*Full Length Research Paper*

# Characterization of paddy soil compaction based on soil apparent electrical conductivity zones

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Soil apparent electrical conductivity ($EC_a$) is one of the most common and frequently used measurements to determine field soil variability, especially for precision farming. Soil cone index (CI) is a measure of soil compaction that poses a big challenge for water management in poorly drained soils. The soil compaction affects the root penetration and development of the rice plant. The purpose of this study was to characterize the CI within the $EC_a$ zones for a Malaysian paddy soil. The study of soil compaction and $EC_a$ was conducted on silty clay paddy soil at Sawah Sempadan, Tanjung Karang, Selangor (latitude 3°35" N and longitude 101°05" E). Measurement of $EC_a$ and CI were done using Veris 3100 and hand-operated soil cone penetrometer, respectively. The deep $EC_a$ ($EC_a$d) was compared to the minimum, mean and maximum CI and also within $EC_a$d zone. The maximum CI was found at 0.147 MPa with average maximum at 0.081 MPa. The results indicate that the hardest layer exists at a depth of 10 to 20 cm. $EC_a$d in Zone 2 (50 to 100 mS m$^{-1}$) showed that the CI values have the highest significant negative correlation with $EC_a$d. The significant correlation of $EC_a$d and soil cone index was found at mid range of the soil $EC_a$d.

**Keywords:** Zone delineation, paddy field, cone index, regression.

## INTRODUCTION

Soil variability always exists within a field and can be mapped using some precision farming tools and software. Corwin and Lesch (2003) found that the soil electrical conductivity has become one of the most frequently used measurements to characterize field variability for application of precision farming. Soil sensor such as the Veris EC sensor is a useful tool in mapping soil apparent electrical conductivity ($EC_a$) in order to identify areas of contrasting soil properties (Amin et al., 2004; Aimrun et al., 2007). The bulk soil electrical conductivity measurement called soil apparent electrical conductivity ($EC_a$) measures conductance through soil

solution and solid soil particles and also via exchangeable cations which exist at the solid-liquid interface of clay mineral (Corwin and Lesch, 2003).

Paddy soil is basically compacted which is caused by vehicle traffic such as tractors and combine harvesters. When soil is compacted, there are changes in physical properties of soil such as, soil structure, pore space, and density, which play an important role in the growth and development of plants (Sudduth et al., 2008). Soil compaction has been used to assess root growth and penetration. The soil compaction is measured by the value of cone index. The higher the cone index, the greater is the amount of energy that must be expended by the roots to widen the soil pores (Chen et al., 2005).

The cone index (CI) is a measure of a soil's resistance to penetration and is regarded as an indicator of soil strength. Two distinct peaks in the CI profile are labeled hardpan and fragipan depth where it can be determined, based on value of CI. The CI must have at least three consecutive data points that exceed 1 MPa (145 psi) to be classified as hardpan layer as mentioned by

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**Abbreviations: $EC_a$,** Apparent electrical conductivity; **CI,** cone index; **$EC_a$d,** deep $EC_a$; **$EC_a$s,** shallow $EC_a$; **TAKRIS,** Tanjung Karang rice irrigation scheme; **r,** coeficient of correlation.

**Figure 1.** Study area at blocks C, J, and O at TAKRIS, Tanjung Karang, Selangor, Malaysia.
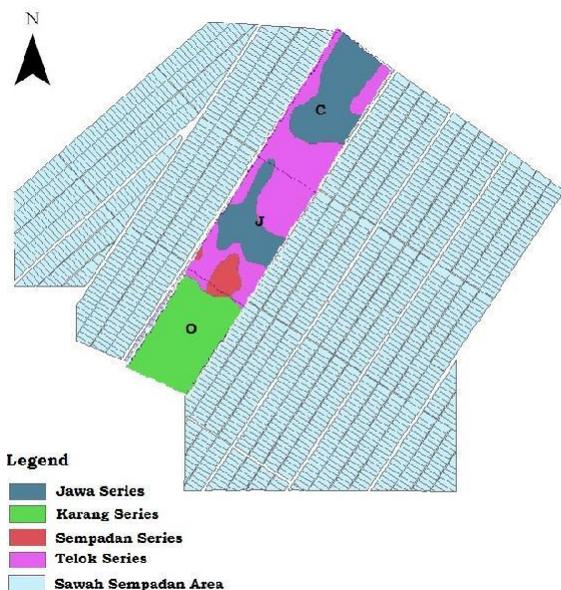


**Figure 2.** Soil series in blocks C, J and O, covering area of 380 ha in Sawah Sempadan showing Jawa, Karang, Sempadan and Telok series.

Isaac et al. (2002) for maize plant. The readings of cone penetrometer require a "stop-and-go", making it difficult to collect enough data to accurately map compaction variations within a field (Sudduth et al., 2008).

