Soil Quality and Leaf Assessments of PHC Plantations, DR Congo

Boteka, Lokutu and Yaligimba Plantations, DRC

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Cover page photo: a picture showing the majority of the team members including some PHC staff conducting the soil sampling, foliage sampling, field and weed assessment at the Yaligimba plantation

Photo credit: Samuel Mesele

Collaborators and acknowledgement

We gratefully acknowledge the management of PHC for commissioning IITA to conduct the soil and leaf assessment of her plantations at Boteka, Lokutu and Yaligimba. We acknowledge the contributions of the following persons from PHC that were part of the working group:

- Jean Jules Kiazayawoko Area General Manager of Yaligimba)
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- Barthélémy Mboti (Area General Manager of Boteka)
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- Mr Frederick Schreurs, CEO of the Business Incubation Platform
- Dr Jeroen Huising, Senior Soil Scientist
- Dr Samuel Mesele, Soil Scientist
- Mr Murhabazi Mirali Gentil, Field surveyor
- Mr Cirhuza Mirali Jackson, Field surveyor
- Mr Mukanirwa Rusongeka Faustin, Field surveyor

The following persons from IITA and other organizations who participated in this study, in their various capacities:

- Mr Tunrayo Alabi, Head Gespatial unit, mapping and digitizing
- Mr Jeremy Cordingley, Head CropNuts, Kenya

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Executive summary

In November and December 2021, a team of IITA visited the three oil palm plantations of PHC, called Boteka, Lokutu and Yaligimba, as part of an assignment to assess the condition of the oil palm plantations and to provide general recommendations for soil and weed management. This report deals with the soil component. The weed assessment has been reported separately.

For the assessment of the soil condition and nutrient status of the palms 380 locations have been visited for the three plantations together. The number of sampling points is determined by the point density required for this type of studies (semi-detailed), which was set at two sampling points per 100 ha. The total area of the three plantations together was originally specified as 19,000 ha, but we surveyed 22,459 ha in the end. For the spatial distribution of the sampling points, we used the map of the plantations that shows the individual blocks, and a sampling point was allocated to the centroid of each polygon. It results in a very regular pattern of the sampling point locations and a very good spread of the points over the plantation that is most suited for this kind of studies.

For the survey soil samples were collected for further analysis, observations made on the soil profile and terrain, leaf tissue samples were collected for further analysis on the nutrient content, observations were made of the leaf for symptoms of nutrient deficiencies and possible indicators of disease, and the sex ratio was determined for 17 individual plants and means calculated. Distinction was made between sampling points for which both topsoil and subsoil samples were taken (the "reference sites") and sampling points where only topsoil samples were taken (the "ordinary sampling sites"). All other observations were the same for both types of sites. The reference sites were visited by the complete teams, including the agronomists of PHC recently hired (12 in total) for training purposes. The remaining sampling points were done by a smaller team consisting of one IITA staff per plantation plus four agronomists of PHC per plantation to be able to finish the work in time. The exact location of the sampling point was georeferenced and the trees from where the soil samples as well as the leaf tissue samples were taken have been marked (with paint, either yellow or red) so that the exact same location and trees can be used for sample collection for monitoring purposes.

Field data has been recorded electronically, using ODK Collect. All data is available and made accessible, including pictures taken of the plantation and of the palm frond for each location (the same frond as from which the tissue sample is taken). The pictures can be used for verification and reference, and assessment of the condition of palm and for signs of nutrient limitations. Furthermore, data files are presented for each of the plantation providing the results of the analyses of the top and sub-soil samples, the results of the analysis of the plant tissue and the results of the sex ration assessment.

The condition of the three plantations is largely comparable. Boteka, having the more sandy soils also shows nutrient limitations that are typically associated with this type of soils (as result of leaching). Magnesium is at extremely low concentration, as is the exchangeable potassium and this is reflected in the nutrient concentration of the leaf tissue and is also reflected in the visible signs of nutrient deficiency on the leaf. Furthermore, sulphur concentrations are low for all plantations, and this is likewise reflected in the low leaf tissue concentration. Micronutrient

concentrations are low in all plantations and especially boron, which is a critical importance to oil palm, is found at deficiency levels and there are also signs of boron deficiency on the leaves. Chlorine, which is of relevance especially for oil palm, is generally ‘low’ in Lokutu. It varies from ‘low’ to ‘adequate’ (or optimum) for Boteka and Yaligimba plantations. Phosphorus is generally ‘low’ for Lokutu, seems ‘adequate’ on average for Boteka (but varies a lot) and is in-between for Yaligimba. Nitrogen seems to be available in adequate levels in the soil, which is a result of past fertiliser application, however.

Soils in all plantations are quite acidic. Soil organic carbon varies strongly within the plantation from ‘extremely low’ to ‘high’ at certain points.

