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Assessment of the Variability of Soil Properties for OFC Cultivation under Minor Irrigation Systems

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Abstract

Combined paddy and other field crops (OFC) fields are unique from other wetland or upland soils, because of seasonal alternation of wetting and drying conditions resulting anaerobic and aerobic conditions. Therefore, objective of this study was to assess spatio-temporal variation of soil properties in paddy fields under minor tanks with respect to OFC cultivation. Soil samples were collected at two soil depths from 24 locations covering the entire command area of the *Bayawa* Minor Irrigation Tank (MIT), Sri Lanka. Soil properties were analyzed and mapped using Arc GIS. Hardpan depth (HPD) was also determined by collecting undisturbed core samples at 0, 15, 25, 30, 45 and 60 cm depths from the same locations Statistical analysis was done to identify spatio-temporal variability of each property. Results revealed that, *Bayawa* command area showed low coefficient of variation (CV) for pH and bulk density, but high CV for saturated hydraulic conductivity (K_s). HPD was found to be varied in each section within the effective root zone. Overall, low K_s, high clay content, high field capacity, poor drainage and the presence of hardpan are major obstacles to introduce OFC. Therefore, introduction of site specific OFC by considering the variability of soil properties is very important for sustainability of the MIT system.

Keywords: Cropping intensity, drainage, hardpan, minor irrigation tanks, OFC

INTRODUCTION

Background

Green revolution technologies have allowed fulfilling the food supply demand of the increasing population in Asia during past few decades (Bueno and Ladha, 2009). However, the pressure on soil, water and other resources has intensified. Arable lands are continuously being decreased because of soil pollution, land degradation, land abandonment, urbanization, and other reasons (Gathala, 2011), but the population and the demand for food are on the continuously increasing trend. As such, increasing cropping intensity (CI) from one cropping to double or triple cropping per year is an efficient way to increase land productivity and guarantee the food security.

Lands for OFC cultivation

Sri Lanka has almost reached the self-sufficiency in rice (Department of Census and Statistics, 2010). Hence, the Ministry of Agriculture has started launching many programs to reach the self-sufficiency in OFC by 2016 (Ministry of Agriculture, 2015). For achieving this target, land available in upland areas for OFC is not enough and fulfilling the irrigation requirement for these lands is also complicated. Lands under minor irrigation tanks (MITs), therefore, have high potentials for OFC, since the paddy production has become uneconomical in marginal paddy lands, especially in the wet zone (WZ) as well as under MITs located in intermediate zone (IZ) and dry zone (DZ) of Sri Lanka (Jayawardane and Weerasena, 2000). In addition, paddy fields under MITs have relatively well established surface irrigation systems than upland fields. Accordingly, identification and evaluation of potentials lands for OFC cultivation under MTs is very important and timely.

Soil physical and chemical properties in paddy fields

Soil properties are key factors for observed declining yields in agriculture including paddy fields (Mutiu *et al*., 2015). Soil is one of most important natural resources in agricultural ecosystems including paddy fields. Soils should be at optimum condition with its physical, chemical and biological properties together with other management practices to enhance the productivity and cater to the future demand. Variability of soil properties, both spatially and temporally, is a great challenge for efficient land, water and crop management for maintaining an economical yield. Some earlier studies in Ghana showed that variability of soil properties could have detrimental effects on crop performances (Haefele and Wopereis, 2005). According to a study by Mzuku *et al*. (2005), land productivity and the spatial pattern of land productivity could be caused by a corresponding variation in certain soil properties. Authors suggested that utilization of site-specific management zones could help manage the in-field variability of yield-limiting soil physical properties. Another study by Olabode and Oriola (2013) reported yield limiting soil physical and chemical properties with proper management could enhance favorable conditions and increase paddy yield. Spatial variability of many soil properties are also highly varied with topography of the field (Wei Zhou *et al*., 2014). In addition, site-specific management of these properties would be helpful to increase nutrient use efficiency and decrease soil degradation due to over application of inorganic fertilizer (Singh and Ryan, 2015). But research on spatial and temporal variability analysis of soil properties, particularly in paddy fields under MITs systems, with reference to OFC cultivation is very limited. The knowledge of the variability of soil physical properties under MITs therefore is essential to fulfill the future demand of OFC and food security in Sri Lanka.

Effect of crop rotation in paddy fields

Fields in MITs under Paddy-OFC rotation are unique when compared to other wetland or upland soils, because of the agronomic practices, seasonal alternation of wetting and drying cycles and the frequent changes of anaerobic and aerobic conditions. The chemical speciation and biological effectiveness of soil nutrients can be highly varied with these wetting and drying cycles (Hashimoto *et al*., 2017). According to the conceptual framework shown in Figure 1, properties and functions of soil get complicated under Paddy-OFC rotations in paddy fields. Hence, analyses of these physical and chemical properties and their changes with reference to OFC before introducing those to paddy fields are very important.

