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Research Article

Status of Soil Chemical Properties in Long-run Sugarcane Soils under Rain-fed Conditions: A Case Study at Settler Estate, Pelwatte, Sri Lanka

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Abstract

Pelwatte is a predominant sugarcane-growing region in Sri Lanka, primarily relying on rain-fed conditions for approximately 30 years. This study was conducted to assess the soil status and variability of the Settler region influenced by sugarcane cultivation. The study area covered around 1500 ha of sugarcane-growing lands where the predominant great soil groups are Reddish Brown Earth and Alluvial. A total of 61 soil samples were collected during the soil survey and samples were analysed for soil chemical properties including, pH, Electrical conductivity, organic carbon, total Nitrogen, available Phosphorous, and exchangeable Potassium. Geospatial variability was discerned, and continuous digital maps for each soil property were created using ordinary point kriging interpolation within ArcGIS 10.2 software. The soil pH (6.0 to 9.0, 0-30 cm) was generally favorable for sugarcane, with occasional less favorable isolated patches. Electrical conductivity (0-30 cm) ranged from 0.001 Sm^{-1} to 0.03 Sm^{-1}, indicating favorable, non-saline soil conditions. Soils in the studied area exhibited a very high variability with regard to total nitrogen (309.3 - 1,064.1 $mgkg^{-1}$), available phosphorous (0.8 – 33.2 $mgkg^{-1}$), and exchangeable potassium (non-detectable level - 331.4 $mgkg^{-1}$) contents. A positive correlation was observed between soil total nitrogen and soil organic carbon, and soil organic carbon levels in the 0-15 cm depth were suboptimal, ranging from 0.3 to 1.1%, raising concerns about its impact on plant nutrient availability. These findings underscore the imperative need for the implementation of a tailored, site-specific integrated plant nutrient management system within the Settler estate of Pelwatte, particularly in light of the observed soil heterogeneity.

***Keywords**: Digital soil mapping, interpolation, soil chemical parameters, sugarcane*

1. Introduction

Sugarcane (*Saccharum* spp. Hybrid) is the sole commercially grown crop in Sri Lanka for sugar production. The current sugarcane cultivation area encompasses approximately 25,000 hectares in *Udawalawe, Sevanagala, Badulla, Moneragala, Siyablanduwa,* and *Hingurana* regions, while *Kantale* and *Kilinochchi* areas are undergoing expansion. Sri Lanka hosts four functional sugarcane processing factories, namely *Pelwatte, Sevanagala, Hingurana*, and *Ethimale*.

Pelwatte sugar factory commenced its operations in 1986 and currently possesses a crushing capacity of 3,300 TCD (Tonnes of cane per day) (Keerthipala, 2016). It is managed by the state-owned Lanka Sugar Company (Pvt) Ltd, and the operating plantation area extends over an approximate extent of 9,500 ha. The *Pelwatte* sugar project's plantation spans across two distinct sections, namely the Nucleus estate and Settler estate, occupying approximately 4,200 ha and 3800 ha, respectively. The Nucleus estate is managed entirely by the factory plantation management, whereas the Settler estate lands have been distributed among smallholder farmers via a smallholder Settler/allottee system (Dimantha and Amarasinghe, 1989). Sugarcane has been cultivated continuously for over 30 years at both the Nucleus and Settler estates of the *Pelwatte* sugar project. This long-term conventional cultivation can be the main reason for poor yield and ratoonability performances, particularly in the Settler estate that relies only on rain-fed conditions. The declining soil quality in the affected area raises suspicions as a potential contributing factor.

Approximately, the average nutrient removal is about 15 $kgha^{-1}$ of Nitrogen, 38.91 $kgha^{-1}$ Phosphorous, 347.76 $kgha^{-1}$ of Potassium, 76.45 $kgha^{-1}$ of Calcium and 48.92 $kgha^{-1}$ of Magnesium at the harvesting of sugarcane crop. (Bodhinayake and Dharmawardane, 2001). To counteract these soil nutrient losses, conventional agricultural practices supplement plant nutrients using chemical fertilisers. The Sugarcane Research Institute (SRI) of Sri Lanka has developed fertiliser recommendations for sugarcane cultivation areas in the country, taking into account factors such as soil type and irrigation regimes (irrigated or rain-fed) for commercial-level implementation. However, it is crucial to monitor these soils and regularly update soil information to ensure the nutritional sustainability of sugarcane-growing soils.