Assessment and interpretation of spatial variability of

soil compaction and apparent electrical conductivity are very important for precision farming. Farmers need quick, reliable, and inexpensive technique and sensing technology to measure soil variability such as soil compaction and other properties that can characterize soil variability in their fields. The objective of this study was to characterize the relationship between $EC_a$ and the soil profile based on CI for identifying soil variability in a paddy field in a humid tropical region practicing double cropping of rice per year.

## MATERIALS AND METHODS

### Study site

This study was conducted at Sawah Sempadan irrigation compartment, of the Tanjung Karang rice irrigation scheme (TAKRIS), (Figure 1) in the district of Kuala Selangor, Malaysia. The total area of Sawah Sempadan is 2,300 ha and divided into 24 blocks namely Blocks A to X. However, only blocks C, J and O were selected. Each block consists of about 100 lots and the size of each lot is 1.2 ha (200 × 60 m). These three blocks are located on the same tertiary irrigation canals and block C is located in the upstream, close to the main canal, and then followed by blocks J and O. The total area was 380 ha with 312 paddy lots. The soil series for the whole area are *Jawa (Sulfic Tropaquept), Teluk (Sulfic Tropaquept), Sempadan (Sulfic Tropaquept)* and *Karang (Thypic Sulfaquept),* (Aimrun et al., 2002) and can be referred on Figure 2. The soil series were grouped as acid sulfat soil from this order; mineral soil-alluvium soil- marine alluvium (parent material)-acid sulfat soil. The characteristics are having poor drainage and fine texture. The field study was carried out in December 2007 after harvest of the second season.

**Figure 3.** The veris 3100 sensor showing GPS receiver and six coulters to determine electrical resistance across the soil profile.

### Soil apparent electrical conductivity

Data acquisition of $EC_a$ was obtained by using a sensor known as Veris 3100 sensor (Figure 3). The sensor was pulled across each field behind a tractor in a series of parallel transects spaced about 15 m apart. The sensor was calibrated using an Ohmmeter to ensure that its resistance is lesser than 2 Ohm. This sensor was used in conjunction with a differential global positioning system (DGPS) receiver and Veris data logger. The $EC_a$ data were geo-referenced to create spatial variability map.

The sensor has three pairs of coulter-electrodes to determine soil $EC_a$. The coulters penetrate the soil into a depth of 6 cm. One pair of the coulter emit an electrical current and the other two pairs detect the resistance (Lund et al., 1999; Amin et al., 2004; Aimrun, 2006). The six coulters can be named and arranged as 1, 2, 3, 4, 5 and 6 from left to right. The center pair (plates 2 and 5) passes the electric current (reference) into the soil. The coulters 3 and 4 integrate resistance between depths of 0 and 30 cm (shallow), while the outside pair (coulter plates 1 and 6) integrates the electrical resistance between 0 and 90 cm (deep). The veris data logger recorded the latitude, longitude, elevation, shallow $EC_a$ ($EC_a$s) and deep $EC_a$ ($EC_a$d) data (mS m$^{-1}$) in an ASCII text format. The reading of $EC_a$ in the data logger is conversion of resistance to conductivity (1/resistance=conductivity). The EC data logger was available to receive reading only when DGPS signal was available. The data were then transfered from the data logger to a computer. The data quality screening was done by removing all negative values and it is generally not more than 10% of the total data count, otherwise it should be collected again.

### Zone delineation based on $EC_a$d

The $EC_a$ data in ASCII format was transferred from the veris data logger to a diskette and then to a computer. ArcGIS software was used to view, analyze the $EC_a$ data and to create a map. Spatial analysis was done to interpolate the data using kriging method, and then to produce the soil $EC_a$ variability map. The $EC_a$d zones were delineated to three classes or zones. Zone 1 was defined as low for the $EC_a$d value lesser than 50 mS m$^{-1}$, zone 2 was defined as moderate (51 to 100 mS m$^{-1}$), and zone 3 was defined as high for $EC_a$ value of higher than 100 mS m$^{-1}$. The sampling point were decided based on these zones. The $EC_a$d was chosen as a map

base for zone delineation, because it was found that the zone pattern is always similar for many seasons (Aimrun, 2006). Chinthia et al. (2001) stated that field classification zones using $EC_a$ can provide an effective map for soil sampling.

Figure 4a shows soil variability map for Block C which is located in the upstream and close to the main canal. The map of $EC_a$d showed the variability clearly, especially for low and high $EC_a$ levels. Earlier study by Aimrun (2006) and Aimrun et al. (2009) also found the pattern of a former river clearly as continuous lines in the northern and central regions of the study area. The former river was about 45 m wide. The kriging map of Block J (Figure 4b) shows the variability of $EC_a$d only for moderate and high level. The level $EC_a$d for Block O (Figure 5 c) was high with $EC_a$d value of more than 100 mS m$^{-1}$ and no variability were found in this block. Block O is located closer to the sea (approximate 7 km) indicating higher salt content, hence, higher $EC_a$d compared to the other blocks (approximate 11 km).