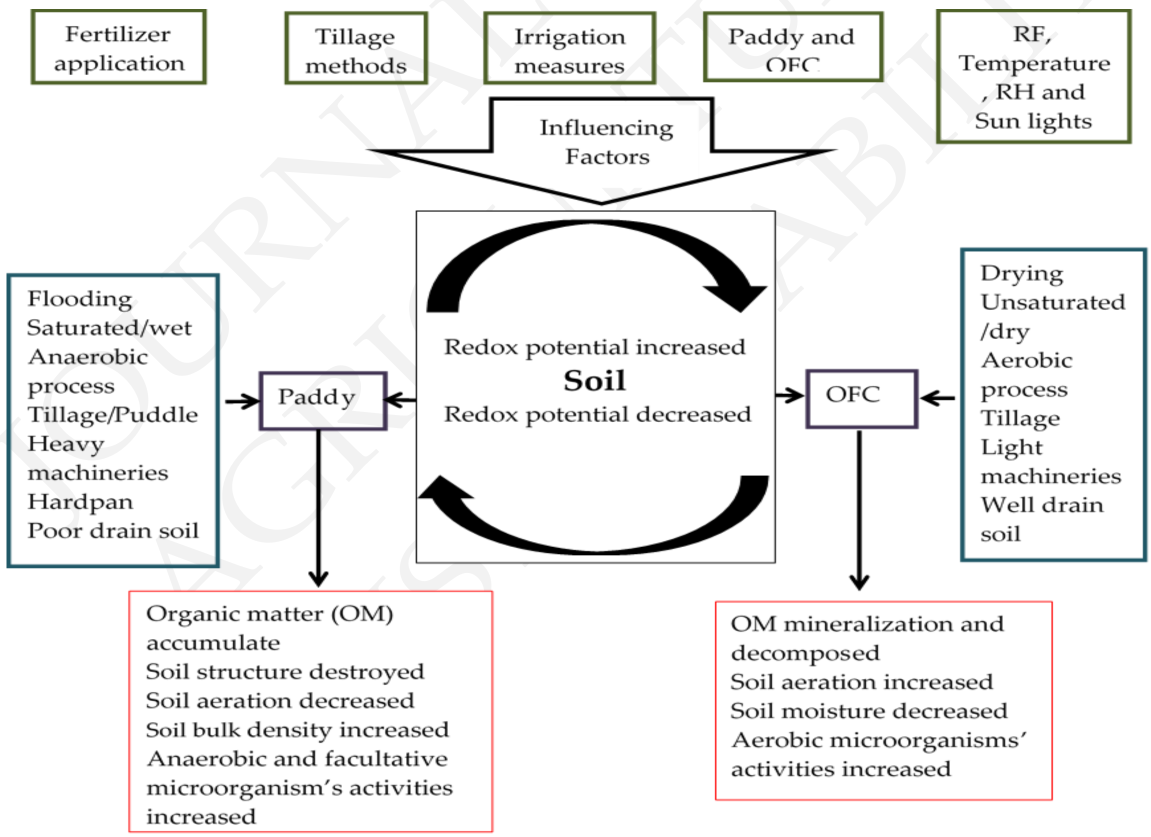

Figure 1: Conceptual framework for variation of soil properties due to paddy-OFC rotation

Hardpan development in command area

Hardpan facilitates lowland paddy cultivation by restricting deep drainage to provide saturated field conditions. Usually the hardpan locates at a depth of 20 to

30 cm (Shi-Kai and Chan, 2002). Hardpan is developed due to continuous cultivation of the same crop and the usage of heavy machineries. When BD is above 1.75 g/cm^3, roots cannot penetrate (Blake and Hartge, 1986) and it can be a serious problem in upland farming due to impeding drainage and restricting root growth. The HPD depends on soil texture, moisture content (MC) and the machinery used (GRDC, 2002). As an advantage, hardpan can prevent sinking of tillage equipment during cultivation (Shi-Kai and Chan, 2002) but it is become a restriction for OFC if a farmer wants to use the same field without any alteration to hardpan. Hence, determination of depth and thickness of hardpan is very important before introducing OFC to paddy fields. Therefore objectives of this study were to assess spatio-temporal variability of soil physical and chemical properties and HPD in paddy fields under the *Baywa* MIT system.

METHODOLOGY

Soil sampling and laboratory analysis

This study was carried out during two major cultivation seasons, to identify suitability of the command area for OFC cultivation. Soil samples were collected from the *Bayawa* command area at the beginning of *Maha* (30/09/2014) and *Yala* seasons (10/03/2015) from 24 locations (Fig. 2). The sampling locations were selected as to represent three different sections [Head-H, Middle-M and Tail-T]. Soil samples were collected at two depths [top (0 cm) and subsurface (30 cm)] using a Gouge auger and sub composite soil samples were obtained around geo-referenced points. Geographical coordinates of all sampling locations were recorded using a Global Positioning System (GPS). MC, BD, and Field capacity (FC) were analyzed using fresh soil samples and rest of samples were air dried, crushed and passed through a 2 mm sieve prior to analysis. Soil properties measured were; texture (only in *Maha* season), saturated hydraulic conductivity (K_s), organic matter (OM), pH, PO^{3-}_4, electrical conductivity (EC) and NO_3^-. To assess the HPD, , BD determination method (Mulqueen *et al*., 1977) was used and core samples were collected separately from the same locations at 0, 15, 25, 30, 45 and 60 cm depths at the beginning of *Yala* season.

Gravimetric MC was estimated by the oven dry method and BD was measured using undisturbed core samples. Gravimetric direct method was used to estimate FC (Walker, 1989) and K_s was estimated using constant head permeameter apparatus. Soil texture was determined by the hydrometer method and dichromate oxidation method was used to measure soil OM content (Walkley and Black, 1934). Soil pH was measured using a glass electrode pH meter (module no Orion 2 Star pH Benchtop) in distilled water using a soil to water ratio of 1:2.5. An EC meter (module no 145) was used to measure the EC of 1:5 soil water suspensions. NO_3^- was measured using *Kjeldahl* method (Robin *et al*., 1925) and available phosphorous was determined by the Olsen method (Kuo, 1996).

