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SPATIAL CHANGES OF SOIL STRUCTURAL PROPERTIES AND ORGANIC CARBON STORAGE OF ARABLE FARMLAND AT UMUAHIA, ABIA STATE

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ABSTRACT

Precision agriculture requires that spatial changes of soil structural properties and soil organic carbon (SOC) accumulation be established for effective soil management. A research was carried out to ascertain the spatial variation of soil structural properties and organic carbon accumulation of an arable farmland at Umuahia. The experiment was conducted by delineating the land into three (3) portions. Three auger and core soil samples each were randomly collected from each portion, and this gave nine (9) observational points which were georeferenced. The soil samples were prepared and analysed in a laboratory for determination of parameters. The data generated were analysed for spatial variation using a GIS software package. The highest SOC accumulation of 26.46 ton / ha was obtained at the extreme north and northwestern regions of the land, while the lowest SOC accumulation of 19.71 ton / ha was obtained at extreme southeastern region of the land. The entire central area to the north western portion of the land had lowest bulk density (BD) of 1.33 kg / m^3, while the southward to the north eastern portions of the land had the highest BD of 1.37 kg / m^3. The highest hydraulic conductivity of 4.75 cm / mins was observed at the south western portion. The southward and extreme north eastern portions of the land had the highest mean weight diameter (MWD) of 0.95 mm, while the lowest MWD of 0.75 mm was observed at the central areaand extended to the north western portions of the land. There were also spatial changes in the total porosity, and micro aggregate stability indices across the land area. Suitable agronomic practices need to be adopted within the various portions of the land in managing the soil.

Keywords: bulk density, aggregate stability, organic carbon, soil management
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INTRODUCTION

Soil structure and organic carbon greatly influence aggregate stability and soil bulk density, and these in turn influence total porosity, thereby affecting water infiltration and retention, access to water and nutrients by plants. The bulk density and aggregate stability also affect seedling emergence, root penetration, plant growth and soil erodibility (Nathalie, 2014). They are however influenced by human activities through land use and management such that their variability, both laterally and vertically, across soils follows systematic changes (Amusan et al., 2006; Mbagwu & Auerswald, 1999, Amanze et al., 2017). Cultivation of soils continuously increases sand content and bulk density of soils, reduced aggregation and the ability of soil to retain water (Malgwi and Abu, 2011); this, however may vary across the land area depending on the varying degree of tillage (Malgwi and Abu, 2011). Intensive soil tillage accentuates soil respiration and alters the temperature and moisture status of topsoil leading to increased rate soil organic matter decomposition (Balesdent et al., 2000) which also affects soil aggregation and aggregate stability (Balesdent et al., 2000).

Spatial variability of soil properties can be natural resulting from pedogenic processes conditioned by geology, topography, climate, land use and soil management practices (Quine and Zhang, 2002). They further noted that this variability of soil properties can occur at varying locations on the land surface or across the soil depths with the major contributing factor being soil redistribution by tillage. Baldrian (2014) and Amanze et al. (2022) explained that soil spatial variability can develop from differences in litter distribution and decomposition across the land surface, changes in vegetation cover and plant species across the landscape, as well as variation in drainage pattern. He noted that the variation in these factors across the land surface influences the variation in the physicochemical and biological properties across the land surface. Moreover, Ole et al. (2014) showed that the spatial process of soil physical characteristics across the land can be influenced by spatial changes in soil type, rainfall pattern and distribution, evapotranspiration, land use system and soil management practices. The report of Sharma et al. (2011) confirmed that soil physical and chemical properties including soil texture, bulk density, and saturated hydraulic conductivity varied significantly across an agricultural land as influenced by cropping systems and soil forming processes. Their report indicated that variation in soil tillage caused significant changes in soil properties across the cultivated land. However, their findings revealed that the cultivated land had relatively reduced variation of the soil properties compared to the natural grassland. Also, Kilic et al. (2012) noted different degrees of variation in soil properties across fields under different land use systems.

Therefore, the understanding of the spatial variation in soil properties across a land area is crucial in the efforts to facilitate site specific soil management practices for enhanced soil quality and crop productivity. The site specific soil management entails management of varying locations within a land on the basis of their unique properties, thus eliminate generalization and wastage.

MATERIALS AND METHODS

Location and Description of Study Area

The research was carried out at Umuahia, Abia State. The area lies within latitude 5°29ˡN to 5°31ˡN and longitude 7°30ˡE to 7°32ˡE with mean annual rainfall distribution of 2200 mm (NiMeT, 2019). The study location is notable for rain and dry spells which occurs from March to October for the rainy season, while the dry spell covers a period of November to February with mean yearly temperature of 28°C (NiMeT, 2019). The landscape of the area is flat to gently undulating with Coastal Plain Sands as the dominant parent material and localized regions of alluvial deposits (Amanze et al., 2016). The soil is classified at great group category as “Hapludult” according to the USDA soil taxonomy typical of soil of the tropical rainforest (Amanze et al., 2016).

