Research Article

Unveiling and Mapping Physiochemical Parameters of Soil in Newly Developed Land Blocks under Land Consolidation Project at Nachchaduwa Irrigation Scheme, Anuradhapura

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Abstract

The Department of Irrigation in North Central Province of Sri Lanka has implemented a land consolidation project at Nachchaduwa tank irrigation scheme with the objectives of making easy access for farm mechanization, improving water management efficiency and reducing the cost of production in paddy farming. As a parallel activity, a study was carried out to assess soil physiochemical parameters of land blocks to come up with some recommendations to correct nutrient imbalances before handing them over to landowners. Soil samples were collected randomly from 0-30 cm depth from each land block. The locations of sampling points were recorded using a handheld GPS receiver. Collected soil samples were analyzed to determine soil pH, electrical conductivity (EC), soil organic matter (OM), total nitrogen (N), available phosphorus (P), exchangeable potassium (K) soil texture and the bulk density. Most appropriate interpolation technique in ArcGIS were selected based on accuracy assessment and selected technique was employed to map soil parameters. Results revealed that soil pH varied from 6.3 to 10.1 across the land blocks indicating moderately acidic to strongly alkaline. Soil EC values were within the range from 0.02 to 0.27 mSm^{-1} showing no potential for salinity development. The soil OM content was very low and it varied from 0.2% to 0.8%. Total N content was in the range of 0.007% to 0.089%. The available P and exchangeable K contents were within the range of 2.2 to 45.6 mg kg^{-1} and 32 – 166 mgkg^{-1} respectively. The soil texture showed spatial variation from loamy sand to sandy loam. The bulk density varied from 1.5 – 1.8 gcm^{-3} indicating somewhat compacted nature of the topsoil. The results revealed the necessity of enriching soil nutrient levels especially soil N level and organic matter content by supplementary sources. The prepared *spatial variability maps can be used as base material to develop site specific nutrient management plans for each and every land allotment.*

***Keywords**: Interpolation techniques, Nutrient management, Soil analysis, Soil mapping, Soil sampling*

1. Introduction

Land consolidation is the rearrangement of land parcels with the aim of landowners to obtain more productive larger parcels. It is an effective tool to improve farmland infrastructures, soil quality, and sustain a healthy farmland ecosystem to enhance food security and regional sustainable development (Vitikainen, 2004). Land consolidation first appeared in Europe and Germany is considered as the birthplace of modern land consolidation (Backman, 2002). The land consolidation policies were then implemented in Netherlands, Russia, Canada, and in Asian countries such as Japan, China and Korea (Pašakarnis and Maliene, 2010). Land consolidation is an effective way for solving land fragmentation, a major issue in land use planning that hinders rational agricultural development especially in the rural sector (Demetrioua et al., 2012).

Approximately one-third of the total land extent of Sri Lanka is used for agricultural purposes. However, discrepancies between the existing land use practices and sustainable land use mechanisms have become a major limitation (Samaratunga and Marawila, 2006). The main issues which are observed in agricultural sector in Sri Lanka include small land parcels, land fragmentation, and poor land management practices (Thibbotuwawa and Weerahewa, 2004). The extent of lands available for crop production is becoming more and more fragmented, hence less productive in terms of agricultural development. In this context, the importance of land consolidation is being recognized as a feasible approach which stimulates the development of the agricultural sector.

When implementing land consolidation projects, it changes physical and chemical properties of soil through a series of land operations that in turn affect the soil fertility. Land levelling affects the changes of soil bulk density, soil structure, organic matter content in the soil through topsoil stripping and backfilling. It also affects infiltration, irrigation and drainage and surface runoff as well.

