RESEARCH ARTICLE

Comparison of soil fertility status of irrigated and rain-fed lowland paddy farming systems in *Ibbagamuwa* divisional secretariat division, Sri Lanka

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ABSTRACT

Paddy farming under irrigated and rain-fed systems are commonly practiced in Ibbagamuwa Divisional Secretariat Division (DSD) in Low Country Intermediate Zone (LCIZ) of Sri Lanka. The mean yields of irrigated (3.5 t ha^{-1}) and rain-fed system (3.0 t ha^{-1}) are significantly (P<0.05) low compared to other parts of the LCIZ. It is a known fact that, soil factors are highly influential on crop yield. This study was conducted to evaluate some chemical and physical characteristics of soil in irrigated and rain-fed paddy farming systems in Ibbagamuwa DSD and map their variation. Soil samples were collected from two paddy fields (irrigated and rain-fed) separately and analysed for soil pH, electrical conductivity (EC), available P, exchangeable K, available Zn and bulk density. Thematic maps were prepared for different soil parameters using Geographical Information System (GIS) technique. Mapping of available soil N was not considered in this study because soil N level decreases continuously even within short time period. Soil analyses indicate that, available P, exchangeable K and Zn were lower than the respective critical values in both fields. EC levels in both fields were less than 0.12 dS m^{-1} indicating better condition for rice cultivation. No significant difference (P>0.05) was observed between irrigated and rain-fed fields with respect to soil pH and organic matter (OM) content. Soil pH of 70% of irrigated fields and entire rain-fed fields was less than 5.5. All most all the fields showed soil organic matter content less than 3%. Soils of rain-fed fields were more compacted and showed higher bulk density values (P< 0.05) than that of the irrigated fields. In irrigated fields, soil texture at 0 – 60 cm depth varied from sand to loamy sand whereas in rain-fed fields the same was mainly loamy sand, sandy loam and sandy clay loam. Result suggested that soil fertility of entire irrigated and rain-fed fields is generally poor and need to adopt remedial measures. Site specific nutrient management and organic matter incorporation may be useful to improve soil fertility status in both fields.

Keywords: *Fertility mapping, rain-fed farming, soil chemical and physical parameters*

INTRODUCTION

Rice is mainly grown under irrigated and rain-fed conditions in Sri Lanka. Irrigated rice farming in Sri Lanka is classified into major, medium and minor schemes on the basis of land extent of the command area. Irrigation schemes which have a command area of more than 1,000 ha are defined as major irrigation schemes whereas the systems between 80 and 1,000 ha are considered to be medium irrigation schemes. Irrigation schemes, that with a command area 80 ha or less, are defined as minor irrigation schemes (Thiruchelvan, 2009). Rain-fed lands are dependent mostly on the rainfall for water supply. Paddy lands under irrigation schemes are mainly distributed within dry and intermediate zones of the country while rain-fed systems are spread all over the country (Henegedara, 2002). The paddy land extent in Sri Lanka under major irrigation, minor irrigation and rain-fed is approximately 561,000, 247,000 and 255,000 ha, respectively (Anon, 2014). In *Yala* season (May to September), the average yield under irrigated and rain-fed paddy farming in *Ibbagamuwa* DSD was 3.5 and 3.0 t ha^{-1}, respectively (Anon, 2015). Rice yields are highly variable among these systems showing that soil fertility has become a critical factor.

Soils are complex mixtures of minerals, organic compounds, and living organisms that interact continuously in response to natural and imposed biological, chemical and physical forces. Soil parameters show a significant spatial variation because soils are formed from different rocks and minerals. Soil, chemical, physical and biological reactions occur continuously and are closely interrelated (Cambardella and Karlen, 1999). Soil parameters support plant, and act as reservoirs for the water and nutrients needed by plants.