Characterization of the Land Use

The land was a continuously cultivated arable farmland planted to cassava (*Manihot esculentus*), yam (*Dioscorea spp.*) and pumpkin (*Telferia occidentalis*). The degree of vegetation cover across the land varied with the plant species cultivated and the cropping system. The land covered an area of 1865.7 m^2 and was gently sloped. The soil fertility management varied across the land ranging from the use of mineral fertilizer (NPK) to organic fertilizers. The texture of the soil was sandy laom with the mean values of the soil separates recorded as 161 g / kg clay, 752 g / kg sand and 87 g / kg silt (Amanze *et al*., 2017). It has mean organic carbon content of 13.5 g / kg (Amanze et al., 2017).

Soil sample collection and preparation

The land was partitioned into three (3) portions based on topography. Three disturbed and undisturbed soil samples each were randomly collected from each portion making a total of nine (9) observational points which were georeferenced (see Table 1). The disturbed soil samples were air – dried and divided into three portions. One portion was sieved using 2 mm mesh for determination of particle size distribution, another portion was sieved using 0.5 mm mesh for determination of organic carbon content, and the other portion was passed through a 4 mm mesh for the determination of mean weight diameter (MWD) of water stable aggregates (WSA). The undisturbed core soil samples were saturated in water before determination of saturated hydraulic conductivity (K_{sat}) and later oven – dried for determination of bulk density (BD).

Laboratory Analyses

Particle size distribution was determined using the hydrometer method as described by Gee and Or (2002). **Micro aggregate stability** was determined using the amount of silt and clay in calgon – dispersed as well as water – dispersed samples during particle size analysis described by Gee and Or (2002). Hence, the various micro aggregate stability indices were calculated thus;

$$\% \text{ Dispersion ratio} = \frac{\%[\text{Silt} + \text{Clay}(H2O)]}{\%[\text{Silt} + \text{Clay}(\text{calgon})]} \times 100 \ldots\ldots\ldots\ldots 1$$

$$\% \text{ Aggregated Silt} + \text{Clay} = \%[\text{Silt} + \text{Clay(calgon)}] - \%[\text{Silt} + \text{Clay(H2O)}] \ldots\ldots\ldots 2$$

$$\%\text{Clay flocculation index (CFI)} = \frac{\%\text{Clay(calgon)} - \%\text{ Clay(H2O)}}{\%\text{ Clay(calgon)}}\ X\ 100 \ldots\ldots\ldots\ldots 3$$

$$\%\text{Clay dispersion index (CDI} = \frac{\%\text{ Clay (H2O)}}{\%\text{Clay (calgon)}}\ X\ 100 \ldots\ldots\ldots\ldots 4$$

Mean weight diameter (MWD) of Water Stable Aggregates (WSA) was determined by the wet-sieving method to determine the water stable aggregates of varying size as explained in Kemper and Rosenau (1986). Then, mean weight diameter (MWD) of the water stable aggregates was calculated as follows:

$$\text{MWD} = \sum_{i=1}^{n} XiWi \ldots\ldots\ldots\ldots 5$$

Where Xi is the mean diameter of the ith sieve and Wi is the proportion of the weight of aggregates in the ith sieve.

Saturated hydraulic conductivity (K_{sat}) was determined by the constant head method explained by Klute (1986), then K_{sat} was calculated using Darcy's equation as explained by Youngs (2001) as shown below.

$$\text{Ksat} = \frac{\text{QL}}{\text{AT}\Delta\text{H}} \ldots\ldots\ldots\ldots 6$$

Where Q is quantity of water discharged (cm^3), L is length of soil column (cm), A is the interior cross – sectional area of the soil column (cm^2), ΔH is head pressure difference causing the flow or hydraulic gradient and T is time of water flow (s).

Bulk density (BD): This was determined using the core method as described by Anderson and Ingram (1993).**Total porosity (Pt)** was calculated as follows;

$$\text{Total porosity} = \left(1 - \frac{\text{Bulk density}}{\text{Particle density}}\right) \text{X } 100 \ldots\ldots\ldots\ldots 7$$

Organic carbon: This was determined by the dichromate oxidation procedure of Walkley and Black as modified by Nelson and Sommers (1982). Total carbon accumulated in the soil was calculated according to the procedure explained by Peter (2013) as shown below:

$$C_T = C_F \text{ x D x V} \ldots\ldots\ldots\ldots 8$$

where C_T is total organic carbon for the layer (metric ton), C_F is the fraction of carbon (percentage carbon divided by 100), D is bulk density of the soil, V is the volume of the soil layer (m^3).

Data Analyses

The data were analyzed for spatial variability using a GIS analytical software package by the use of the recorded geographical coordinates and the soil data for the various soil parameters.

Results and Discussions

The results of the parameters were presented by the colour spectrums in the figures that followed. The colour variations in the arch map indicate the varying degree or intensity of the parameters measured across the land coverage. The degree or intensity increases as the colour goes darker.