In the context of plant nutrition, the levels of soil N, P, K, organic carbon content, electrical conductivity (EC), and pH can be recognized as basic indices for identifying the status of particular soil. Therefore, reliable information on the spatial variation of these soil parameters is quite important for decision-making in site-specific crop nutrition management. Therefore, this study aimed to evaluate the soil status in the Settler estate of the *Pelwatte* sugar industry, while also providing an opportunity to assess and characterize the spatial variability of crucial soil chemical properties that impact sugarcane production.

2. Material and Methods

2.1. Study Area

The study area covered around 1,500 ha of sugarcane growing lands in the Settler estate of Lanka Sugar (Pvt) Ltd at *Pelwatte* which operates under rain-fed conditions mainly (central coordinates: 6°36'50.76''N, 81°12'38.99''E). Reddish Brown Earth (order – Alfisols) and Alluvial (Order – Entisols) soils are the great soil groups that can be found in this area (Mapa *et al*., 2002). The subjected Settler estate of *Pelwatte* is located on the right bank of the Kuda Oya River in the southeast region of the Dry Zone of Sri Lanka. Agro-ecologically, it belongs to DL1a and DL 1b regions where they receive 900-1,200 mm of annual average rainfall (Punyawardena, 2010).

2.2. Soil sampling and laboratory analysis

A coupled purposive and random sampling technique was used to obtain soil samples from 61 sampling points including two soil depths that are 0-15 and 15-30 cm. In the process of selecting sampling points, an evaluation of the soil heterogeneity within the study area was conducted, taking into account topographical features, land use patterns, and geological attributes. This assessment revealed the need for a larger sample size to comprehensively capture the observed variability. All sampling locations were georeferenced using a Garmin GPS (Garmin Monterra) receiver. The aerial view of the study area and distribution of sampling points at the Settler estate of *Pelwatte* is depicted in the following Figure 1

Five sub-samples were collected from two depths within a 50 m radius at each sampling location. Sub-samples were bulked to obtain a composite sample for both soil depths. Soil samples were air-dried and sieved through a 2 mm sieve and the 0.5 mm sieve was used to prepare soils as per parameter analysis. Soil samples were analysed for soil chemical properties pH, Electrical conductivity (EC), organic carbon content (OC %), total nitrogen (N), available phosphorus (P) and exchangeable potassium (K) by following standard procedures.

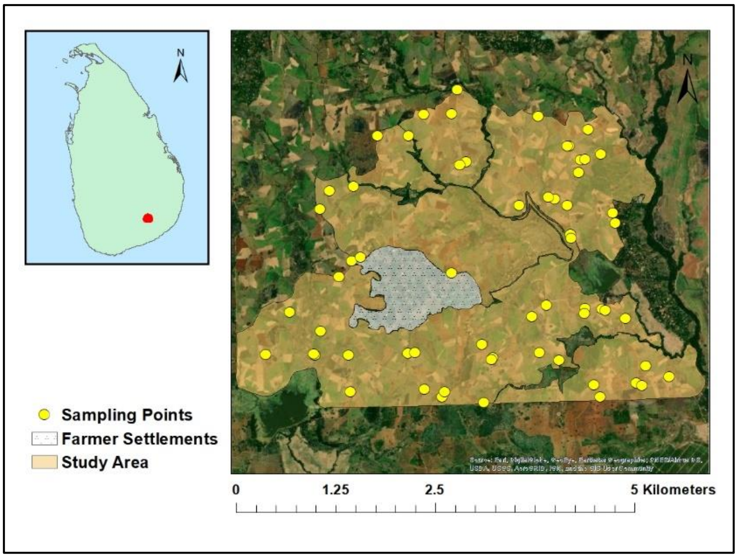


Figure 1: Study area and distribution of sampling points at Settler estate *Pelwatte*