The land consolidation project implemented by the Department of Irrigation at *Nachchaduwa* scheme consists of 26 ha belonging to 44 land owners which are fed with irrigation water from the *Nachchaduwa* reservoir. The main objective of the project was to increase the productivity of land, water and labour by way of increasing water use efficiency, increasing the cultivable land extent, making easy access for farm machinery and reducing the cost of production (Illangasinghe, 2022). However, restructuring of existing farmlands may affect soil fertility status in both positive and negative manner because of the drastic changes that occur in the soils during the process of deep ploughing, topsoil stripping and backfilling. This may create an impact on soil bulk density, organic matter and available nutrients resulting in some surface nutrient loss or mixed uneven. These are all not conducive to the cultivation of the soil. Hence, mapping of soil fertility parameters of land blocks after finishing all soil works is vital to estimate soil fertility levels before handing them over to farmers. This information can be illustrated by mapping of spatial variability of soil parameters. Therefore, preparing soil fertility maps will provide a better picture of the project area to make recommendations to enhance the soil fertility of land blocks. Hence, this study was carried out to assess soil physio-chemical parameters of land blocks in *Nachchaduwa* land consolidation project to prepare maps to show spatial variability of soil parameters which would be a base material to build up soil fertility of newly developed land blocks.

2. Materials and Methods

2.1. Location

The study site is located in the command area of *Nachchaduwa* reservoir and it is surrounded by two streams namely *Malwathu Oya* stream and *Pita ela* stream in Sri Lanka (8.3114° N, 80.4037° E). The soil type is imperfectly drained Reddish Brown Earth (Typic Haplustalfs) and the main land use is paddy farming (Mapa et al. 2010). The mean annual rainfall and the temperature in the study area is 1450 mm and 31 ^{0}C respectively. The area is mainly fed by *Nachchduwa* irrigation scheme and both *Yala* and *Maha* seasons are cultivated with paddy.

2.2. Soil sampling, preparation and analyses

There were 44 newly developed land blocks under the land consolidation project. Seventy-five soil samples were collected randomly from land blocks to represent the entire location. At least one composite sample combining five sub samples was drawn from each block. However, more t composite samples were drawn from land blocks where soil is highly heterogeneous. Sampling was done using Edelman soil auger at 0 – 30 cm depth. For bulk density measurements, soil core samples were drawn separately. All sampling points were recorded using a GPS receiver.

Collected soil samples were air dried at room temperature and larger plant debris and gravels were removed. Larger soil clods were crushed using a hammer, mortar and pestle prior to passes through 2 mm sieve. Prepared samples were filled into polythene bags and kept for analyses.

The soil reaction was measured by glass electrode/pH meter system using 1: 2.5 soil water suspension (Rowell, 1994). An electronic digital conductivity meter was used to determine soil EC (Chapman and Pratt, 1961). Total N content was determined using the Kjeldahl procedure (Bremner and Mulvaney, 1982). Soil P and exchangeable K contents were measured after extracting with Mehlich III extraction (Mehlich, 1984). Walkley and Black method was employed to determine soil OM percentage (Walkley and Black, 1934). The soil texture was measured using the pipette method (Gee and Bauder, 1986) and soil bulk density was determined by the core sampling method. Soil colour was determined using Munsell colour chart. Each measurement was made in triplicate.

2.3. Mapping of spatial variability of soil parameters

Spatial variability of soil parameters was mapped using ArcGIS software. Since the cross-validation is the appropriate process to assesses and contrasts the effectiveness of various interpolation approaches (Stiglitz *et al*., 2016), the same was applied and select Inverse distance weighted (IDW) and Kriging methods to create maps. The mean error (ME) Eq. 01, the root mean square error (RMSE) Eq. 02, and the mean absolute error (MAE) Eq. 03 were used to evaluate the accuracy of the interpolation methods (Table 01). Based on the accuracy assessment, the IDW method was used to interpolate the soil pH, EC, total N, available P and exchangeable K. Kriging method was used to interpolate the soil organic matter variability.