Spatial Variation of Soil Organic Carbon Accumulation

The spatial changes in soil organic carbon (SOC) accumulation are shown in fig. 1. The highest range of SOC accumulation of 26 - 27 ton / ha was obtained at the extreme north and northwestern regions of the land, and the lowest SOC accumulation of the range of 19 - 20 ton / ha was obtained at extreme southeastern region of the land.

The reason for the changes in SOC accumulation across the land could be attributed to variation in plant density and rate of residue accumulation by litter fall across the land use (Holland, 2004; Baldrian, 2014). Also, variation in residue management as well as differences in the intensity of tillage operations across the land may have contributed to this effect (Sharma et al., 2011). Therefore, regions of highest SOC accumulation may be regions of reduced intensity of tillage, increased residue return and plant density, and vice versa.

Spatial Variation of Soil Bulk Density

The Fig. 2 shows the spatial variation of soil bulk density (BD) across the land. The variation was gradual with the BD increasing from the central region that had the lowest BD of 1.32 kg / m^3 to the extreme Northeast and Southwest which had the highest BD of 1.38 kg / m^3. However, the land was dominated by regions with lower BD ranging from 1.33 – 1.35 kg / m^3.

The changes in soil BD across the land may have resulted from the changes in the degree of ground cover by vegetation and differences in the intensity of movement of humans across the landmass. The regions of higher BD may have been exposed to greater intensity of human movement and possible poor vegetation cover that allowed for the high raindrop impact on the soil resulting to increased soil compaction and BD. Conversely, the regions of lower and lowest BD were possibly regions of higher vegetation cover and reduced human movements relative to the other regions of the land. This agrees with the report of Amanze et al., (2017) and Baldrian, (2014) that spatial variation of BD can occur as a result of variation in vegetation cover and differences in litter distribution and decomposition across a land area.

Spatial variation of Saturated Hydraulic Conductivity

The Arch map in Fig. 3 reveals the spatial variation of saturated hydraulic conductivity (K_{sat}) across the study area. The land was dominated by areas of lowest K_{sat} range of 3.0 – 3.5 cm / min, and this extends from the central region to the entire northern region of the land, while the region of highest K_{sat} range of 4.5 – 5.0 cm / mins was observed at the extreme Southwest of the land.

The variation in K_{sat} across the study area could be attributed to the possible variations in soil management practices and soil texture which may have influenced the interactions of organic matter content, BD and soil aggregation in affecting the K_{sat} (Quiane and Zhang, 2002). Therefore, regions of slow K_{sat} may be associated with poor soil aggregation, reduced organic matter content, fine texture and increased BD. Contrariwise, regions of rapid K_{sat} may have been influenced by a favourable interaction of BD, coarse texture, organic matter content and soil aggregation. Hydraulic conductivity of soils is enhanced by reduced soil BD, increased organic matter content and improved aggregation and aggregate stability (Oguike *et al*, 2017)

Spatial variation of Total Porosity

There was gradual variation of percentage total porosity (TP) across the land use (Fig. 4). The land was dominated by regions of highest TP ranging from 49.5 – 50 %, and this covers the entire central region to the Northwest region of the land. The lowest TP in the range of 48 - 48.5 % was observed at the extreme Northeast and Southern regions of the land.

The variation in the total porosity of the studied land use was probably a resultant effect of variation in vegetation cover, soil management practices, soil texture and aggregation across the landmass (Ole *et al*., 2014). Consequently, regions of increased percentage TP was possibly regions of light texture, reduced tillage operation and soil management practices that reduced soil compaction and enhanced soil macro and micro porosity, while regions of decreased percentage TP may have been associated with intensive tillage operation that resulted in soil compaction and disruption of macro and micro pores (Oguike *et al*., 2017 and Amanze, *et al*, 2017).

Spatial variation of Clay Flocculation Index

The Fig. 5 reveals that there is spatial variation of clay flocculation index (CFI) across the land with the dominance of regions of highest CFI range of 76 – 77 %. This region of highest CFI covered two – third (2/3) of the Western region and extended to the extreme North region of the land, while region of lowest CFI of range 73 – 74 % occupied only the Eastward of the central region of the land.

The variations in CFI across the land area could be inferred on the changes in BD, clay content and organic matter accumulation of the soils (Amanze *et al*, 2022). Then, whereas regions of increased CFI were possibly characterized by increased clay content and BD and reduced soil organic matter, regions of reduced CFI were on the other hand characterized by reduced clay content, increased organic carbon and reduced BD. The reports of Stevenson (1992) and Amaze *et al.* (2017) earlier showed that CFI of soils increase with increase in clay content as the clay served as the binding agent of soil particles at micro level while increase in organic matter content served to decrease CFI by increasing the critical flocculation index of the soil. Meanwhile, this variation in clay content and organic carbon contents of the soil may have been caused by variation in topography of the land and differences in litter distribution and decomposition across the land (Baldrain, 2014).