The chemical parameter, pH was measured in a 1:2.5 soil: distilled water ratio suspension using a pH meter (Adwa-AD1030) with glass electrodes. EC was measured in a 1: 5 soils to distilled water ratio, suspension using a conductivity meter (TOA-CM20S). The analysis of organic carbon content was followed by Walky and Black method. Standard Kjeldhal procedure was followed for total N analysis with the modified colourimetric method by using UV-VIS - spectrophotometer (UV-2600-Shimadzu) (Bermer *et al*., 1982). The available P was analysed through the standard Olsen method followed by 0.5 M $NaHCO_3$ extraction with Ammonium Molybdate and Ascorbic by modified colourimetric method (Watanabe and Olsen, 1965)using UV-VIS - spectrophotometer (UV-2600-Shimadzu). The exchangeable K was analysed through the ammonium acetate extraction method (Hesse, 1971) using the Atomic Absorption Spectrophotometer (AA 6300- Shimadzu).

2.3. Data analysis

All variables were subjected to exploratory data analysis, and the data set was first evaluated for normal distribution in order to detect numerical and spatial outliers. This included the calculation of statistical parameters such as median, mean, standard deviation (SD), coefficient of skewness and coefficient of variation (CV).

Pearson Correlation was performed to Study the relationship between the variables studied. Significance was tested against to the 5% probability level. The SPSS 13.0 software was used for exploratory data analysis.

2.4. Geospatial analysis

Google Earth Pro software was utilized at the initial sampling point identification and Ordinary point kriging interpolation techniques were used to create continuous digital maps of each soil property. The Arc GIS 10.2 software was used for all geospatial analysis.

3. Results and Discussion

The chemical properties of soils that affect the growth and development of sugarcane i.e. soil pH, EC, main soil macro elements (total N, available-P, exchangeable K) and soil OC % were analysed separately for 0-15 cm and 15-30 cm depths to understand the present fertility status of the subjected area. The analysed major soil parameters of the targeted Settler estate of *Pelwatte* are shown as a summary in the following Table 1 and 2.

Table 1: Variation of soil parameters measured in 0-15 cm depth of the *Pelwatte*-Settler estate

Parameter	Range	Minimum	Maximum	Mean
Soil pH	2.57	6.08	8.65	6.76 ±0.45
Soil EC (Sm^{-1})	0.0246	0.0013	0.0259	0.0031±0.003
Soil total N ($mgkg^{-1}$)	754.8	309.3	1,064.1	680.6±160.3
Soil available P ($mgkg^{-1}$)	31.8	1.5	33.2	7.5±6.0
Soil exchangeable K ($mgkg^{-1}$)	331.4	ND	331.4	175.5±75.4
Soil OC %	0.74	0.38	1.11	0.65±0.14

Table 2: The soil parameter values of 15-30 cm depth at the *Pelwatte*-Settler estate

Parameter	Range	Minimum	Maximum	Mean
Soil pH	3.60	5.96	9.56	6.77±0.60
Soil EC (Sm^{-1})	0.0300	0.0012	0.0312	0.0036±0.005
Soil total N ($mgkg^{-1}$)	654.5	326.1	980.6	673.7±142.0
Soil available P($mgkg^{-1}$)	31.0	0.8	31.8	5.0±5.7
Soil exchangeable K ($mgkg^{-1}$)	244.2	ND	244.2	107.2±68.0

3.1. Soil pH

According to the results, the average surface soil pH (0-30 cm depth) in sugarcane-growing soils at *Pelwatte* Settler estate ranged from 6.0 to 9.0 and the mean pH observed in the study area was 6.76 and 6.77 in 0-15cm and lower 15-30 cm layer soils, respectively. The highest pH was recorded as 8.65 in upper 0-15cm soil and 9.56 in lower 15-30 cm soil. According to that, it is identified that there were some patches which are out from the cultivable soil pH range (5.5 to 8.5) of sugarcane. Based on analytical results, predicted maps of soil pH for the Settler estate of *Pelwatte* were developed by using Arc GIS 10.2 software through ordinary kriging and the geospatial variation of soil pH is depicted in the following Figure 2.