Tropical soils are highly weathered soils which contain high concentrations of aluminum and iron oxides (Tisdale *et al.*, 1993). Submerged condition of paddy soils leads to many changes of soil parameters. These severe changes have marked effects on soil physical and chemical conditions and availability of soil nutrients and moisture (Ponnamperuma, 1972). Alternating periods of soil oxidation and reduction resulted due to the change of hydrological conditions lead to large gaseous and leaching losses of nitrogen and the immobilisation of other nutrients, together with changes in soil acidity and concentrations of toxic iron and aluminum (Burford *et al.*, 1989).

Mapping of soil properties is a widely used technique in soil management programmes. Geographical Information System (GIS) is a potential and reliable tool used for retrieval and mapping of natural resources which are often difficult to be manually handled. It facilitates handling of multiple data obtained from different sources (Mandal and Sharma, 2009). Studies on mapping of geo spatial distribution of soil fertility parameters in rice growing soils in Sri Lanka is very limited. Apart from that, mapping of soil fertility parameters provides better understanding of soil fertility status to develop site-specific nutrient management plans. Hence, this study was conducted to map and compare some soil chemical and physical parameters of two fields under irrigated and rain-fed paddy farming in *Ibbagamuwa* DSD in Low Country Intermediate Zone of Sri Lanka.

MATERIAL AND METHODS

Experimental site

A field study was conducted at *Ibbagamuwa* DSD in the Low Country Intermediate Zone (LCIZ) (IL_{1b}) Agro Ecological Region of Sri Lanka. Farmer fields were selected randomly at *Wadupola* for irrigated paddy system and *Udawela* for rain-fed paddy system. Laboratory analysis was conducted at the Soil Science Laboratory, Rice Research and Development Institute, Batalagoda, Ibbagamuwa, Sri Lanka, as given below. Boundaries of irrigated and rain-fed paddy fields were demarcated by using GPS (Global Position System) receiver. One-hectare land from irrigated and one-hectare land from rain-fed to represent both farming systems were selected for soil sampling. Forty soil samples were obtained from both lands to cover approximately 500 m^2 area from one sample.

Soil sampling

Soil samples were randomly collected prior to land preparation in order to avoid any disturbance to the soil profile from each irrigated and rain-fed fields, at 0 – 20, 20 – 40 and 40 – 60 cm depths. Sampling points were marked by using a GPS receiver. Samples were collected in to clean and tagged polythene bags. Undisturbed soil samples were drawn for bulk density determinations at 0 – 20 cm depth. Collected soil samples were air dried at room temperature. Large impurities were removed and samples were crushed by using clean mortar and pestle to break the aggregated structure. Then, soil was passed through 2 mm sieve to remove clods and unwanted debris. Sieved soil samples were stored in air tight polythene bags. Soil samples were analysed for different chemical and physical parameters and methods adopted for analyses is shown in Table 01.

Soil analysis

Soil N, P, K and Zn are the most limiting nutrients in paddy soils in many parts of the country (Bandara, 2005). Since N level in the paddy soil decreases continuously with time due to denitrification and nitrate leaching, there is no point of mapping of soil N level. Hence, soil samples were analysed to determine other 3 limiting nutrients (i.e. P, K and Zn) for the preparation of variability maps. Mean values of tested parameters of irrigated and rain-fed farming systems were compared using pooled T test. Data were interpolated and clipped with the study area. Then, the map was reclassified into few categories (Table 2) which are appropriate to each soil parameters. Arc View 3.2a software was used for the map preparation in GIS.

Table 1: Methods adopted for soil analysis.

Parameter	Method
Soil pH	Potentiometric 1:2.5 soil water suspension (Jackson, 1973)
Soil EC	Soil water suspension 1:2.5 (Bruah and Barthakur, 1997)
Available P	Olsen's method (Olsen and Sommers 1982)
Exchangeable K	Ammonium acetate (Jackson, 1973)
Zinc	DTPA (Lindsay and Norvell, 1978)
Soil organic matter	Walkely and Black (Walkely and Black, 1934)
Bulk density	Core (Keen and Raczkowaski, 1921)
Soil texture	Hydrometer (Bouyoucos, 1967)
Soil moisture content	Oven dry method (Bruah and Barthakur, 1997)

Table 2: Reclassified classes of soil parameters based on values obtained from soil analysis.