Spatial variation of Clay Dispersion Index

There is spatial variation of clay dispersion index (CDI) across the land as shown in Fig. 6. The region of lowest CDI of range 23 – 24 % occupied over two – third (2/3) of the Western region and extended to the extreme Northern parts, while the highest CDI of range 26 – 27 % was observed at the extreme East of the central part of the land.

The variation in CDI across the land was premised on the variation in topography, soil management practices and vegetation cover which possibly influenced the distribution of clay and organic matter contents across the land (Sharma *et al*., 2011). Therefore, the region of increased CDI was possibly characterized by increased organic matter content and increased clay content arising from increased accumulation of litter fall from higher plant cover and increased accumulation of clay particles due to the position of the region at the lower slope, respectively. Conversely, regions of decreased CDI may be region of decreased clay content and reduced organic matter. Nelson and Oades (1998) and Amanze, *et al* (2017) had earlier reported a negative interaction between OC and clay within soil colloidal mixture such that the negatively charged OC compounds increase the net negative charge of the colloidal mixture which increased the repulsive force among the clay particles leading to instability of soil microaggregates and dispersion of clay particles.

Spatial variation of Dispersion Ratio

There was variation in dispersion ration (DR) across the land (fig. 7). The soils of the western region of the land had the highest DR in the range of 20.5 – 21 %, while the lowest DR in the range of 18.5 – 19 % was observed at the soils of the eastern region of the land.

The dispersion ratio was influenced by the variation in the quantity of silt and clay in the soils across the land. The regions of reduced dispersion ratio were regions of better micro aggregation resulting from the possible higher content of silt and clay relative to the other regions. The higher content of these fine particles may have increased aggregation by increased cohesion and adhesion resulting from their increased large surface area. On the contrary, regions of increased dispersion ratio may have been characterized by reduced content of silt and clay with resultant decrease in the overall surface area that limited the strength of the cohesive and adhesive forces in binding the particles together. This finding corroborates the report of Amanze *et al.* (2022) that soils of increased content of fine particles (silt and clay) had better stability of micro aggregates than soils of relatively lower content of fine particles under similar management conditions.

Spatial variation of Aggregated Silt + Clay

The fig. 8 shows the spatial variation of aggregated silt + clay (ASC) across the land area. The region of highest range of ASC (20.5 – 21 %) dominated the land, while the regions of lowest range of ASC (18.5 – 19 %) were observed at localized areas of the extreme northeast and southwest of the land.

The ASC is dependent on the quantity of silt and clay in the soil, thus the variation in the content of silt and clay across the studied area was the reason for the spatial changes in ASC across the land. Regions of highest ASC were possibly areas of increased content of silt and clay, while regions of lowest ASC could be areas of decreased content of clay and silt. Increased content of silt and clay particles resulted in increased micro aggregate stability of soils (Oguike & Mbagwu, 2009). This may be attributed to the large surface area of the fine particles which increased the cohesion of the particles within themselves and adhesion to each other. On the contrary, regions of decreased ASC may have been characterized by reduced content of silt and clay with resultant decrease in the overall surface area that limited the strength of the cohesive and adhesive forces in binding the particles together (Amanze et al., 2022).

Spatial variation of Mean Weight Diameter

There was variation of mean weight diameter (MWD) across the land area (Fig. 9). Regions of highest range of MWD (0.9 – 1.0 mm) were located at the entire southern part and extreme northeastern part of the land, and the lowest range of MWD (0.7 – 0.75 mm) was observed across the central region to the northwestern part of the land.

The changes in MWD across the land may have been influenced by variation in ground cover, organic matter (OM) and clay contents of the soils across the land area (Mbagwu & Auerswald, 1999, Amanze et al,. 2017). Therefore, regions of increased MWD may have been characterized by increased content of OM, adequate ground cover and greater amount of clay content. Contrariwise, the regions of reduced MWD were possibly regions of relatively poor ground cover, as well as decreased OM and clay contents. This report is consistent with the findings of Balesdent et al. (2000) that soil OM and clay particles contributed to the binding force in improving the stability of soil aggregates at the macro level, while good ground cover helped in protecting the aggregates against rainfall impacts.

CONCLUSION

There was variation of all the structural parameters measured across the soils of the study area. Notably, the variations in the parameters were gradual with small margin between the highest and lowest values of the various properties measured. The observations made require that the various portions of the land be given specific attention in managing the structure and hydraulic parameters. Regions of reduced macro aggregation should be improved by more inputs of organic manure; minimum tillage should be practiced at regions of poor micro aggregates stability, while adequate drainage plan should be put in place in managing soils within the regions of slow hydraulic conductivity.