According to the spatial distribution, the higher pH of the soil was occupied by lower parts of the landscape in the studied area. It indicates medium to strong basic conditions (above pH 8), thus, affecting nutrient availability to the crop. It may have been due to the accumulation of basic cations brought down naturally through run-off. Comparatively lower pH values (< 7.0 pH) were related to the upper part of the catena in the studied area where higher run-off and leaching of basic cations may have taken place in comparison to lower-lying areas. However, there was no significant difference among the 0-15 cm soil and 15 – 30 cm soil depths in the pH of the Settler estate *Pelwatte* region. Soil pH has a strong influence on nutrient availability in the soil and loss of Ca, Mg and S from the soil are accentuated by strongly acidic conditions in the soil combined with leaching by rainfall. The optimum soil pH for sugarcane is 5.5-6.5 level. But, pH 5-8 conditions are desirable for cultivation (Dharmawardene, 2004).

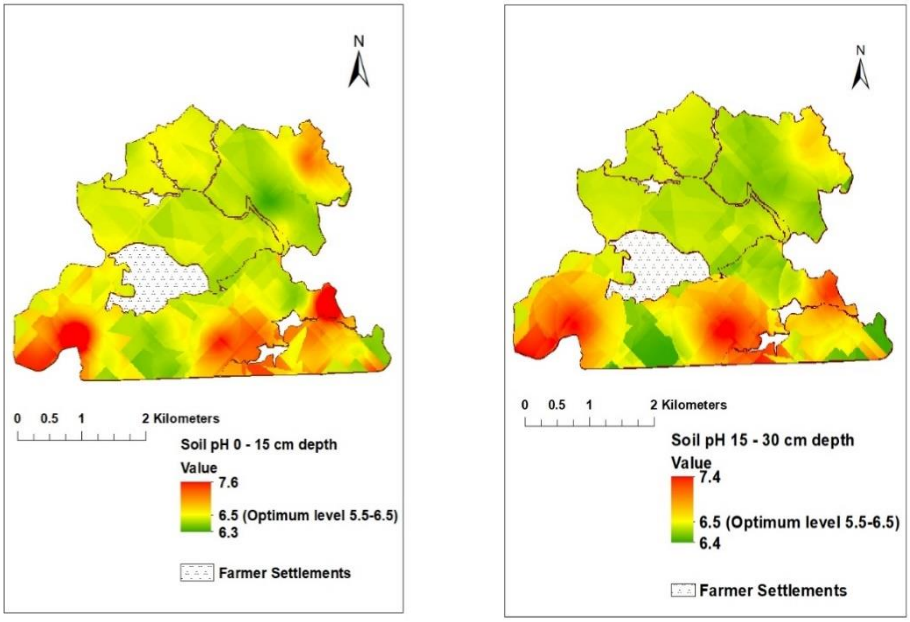
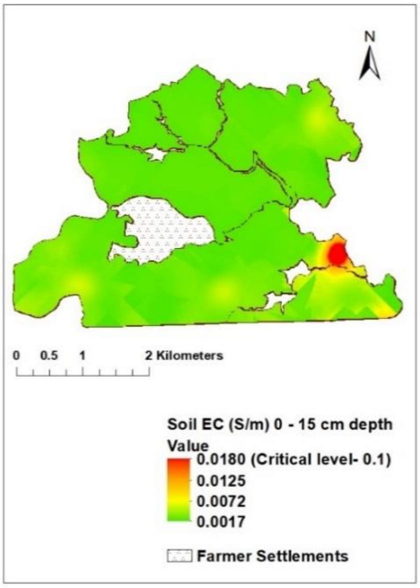


Figure 2: Predicted maps of soil pH in 0-15 and 15-30 cm depth for the Settler estate of *Pelwatte*

According to the correlation analysis results, soil pH at 0-15 cm depth was positively correlated with the soil EC in both 0-15 cm ($r = 0.8$, $p < 0.001$) and 15-30 cm soil depths ($r = 0.7$, $p<0.001$). The pH of lower layer soil was also positively correlated with the EC in both upper ($r=0.8$) and lower ($r=0.8$) layer soils at a 1% significant level. Soils with higher pH levels can be influenced by higher concentrations of cations especially calcium and magnesium ions which can increase the soil's EC (Mapa *et al*., 2002).

3.2. Soil electrical conductivity

The average surface soil EC (0-30 cm depth) in sugarcane-growing soils at *Pelwatte* Settler estate ranged from 0.001 Sm^{-1} to 0.03 Sm^{-1} and soils of the subjected area were at a favourable level without any salinization effect.