$$\mathrm{ME} = \frac{\sum_{i=1}^{n} y_i - x_i}{n}. \qquad \text{Eq 01}$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N} \|y(i) - \hat{y}(i)\|^2}{N}}, \qquad \text{Eq 02}$$

$$\mathrm{MAE} = \frac{\sum_{i=1}^{n} |y_i - x_i|}{n} = \frac{\sum_{i=1}^{n} |e_i|}{n}. \qquad \text{Eq 03}$$

Table 1: Values of root mean square error (RMSE), mean absolute error (MAE) and the mean error (ME) for the relevant soil chemical parameters

Soil Properties	IDW			Kriging		
	RMSE	MAE	ME	RMSE	MAE	ME
pH	0.355747	0.331002	-0.10857	0.4708	0.445	-0.18833
EC	31.94687	31.61231	31.61231	40.62689	32.7	32.7
OM	0.256695	0.210082	0.033048	0.228856	0.1768	-0.00234
Total N	0.01098	0.008337	0.006512	0.015808	0.013259	0.010931
Ava. P	7.748948	5.317555	-2.41811	8.340857	12.60026	-2.52005
Ex. K	20.86247	15.20227	10.26713	25.36049	18.22545	12.5635

3. Results and Discussion

3.1. Soil pH

The spatial variation of soil pH of the study site is shown in Figure 1. It has varied from 6.3 to 10.1 indicating slightly acidic to strongly alkaline nature of the soil. All land blocks other than 03 blocks have shown soil pH above 7.5. Mean pH value of the study area was 7.9. It exhibited a moderately alkaline condition considerably higher than optimum pH for rice. Paddy grows well in soils having a pH range from 5.5 to 6.5. (Yu, 1991). Ponnamperuma (1977) stated that the optimum soil pH for better nutrient uptake by rice from soil solution is 6.6. Alkalinity hinders plant growth by limiting water flow to the roots and preventing root expansion. It also causes shortages of phosphorus and zinc, two essential elements for rice crop (Yu, 1991). Hence, amending soil pH to bring more towards near neutral range is advisable. Application of ammonium sulfate as the N source can be recommended instead of urea to a certain period for adjusting soil pH. Excess irrigation may also be recommended to reduce soil alkalinity by flushing out of base forming sats from the soil.

3.2. Electrical conductivity

The variation of the soil EC of the land blocks is illustrated in Figure 2. Soil EC in the study area was within the range from 27 to 276 μSm^{-1}. Mean EC value of study area was 59 μSm^{-1}. The highest EC value (276 μSm^{-1}) was reported in block no 34 and the lowest value of 27 μSm^{-1} was reported in block no 27. The same land blocks which reported higher pH values have also shown higher EC values as well. However, there is no potential to develop soil salinity in the study area because reported EC levels were far below than the critical level of 02 dSm^{-1} (Corwin, and Yemoto, 2020).