### Sampling points

The soil samples were taken from 30 points within the study area. Figure 4 shows the soil variability map used for determing the sampling points. For zones 1, 2 and 3, the number of soil sampling points were 12, 10 and 8 points, respectively. Block C had high variability (three zones were found), so more points were collected from this area (15 points). Block J had lower variability than Block C, and Block O had no obvious variability. The total numbers of sampling points were 8 and 7 points for Block J and O, respectively.

### The cone index measurement

The soil compaction was determined by using CI value, based on soil resistance to penetration. The hand-operated soil cone penetrometer was used in this study following the American Society of Agricultural Engineering (ASAE) standards (S313.2) (ASAE, 1999). The equipment has cone base size of 32.3 cm² and 2.027 cm diameter, with 1.6 cm diameter shaft for soft soil. Graduation on the driving shaft is 2.54 cm apart and used to identify the depth of hand- operated device (Figure 5). The equipment was pressed up to 50 cm from the soil surface and the readings were recorded
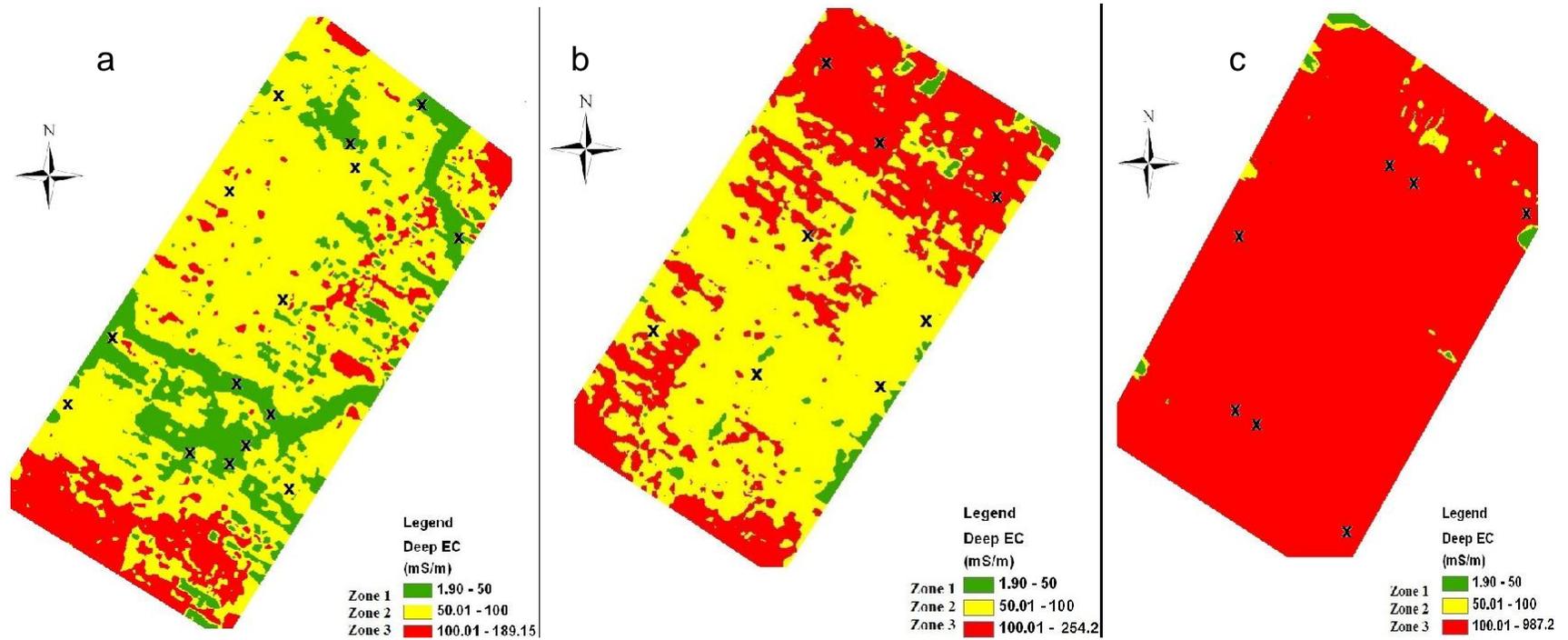
**Figure 4.** Kriging map of $EC_a$d for determining soil sampling points; (a) Block C; (b) Block J; and (c) Block O. Sampling point are marked by (x).

at every 2.5 cm (1 inch). The cone Index (CI) is defined as the force per unit area required to push the penetrometer through a specified small increment of soil. CI can be calculated by using the formula:

Cone index (MPa) = (division × 0.05 kg × $9.81 \times 10^{-6}$ ) ÷ A ($m^2$)

Where: 1 division in pressure gauge = 0.05 kg and A is cone basearea ($3.23 \times 10^{-4}$ $m^2$)

### Statistical analysis

It is known that we can never be completely (100%) certain that a relationship exists between the two variables. There are too many sources of error to be controlled, for example, sampling error, researcher bias, problems with reliability and validity and simple mistakes. Correlation is a type of analysis to find the relation between two variables and show how the variables are related. The purpose is to get the significant relation and explainable by considering the value of r. The bivariate correlation procedure was chosen to determine the correlation. Pearson correlation was selected because the relation between variables is a linear association.