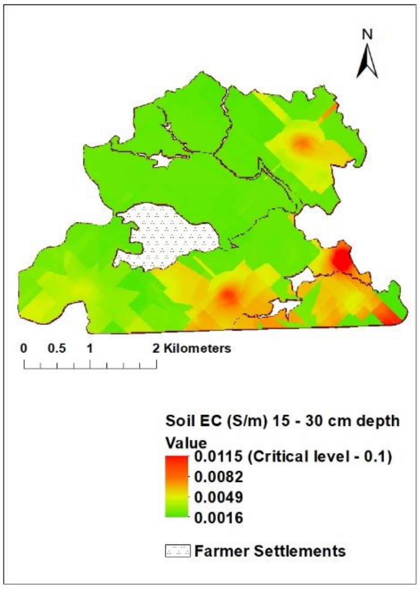


Figure 3: Predicted maps of soil EC in 0-15 and 15-30 cm depth for the Settler estate of *Pelwatte*

Predicted maps of soil EC prepared are given in Figure 3.The highest EC was recorded as 0.03 Sm^{-1} high values were distributed in lower parts of the catena. The reason may be the accumulation of basic cations brought down naturally through run-off (Dharmawardene, 2004). Other than that, continuous cultivation of sugarcane in a long run may increase the soil EC of the subjected *Pelwatte* Settler region. The soil EC is a measure of the ability of the soil to conduct an electrical current. Most importantly to fertility, EC is an indication of the availability of nutrients in the soil and soil salinity. A level of EC higher than 0.4 Sm^{-1} in a particular soil is considered as saline soil. Sugarcane can be grown successfully in soils with EC less than 0.1 Sm^{-1} level (Dharmawardene, 2004).

3. Soil Nitrogen

The mean surface soil total N content (0-15cm depth) in sugarcane-growing soils at *Pelwatte* Settler estate was 680.6 $mgkg^{-1}$ and the subsurface (15 – 30 cm depth) mean soil total N content was 673.7 $mgkg^{-1}$ level. The geospatial variation of soil N is presented in Figure 4.

However, there was no significant difference in soil N between the upper 0-15cm soil and lower 15-30 cm soil. According to the results, it is revealed that soil N status in the Settler estate of *Pelwatte* was at a lower level compared to the sugarcane crop requirement that 900 $mgkg^{-1}$ (Ridge, 2013; Calcino, 2010) of soil N critical level. However, Soil N can be considered as a highly variable soil parameter belonging to the time of sampling, existing weather, crop conditions, etc. Further, continuous cultivation, land preparation and higher run-off and erosion during the rainy season in the region can be caused to the lower N contents in the soil especially.

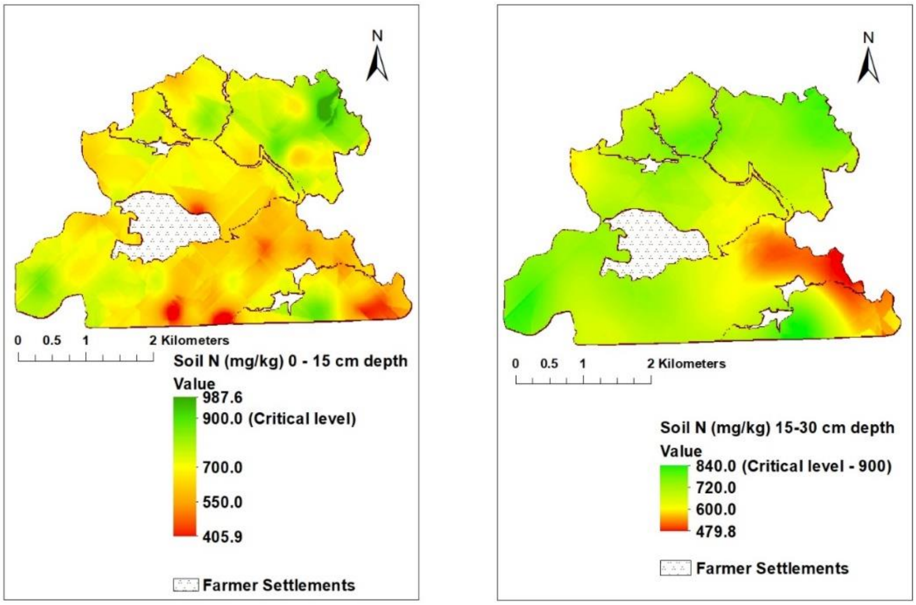
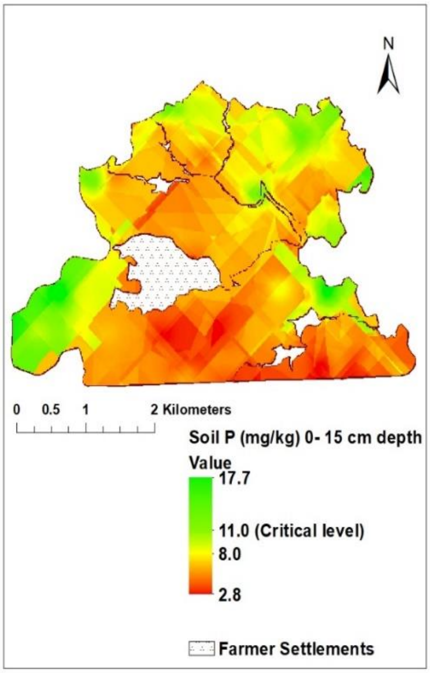