Soil parameters	Classes	
	Irrigated	Rain-fed
Soil Bulk density (g cm^{-3})	1.10 – 1.20	1.50 – 1.60
	1.21 – 1.30	1.61 – 1.70
	1.31 – 1.40	
Soil pH	5.0 – 5.5	3.5 – 5.0
	5.6 – 6.0	5.1 – 5.5
	6.1 – 6.5	
Soil EC (dS m^{-1})	<0.125	<0.125
Available P (ppm)	<10	<10
	10 – 24	
Exchangeable K (ppm)	<78	<78
		<78 – 156
Available Zn (ppm)	<1	<1
Soil OM (%)	1.0 – 2.0	1
	2.1 – 3.0	

RESULTS AND DISCUSSION

Soil chemical characteristics

Soil pH

Soil pH is a basic chemical characteristic of soil which has a direct impact on nutrient availability for plant uptake (Brady and Weil, 2002). Chemical analysis revealed that, soil pH ranged from 5.1 – 6.5 in irrigated fields and 3.9 – 5.4 in rain-fed. The low pH reported in both fields could be attributed to the leaching of base forming cations from the surface soils. Leaching of base forming cations are more prominent in rain-fed fields probably due to poor development of hardpan beneath the root zone depth. Soil pH of 70% of irrigated fields and entire rain-fed fields was less than 5.5 (Figure 1 a & b). It indicates that the soils of both fields were acidic in nature. Wickramasinghe and Wijewardena (2000) also reported that most of the rice growing soils in LCIZ are neutral to slightly acidic in nature. Iron toxicity is a common soil related problem when soil is acidic in nature.

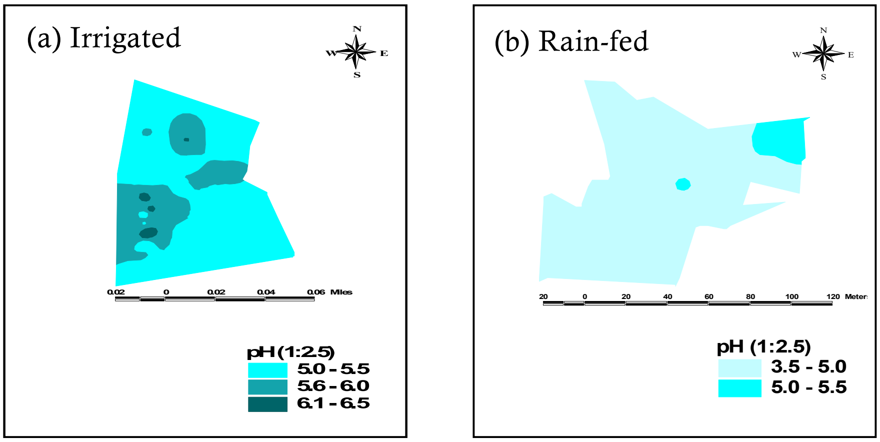

Figure 1: Distribution pattern of soil pH in the (a) irrigated and (b) rain-fed fields.

Apart from that, high availability of Fe in the soil reduces K uptake by plants. In general P, K, Ca and Mg are deficient in acidic soils (Brady and Weil, 2002). Soil analysis clearly indicated that soil available P and exchangeable K levels were well below the critical levels of 10 and 156 ppm, respectively. All these factors could be the possible reasons for the low yield reported in the study area. The favorable pH range for paddy cultivation is 6.5 – 7.5 (Ponnamperuma, 1972).