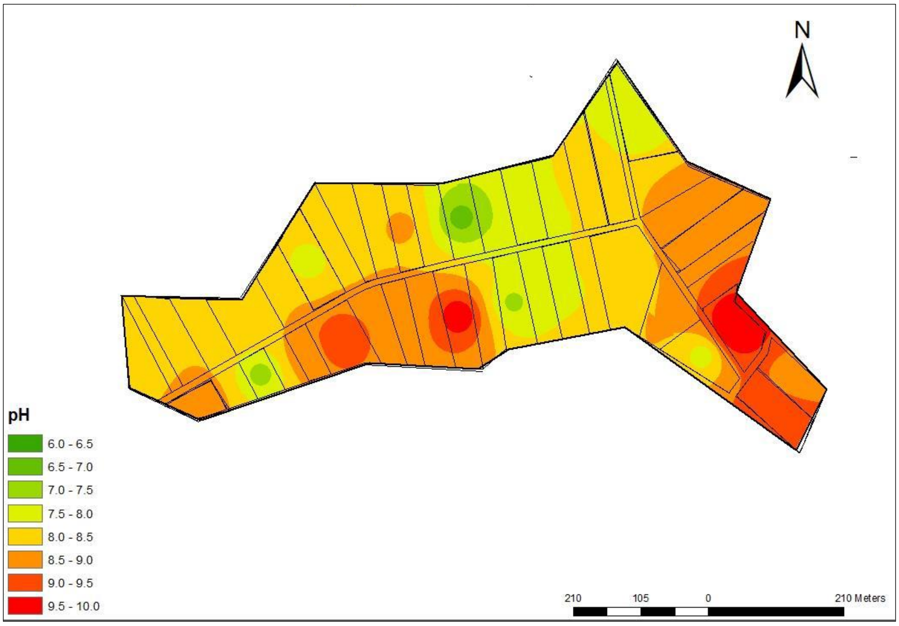

Figure: 1 Spatial variation of soil pH

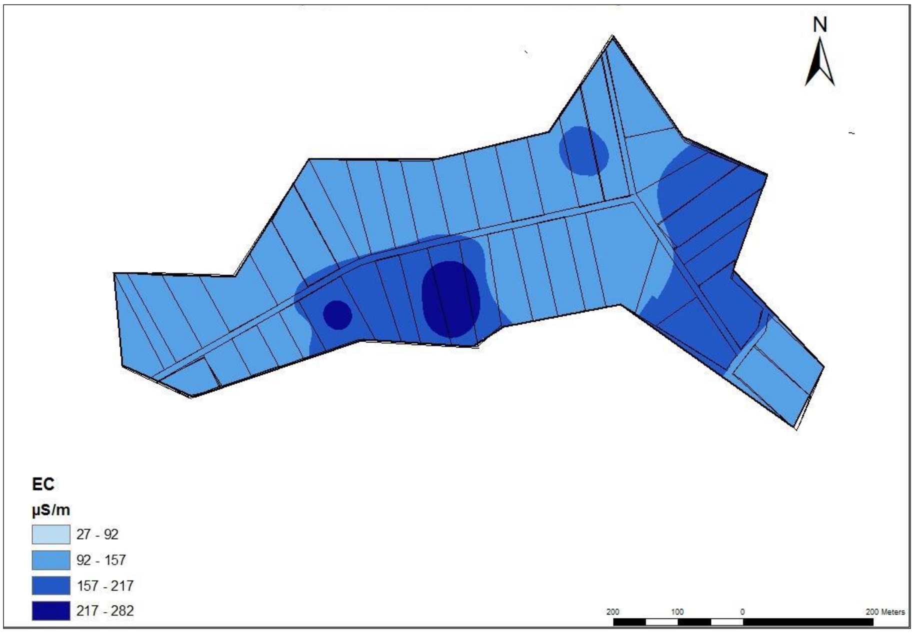

Figure 2: Spatial variation of soil electrical conductivity

2.4. Soil organic matter

Soil OM content of the study area was within the range of 0.02% - 0.82% with the mean value of 0.34% (Figure 3). Both left and right corners of the study area showed slightly higher OM content compared to the land blocks in the middle part. At the initial stage of the earth work, the topsoil of the entire area has been carefully removed and collected to the certain places and then redistributed again all over the field after finishing of consolidation process. However, when taking soil samples from 0-30 cm depth it may include not only top soil but the part of subsoil as well. This may be a possible reason for low soil OM content reported in all most all land blocks.

Apart from that, deep plowing of topsoil and stripping over longer period of time can lower soil OM content due to higher mineralization rate at dry zone where ambient temperature is somewhere around 32°C (Curry and Good 1992). The rates of soil OM decomposition and N mineralization, as well as the distribution of C and N, are all significantly influenced by soil operations. However, to obtain a better yield, at least 2% - 3% soil OM content has to be maintained (Aishah et al., 2010). Increasing soil OM is very much important because it is the most significant indication of soil quality and the fertility (Liu, et al., 2021). Therefore, careful management of the crop residues and introducing a cover crop between two main seasons are advisable to increase soil C intake.