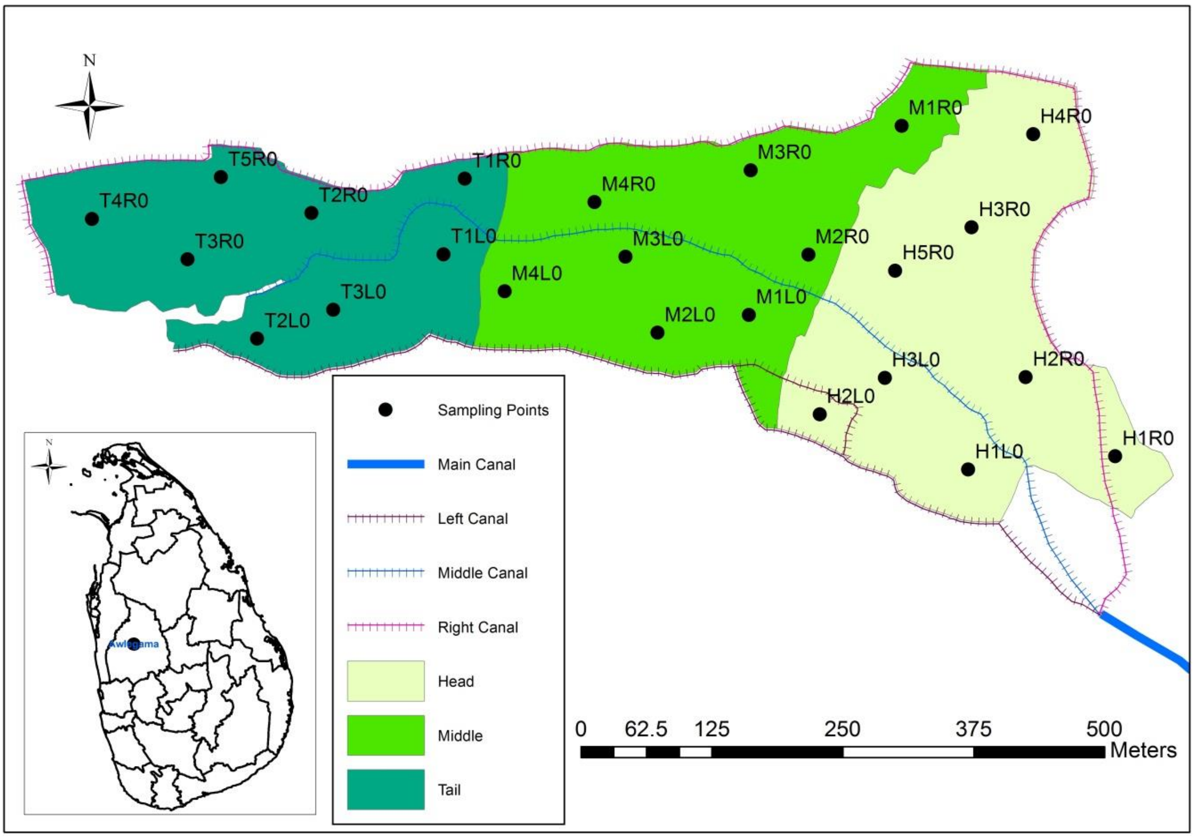

Figure 2: Soil sampling locations in head, middle and tail sections of the command area

Statistical analysis and soil mapping

Exploratory data analysis was performed to calculate mean, standard deviation (SD), Skewness (SC), Kurtosis (KC) and coefficient of variation (CV). Two sample t-tests were performed to analyze variability of soil properties at top and subsurface soils in *Yala* and *Maha* seasons as well as three sections within the command area. Arc GIS 10.2 version was used to map the spatial variability of soil properties, during two cultivation seasons. Due to limited number of sampling locations, inverse distance weightage (IDW) interpolation technique was used to map those selected soil properties.

RESULTS AND DISCUSSION

Spatio-temporal variation of soil properties

Spatio-temporal variability of selected soil properties are shown in Figures 3 to 8. Residual MC at beginning of the season is one of the critical factors to decide the type of crops going to cultivate. The top soil layer has higher MC than the sub soil layer and this is relatively higher in the tail section in both seasons (Fig. 3) as expected. Because tail section is always at lower elevation where all the runoff water accumulates and groundwater table is closer to the surface. Due to this high MC at the begging of the season, farmers always tend to cultivate paddy, but not OFC. Measured K_s ranged from 0.03 m/day (*Yala* 30 cm) to 7.88 m/day (*Yala* 0 cm) (Fig. 4). Top soil shows a relatively higher spatial variation of K_s in both *Yala* and *Maha* seasons. Also in sub soil layers, very poor K_s was observed, compared to top soil. Comparatively higher K_s and higher variability of K_s is obvious in frequently disturbing top soil layer compared to the compacted bottom layer. When comparing K_s values in three sections, the tail section shows very poor drainage conditions in each layer during both seasons. Because, generally these areas are clay rich poorly drained soils common under most MITs. Overall, the left part of the head section shows good drainage conditions with respect to K_s and MC values provide a good potential for OFC.

Spatio-temporal variability of soil pH is complex in both seasons. The head section shows a slightly acidic condition in both top and sub soli layers (Fig. 5), while the tail section shows neutral or basic conditions. OM content varies from 0.31% to 5.62% and the distribution is positively skewed due to high values observed in the tail section (Fig. 6, Tables 2 and 3). OM is one of the key parameters determining the quality of a soil, which is important for nutrient mineralization, soil structural improvements, and favorable soil water relations (Gupta and Jaggi, 1979). Since OM content governs other soil physical, chemical and biological properties, it is known to be a vital quality parameter to sustain paddy ecosystems. However, according to our assessment, the most parts of the command area have 1-2% OM content indicating depletion of OM. Panabokke (1996) reported that low OM content in MITs system might be due to intensive cultivation of paddy continuously (monoculture) without or less addition of OM to soils. Therefore, crop diversification is one of the key agronomic practices to increase OM in top and subsurface soils, which will help to maintain better soil conditions for improving the productivity.

Spatio-temporal variation of NO_3^- is almost similar in two soil layers during both seasons. Tail section shows a slightly higher NO_3^- content than the head section. This variation could be due to high percentage of clay (>50 %) and very low K_s at the tail section compared to high sandy and high K_s conditions at the head section (Fig. 7). PO_4^{3-} in the top and sub soil shown same spatio-temporal variation as NO_3^- among all sections. However, lower part of the middle and the whole tail sections show higher PO_4^{3-} content with comparison to the head section (Fig. 8). Because of the drainage canal located at middle of the command area open to the tail section allowing all sediments come with drainage water to be deposited in the tail section.