Soil electrical conductivity (EC)

The pattern of soil EC distribution of the irrigated and rain-fed areas are illustrated in Figures 2 (a & b). Soil EC is the most reliable indicator to measure soluble salt content or the salinity level in the soil. Based on EC values (1:1.5 soil water suspension), soils are classified as non-saline (<1 dS m^{-1}) moderately saline (1 – 2 dS m^{-1}) and potential to develop saline soils (>2 dS m^{-1}) (Dahnke and Whitney, 1988). High salinity level affects adversely on vegetative growth and the yield of the rice crop. Soil EC level observed in both irrigated and rain-fed fields was below 0.125 dS m^{-1} indicating no potential to develop soil salinity. However, increase of soil salinity is a soil related problem in intermediate and dry zone paddy farming. Sirisena (2005) reported that elevated EC in the intermediate and dry zone rice soils leads to significant yield reduction.

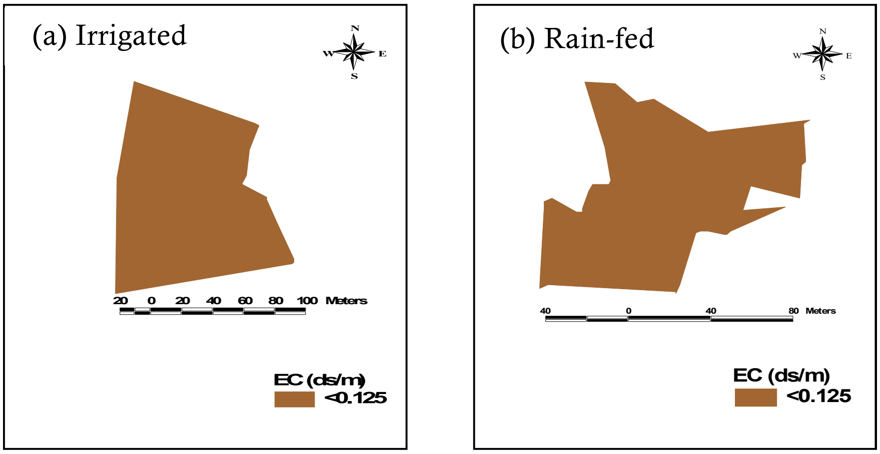

Figure 2: Distribution pattern of soil EC in (a) irrigated and (b) rain-fed fields.

Soil exchangeable potassium

Potassium is one of the essential elements required for plant growth (Sparks, 1987). The critical exchangeable K level for rice is 156 ppm (Bandara, 2005). Exchangeable K distribution in entire irrigated field was less than 78 ppm which is half of the critical level. Except few small locations, whole area of the rain-fed field also reported less than 78 ppm of exchangeable K (Figure 3 a & b). The result revealed that exchangeable K was deficient in both irrigated and rain-fed fields.

A possible reason could be acidic nature of the soil because K availability is low in acidic soils. Sandy nature of the soil texture of both rain-fed and irrigated fields could be another reason (Table 03). Tisdale *et al.* (1993) reported that CEC of coarse textured soil is low and hence K leaching is more prominent compared to fine textured soils. Therefore, sufficient amount of K should be provided at the required stages of the crop. Potassium requirement of the rice increases rapidly 4 weeks after planting and it comes to the peak at the time of panicle initiation (Sirisena *et al.*, 2010).

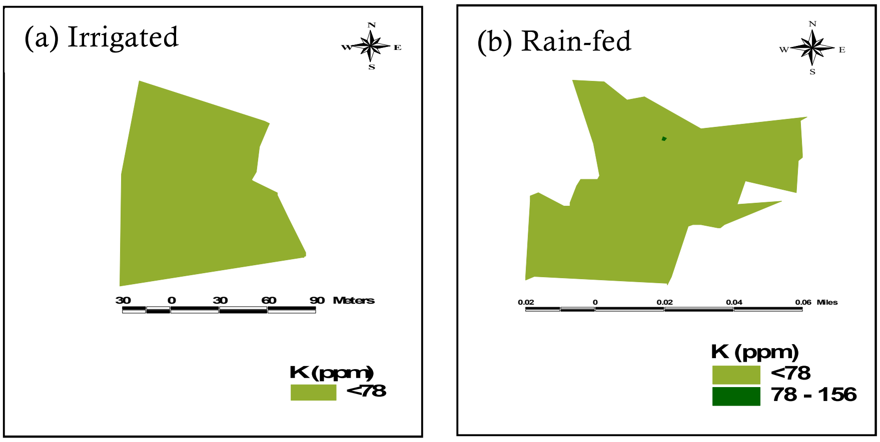

Figure 3: Distribution pattern of exchangeable K in (a) irrigated and (b) rain-fed fields.

