	49.99	99.99	9.99	19.99	43.88^b	89.45^b	2.75	5.76
5	1327	8718	5.70 (3.93)	37.42 (25.85)	50.01	100.00	141.31	208.41	91.30	108.41	55.76^a	116.93^a	6.99	11.76
Total area			144.77	144.77										

Values in brackets indicate percentage

The new classification results for the shallow EC_a displayed the appearance of the former water routes, but they were still blur (Fig. 5a-c). However, the previous classification method was unable to justify them. Most of the area was occupied by classes 2 and 3 for all the seasons for more than 50 ha (34.50%) except for class 3 in season 1. Class 1 occupied the area of 32.56 (22.49%), 14.66 (10.13%) and 14.25 ha (9.84%) for seasons 1, 2 and 3, respectively. This indicated that the area of low shallow EC_a (<20.00 mS m^{-1}) was less than 23% of the total area. Class 5 of more than 50 mS m^{-1} occupied the smallest area (less than 6%) for all seasons (Table 4).

The new classification approach should be justified for its strength. Strength of the classification approach can be illustrated by compactness and isolation (Cormack 1971; Gordon 1981). The

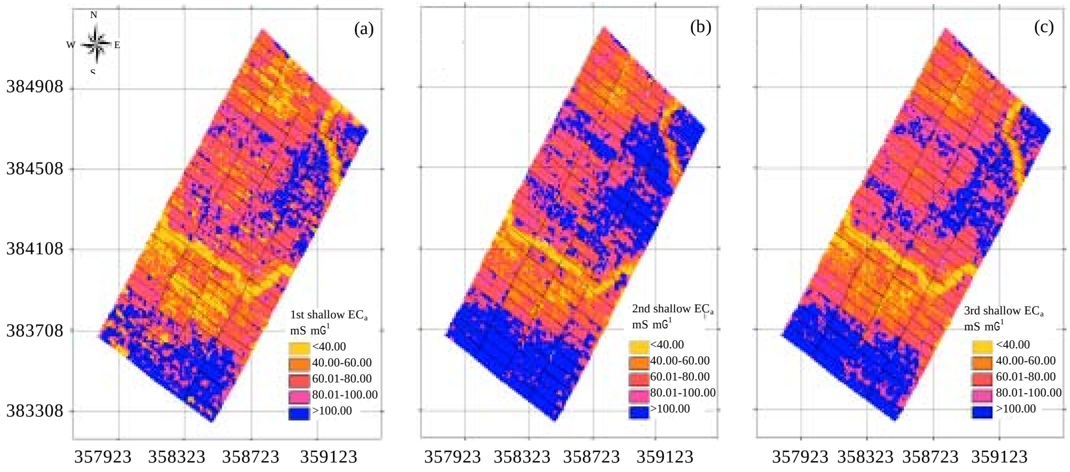


Fig. 6: Kriged map for deep EC_a (mS m^{-1}) classified by smart quantiles (a) season 1, (b) season 2 and (c) season 3

compactness is referred to low within class variance or all objects within a class are highly similar to each other. The isolation is referred to high distance between classes or the objects within a class are dissimilar to objects in all other classes. This study chose the statistical method of grouping test, such as DMRT and LSD to identify the isolation of the class where their mean values should be significantly different from each other. The labeled letter for mean values at each class indicated significant difference ($p<0.001$) showing the isolation between classes when classified by adjusted smart quantiles approach. The standard deviation, especially for classes 2, 3 and 4, indicated the compactness of the classification approach, when the standard deviation were low and only classes 1 and 5 had higher standard deviation due to unlimited values within the class. Therefore, this adjusted smart quantiles classification approach was accepted due to its classification strength.