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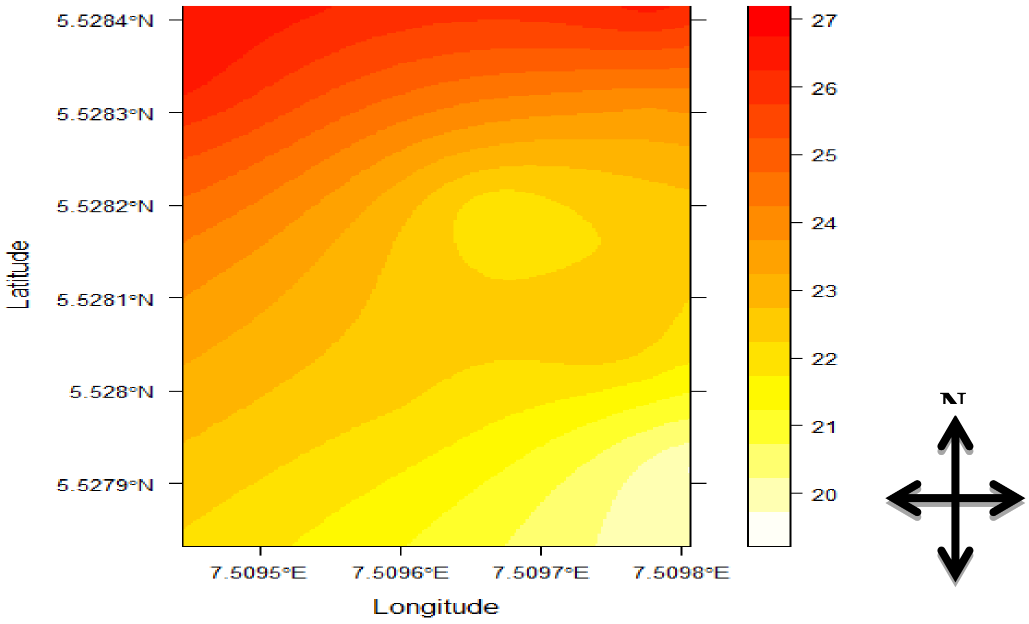
APPENDICES

Tables and Figures

Table 1: Geographical position of the sampling units in the Arable farmland

Land use type	Sampling units	Elevation (masl)	Geographical Coordinates
Arable farmland	1	157	05^{0}31' 40.2"N; 07^0 30' 34.4"E
	2	157	05^{0}31' 40.7"N; 07^0 30' 34.6"E
	3	156	05^{0}31' 40.5"N; 07^0 30' 35.3"E
	4	155	05^{0}31' 41.0"N; 07^0 30' 35.1"E
	5	156	05^{0}31' 41.4"N; 07^0 30' 35.2"E
	6	155	05^{0}31' 41.5"N; 07^0 30' 34.8"E
	7	155	05^{0}31' 41.9"N; 07^0 30' 35.2"E
	8	155	05^{0}31' 42.0"N; 07^0 30' 34.0"E
	9	153	05^{0}31' 42.3"N; 07^0 30' 35.2"E