Regression analyses were run to see the prediction model from independent variable with dependent variable. Before this analysis was run, the correlation was done to make sure the variables have significant correlation to each other. There are two types of regression, that is, linear and non-linear. Linear regression was chosen to find the prediction of one variable with another variable. The analysis shows the prediction model from multiple

dependent variables. The $R^2$ was used as an indicator to determine how well the model fits the given data. The highest $R^2$ was chosen as the best model. Ronnie et al. (2003) used stepwise method in regression analysis and found that $EC_a$ was often a key loading factor that changes in soil texture.

## RESULTS AND DISCUSSION

### Soil apparent electrical conductivity

The $EC_a$ measurements were integrated over a soil depth of 0 to 30 cm for $EC_a$s and 0 to 90 cm for $EC_a$d. Total number of $EC_a$ data was 115 908
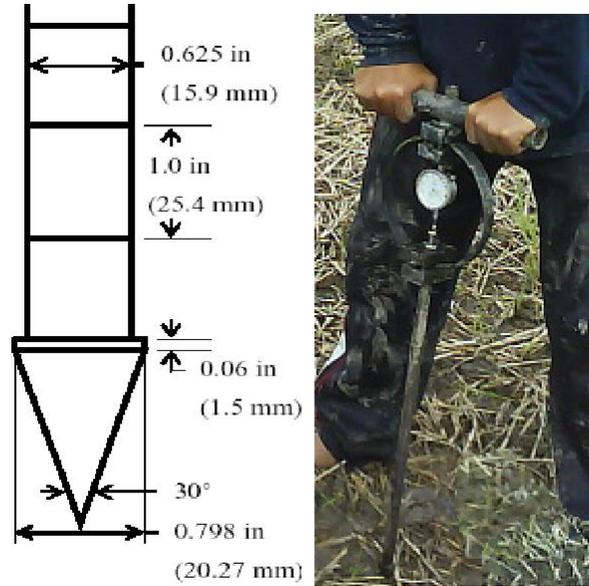
**Figure 5.** The ASAE standard cone and hand-operated cone penetrometer pushed into the paddy soil profile.

**Table 1.** Descriptive statistics for $EC_a$.

| Block | $EC_a$ | n | Min | Max | Mean | Std.D | CV |
|---|---|---|---|---|---|---|---|
| Block C | $EC_a$s | 48070 | 1.00 | 369.6 | 43.63 | 19.3 | 41.5 |
| | $EC_a$d | 48070 | 1.00 | 413.70 | 73.0 | 33.5 | 45.9 |
| Block J | $EC_a$s | 37937 | 1.00 | 346.1 | 42.21 | 15.7 | 37.3 |
| | $EC_a$d | 37937 | 1.00 | 933.6 | 96.86 | 32.8 | 33.9 |
| Block O | $EC_a$s | 29901 | 1.00 | 307.60 | 116.61 | 46.3 | 39.7 |
| | $EC_a$d | 29901 | 1.00 | 992.5 | 254.29 | 80.1 | 31.5 |
| At sampling points | $EC_a$s | 30 | 7.89 | 163.57 | 55.22 | 38.2 | 69.2 |
| | $EC_a$d | 30 | 11.0 | 370 | 108.3 | 90.3 | 83.4 |

*n = No. of sampling point samples.

points for an area of 380 ha. The average number of $EC_a$ data for each lot was 366 points and slightly lesser as compared to 500 points used by Aimrun et al. (2007) for their research at Seberang Perai paddy field, Pulau Pinang. The number of data depended on the speed of the tractor and the condition of the soil surface. With the logging interval of one second, a slow drive can collect more data points (Amin, 2004).

The descriptive statistics of soil $EC_a$ within the 3 blocks are shown in Table 1. The values of $EC_a$s at sampling points were found to be 7.89, 163.57 and 55.2 mS m$^{-1}$ for minimum, maximum and mean, respectively. For $EC_a$d, the values of minimum, maximum and mean were 11.00, 370.00 and 108.3 mS m$^{-1}$, respectively. The CV$_s$ For

$EC_a$s and $EC_a$d, were 69.2 and 83.41%, respectively. This higher CV of the sampling points were due to the zones of the soil variability map. The mean $EC_a$s values at Block C, J and O were 43.63, 42.21 and 116.6 mS m$^{-1}$, respectively. The mean $EC_a$d values at Block C, J and O were 73.0, 96.86 and 254.29 mS m$^{-1}$, respectively.