Deep EC_a maps which were classified according to adjusted smart quantiles method visualized clearer the former water routes. The new classification for the deep EC_a was identified as less than 40, 40 to 60, 60 to 80, 80 to 100 and more than 100 mS m^{-1}. The former water routes where deep EC_a was very low (class 1) had clear shape with the width of about 45 m. They were found in the northeastern part as a short distance and another crossing the study area from the east to the west. Low deep EC_a was also found at the edge surrounding the former water routes. Most of the high EC_a were distributed in the south and central east as illustrated by the darker color of class 5. This appearance of the former water routes found in all seasons indicated that deep EC_a was a good indicator to describe the variability pattern over the period (Fig. 6a-c). Most of the deep EC_a values fell into class 3 (more than 20.00% of the total area), class 4 and class 5. Class 1 (<40 mS m^{-1}) was found in small areas of less than 12% of the total area for all the seasons. Season 2 had the smallest area of the lowest deep EC_a. This indicates that most of the area had high (>40 mS m^{-1}) EC_a values in the subsoil layer.

The significant difference between the mean of deep EC_a values at 95% confidence level ($\alpha = 0.05$) indicated the isolation of the classification, while low variance (standard deviation), except for classes 1 and 5 which was wide range, indicates the compactness. Hence, there was the effectiveness of classification method. Both shallow and deep EC_a maps showed the difference to soil series map. This was because of the different sampling scale, where soil EC_a was more intensive sampling points as compared to detailed soil survey map, which was at about 200 m grid.

Ec$_a$ zonal characteristics

Shallow EC$_a$ zones: Soil EC$_a$ could provide a measure of the spatial differences associated with soil physical and chemical properties, which for paddy soil may be a measure of soil suitability for crop growth, its water demand and its productivity. The EC$_a$ maps indicate that it is similar to some soil nutrient maps. It was found that the technique could identify the zone of old water route located within the study area while detailed soil series map alone could not have found it. The relation of EC$_a$ to soil P, K, Mg and CEC in the paddy fields indicates that their concentration can be estimated. Hence, quick nutrients determination can be done through the EC$_a$ sensor detection. The average values of EC$_a$ are significantly different between shallow (0-30 cm) and deep depths (0-90 cm) signifying differences in soil structure and nutrient status. The sensor can measure the soil EC$_a$ through the field quickly for detailed features of the paddy soil and can be operated by just one worker. The EC$_a$ map provides some ideas for future soil management. The results show that this is a good technique for the soil spatial description and farm nutrient assessments.

The mean values of soil properties within the zones were calculated from raw values (non-kriged or interpolated data) and they were not from the spatial kriged values as in spatial variability description. Hence, the total population equals to the sampling points (total n = 236). The hypothesis for EC$_a$ zone establishment was the soil properties within the zone were significantly different from zone to zone which indicates that soil EC$_a$ is a good delineation (classification) approach for soil properties.

Zone 1 as delineated by shallow EC$_a$ had significant low EC, Ca, Fe and total cation for all the seasons as compared to the other zones. Also CEC, Mg, K, Na, ESP, clay and silt in season 1 were found to be significantly low. Season 2 had the additional soil properties of N, K and BS, while season 3 had the additional soil pH, OM, OC, S and P. The low soil properties within zone 1 for all the seasons indicated the stability of zone 1 characteristics, where it can be concluded that zone 1 had significant low soil EC, Ca, Fe and total cation. Soil K in season 3 was found to be the opposite of seasons 1 and 2, where it increased and zone 1 in season 3 had significantly higher K. Soil Fe in season 3 had the same group between zones 1 and 5 indicating non significant difference (Table 5). The zone contained high fine sand for all the seasons. Season 1 had high sand and, season 2 had high Al, K and moisture content as compared to zone 5. Season 3 had the additional of ESP and sand which were higher than the other zones.

Deep EC$_a$ zones: Sampling points in each zone were unequal, where the zone that covered bigger area may have more sampling points and *vice versa*. Zone 1 had the lowest number of sampling points (n = 30), while zone 3 was the highest number (n = 74) after delineating by deep EC$_a$.