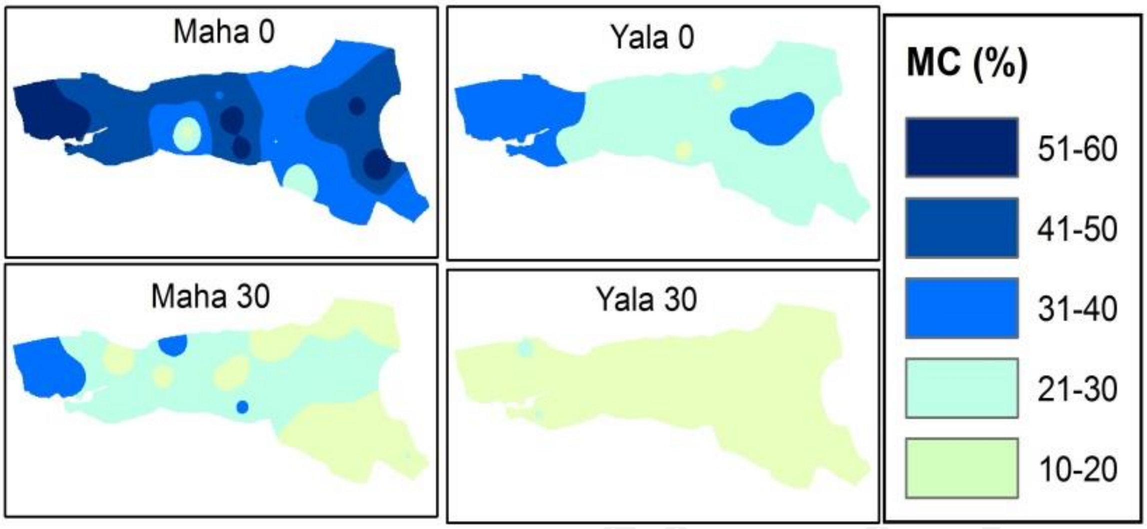

Figure 3: MC (%) variation in top and sub soil layers

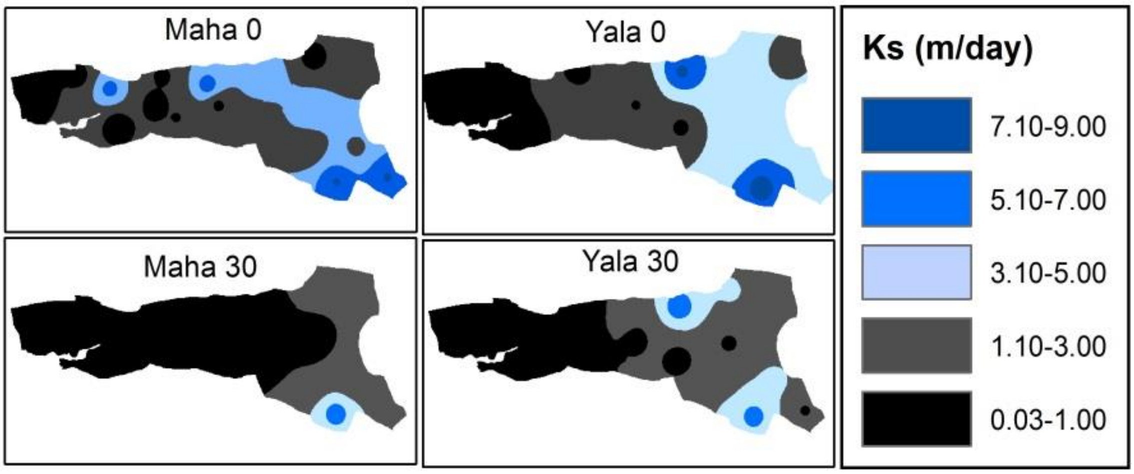

Figure 4: K_s (m/day) variation in top and sub soil

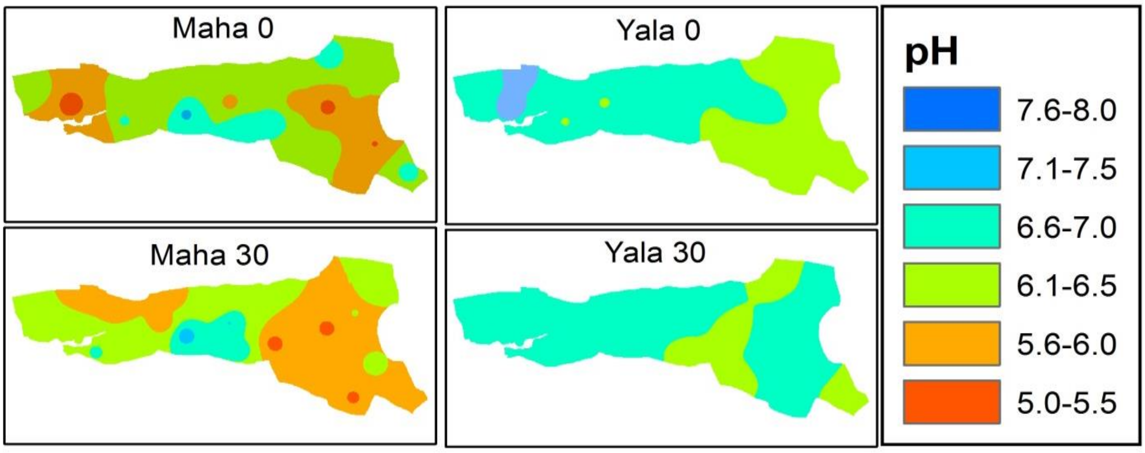

Figure 5: pH variation in top and sub soil layers

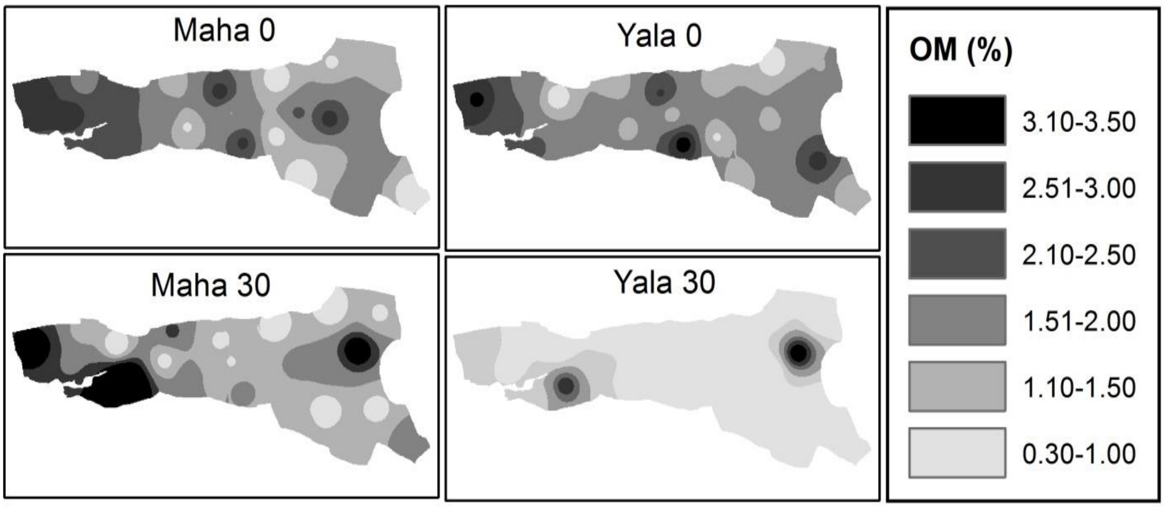

Figure 6: OM (%) variation in top and sub soil layers

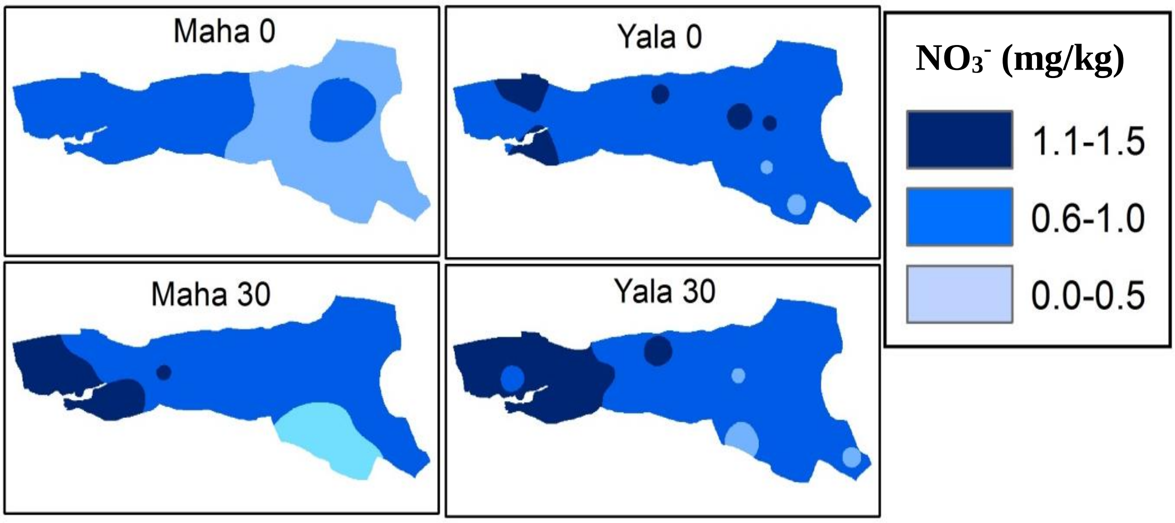

Figure 7: NO_3^- (mg/kg) variation in top and sub soil layers

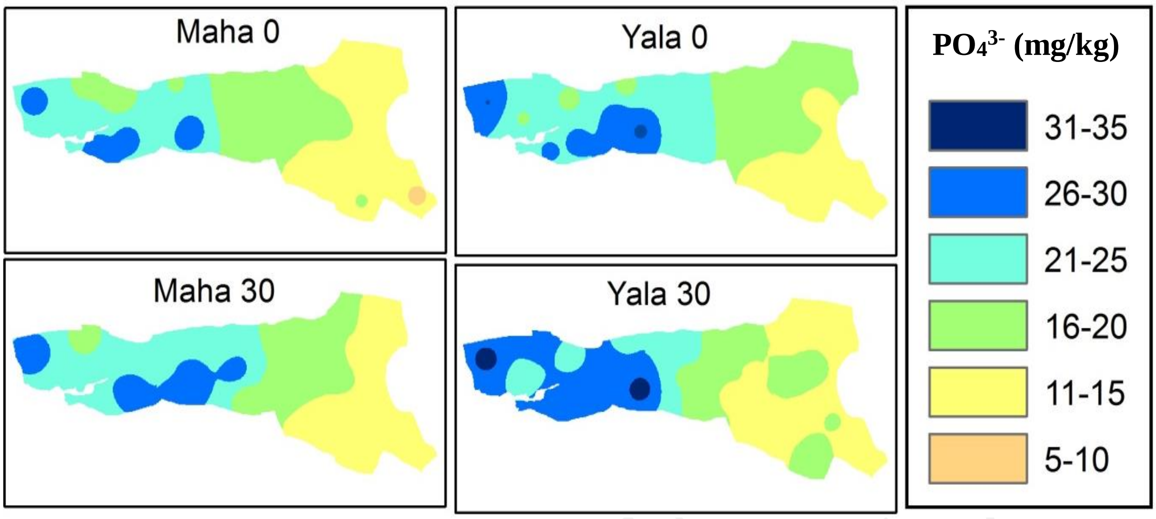

Figure 8: PO_4^{3-} (mg/kg) variation in top and sub soil layers

Descriptive statistics

Tables 2 and 3 show, CV, which is the ratio between the standard deviation and the mean expressed as a percentage, is a useful measure of overall variability. In this analysis, CV ranged from 3.83% (pH, *Yala*, 30 cm) to 120.9% (K_s, *Maha*, 30 cm) for all the tested soil properties. According to a classification at Table 1, pH and BD (*Yala*) show low variability and Ks shows higher variability. All other properties tested, show moderate variability.