Figure 4: Predicted maps of soil N in 0-15 and 15-30cm depth for the Settler estate of *Pelwatte*

According to the results of correlation analysis, soil total N in both soil layers were positively correlated with soil OC % in the surface soil layer at 1% significant level and correspondence probability values were $p<0.001(r=0.5)$ and $p=0.001$ $(r=0.4)$ respectively. Therefore, adaptations to enhance soil organic matter contents in the subjected soil are highly required to alleviate the soil N complications in the Settler region of *Pelwatte*.

3.4. Soil phosphorus

The average soil available P content in the *Pelwatte* Settler region was less than the critical level (< 11.00 mgkg^{-1}) of sugarcane (Ridge, 2013; Calcino, 2010). The mean surface soil available P content (0-15cm depth) in *Pelwatte* Settler estate sugarcane-growing soils was 7.5 mgkg^{-1} and the subsurface (15 – 30 cm depth) mean soil available P content was at 4.9 mgkg^{-1} level. There was no significant difference in soil P among the two soil depths. Based on analytical results, predicted maps of soil P for the Settler estate of *Pelwatte* were developed by using Arc GIS 10.2 software through ordinary kriging and the geospatial variation of soil P is depicted in the following Figure 5.



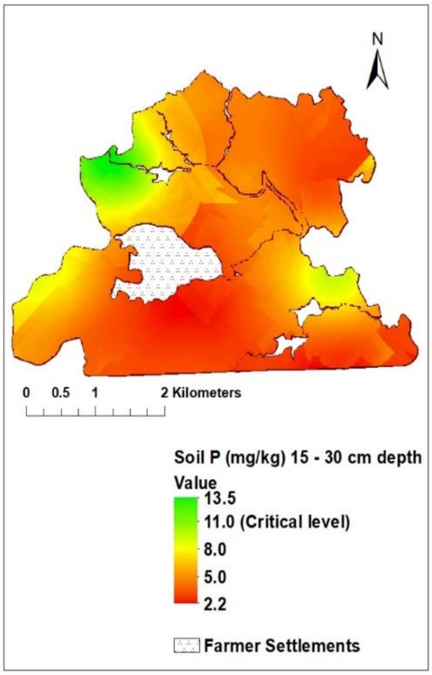


Figure 5: Predicted maps of soil P in 0-15 and 15-30 cm depth for the Settler estate of *Pelwatte*

Soil P contents in two soil depths (0 -15 cm and 15-30 cm) were positively correlated to each other ($p < 0.001$, $r = 0.6$) and the P contents in the upper layer soils (0-15 cm) were in higher comparatively. According to the generated map on soil available P for the Settler estate *Pelwatte*, it is also shown that comparatively lower soil P contents were related to the zones that face higher run-off and erosion during the rainy season especially. As it is to the Soil N, it can be suspected that the intensive cultivation for a long time in the *Pelwatte* Settler region has become poor in soil P content further. Soil P is important in the development of the spindle in sugarcane, and for early root formation and growth. It is essential for the formation of a vigorous root system and plays an important role in photosynthesis and many other biochemical processes, such as cell division and growth. P also contributes to disease resistance in most plants (Calcino, 2010). P-deficient sugarcane will have thin, short stalks and internodes, and tillering will be poor. The Settler estate in *Pelwatte* may exhibit a decline in cane yields and ratoonability performance due to a pronounced P deficiency.