The stratification of zone 1 by deep EC$_a$ gave significant low Mg, Na and total cation for all the seasons as compared to the other zones. Moreover, Ca and ESP in seasons 1 and 2 were found to be significantly low. Seasons 1 and 3 had additional P, K and clay and, seasons 2 and 3 had an additional BS. Season 3 had additional pH and Fe. The low mean soil properties within zone 1 for all the seasons indicated the stability of zone 1 characteristics, where it can be concluded that zone 1 had significant low Mg, Na and total cation. This low Na may be due to the deep soil profile and the greater distance to reach the parent material of marine clay that was the former water routes. However, the accumulation of plant residues as indicated by OC or OM showed significant difference to the other zones in season 3 but, not in seasons 1 and 2 (Table 6). High fine sand and sand in zone 1 were found for all the seasons. According to Aimrun *et al.* (2007), deep EC$_a$ zone can delineate rice yield and soil K where low deep EC$_a$ zone has a significant low yield and a significant

Table 5: Means* of soil properties within shallow EC_a zones for three seasons

		Zone 1			Zone 2			Zone 3			Zone 4			Zone 5		
Soil properties	Unit	Season 1 (n = 40)	Season 2 (n = 27)	Season 3 (n = 34)	Season 1 (n = 100)	Season 2 (n = 89)	Season 3 (n = 44)	Season 1 (n = 59)	Season 2 (n = 77)	Season 3 (n = 57)	Season 1 (n = 27)	Season 2 (n = 35)	Season 3 (n = 56)	Season 1 (n = 10)	Season 2 (n = 8)	Season 3 (n = 45)
Shallow EC_a	mS m^{-1}	15.99^{e}	16.16^{e}	20.42^{e}	25.02^{d}	24.53^{d}	25.38^{d}	33.99^{c}	34.25^{c}	31.06^{c}	43.74^{b}	44.28^{b}	39.15^{b}	53.43^{a}	52.71^{a}	51.95^{a}
pH		4.86^{ab}	4.77^{a}	4.83^{b}	4.81^{ab}	4.86^{a}	4.84^{b}	4.84^{ab}	4.93^{a}	4.89^{b}	4.67^{b}	4.93^{a}	4.98^{a}	4.92^{a}	4.81^{a}	5.01^{a}
EC	dS m^{-1}	0.1745^{b}	0.1330^{b}	0.0941^{b}	0.1702^{b}	0.1623^{ab}	0.0914^{b}	0.2215^{ab}	0.1613^{ab}	0.1132^{a}	0.2326^{a}	0.1789^{ab}	0.1082^{a}	0.1780^{ab}	0.2138^{a}	0.1156^{a}
OM	%	8.50^{a}	8.99^{a}	7.85^{b}	9.30^{a}	9.29^{a}	11.64^{a}	10.07^{a}	8.76^{a}	10.61^{ab}	9.85^{a}	8.27^{a}	10.84^{ab}	8.93^{a}	7.59^{a}	10.01^{ab}
OC		4.93^{a}	5.22^{a}	4.55^{b}	5.39^{a}	5.39^{a}	6.75^{a}	5.84^{a}	5.08^{a}	6.15^{ab}	5.71^{a}	4.80^{a}	6.28^{ab}	5.18^{a}	4.41^{a}	5.81^{ab}
Total S		0.1148^{a}	0.0521^{a}	0.0418^{b}	0.1198^{a}	0.0529^{a}	0.0510^{ab}	0.1263^{a}	0.0495^{a}	0.0574^{a}	0.1229^{a}	0.0505^{a}	0.0585^{a}	0.1192^{a}	0.0474^{a}	0.0507^{ab}
Total N		0.3930^{a}	0.3817^{c}	0.1908^{a}	0.3978^{a}	0.4784^{bc}	0.6786^{a}	0.4067^{a}	0.5054^{bc}	0.3819^{a}	0.3281^{a}	0.6694^{b}	0.3679^{a}	0.3645^{a}	0.9241^{a}	0.5655^{a}