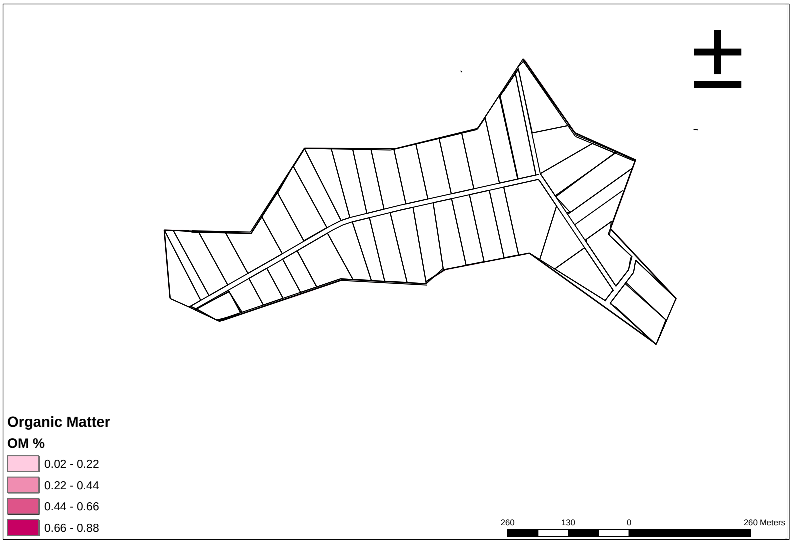

Figure 3: Spatial variation of soil OM

2.5. Total nitrogen

Total nitrogen in the soil is a crucial component for plant growth. It promotes rapid plant growth and improves grain yield and grain quality through higher tillering, leaf area development, grain formation and filling (Bahmaniar and Ranjbar, 2007). The spatial variation of the soil N content is illustrated in Figure 4. It has varied from 0.007 - 0.089%. The mean value of the N content in the study area was 0.031%. Results indicate very low availability of soil N all over the field.

Optimum soil N level for paddy requirement is 0.2% - 0.3% (Aishah et al., 2010). However, total N content in the study area is far below the optimum N content for paddy farming. Hence, it is strongly advisable to add total N dosage recommended by the Department of Agriculture from the beginning of the cultivation. Ammonium sulfate will be a better option instead of urea application as soil is moderately alkaline in many land blocks. Introducing an in-situ green manure legume such as sun hemp is a cost-effective option to increase soil N as well as organic matter content within shorter time period.