3.5. Soil Potassium

According to the analytical results, the mean surface soil exchangeable K content (0-15 cm depth) in *Pelwatte* Settler estate sugarcane-growing soils was 175.4 mgkg^{-1} while the subsurface (15 – 30 cm depth) mean soil exchangeable K content was 107.2 mgkg^{-1} level which are little higher than to the critical level (39 mgkg^{-1}) of soil K of sugarcane (Ridge, 2013; Calcino, 2010). The highest exchangeable K content values were recorded as 331. 4 mgkg^{-1} in the soil of 0-15 cm depth and 241.2 mgkg^{-1} in the soil of 15-30 cm depth. Even though, there were some remarkable patches where the soil exchangeable K contents are at a not-detectable level. Based on these, predicted maps of soil K for the Settler estate of *Pelwatte* were developed by using Arc GIS 10.2 software through ordinary kriging and the geospatial variation of soil K is depicted in Figure 6.

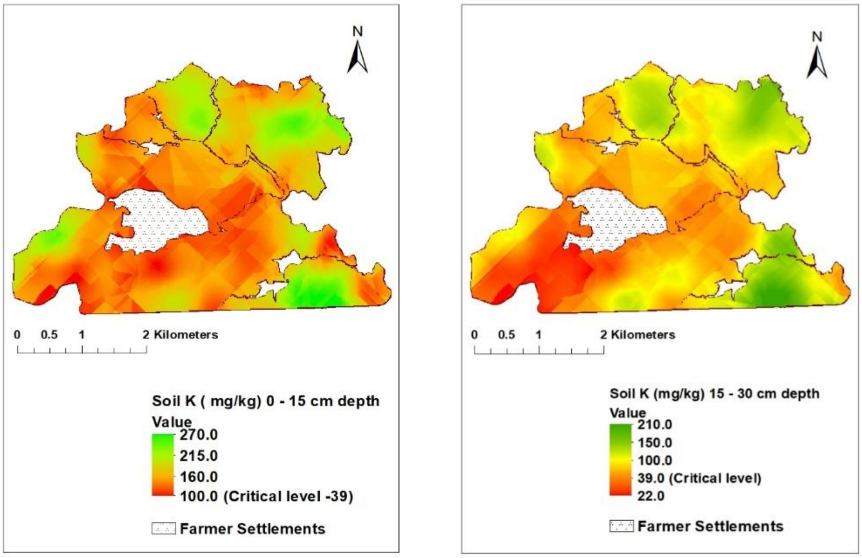


Figure 6: Predicted maps of soil K in 0-15 and 15-30 cm depth for the Settler estate of *Pelwatte*

If the mean exchangeable K values in the Settler estate *Pelwatte* region are at a satisfactory level, there are deficient patches in exchangeable K contents which require extra attention in nutrient management. However, there was no significant difference in soil K among the two soil depths but, it was positively correlated to each other ($p<0.001$, $r=0.6$) and the contents of exchangeable K in the upper soil layer (0-15 cm) was in higher level comparatively.

Soil K is taken up by sugarcane as ions, and Calcino (2010) has reported that it has many roles in sugarcane. It is essential for plant growth and photosynthesis due to its role in chlorophyll development in the leaves, helps the plant use other nutrients and water more efficiently, controls the movement of sugars in the plant, regulates the stomatal opening and closing, promotes root development, assists in the uptake of water and nutrients by osmosis, helps prevent premature cell death, and controls starch formation. The cane yield response to K fertiliser depends on soil reserves of K in exchangeable and non-exchangeable forms and it has been reported in the literature that K applications can reduce the impact of moisture stress on crop growth. Sugarcane is a luxury user of K, and this can result in elevated ash levels in juice at the mill where high rates of K fertiliser are used (Ridge, 2013).