Avai. P	ppm	45.46^{a}	35.77^{a}	7.66^{b}	65.03^{a}	35.97^{a}	8.91^{b}	53.12^{a}	35.40^{a}	10.75^{a}	45.43^{a}	32.98^{a}	11.17^{a}	50.73^{a}	35.74^{a}	11.92^{a}
CEC	$cmol_c$ kg^{-1}	15.13^{b}	19.02^{a}	14.61^{c}	17.29^{ab}	19.65^{a}	16.90^{b}	18.40^{a}	20.02^{a}	18.12^{ab}	17.55^{ab}	20.30^{a}	19.17^{a}	18.71^{a}	18.08^{a}	19.23^{a}
Ca		6.49^{b}	5.86^{c}	3.61^{b}	6.93^{ab}	6.30^{c}	3.56^{b}	8.00^{a}	6.54^{bc}	4.56^{a}	7.46^{ab}	7.76^{ab}	3.74^{b}	8.25^{a}	7.99^{a}	3.84^{ab}
Mg		2.82^{b}	4.11^{a}	1.13^{d}	3.25^{b}	4.47^{a}	1.57^{c}	3.47^{ab}	4.92^{a}	2.12^{b}	3.29^{b}	5.46^{a}	2.31^{ab}	4.27^{a}	4.31^{a}	2.57^{a}
K		0.32^{b}	0.53^{a}	0.27^{c}	0.32^{b}	0.58^{a}	0.26^{c}	0.34^{b}	0.60^{a}	0.34^{ab}	0.35^{b}	0.57^{a}	0.31^{bc}	0.40^{a}	0.34^{b}	0.38^{a}
N^{a}		0.28^{d}	0.33^{a}	0.42^{a}	0.36^{cd}	0.34^{a}	0.41^{a}	0.43^{bc}	0.35^{a}	0.46^{a}	0.49^{b}	0.37^{a}	0.43^{a}	0.61^{a}	0.37^{a}	0.42^{a}
Al		1.99^{ab}	2.89^{a}	3.25^{ab}	2.43^{a}	2.71^{ab}	3.60^{a}	2.03^{ab}	2.53^{ab}	3.10^{ab}	2.41^{a}	2.01^{ab}	2.73^{bc}	1.40^{b}	1.91^{b}	2.17^{c}
Fe		0.28^{b}	0.30^{b}	0.31^{d}	0.34^{ab}	0.31^{ab}	0.36^{cd}	0.38^{ab}	0.32^{ab}	0.42^{bc}	0.30^{b}	0.37^{a}	0.43^{b}	0.43^{a}	0.28^{b}	0.50^{a}
Total cation		9.77^{c}	10.83^{c}	5.43^{b}	10.86^{bc}	11.70^{bc}	5.80^{b}	12.25^{ab}	12.40^{abc}	7.50^{a}	11.59^{bc}	14.16^{a}	6.79^{a}	13.53^{a}	13.02^{ab}	7.22^{a}
BS	%	68.49^{a}	58.50b	38.86^{ab}	64.10^{a}	61.93^{ab}	37.20^{ab}	67.38^{a}	65.15^{ab}	42.70^{a}	68.35^{a}	71.12^{a}	36.00^{b}	73.37^{a}	71.840^{a}	39.00^{ab}
ESP		1.98^{c}	1.79^{a}	3.14^{a}	2.16^{c}	1.81^{a}	2.71^{ab}	2.41^{bc}	1.81^{a}	2.79^{ab}	2.84b	1.87^{a}	2.33b	3.31^{a}	2.07^{a}	2.30^{b}
Dry bulk density	g cm^{-3}	1.27^{a}	1.23^{a}	0.99^{a}	1.17^{a}	1.24^{a}	0.95^{ab}	1.17^{a}	1.23^{a}	0.90b	1.24^{a}	1.23^{a}	0.95^{ab}	1.20^{a}	1.35^{a}	0.97^{a}
Moisture content	%	50.21^{a}	70.96^{a}	52.15^{a}	58.09^{a}	69.16^{a}	56.22^{a}	55.89^{a}	70.74^{a}	55.26^{a}	50.12^{a}	70.49^{a}	53.52^{a}	54.06^{a}	56.84^{b}	54.91^{a}
Clay		34.75^{c}	33.10^{a}	35.48^{c}	38.45^{c}	34.72^{a}	42.00^{b}	42.34^{ab}	36.35^{a}	44.61^{b}	41.52^{ab}	37.64^{a}	49.07^{a}	45.79^{a}	34.10^{a}	48.89^{a}
Silt		33.57^{b}	36.22^{a}	35.33^{a}	36.30^{ab}	37.41^{a}	34.78^{a}	38.08^{a}	39.24^{a}	37.07^{a}	37.56^{ab}	39.61^{a}	34.75^{a}	38.26^{a}	37.89^{a}	36.5100^{a}
Fine sand		31.17^{a}	30.03^{a}	28.59^{a}	24.54^{b}	26.76^{ab}	22.77^{b}	19.12^{bc}	23.25^{ab}	17.70^{c}	20.55^{bc}	22.12^{b}	15.86^{c}	15.53^{c}	27.56^{ab}	14.19^{c}
Coarse sand		0.50^{ab}	0.65^{a}	0.60^{a}	0.61^{a}	1.12^{a}	0.46^{ab}	0.46^{ab}	1.17^{a}	0.62^{a}	0.36^{b}	0.65^{a}	0.33^{b}	0.42^{ab}	0.45^{a}	0.4200^{ab}
Sand		31.67^{a}	30.68^{a}	29.19^{a}	25.15^{b}	27.88^{a}	23.23^{b}	19.58^{bc}	24.43^{a}	18.32^{c}	20.91^{bc}	22.77^{a}	16.19^{c}	15.95^{c}	28.03^{a}	14.61^{c}