BD Fig. 1: Spatial Variation of Soil Organic Carbon storage (ton / ha) e

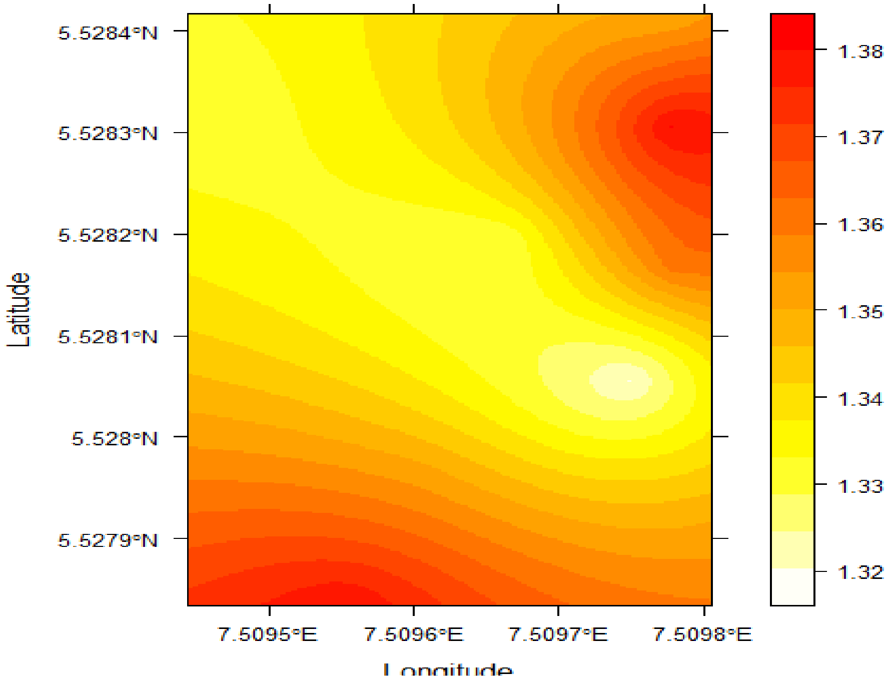


Fig. 2: Spatial Variation of Soil Bulk Density (mg /

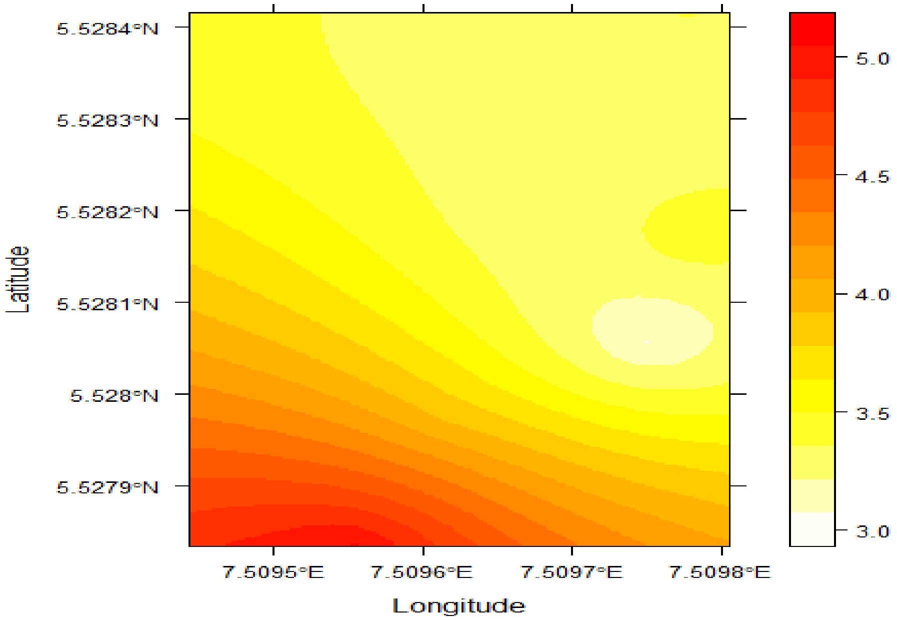


Fig. 3: Spatial Variation of Soil Hydraulic Conductivity (cm /

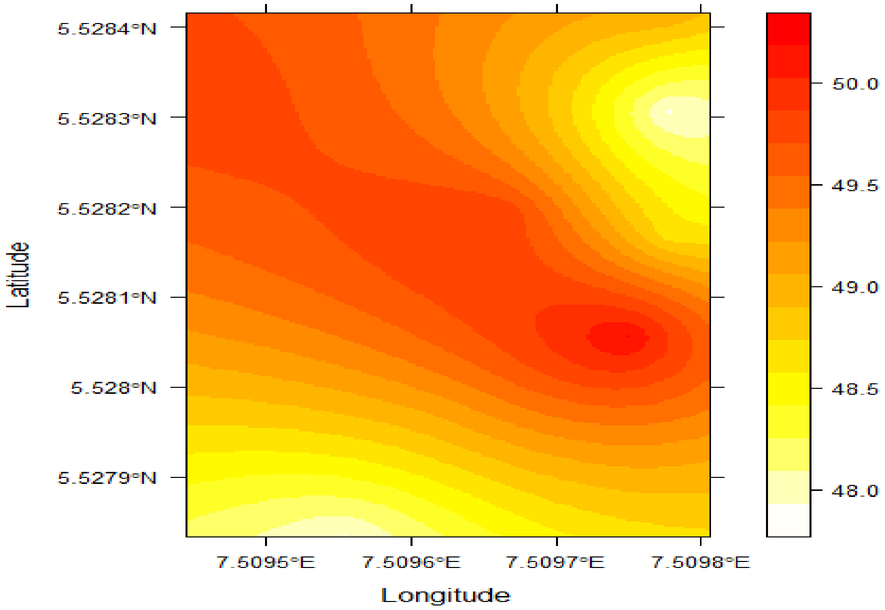


Fig. 4: Spatial Variation of Soil Total Porosity (%)