As per the generated map on soil exchangeable K for the Settler estate *Pelwatte*, it is shown that comparatively lower soil K contents were related to the areas that face higher run-off and erosion during the rainy season especially. In the low-lying areas, it was reported as comparatively higher exchangeable K contents in the soil. Further, it was authenticated by making a positive correlation between exchangeable K (15–30 cm soil depth) and the soil EC of both soil depths at 5% significant level. The correspondence probability values were $p<0.037$ ($r = 0.3$) and $p=0.023$ ($r = 0.3$) respectively.

3.6. Soil organic carbon content (OC %)

For the Settler estate of *Pelwatte*, soil OC% was analysed only for the 0 – 15 cm soil depth and analytical results indicated that OC level is in a poor and alarming situation with a range from 0.3 to 1.1%. The mean OC content was 0.6% and this lower OC% in soil could reduce the plant nutrient availability in the soil. The soil's organic carbon content is a key indicator of soil health and unwanted loss of plant nutrients from the soil is minimised with adequate organic matter. Organic materials can retain N without the risk of nitrate leaching into groundwater and negatively charged organic particles can retain plant nutritional cations. The predicted map of soil OC% is depicted in the following Figure 7.

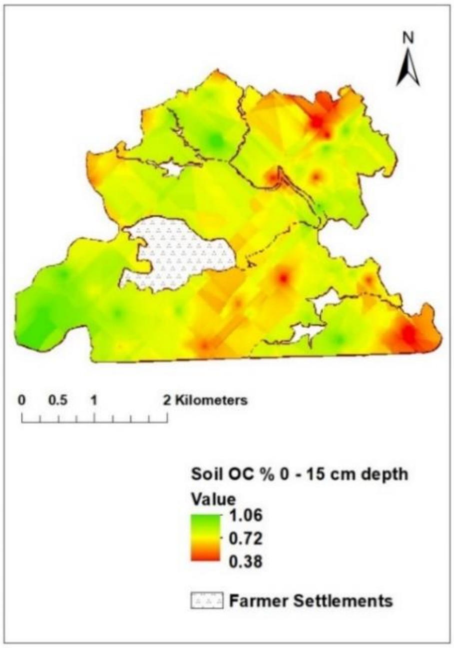


Figure 7: Predicted map of soil OC% in 0-15 cm depths for the Settler estate of *Pelwatte*

Soil nutrients utilized by sugarcane are retained predominantly in the mineral and organic components of the surface soil. Labile nutrients are retained on the exchange complex and are accessed by cane roots from the soil solution. Various processes including weathering, mineralization, erosion, leaching, denitrification, volatilization, fixation, immobilization, additions in rainwater, crop nutrient uptake and removal, and fertilization/addition of ameliorants/ organic matter addition, determine the long-term supply of nutrients for the crop (Meyer, 2017).

In the context of the studied area, extended periods of drought, coupled with seasonal high-intensity rainfall and ongoing land preparation practices, account for the diminished soil organic carbon content. The study revealed that there were positive correlations between the soil OC% and soil N in both studied soil depths. Therefore, adaptations to enhance soil organic matter contents in the studied soils in the Settler region of *Pelwatte* are highly required. In the domain of sugarcane soil management, the implementation of soil amendments utilizing by-products derived from the sugarcane industry, specifically filter-mud and vinasse, alongside the introduction of an efficacious green manure crop, represents a promising avenue for elevating soil organic carbon content and fostering sustainability in the context of plant nutrition.

4. Conclusion

The study's findings underscore the imperative need for precise soil nutrient management at the *Pelwatte* Settler Estate. While the prevailing soil pH aligns favorably with sugarcane cultivation, isolated unsuitable patches were identified, and there is a future risk of salinity in some areas. Plant nutrition assessment revealed suboptimal soil N and P levels, with a strong correlation between soil N and soil organic carbon. Though average exchangeable K was satisfactory, patches with undetectable K levels require special attention. Alarmingly deficient soil organic carbon, likely due to extended dry spells, intense rainfall, and continuous cultivation, necessitates measures to augment organic matter. The results highlight significant spatial variability in plant nutritional properties, emphasizing the need for a site-specific, integrated plant nutrient management system. Additionally, geospatial data collected can facilitate in-depth spatial analysis, including variogram modeling and mapping of critical soil properties across *Pelwatte* sugarcane cultivation areas.

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