The results showed the values of $EC_a$ increased from Block C to O (upstream to downstream). This happened because the soils in Block O and Block C are too different in their characteristics. As can be observed, soils in Block O have very shallow topsoil layer and greyey soil was found at very shallow depth. While Block C has lower average $EC_a$ because of many areas are occupied by peat soil and acid sulfate for *Jawa* and *Telok* series. The

**Table 2.** The classes of CI values.

| Depth | Depth 1 | Depth 2 | Depth 3 | Depth 4 |
|---|---|---|---|---|
| cm (Inches) | 0 to 13 (0 to 5) | 13 to 26 (5 to 10) | 26 to 39 (10 to 15) | 39 to 52 (15 to 20) |
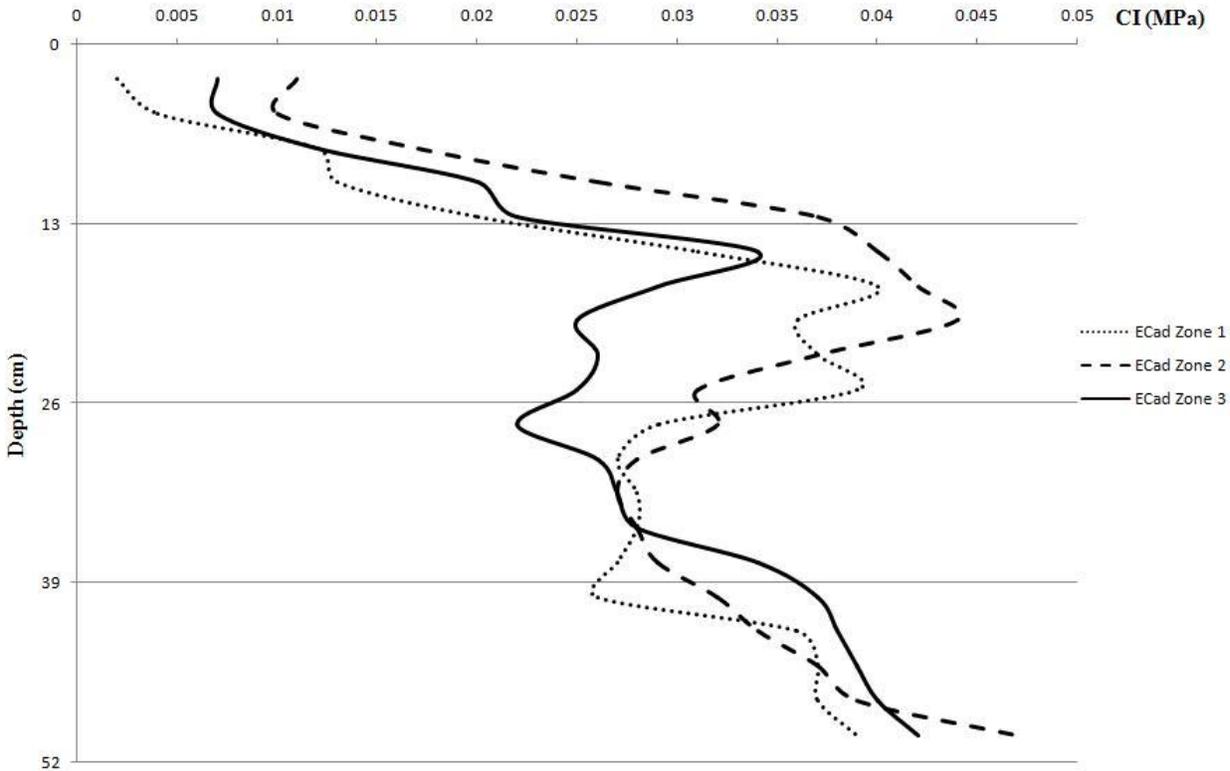


**Figure 6.** Graph of minimum CI values with paddy soil depth for various $EC_ad$ zones.

mean values of the $EC_ad$ were higher than those at the shallow depths. The effect of soil parent materials at the subsoil layer probably caused the higher $EC_a$ values (Aimrun, 2006).

Previous studies in paddy fields at Malaysian Agricultural Research and Development Institute (MARDI) Seberang Perai Station, Penang, by Aimrun et al. (2007) found the values for $EC_as$ ranged from 0.9 to 64 mS m$^{-1}$ with the average and standard deviation of 5.67 and 3.04 mS m$^{-1}$, respectively for an area of 9 ha. The $EC_ad$ values from 5202 data points ranged from 1.3 to 48.9 mS m$^{-1}$ with the average and the standard deviation of 9.1 and 6.8 mS m$^{-1}$, respectively. Comparing these two sites, the data of $EC_a$ at Sawah Sempadan were higher than those at Seberang Prai, Pulau Pinang. The percentages of clay were found to have positive correlation with $EC_a$ with values for Sawah Sempadan and Seberang Perai of 46.77 and 21.68 %, respectively. The low $EC_a$ at Seberang Perai was probably due to less clay particles to transmit the electric current.