Soil available phosphorous

Phosphorus is the second most limiting nutrient after nitrogen especially in tropical soils, and has negative impacts on crop yield if required amount is not available in the soil (Tisdale *et al.*, 1993). The distribution pattern revealed that soil available P in entire rain-fed field was less than 10 ppm. Apart from few locations, all other area of irrigated field also showed soil available P below 10 ppm (Figure 4 a & b). According to soil analysis, available P ranged from 6.4 – 12.2 ppm in irrigated field and 3.3 – 8.7 in rain-fed field. Bandara (2005) reported that critical level of soil available P for rice is 10 ppm. Many parts of the irrigated field and the entire rain-fed field reported less than the critical level of soil P thus there is a potential to occur some P deficiency. This may be probably due to the acidic nature of the soil tested.

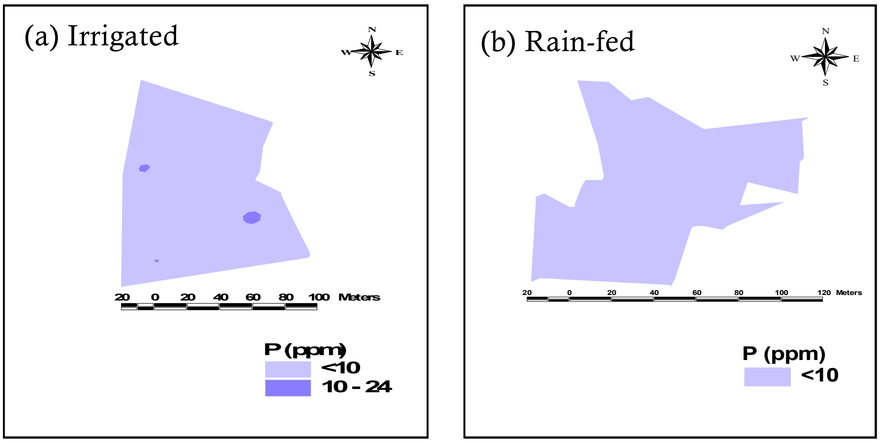

Figure 4: Distribution pattern of soil available P in (a) irrigated and (b) rain-fed fields.

Tisdale *et al.* (1993) reported that P precipitation and adsorption depend on soil pH. P availability is low in both acidic and alkaline soils (Raju, 2003). According to Mapa *et al.* (2005), available P in LCIZ was 7 ppm in surface and 5 ppm in sub surface soils. However, P enrichment in rice growing fields is a prominent issue in many parts of the country because of over application of phosphate fertilizers due to fertilizer subsidy scheme introduced for rice cultivation (Sirisena *et al.*, 2010).

Available zinc in the soil

Zinc is a deficient nutrient in rice growing soils in many parts of Sri Lanka (Sirisena, 2013). The distribution patterns of the Zn in the irrigated and rain-fed fields are shown in Figure 5 a & b. Both fields showed less than 1 ppm of available Zn content in the soil. The critical level of Zn for better growth of rice is 1 – 2 ppm (Bandara, 2005). Since available Zn content is below the critical level, application of $ZnSO_4$ can be recommended to remediate the deficiency.