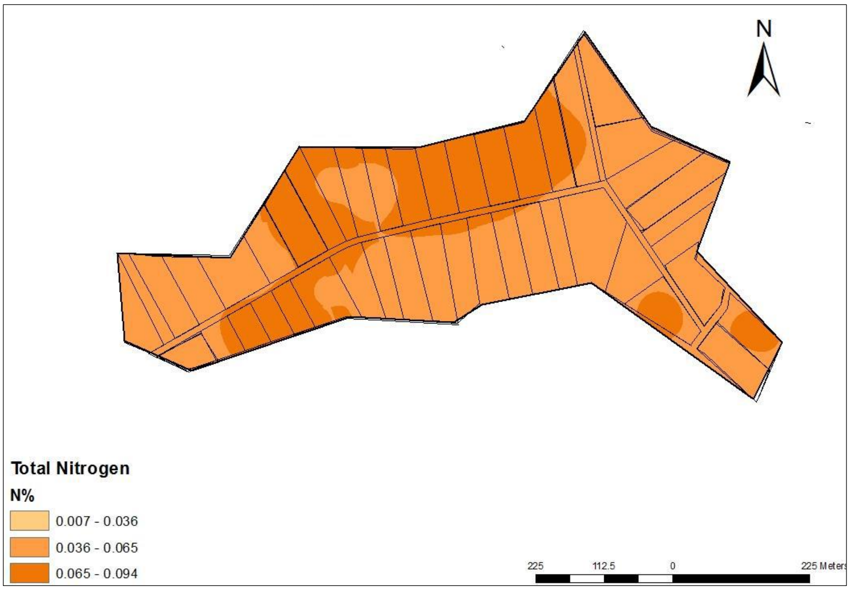

Figure 4: Spatial variation of total N

2.6. Available phosphorus and exchangeable potassium

Phosphorus is one of the key nutrients essential for agricultural crop production. Optimum soil P requirement for paddy farming is in the range of 8 - 15 ppm. The spatial variation of P in the study area is shown in Figure 5. Available phosphorus varied from 2.2 ppm (very low) to 45.6 ppm (very high). Mean value of the P content in the study area was 8.8 ppm. However, soil P content in most of the land blocks were above 8 ppm indicating better condition for paddy farming.

Phosphorus availability in the soil depends on many factors. Among them, soil pH is the major factor. In general P is more available to plant uptake when soil pH is in near neutral range. Soil pH in many land blocks reported above 7.5 indicating slightly alkaline condition. Under such situation P become inaccessible to plant uptake due to precipitate with calcium (Vitousek, 1984). However, soil P content is moderate to fairly high (above 8 ppm) in many land blocks. This may probably due to P containing minerals in the bed rock and the activity of P solubilizing bacteria available in the soil. According to the results P fertilizer application can be reduced from 25 -50% of recommended rate without affecting final yield.

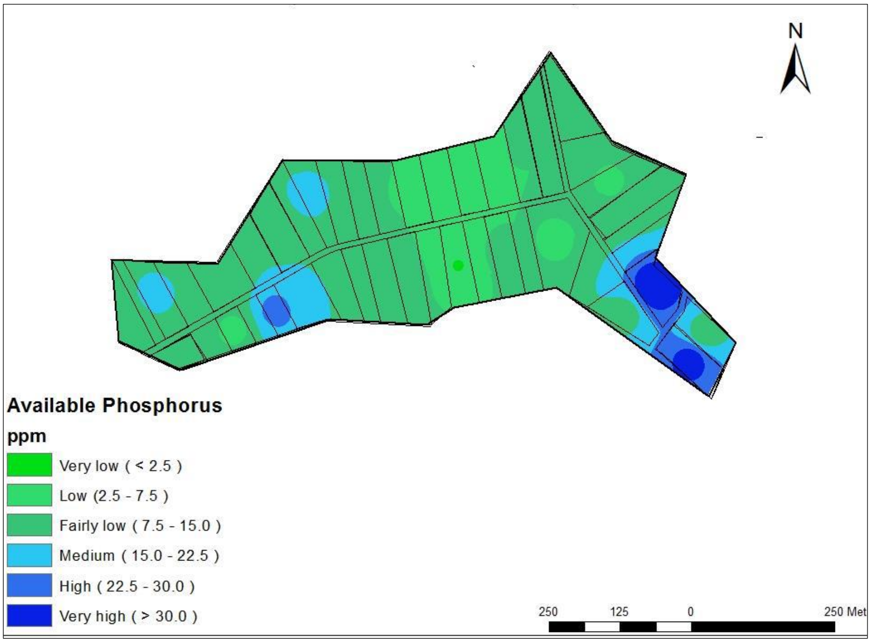

Figure 5: Spatial variation of soil available P

The exchangeable soil K have shown a great variation from 32 to 167 ppm among land blocks (Figure 6). Most of the land blocks had exchangeable K above 80 ppm. However, the optimum level of K for paddy cultivation is 160 ppm. Therefore, it is not necessary to add K fertilizers when soil K content is above 160 ppm. Potassium has a multifunctional role in rice production, in increasing resistance to pests and diseases, stimulating photosynthetic process, increasing plant turgor and making stress tolerance. (Dhillon et al., 2019). Potassium exhibits higher availability in the alkaline soils because Ca displace K in clay minerals. However, most of the land blocks showed less soil K content indicating the necessity of adding recommended dosage of K fertilizers.