*Mean values in row for the different zones of the same season were significant at $\alpha = 0.05$ by DMRT

Table 6: Means* of soil properties within deep EC_a zones for three seasons

		Zone 1			Zone 2			Zone 3			Zone 4			Zone 5		
Soil properties	Unit	Season 1 (n = 30)	Season 2 (n = 10)	Season 3 (n = 15)	Season 1 (n = 39)	Season 2 (n = 45)	Season 3 (n = 54)	Season 1 (n = 74)	Season 2 (n = 46)	Season 3 (n = 53)	Season 1 (n = 42)	Season 2 (n = 55)	Season 3 (n = 55)	Season 1 (n = 51)	Season 2 (n = 80)	Season 3 (n = 59)
Shallow EC_a	mS m^{-1}	36.07^{e}	33.55^{e}	33.18^{e}	55.45^{d}	50.41^{d}	51.53^{d}	72.14^{c}	70.32^{c}	70.01^{c}	84.95^{b}	89.24^{b}	88.30^{b}	106.00^{a}	129.06^{a}	120.25^{a}
pH		4.82^{a}	4.78^{ab}	$4.\ 78^{bc}$	4.85^{a}	4.76^{b}	4.81^{c}	4.78^{a}	4.90^{ab}	4.90^{bc}	4.78^{a}	4.88^{ab}	4.92^{b}	4.85^{a}	4.95^{a}	5.03^{a}
EC	dS m^{-1}	0.1847^{a}	0.1550^{a}	0.1013^{abc}	0.1721^{a}	0.1427^{a}	0.0987^{bc}	0.1774^{a}	0.1774^{a}	0.0968^{c}	0.2169^{a}	0.1664^{a}	0.1140^{a}	0.2086^{a}	0.1643^{a}	0.1132^{ab}
OM	%	8.99^{ab}	9.39^{a}	12.61^{a}	7.88^{b}	7.43^{b}	9.08^{a}	9.88^{a}	9.22^{ab}	10.18^{a}	9.98^{a}	9.70^{a}	12.70^{a}	9.64^{a}	8.85^{ab}	8.87^{a}
OC		5.21^{ab}	5.45^{a}	7.31^{a}	4.57^{b}	4.31^{b}	5.27^{a}	5.73^{a}	5.35^{ab}	5.90^{a}	5.79^{a}	5.63^{a}	7.37^{a}	5.59^{a}	5.13^{ab}	5.15^{a}
Total S		0.1167^{ab}	0.0585^{a}	0.0592^{ab}	0.1118^{b}	0.0406^{b}	0.0433^{c}	0.1245^{a}	0.0506^{ab}	0.0498^{bc}	0.1239^{a}	0.0569^{a}	0.0686^{a}	0.1227^{a}	0.0526^{a}	0.0483^{bc}
Total N		0.3616^{ab}	0.4604^{ab}	0.7778^{a}	0.3899^{ab}	0.3980^{b}	0.4023^{a}	0.4247^{a}	0.4612^{ab}	0.5259^{a}	0.3980^{ab}	0.5536^{ab}	0.4876^{a}	0.3490^{b}	0.6011^{a}	0.2727^{a}
Avai. P	ppm	30.53^{b}	34.79^{a}	8.56^{c}	74.37^{a}	35.34^{a}	8.97^{bc}	59.99^{ab}	37.89^{a}	9.93^{abc}	55.31^{ab}	36.52^{a}	10.89^{ab}	51.20^{ab}	33.04^{a}	11.68^{a}
CEC	$cmol_c\ kg^{-1}$	15.93^{a}	18.83^{ab}	17.36^{b}	15.78^{a}	18.01^{b}	14.94^{c}	17.81^{a}	19.52^{ab}	17.68^{b}	17.85^{a}	20.87^{a}	20.28^{a}	18.02^{a}	20.18^{ab}	18.51^{ab}
Ca		6.74^{b}	5.29^{c}	3.47^{ab}	6.58^{b}	5.65^{bc}	3.31^{b}	7.22^{ab}	6.63^{ab}	4.27^{a}	7.34^{ab}	6.51^{abc}	4.29^{a}	7.99^{a}	7.35^{a}	3.88^{ab}