Table 1: Relationship between CV and degree of variability (Hillel, 1980)

CV (%)	Degree of variability
<10	Low
11-100	Moderate
>101	High

Clay soils are considered more fertile, but are difficult to work in comparison to easy to work and less fertile sandy soils. Based on the soil classification using textural triangle, the study area has sandy loam, clay loam and clay soils. Clay contents in the top and sub soils range in between 24.5 to 51.4%, showing high water retention capacity as well as poor drainage conditions in most areas of the command area. This high water retention ability is also confirmed by estimated FC values ranged from 21.1 to 47.23%.

When the K_s higher than 1 m/day, such soils do not show any drainage problems and then a drainage system is not required (Klute and Dirkson, 1986). On the other hand, when the K_s is less than 0.1 m/ day, drainage system is needed to remove excess water for better crop growth (Klute and Dirkson, 1986). According to results obtained in this study, more than 40% of K_s values are less than 1 m/day and leads to poor drainage conditions. This situation especially exists in tail and lower part of middle sections. These results reveal that a better drainage system is necessary to cultivate OFC in middle and tail sections.

The most productive and the highest nutrient available soils are found with soil pH from 6.0 to 7.5 (Rowell, 1994). In the *Bayawa* MIT system, both top and sub soils can be considered as highly productive soils. The pH of the soil helps to increase availability of macro and micro nutrients to support better crop growth. Salts are added through irrigation water and inorganic fertilizer, and salts accumulation is relatively high in poorly drained areas in particular. Salinity damage to crops especially during dry weather conditions and lead to loss of crop yields. However, according to our measurements and classification by Rowell (1994), the study area has very low salinity levels, which is good for crop growth.

The study area has very low OM content, except tail end at 30 cm depth. Based on the field survey results, it was revealed that farmers had not applied rice straw to their fields as recommended by the Department of Agriculture. This might be a reason for low OM content in soil. Nitrogen is the most diverse and variable nutrient and these are similar to most of other cropping systems (Table 2 and 3). Soil N content can be changed according to climate factors, topographic factors, and soil types and properties (Marx *et al*., 1999). According to NO_3^- classification by Marx *et al*. (1999), *Bayawa* soil has very low NO_3^- concentration. Soil analysis was done at the beginning of *Yala* and *Maha* seasons where monoculture (paddy) was very prominent. This might be the reason for very low soil N amount found from the soil analysis during the study period.

According to Table 4, the spatio-temporal variability of most soil properties significantly varies between head and tail sections. K_s, pH, NO_3^--N and PO^{3-}_4 show significant variations in all sections than other properties. Soil clay content significantly varies in both soil layers in each section. Overall, the spatial variability is dominant among three different sections, but the temporal variability can be neglected since a similar variability was observed in both seasons. So that OFC should be cultivated by considering the spatial variability of the most important physical and chemical properties within the command area.

Table 2: Summary of classical statistical analysis for soil properties in *Maha* seasons

Parameter	Mean		SD		CV (%)		SC		KC	
	0	30 cm	0	30 cm	0	30 cm	0	30 cm	0	30 cm
MC (%)	41.6	22.7	11.7	8.3	28.2	36.5	-0.2	0.3	-0.6	-0.8
BD (g/cm^3)	1.3	1.5	0.2	0.2	15.2	10.1	-0.3	-0.6	-0.4	-0.5
Porosity (%)	52	42.4	7.3	5.8	14	13.8	0.3	0.6	-0.4	-0.5
Sand %	28.5	28.4	9	10.9	31.7	38.6	0.4	0.7	-1.2	-0.4
Clay %	39.9	43	7	6.9	17.6	16.2	-0.7	-1.4	-0.5	2.1
Silt %	31.7	28.5	6.2	7.4	19.6	26	-1.3	-0.5	3.5	-0.2
K_s (m/day)	2.7	1	2.6	1.2	97.7	120.9	0.8	3.2	-0.8	11.9
FC (%)	34.8	36.2	6.1	6.1	17.4	16.7	-0.9	-0.5	0.6	0
pH	6.2	6.5	0.5	0.5	8.0	7.2	0	1	-0.3	0.7
EC (dS/m)	1.3	1.1	0.5	0.6	37.6	56.9	1	2	0.5	4.7
OM (%)	1.7	1.6	0.8	1.2	43.6	71.1	-0.1	2	-1.3	5.4
NO_3^- (mg/kg)	0.6	0.8	0.2	0.3	38.8	43	0.3	-0.1	-0.7	-0.2
PO_4^{3-} (mg/kg)	18	19	5.5	5.9	30.7	31.2	0.4	0.3	-0.7	-0.8

Table 3: Summary of classical statistical analysis for soil properties in *Yala season*

Parameter	Mean		SD		CV (%)		SC		KC	
	0	30 cm	0	30 cm	0	30 cm	0	30 cm	0	30 cm
MC (%)	28.1	15.8	6.42	2.7	22.9	17.2	0.17	0.0	-0.94	-1.2
Porosity (%)	47.1	36.9	4.8	3.6	10.1	9.7	0.2	-0.1	-0.9	-0.6
Sand %	-	-	-	-	-	-	-	-	-	-
Clay %	-	-	-	-	-	-	-	-	-	-
Silt %	-	-	-	-	-	-	-	-	-	-
K_s (m/s)	2.7	1.7	2.4	1.8	91.4	106.8	0.7	1.4	-0.6	1.2
FC (%)	-	-	-	-	-	-	-	-	-	-
pH	6.6	6.7	0.3	0.3	4.3	3.8	0.7	-0.7	0.3	-0.4
EC (dS/m)	1.7	0.7	0.5	0.3	32.1	43.3	0.7	-0.7	0.1	1.2
OM (%)	1.7	0.8	0.7	0.8	39.7	96.7	0.7	2.5	0.1	6.3
NO_3^- (mg/kg)	0.9	0.9	0.2	0.3	22.7	31.1	-0.5	-0.5	-0.1	-0.6
PO_4^{3-} (mg/kg)	19.7	19.9	5.5	6.7	27.7	33.6	0.5	0.4	-0.5	-1.2

Table 4: Comparison of soil properties in each section during *Maha* and *Yala* seasons using calculated t values