**Cone index**

The values of CI were randomly divided into four depths according to depth of penetration of the soil profile (Table 2). The groups were depths 1 to 4. These small groups eased evaluation of the data. The studies by Bockari-Gevao et al. (2005) at Sungai Burong Compartment (latitude 3° 35" N and longitude 101° 05" E) of the TAKRIS, found the values of cone index ranged from 0.11 to 0.28 MPa. Whereas, the results of this study were lower (0.02 to 0.147 MPa). These were possibly due to the different soil series in that area. The soil series in Sungai Burong study site is *Selangor Series and* has medium soil texture compared to fine texture for soil series (*Telok and Jawa*) in this study area (Sawah Sempadan). The study at Kerian paddy field, Perak, Malaysia, by Ngoo and Burkhanuddin (2008) found peak CI at 0.15 MPa. These similar CI was probably due to same parent material (marine alluvium).

Figures 6, 7 and 8 show the graph of CI for minimum,
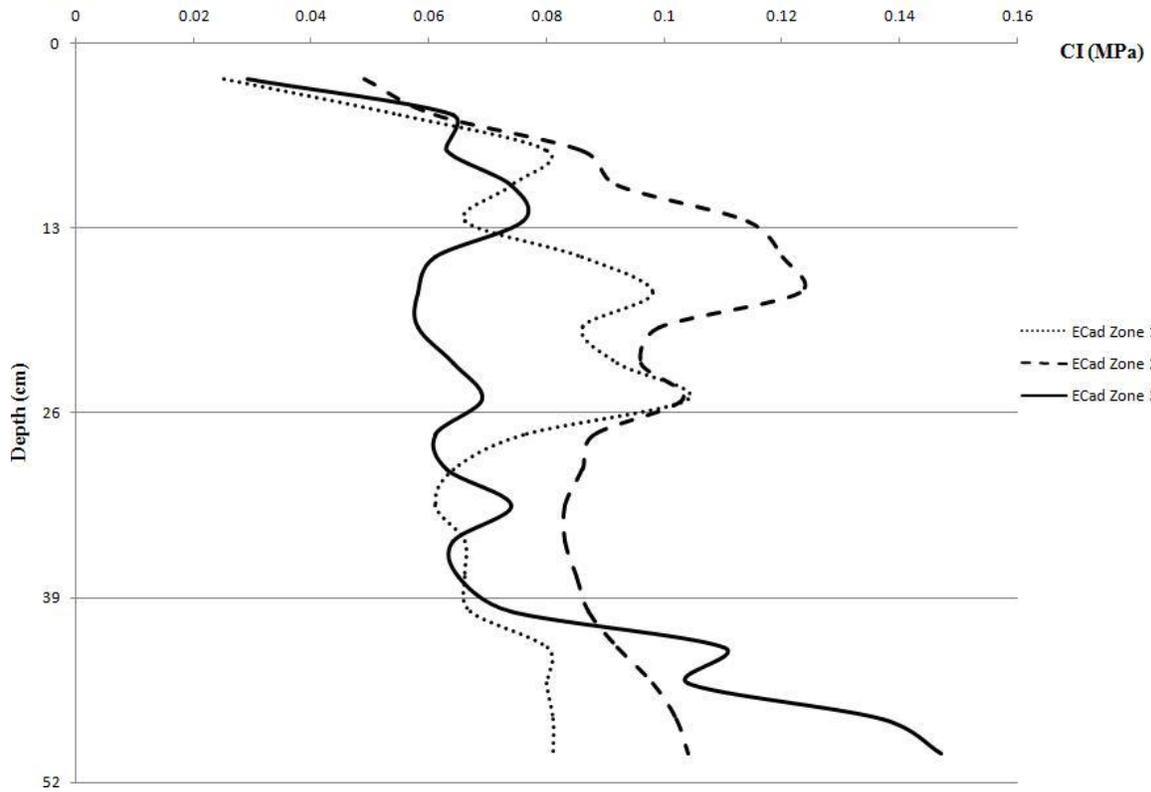
**Figure 7.** Graph of maximum CI values with paddy soil depth for various $EC_ad$ zones.
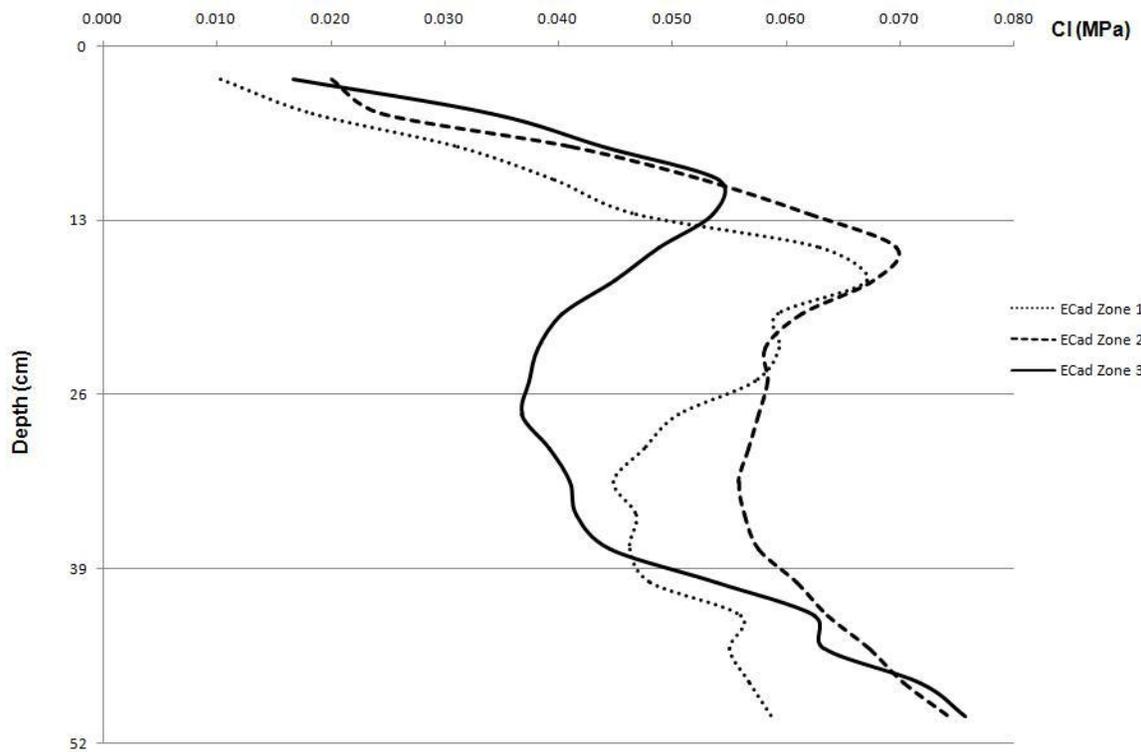