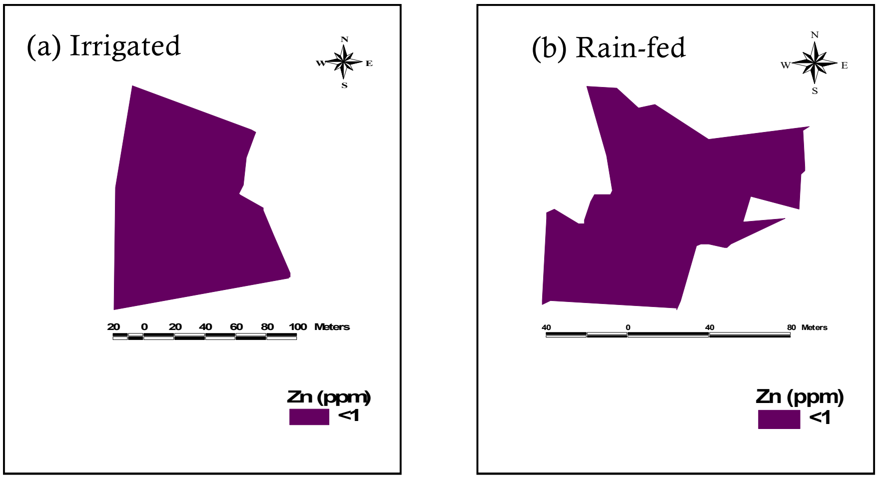

Figure 5: Distribution pattern of soil available Zn in (a) irrigated and (b) rain-fed fields.

Soil organic matter content

Organic matter plays a vital role in improving physical, biological and chemical characteristics of the soil (Hoyle *et al.*, 2011). Therefore, soil organic matter content is considered as an important parameter in rice cultivation. The distribution pattern of the soil OM in the rain-fed and irrigated areas is illustrated in Figure 6 (a & b).

Organic matter content was low (<3%) in both fields and ranged from 1 – 2.6% in the irrigated field and 1 – 1.2% in the rain-fed field. According to Wickramasinghe and Wijewardena (2000), rice growing soils in LCIZ and LCDZ are low in organic carbon. This may be probably due to high temperature in the study area all around the year. High temperature increases the rate of microbial decomposition of OM and reduces the content of soil carbon (Bol *et al.*, 2003). On the other hand, application of organic matter is not a regular practice in rice farming of Sri Lanka.

Moreover, there is a tendency to burn remaining paddy straw in the field before starting land preparation for the next season there by addition of OM is become limited.

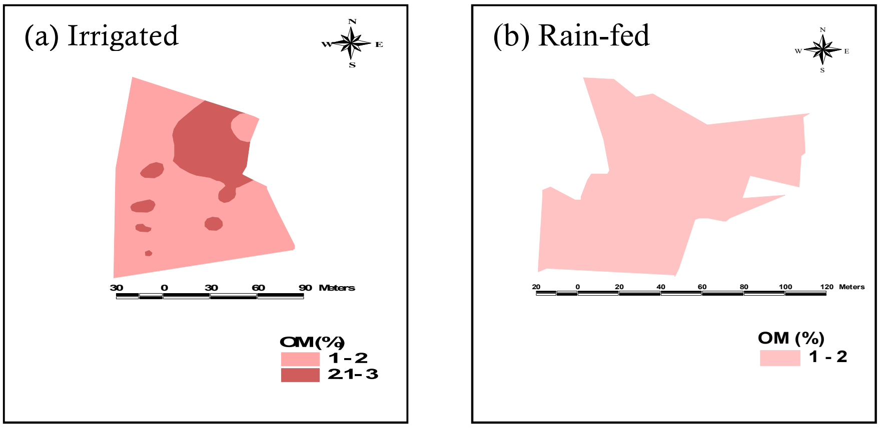

Figure 6: Distribution pattern of soil OM in (a) irrigated and (b) rain-fed fields.