Mg		2.69^{b}	4.24^{b}	1.28^{c}	2.74^{b}	3.88^{b}	1.26^{c}	3.19^{ab}	3.83^{b}	1.90^{b}	3.84^{a}	5.05^{ab}	2.52^{a}	3.71^{a}	5.53^{a}	2.48^{a}
K		0.31^{b}	0.56^{a}	0.25^{b}	0.30^{b}	0.54^{a}	0.28^{ab}	0.34^{ab}	0.57^{a}	0.31^{ab}	0.34^{ab}	0.58^{a}	0.35^{a}	0.35^{a}	0.59^{a}	0.34^{a}
Na		0.29^{d}	0.27^{d}	0.34^{c}	0.33^{cd}	0.31^{cd}	0.40^{bc}	0.37^{bc}	0.33^{bc}	0.46^{ab}	0.43^{ab}	0.36^{ab}	0.50^{a}	0.49^{a}	0.38^{a}	0.42^{abc}
Al		2.07^{a}	2.68^{a}	2.86^{a}	2.18^{a}	2.87^{a}	3.38^{a}	2.30^{a}	2.58^{a}	3.38^{a}	2.46^{a}	2.66^{a}	3.09^{a}	1.97^{a}	2.23^{a}	2.06^{b}
Fe		0.28^{a}	0.30^{ab}	0.38b	0.31^{a}	0.27^{b}	0.31^{b}	0.35^{a}	0.33^{a}	0.38^{b}	0.37^{a}	0.33^{a}	0.45^{a}	0.36^{a}	0.33^{a}	0.50^{a}
Total Cation		10.03^{b}	10.36^{c}	5.34^{b}	9.81^{b}	10.38^{c}	5.25^{b}	11.12^{ab}	11.35^{bc}	6.93^{a}	11.94^{a}	12.50^{ab}	7.66^{a}	12.54^{a}	13.85^{a}	7.12^{a}
BS	%	68.19^{ab}	55.35^{b}	32.76^{b}	63.41^{b}	59.63^{b}	37.53^{ab}	62.77^{b}	61.15^{ab}	40.62^{a}	68.57^{ab}	62.93^{ab}	39.09^{ab}	71.77^{a}	70.76^{a}	39.70^{ab}
ESP		2.00^{c}	1.48^{b}	2.29^{a}	2.15^{bc}	1.77^{a}	2.89^{a}	2.16^{bc}	1.78^{a}	2.77^{a}	2.41^{b}	1.80^{a}	2.58^{a}	2.80^{a}	1.94^{a}	2.37^{a}
Dry bulk density	g cm^{-3}	1.22^{ab}	1.22^{b}	0.94^{a}	1.26^{a}	1.34^{a}	0.96^{a}	1.16^{b}	1.21^{b}	0.94^{a}	1.17^{b}	1.19^{b}	0.91^{a}	1.21^{ab}	1.24^{b}	0.97^{a}
Moisture content	%	53.84^{a}	71.13^{a}	58.96^{a}	51.94^{a}	64.46^{a}	53.80^{ab}	57.97^{a}	72.14^{a}	54.67^{ab}	55.88^{a}	72.14^{a}	57.21^{ab}	53.55^{a}	69.27^{a}	51.36^{b}
Clay		35.07^{b}	34.04^{ab}	38.29^{c}	35.75^{b}	30.74^{b}	36.46^{c}	39.56^{a}	32.71^{b}	44.81^{b}	41.58^{a}	37.65^{a}	49.70^{a}	42.98^{a}	38.42^{a}	49.04^{ab}
Silt		34.35^{a}	34.66^{b}	36.44^{a}	34.65^{a}	34.00^{b}	34.57^{a}	36.92^{a}	37.16^{ab}	35.89^{a}	37.42^{a}	41.03^{a}	37.27^{a}	37.85^{a}	39.69^{a}	35.05^{a}
Fine sand		30.07^{a}	30.71^{a}	24.77^{a}	29.04^{a}	34.50^{a}	28.38^{a}	22.77^{b}	28.79^{a}	18.85^{b}	20.58^{b}	20.20^{b}	12.58^{c}	18.72^{b}	21.04^{b}	15.51^{bc}
Coarse sand		0.51^{ab}	0.60^{a}	0.47^{a}	0.54^{ab}	0.78^{a}	0.60^{a}	0.62^{a}	1.34^{a}	0.45^{a}	0.41^{b}	1.13^{a}	0.45^{a}	0.44^{b}	0.87^{a}	0.42^{a}
Sand		30.58^{a}	31.31^{a}	25.25^{a}	29.58^{a}	35.27^{a}	28.98^{a}	23.39^{b}	30.13^{a}	19.31^{b}	20.99^{b}	21.32^{b}	13.02^{c}	19.17^{b}	21.91^{b}	15.93^{bc}