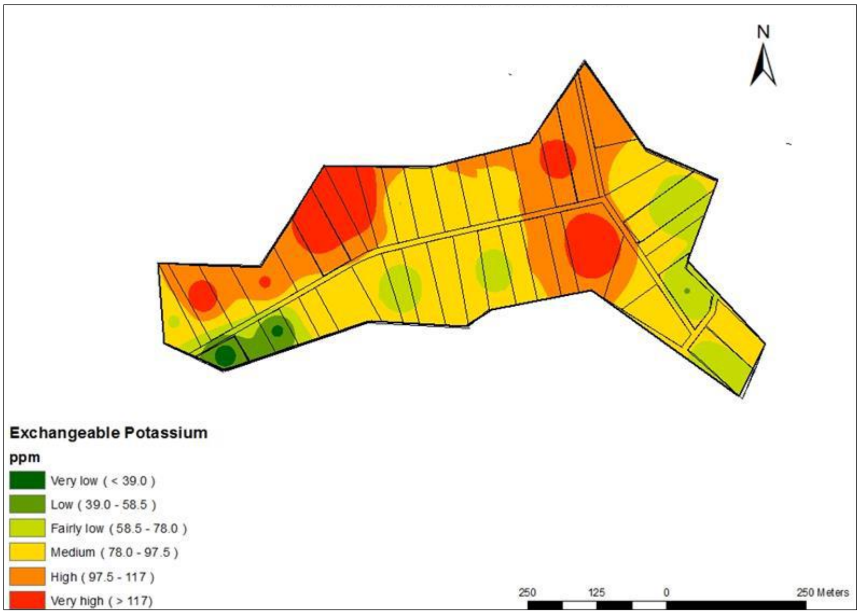

Figure 6: Spatial variation of soil exchangeable K

2.7. Soil Texture and the bulk density

A spatial variation of soil texture was observed after finishing earth works. Four main soil textural classes were identified across the study area, including loamy sand (52%), sandy loam (32%), sand (8%), sandy clay loam (8%). Bulk density measurements have shown that it has been varied from 1.58 gcm $^{-3}$ to 1.84 gcm^{-3} in the study area. Mean value of the bulk density of study area was 1.78 gcm^{-3}. Soil color in the study area was within the range of 2.5Y, 10YR. It varied from dark brown to dark yellowish brown indicating imperfectly drained condition. During initial earth work, surface soil was removed and then redistributed after finishing of block preparation. As a result, composition of the soil was completely altered. This may affect adversely on water retention of paddy tracts probably due to damage occurred the hard pan during soil excavations. Therefore, continuous puddling is very effective to facilitate downward migration of clay particles to develop hard pan beneath the subsoil. Slightly higher bulk density was reported in many land blocks after completion of earthwork. This indicates a little compaction of the soil. The possible reason could be use of heavy machines in land preparation. However, it can be rectified after land preparation due to loosening of the soil.

4. Conclusion

It can be concluded that soil pH of the study area is moderate to strongly alkaline in nature. It may create nutrient imbalances unless otherwise remedial measures are not adopted. The potential risk for salinity development is less in the study area because soil EC values were far below the critical level. Very low OM content and soil N content were reported in all most all land blocks. Soil available P and exchangeable K contents were varied from moderately sufficient to sufficient range. Bulk density of the soil showed slightly higher value indicating slight compaction probably due to use of heavy machineries for land preparation. It is recommended to apply total recommended dosage of N and the half of the P and K dosages at the first season after consolidation of the land blocks. Introducing green manure crop in the fallow period is highly advisable to enhance soil organic matter content up to an acceptable level.

6. Acknowledgement

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