Soil physical characteristics

Soil bulk density (BD)

Soil bulk density is a dynamic physical condition of soil which is influenced by various physical and chemical parameters (Chaudhari *et al.*, 2013). It increases with compaction and decreases with tillage. Soil bulk density ranged from 1.1 to 1.4 g cm^{-3} in irrigated and 1.5 to 1.65 g cm^{-3} in rain-fed fields (Figure 7 a & b). The mean value of the bulk density of rain-fed fields was significantly higher (P<0.05), compared to soil BD of irrigated field. The optimum range of BD for agricultural soil varies from 1.1 to 1.8 g cm^{-3} (Brady and Weil, 2002). Both fields of the present study showed optimum level of bulk density indicating less compaction, which facilitate water and nutrient movement in the soil.

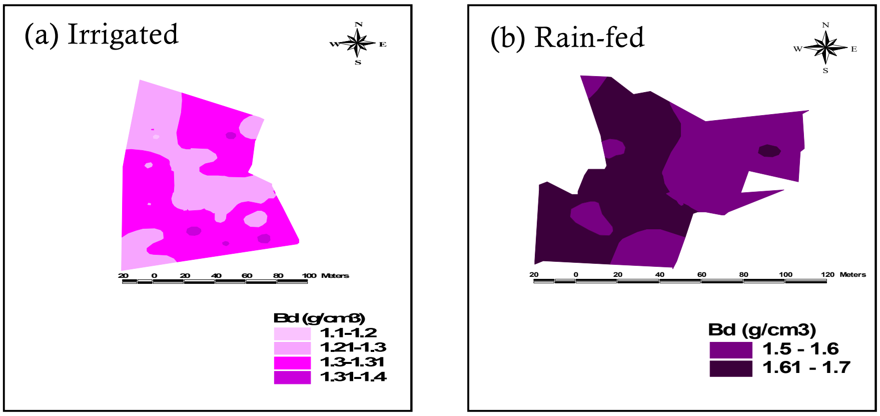

Figure 7: Distribution pattern of soil bulk density in (a) irrigated and (b) rain-fed fields.

Soil texture

Soil texture is a physical property which affects on water holding capacity, drainage, aeration, organic matter decomposition, cation exchange capacity and soil tilth (Berry *et al*., 2007). Soil texture variation of the rain-fed and irrigated fields is shown in Table 3. In irrigated fields, soil texture varied from sand to loamy sand whereas in rain-fed fields soil texture was mainly loamy sand, sandy loam and sandy clay loam. Mapa *et al*. (2005) also reported that texture in LCIZ surface horizon soil is sandy loam and sub-surface horizon is sandy clay loam to clay loam. The sandy nature of the soils in the both fields could be another possible reason for the low availability of plant nutrients. Since sandy soils show low CEC and higher leaching losses the ability to retain nutrient elements is significantly low.

Table 3: Soil texture variation in rain-fed field and irrigated fields.

Field	Depth (cm)	Texture
Irrigated	0 – 20	Sand
	20 – 40	Sand
	40 – 60	Loamy sand
Rain-fed	0 – 20	Loamy sand
	20 – 40	Sandy loam
	40 – 60	Sandy clay loam

CONCLUSIONS

Mapping of soil fertility characteristics can be used to develop soil nutrient management plan for irrigated and rain-fed fields. Since soils in both fields are acidic in nature, iron toxicity could be one of the limiting factors of yield. Hence growing of rice varieties tolerance to iron toxicity would be a better option. Except few small locations, no soil enrichment of P and K could be observed and level of both nutrients are below the critical level. Low EC values reported in both fields indicate less potential to develop soil salinity. Hence application of chemical fertilizer in recommended levels is timely important to enhance the level of nutrients up to critical levels. Soil organic matter content in many parts of the irrigated field and entire rain-fed field is remained in the range 1 – 2%. Sandy nature of soil texture and low organic matter content in both fields enhances cation leaching and reduces nutrient retention. Thus, farmers should be encouraged to incorporate more organic amendments and utilise paddy straw to build up soil carbon pool. The low yield reported in both irrigated and rain-fed fields could be attributed to the deficient level of essential major nutrients and reduced organic matter content in the soil.

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