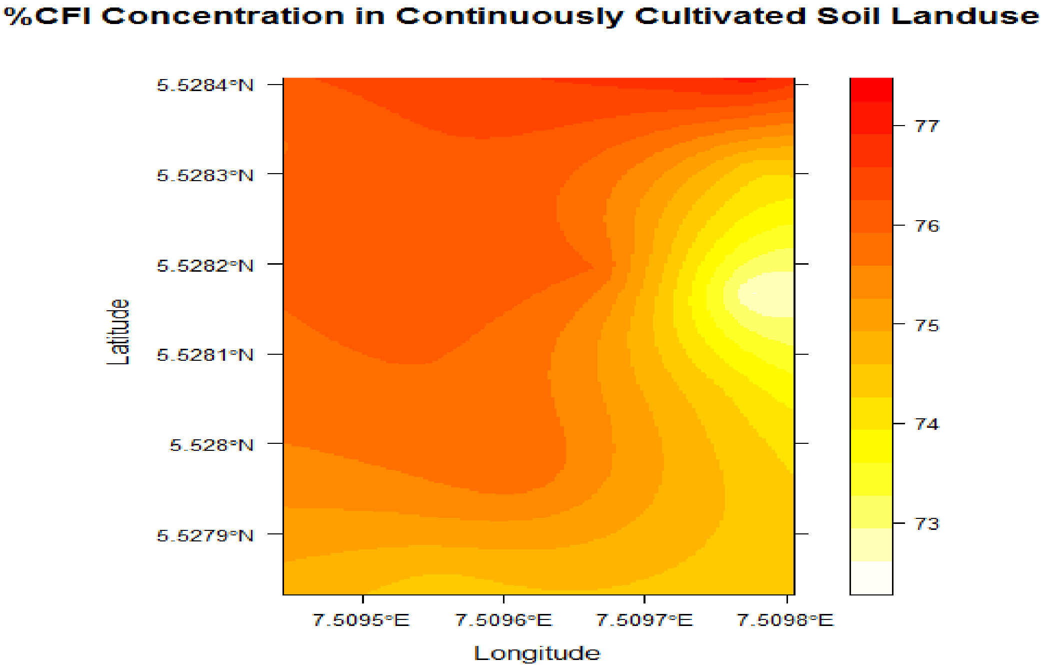


Fig. 5: Spatial variation of Clay Flocculation Index (%)

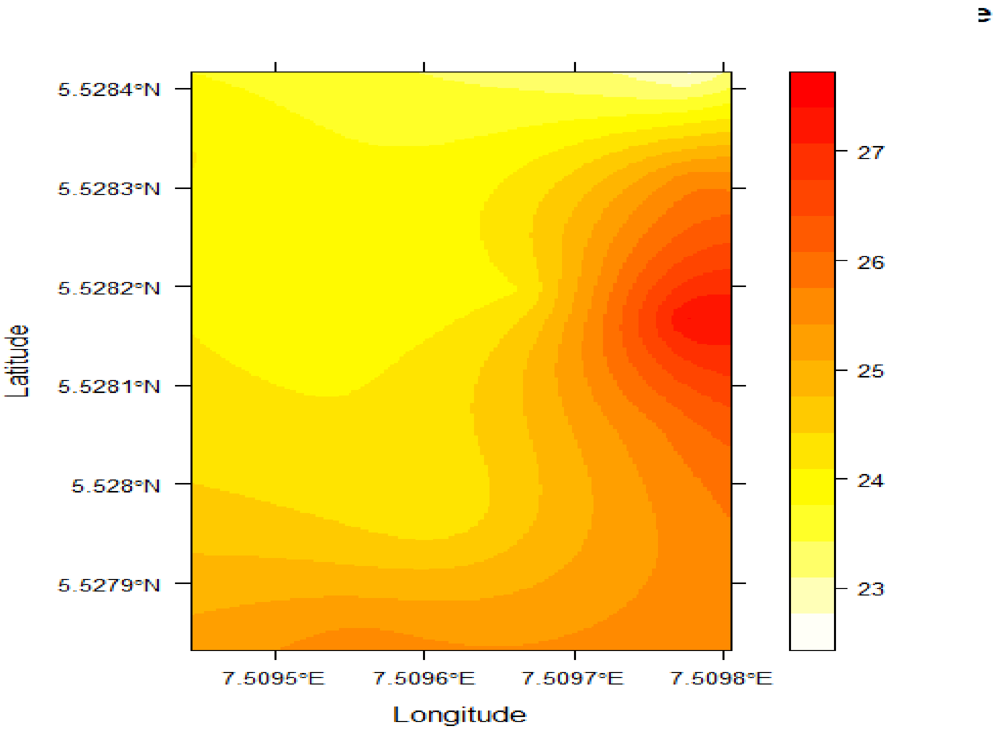


Fig. 6: Spatial variation of Clay Dispersion Index (%)