Properties	***Maha* 0**			*Maha* 30			***Yala* 0**			*Yala* 30		
Section	H vs M	H vs T	M vs T	H vs M	H vs T	M vs T	H vs M	H vs T	M vs T	H vs M	H vs T	M vs T
MC (%)	(-)	*	**	(-)	**	(-)	(-)	**	***	*	***	***
BD (g/cm^3)	(-)	(-)	(-)	(-)	**	*	(-)	*	**	(-)	(-)	***
Porosity (%)	(-)	(-)	(-)	(-)	**	*	(-)	*	**	(-)	(-)	***
Sand (%)	*	**	(-)	*	***	(-)	-	-	-	-	-	-
Clay(%)	***	***	**	*	**	*	-	-	-	-	-	-
Silt (%)	(-)	(-)	(-)	(-)	(-)	(-)	-	-	-	-	-	-
K_s (m/day)	**	***	(-)	*	**	***	(-)	**	**	(-)	***	***
FC (%)	***	***	(-)	**	***	**	-	-	-	-	-	-
pH	**	(-)	**	**	(-)	(-)	**	***	**	(-)	***	***
EC (dS/m)	(-)	(-)	(-)	**	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
OM (%)	(-)	**	*	(-)	(-)	*	(-)	(-)	(-)	(-)	(-)	**
NO_3^- (mg/kg)	(-)	***	***	(-)	***	***	**	**	*	(-)	***	***
PO_4^{3-} (mg/kg)	***	***	**	***	***	(-)	***	***	(-)	**	***	***

***, ** and * are significant at 1%, 5% and 10% probability levels, respectively; (-) no any significant difference; - no data.

HPD in the command area

High BD means, high soil compaction resulting low soil porosity. The root penetration is restricted if BD is higher than 1.75 g/cm^3 (Blake and Hartge, 1986). The BD range from 0.9 (*Maha*) to 1.84 g/cm^3 (*Yala*) at 0-30 cm depth range. More than 85% of sampling locations have less than 1.75 g/cm^3 of BD. These BD values help for better root penetration and increased soil porosity provides favorable conditions for OFC growth.

As shown in Figure 9, the BD values larger than 1.75 g/cm^3 are found in between 25– 40 cm in head-left (HL) region. In contrast, hardpan is not found in head-right (HR) regions since BD values are low. Figure 10 illustrates BD variation in both middle-left (ML) and middle-right (MR) sections than the head section. Compacted two soil layers can be observed in the soil profile. As shown in Figure 11, both tail-left and tail-right regions have BD values higher than 1.75 g/cm^3 at 30 – 35 cm soil depth. These results reveal that hardpan is developed just below the effective root zone in the tail section. Overall, subsurface soil layer indicates downward movement of water restricted by a compacted layer observed at about 25 - 40 cm depth. This compacted and low permeability layer could have been developed due to; (i) high clay contents and blocking of micro pores with downward movement of clay particles, (ii) compaction due to use of heavy machinery, and (iii) continuous cultivation of a mono crop (paddy). Therefore, presence of hardpan and poor drainage conditions in the tail end and part of the head section, except the middle section, cannot be recommended for OFC cultivation. Breaking of the hardpan by deep plowing is essential before OFC cultivation in these sections. However, the main issues is that if farmers want to cultivate paddy again in the following season, redevelopment of hardpan is essential.

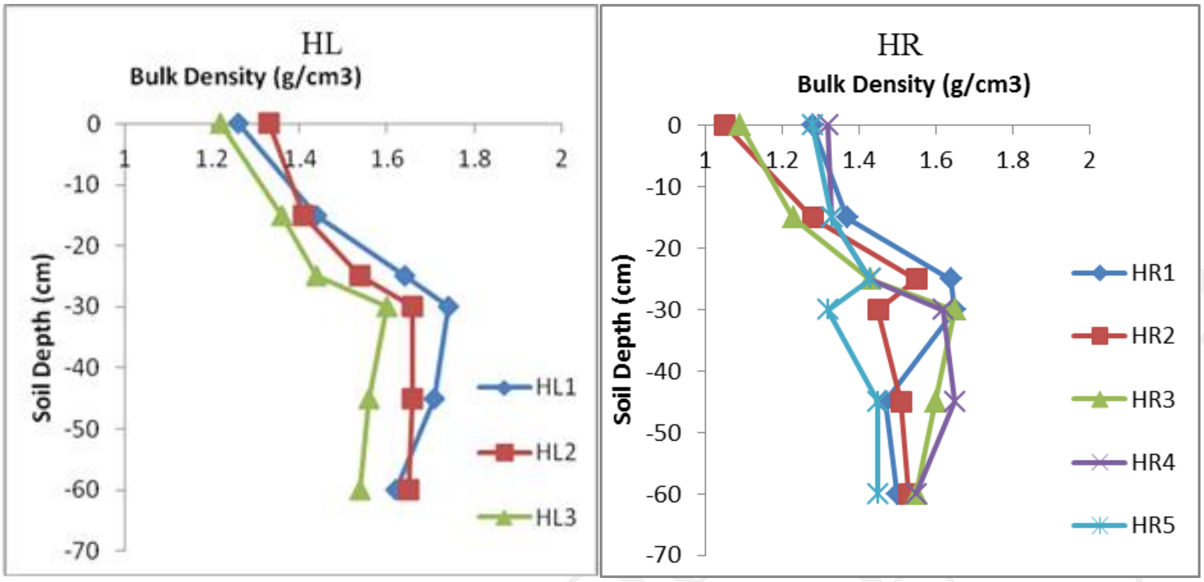

Figure 9: Bulk density variation in head section (HL=head-left and HR=head-right)