The sex ratio varies strongly within each of the plantation. On average it is highest in Boteka (0.55), which is probably because it is the youngest plantation. Yaligimba has an average sex ratio of 0.49 and Lokutu has an average sex ratio of 0.47. These are large differences considering that these are average values for the whole plantation. Within each plantation the sex ratio varies strongly, which is likely the result of management, given that all other factors that determine the sex ratio are constant within the plantation (genetic factors, climate, etc.). Boteka shows the highest variation with a standard deviation of 0.15.

In conclusion the condition of the Boteka plantation seems to be poorest and the conditions at Yaligimba plantation seems to be best, with still a lot of opportunity for improvement.

Introduction

This is a partial report on the assessment of the productivity constraining factors for the three oil palm plantations of PHC in the Democratic Republic of Congo: Boteka, Lokutu and Yaligimba. This report deals with the soil quality and fertility status of the three plantations, as well as the plant nutrient status and the sex ratio.

The three plantations belong among the oldest plantations in Africa. The plantation in Boteka was established in 1911. The ownership and management of the plantations has changed several times over the years. And because of several factors, among which the civil strife not being the least, the plantations have been severely neglected. The current yield is reported to be very low, around maybe 6 to 7 t/ha, though we do not have the exact figures.

The current management, established in 2019, aims to increase productivity and bring them at par with the best plantations in the world. For this purpose, the management is developing a strategic plan to fulfil this ambition. It requires a thorough assessment of the status of the plantation in terms of soil fertility (or nutrient limitations), weeds and sex ratio. (Sex ratio, calculated as the female inflorescence divided by the total inflorescence (male and female) is an important determinant but also indicator of the plant productivity). The management of PHC has asked IITA-BIP to carry out such an assessment and to provide recommendations on the management of soil fertility and weeds. This report addressed the soil fertility aspects and presents data on the sex ratio. We present the data on sex ratio without further evaluation and drawing conclusions. It is assumed that sex ratio is related somehow to soil fertility and nutritional status of the plant, though this has not been established as such and it is also not very clear what defines that relationship. The weed assessment and recommendations for weed management are provided in a separate report.

Soil quality assessment is the measure of the condition of the soil relative to a particular use. In this case, this relates to the support the soil can give to plant growth, pertaining to oil palm which is grown for commercial purposes. Therefore, it refers to the ability of soil to provide nutrients to plants, store water and make it available to plants and it maintains aeration such that soil respiration and gas exchange can take place. It provides a foothold for plant roots and provide for a healthy environment.

We can determine the soil characteristics that determine the soil quality and make as such a general assessment of the soil quality, identifying the constraining factors that limit the functionality of the soil in providing plant nutrients, sufficient water for uptake and other (that support plant growth). And we can match those constraining factors to the specific requirement of the crop to some extent. The factors that determine the uptake of nutrients and water by the plant are many and the processes are very complex. That is why it is difficult to predict the effect of measures aiming to improve soil quality and therefore it is also difficult to provide one-time recommendations for improving soil quality or for fertilizer application. Rather, one should monitor changes in soil condition and plant production as result of the recommended practices to assess its effectiveness and to adjust these practices where and when needed. The current soil inventory should therefore be considered as establishing a baseline.

Soils have important direct and indirect impacts on agricultural productivity and water quality, being the storehouses for water and nutrients. The soil interacts with its environment and is impacted by the landscape features and weather conditions, as well as by the particular use. In this case, the use refers to intensive agricultural use involving fertilizers, agrochemicals, and mechanized operations for land preparation, harvesting, and others.

Soil quality in the plantations may have deteriorated under intensive use, and subsequently, the soil quality may affect the productivity of the oil palms and wherewith the profitability of the plantation enterprise. The variability between and within the plantation districts and blocks are of particular concern as these may affect crop response to fertilizer use or other management practices.

Similarly, plant analysis is a valuable tool in plantation management and could be used for diagnosing nutrient limitations in crops. It primarily serves as a source of information on plant nutrient status. Interpretation of the plant tissue nutrient concentrations is difficult because the nutrient concentrations are not independent of each other, and one should be careful in drawing conclusions on the nutrient concentration alone. Plant tissue analysis in combination with soil test information is a global standard practice for diagnosing nutrient deficiencies in crops and determining fertilizer requirements.

The focus for the soil quality assessment is on the soil physical-chemical properties. We determined the relevant soil parameters to come up with a suggestion for the soil quality indicators to be used for monitoring purposes. We also examined nutrient deficiencies in the palm foliage and evaluated the sex ratio to gain insight on the status of the palms and how to improve their productivity. The sex ratio is a direct determinant of the productivity since it is the number of female inflorescences per production cycle that determines the yield. The sex ratio is influenced by many factors, among which the genetic make-up, environmental factors, and age of the plant. Under 'good' conditions most bunches are female and can lead to high fruit yield. The 'good' conditions refer to water availability especially, as it is known that draught stress leads to an increase in the proportion of male flowers. The effect of soil fertility on the sex ratio is less clear. The interpretation of the sex ratio figures is therefore complicated but the evaluation of difference between blocks in the same plantation in relation to indeed the age of the plants in the block and crop management seems to be relevant. It certainly is a relevant parameter for monitoring effects of improved management.