**Figure 8.** Graph of mean CI values with paddy soil depth for various $EC_ad$ zones.

**Table 3.** The significant correlation of CI and soil $EC_a$ with soil depth, n= 30.

| CI | $EC_a$ | Depth 1 (< 13 cm) | Depth 2 (13 to 26 cm) | Depth 3 (26 to 39 cm) | Depth 4 (> 39 cm) |
|---|---|---|---|---|---|
| Min. | $EC_a s$ | ns | -0.442* | ns | ns |
|  | $EC_a d$ | ns | -0.523** | -0.05* | ns |
| Mean | $EC_a s$ | ns | -0.445* | ns | ns |
|  | $EC_a d$ | ns | -0.541** | ns | ns |
| Max. | $EC_a s$ | ns | -0.383* | ns | ns |
|  | $EC_a d$ | ns | -0.475** | ns | ns |

** Correlation is significant at the 0.01 level; * Correlation is significant at the 0.05 level.

maximum and mean values within each zone based on spatial variability map of $EC_a d$. The graphs increased continuously and reached a peak MPa at depth 2 (13 to 26 cm) and then decreased at depth 3 but increase again at depth 4. The maximum compaction was found as only 0.147 MPa. The hardpan is described as the layer harder to penetrate and no roots are usually found between 10 and 30 cm from the surface (Aimrun et al., 2010; Ngoo and Burkhanuddin, 2008)

Measurements of CI indicated that the hardest layer or the most compacted layer existed at approximately 16 cm depth. The graph shows the CI at $EC_a d$ zone 2 is higher than in zone 1 and 3. This means that mid range $EC_a$ at 51 to 100 mS m$^{-1}$ has highest CI. The CI at zone 3 is lowest; therefore, it has the softest soil or the least bearing capacity indicating the weakest soil strength to withstand the weight of a combine harvester during harvest. Most of the areas of Block C were in zone 3. From the visual observation, combine harvester and tractors were always bogged down due to low bearing capacity on areas with low CI values.