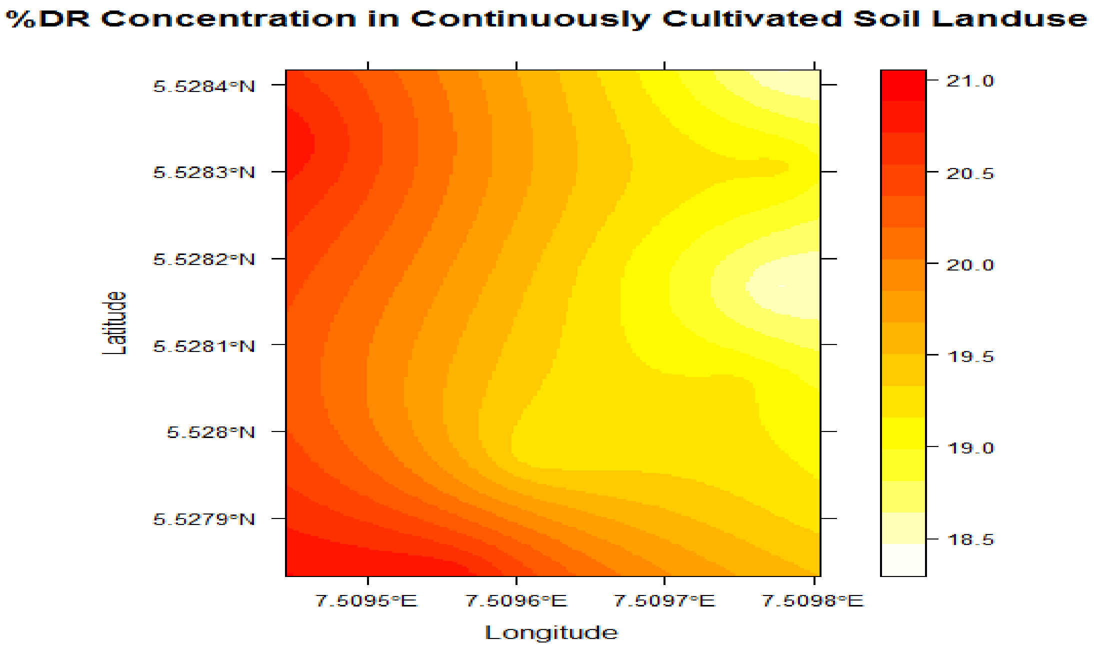


Fig. 7: Spatial variation of Dispersion Ratio (%)

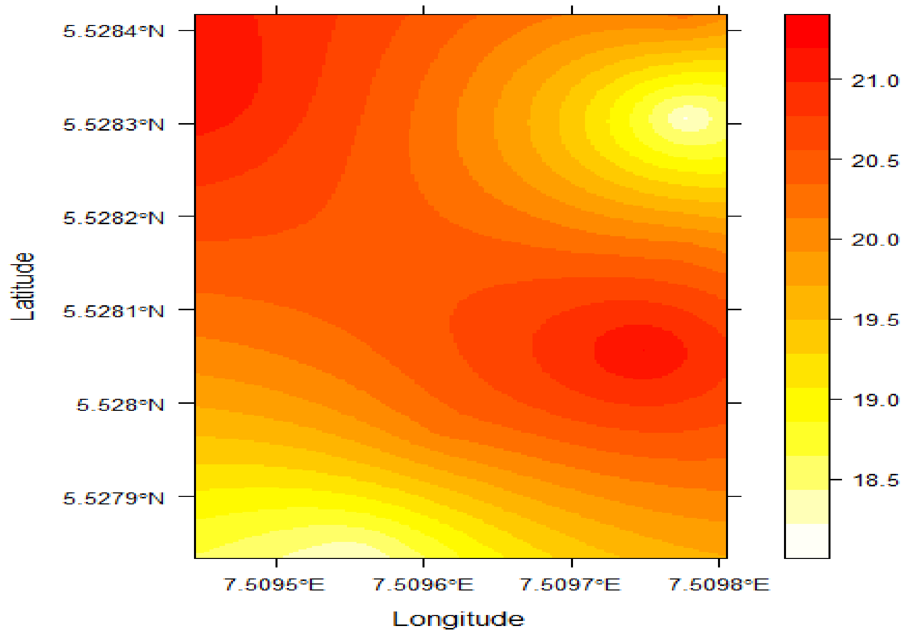


Fig. 8: Spatial variation of Aggregated Silt + Clay (%)

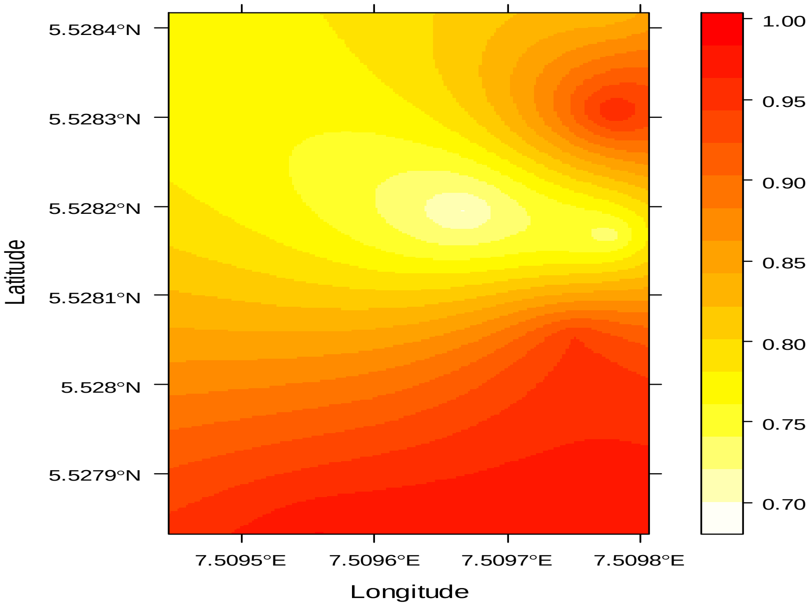


Fig. 8: Spatial variation of Mean Weight Diameter (mm)