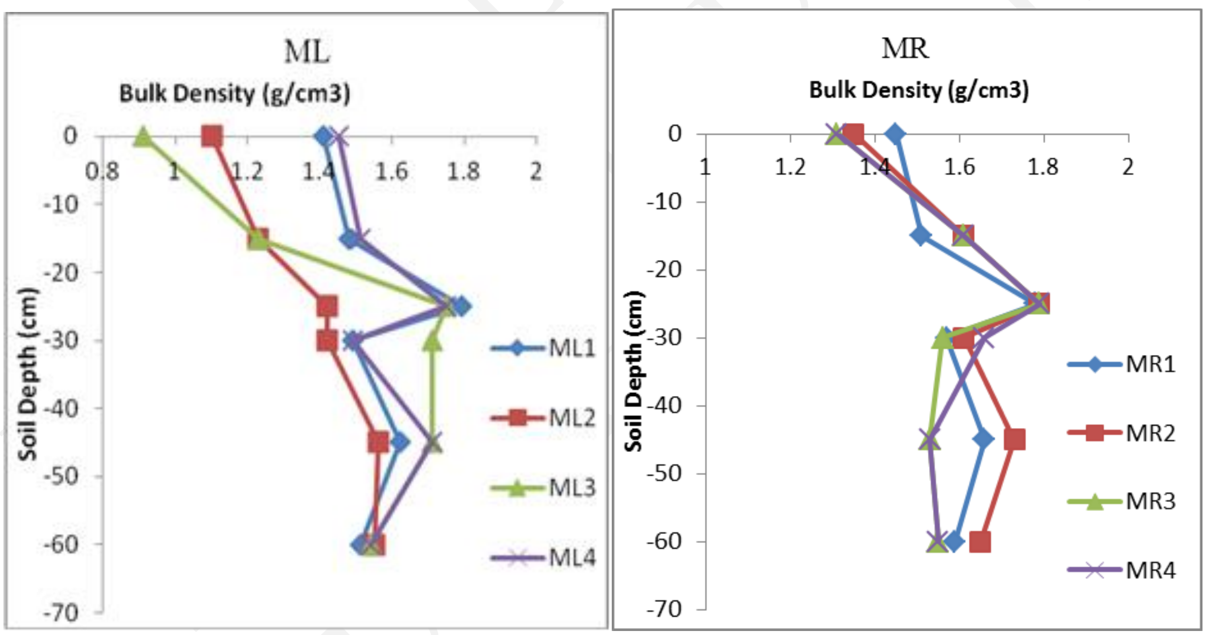

Figure 10: Bulk density variation in the middle section (ML=middle-left and MR=middle-right)

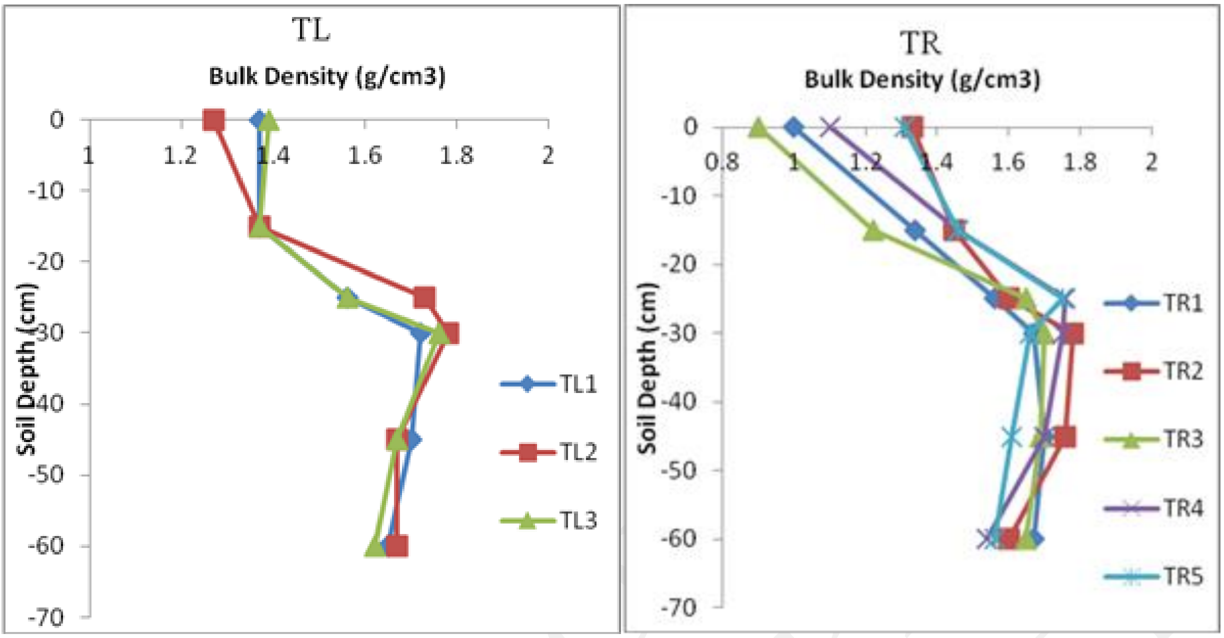

Figure 11: Bulk density variation in tail section (TL=tail-left and TR=tail-right)

CONCLUSION

Low salinity level and the almost neutral pH in the command area shows potentials for OFC cultivation by increasing availability of macro and micro nutrients. Comparatively low clay content (<30%) and higher K_s (3 m/day) values in left part of the head section create potential for OFC. Larger part of the command area has 1-2% OM content indicating depleted conditions, which negatively affects to introduce OFC. Clay content and FC in top and sub soils layers ranged between 24.5% to 51.4% and 21.1 to 47.2%, representatively show high water retention capacity and poor drainage conditions in middle and tail ends of the command area. On the other hand, 40% of the K_s values were less than 1 m/day and confirmed poor drainage conditions in the command area. In addition, hardpan formations in middle and tail end areas were identified within the effective root zone (0 – 30 cm) as the biggest constrains for introducing OFC. In overall, low K_s, high clay content, high FC and the presence of hardpan in the effective root zone are major obstacles to introduce OFC to the command area of the *Bayawa* MIT.

Introduction of site specific OFC based on the spatial variability of soil properties is therefore very important for sustainability of the system. The issue of removing the hardpan for OFC and reformation for paddy cultivation remains unresolved for successful seasonal as well as inter-sessional cultivation.

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