**Correlation analysis**

The matrix correlation of $EC_a$ and cone index was determined by Pearson's 2-tailed technique in SPSS statistical software. There were two relations founds, each group of CI with $EC_a$ zones and CI within each $EC_a d$ zone. The results of correlation analysis between soil $EC_a$ and cone index were clustered based on the soil depth. Table 3 shows $EC_a d$ has significant negative relation with mean CI at 15 to 25 cm (depth 2) with coeficient of correlation, (r) of -0.541** at 0.05 significance level. $EC_a s$ also has the same correlation with r = -0.445* at 0.01 significance level. For maximum values of CI, the condition is the same where it has significant negative correlation with deep and $EC_a s$ at 15 to 25 cm with r = - 0.475** and 0.383*, respectively. Minimum values of CI also give the same results and correlation where r = - 0.523** and 0.445*, respectively. The results show that $EC_a d$ has better correlation compared to $EC_a s$ by

considering the significance level.

Table 4 shows the significant correlation for CI and $EC_a$ within $EC_a d$ zone. The soil $EC_a$ values were found to have significant negative correlation at zone 2 of $EC_a d$. Each depth of CI has significant negative correlation with minimum, mean and maximum CI except for depth 1. No significance (ns) was found in the other zones.

**Regression analysis**

The tests showed that $EC_a d$ have significant correlation to CI within Zone 2. The regression analysis showed that CI could be estimated by using $EC_a d$. The CI in paddy soils was apparently not influenced by $EC_a s$ because no significant correlation was found. Prediction models were developed for each depth except for depth 1 since there was no significant correlation. Table 5 shows the equations to estimate CI based on the $EC_a d$ values. Each model only used $EC_a d$ as independent variable because there was no significant correlation found with $EC_a s$. The constants of the models are different for each model but the coefficients remained the same at 0.001. The general equation is the form of: $CI = a - (0.001\ EC_a d)$ with $R^2$ ranging from 0.318 to 0.784.

The study showed that the spatial variability of the soil apparent electrical conductivity varied highly at Block C as compared to Blocks J and O. Soil $EC_a d$ and $EC_a s$ have significantly negative correlation with cone index at depth 2 (13 to 26 cm) where the highest soil compaction occurs. The study shows that $EC_a d$ can be used as an indicator to determine the hardest layer in the paddy field with mid range $EC_a d$ (zone 2). The hardest layer is found typically between 13 to 26 cm (depth 2).

**ACKNOWLEDGEMENTS**

**Table 4.** Correlation of CI and soil $EC_ad$ zones 1, 2 and 3.

| Zone and $EC_ad$ | | $EC_a$ | Depth 1 | Depth 2 | Depth 3 | Depth 4 |
|---|---|---|---|---|---|---|
| Zone 1 $(1 - 50 \text{ mS m}^{-1})$ n = 12 | Min | $EC_as$ | ns | ns | ns | ns |
| | | $EC_ad$ | ns | ns | ns | ns |
| | Mean | $EC_as$ | ns | ns | ns | ns |
| | | $EC_ad$ | ns | ns | ns | ns |
| | Max | $EC_as$ | ns | ns | ns | ns |
| | | $EC_ad$ | ns | ns | ns | ns |
| Zone 2 $(51 - 100 \text{ mS m}^{-1})$ n = 10 | Min | $EC_as$ | ns | ns | ns | ns |
| | | $EC_ad$ | ns | -0.765** | -0.849** | -0.897** |
| | Mean | $EC_as$ | ns | ns | ns | ns |
| | | $EC_ad$ | ns | -0.731** | -0.858** | -0.877** |
| | Max | $EC_as$ | ns | ns | ns | ns |
| | | $EC_ad$ | ns | -0.617* | -0.871** | -0.858** |
| Zone 3 $(101 \text{ mS m}^{-1}$ and upward) n = 8 | Min | $EC_as$ | ns | ns | ns | ns |
| | | $EC_ad$ | ns | ns | ns | ns |
| | Mean | $EC_as$ | ns | ns | ns | ns |
| | | $EC_ad$ | ns | ns | ns | ns |
| | Max | $EC_as$ | ns | ns | ns | ns |
| | | $EC_ad$ | ns | ns | ns | ns |

**Table 5.** Model development for CI in zone 2.

| | Depth | Model developed | $R^2$ |
|---|---|---|---|
| Minimum | Depth 2 | $0.136 - (0.001 \times EC_ad)$ | 0.543*** |
| | Depth 3 | $0.134 - (0.001 \times EC_ad)$ | 0.693*** |
| | Depth 4 | $0.163 - (0.001 \times EC_ad)$ | 0.784*** |
| Mean | Depth 2 | $0.148 - (0.001 \times EC_ad)$ | 0.487*** |
| | Depth 3 | $0.141 - (0.001 \times EC_ad)$ | 0.709*** |
| | Depth 4 | $0.171 - (0.001 \times EC_ad)$ | 0.746*** |
| Maximum | Depth 2 | $0.162 - (0.001 \times EC_ad)$ | 0.318** |
| | Depth 3 | $0.150 - (0.001 \times EC_ad)$ | 0.743*** |
| | Depth 4 | $0.179 - (0.001 \times EC_ad)$ | 0.711*** |

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