*Mean values in row for the different zones of the same season were significant at $\alpha = 0.05$ by DMRT high K when tested by DMRT at 5% level. Some soil properties showed non significant difference in all the zones. These were pH, EC, CEC, Al, Fe, moisture content and silt for season 1, EC, P, K, Al, moisture content and coarse sand for season 2 and OM, OC, N, Al, dry bulk density, silt and coarse sand for season 3.

CONCLUSIONS

The tractor speed has affected the number of EC_a readings, where a small and low speed tractor collected more readings as compared to a bigger one. Since, the logging depended on the time interval of 1 s, the measured distance grid between points was about 0.8 m for season 1, 1.25 m for season 2 and 1.35 m for season 3. The short distance in season 1 was caused by low speed of the 35 HP tractor. The EC sensor is very useful in soil spatial and temporal variability mapping, where it can acquire the soil information quickly (less operation time) with less operators. The mean shallow EC_a values were lower than mean deep EC_a values. This may be due to their parent material (marine clay), which is at the lower layer, hence increased deep EC_a values. Most of the soil properties and EC_a changed over the seasons, except for total N. Many of the soil properties such as K, moisture content, silt and coarse sand were similar for seasons 1 and 3. Both shallow and deep EC_a maps retained their patterns even though the mean values were different. Deep EC_a showed the pattern of the former canal routes clearly as continuous lines (about 45 m width) at the northern and central regions of the study area. Most of the high EC_a levels were found in the southern and central regions. All the three seasons showed that the pattern of the map retained the same shape (clear former water route in low EC_a zone and zone of high EC_a). This exploration has shown different maps with higher contrast as compared to the existing soil series map for the study area. It showed that very detailed (as collected at every one meter) soil zoning map can be produced and delineated faster using soil EC_a sensor at a submetre grid (less than 1 m) collected at every 1 s interval. Zone 1 of shallow EC_a had significantly lower soil EC, Ca, K and Fe, but significantly higher fine sand and sand contents. Zone 1 of deep EC_a had significantly lower Mg, Na and total cation. This low Na may be due to deep soil profile reaching the parent material of marine clay (marine alluvial), where it used to be a former water route. Higher fine sand and sand in zone 1 were found for all the seasons. The results suggested that field-scale EC_a survey could delimit distinct zones of soil condition among which soil nutrient levels differ, providing an effective basis for soil sampling on a zone basis. This will help farmers to identify their farm for variable rate application.

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