The overall objective of this assessment was to indicate if there are any biophysical parameters militating against the proper growth and development of the oil palms and to provide suggestions on what to do to increase the productivity of the plantations. This report focusses essentially on the soil, plant tissue analysis and sex ratio determination across Boteka, Lokutu and Yaligimba plantations, in the Democratic Republic of Congo.

Time schedule

Date	Activities	Team
13 – 17 Nov. 2021	Fieldwork and training of plantation staff how to take samples at Lokutu	All field teams
19 – 23 Nov. 2021	Fieldwork and training of plantation staff how to take samples at Yaligimba	All field teams
29 Nov – 2 Dec. 2021	Fieldwork and training of plantation staff how to take samples at Boteka	All field teams
17 Nov. to 2 Dec 2021	Fieldwork and complete samples collection at Lokutu	Gentile and PHC Lokutu staff
23 Nov. to 8 Dec 2021	Fieldwork and complete samples collection at Yaligimba	Jackson and PHC Yaligimba staff
2 – 8 Dec. 2021	Fieldwork and complete samples collection at Boteka	Faustin and PHC Boteka staff
Jan – Apr 2022	Samples preparation and lab analysis at IITA Bukauv	IITA Bukavuv team
Jan – Apr 2022	Samples preparation and lab analysis at CropNuts, Kenya	CropNuts team
Mar - Apr 2022	GIS Mapping and image interpretation	Geospatial team
May 2022	Data quality control	IITA soil management
Jun 2022	Report writing and recommendations	IITA soil management
Jun 2022	Presentation and submission of final report	FS, EJH, SAM

Methodology

The soil survey was carried out to determine the soil type at each farm and to develop maps characterizing the soil functional properties. The soil and site characteristics were evaluated at locations pre-determined by the sampling design.

Sampling design

For the assessment of soil condition at this kind of scale a sampling density of two sampling points per 100ha is required. Departing from the 19,000 ha originally specified as being the size of the three plantations together, it follows that the total number of sampling points was set at 380. The sampling design did not follow a specific approach in that it used a systematic grid or random sampling approach for example. Rather, the polygon map of the plantation was used and for each polygon the gravity point (or centroid) was determined and assigned a sampling point. The polygons generally represent individual blocks, but in cases there are two (or more) polygons describing one block. The result is that we have one sampling point per block (located in the centre of the block) in general and occasionally two (or sometimes three) sampling points per block. The implication is that the points are well spread over the plantation, allowing the use of spatial interpolation techniques to generate maps of the soil properties and to assess the spatial variability at each plantation. The individual points are not representative of the block itself. Where points fell outside the plantation in the predesign, efforts were made to place the sampling points at the centre of the blocks of the plantation.

Soil sample collection

We took soil samples at each sampling point for laboratory analysis following a protocol that was modified for the oil palm plantation. Soil samples were taken using an Edelman-type auger. Composite soil samples were collected at each point, taking samples from four (4) sub-locations. That is, taking samples at opposite sides of the palm tree at about 1 m from the tree. This is done for two (2) trees per sampling point. The tree that is closest to sampling point location specified is considered the first tree. The second tree from where the soil samples are taken is the tree second closest to the actual sampling point location. Both trees are being marked with paint so that they can easily being identified when samples for monitoring need to be taken. Coordinates of the actual sampling point location are recorded. Samples are taken from within the area that is being cleared around the trunk of the tree and where also the fertiliser is applied. Topsoil samples were taken at 0-20 cm for all sampling points. Subsoil samples were taken at 20-50 cm only at the reference sites.

The reference sites are defined as the sampling points visited physically by the complete field team, including the experts and field technician from IITA, and including the agronomists (new recruits) of PHC that were being trained on the field observations and sample collection. The reference sites were selected at representative locations for the whole plantation such that all estates and most districts were visited such that we could get a good impression of the variability within the plantation in terms of soil and terrain condition and in terms of the condition of the trees and general condition of the plantation at that particular point.. It is at the reference sites that the agronomists of PHC were trained on soil sample collection, leaf and weed assessment. All samples were barcoded, double-bagged and shipped to the laboratory.

On all site other than the reference sites topsoil samples were taken only, considering that the properties of the subsoil will not vary that much, having observed as well that the same type of soil prevails within the whole plantation.

Field assessment and site characterization

As part of the field survey, information was collected on soil depth restrictions to understand the effective rooting depth. We measured the soil depth restrictions by using the soil auger. The depth restriction is indicated by the depth at which we could not drill further down the soil while exerting considerable force. Depth restriction does not necessarily equate to rooting depth restriction but is a good indicator of effective soil depth. We have also included observations on the drainage conditions and soil texture as well as site characteristics like to landform, slope, and topographic position as well as recording whether there are signs of erosion and flooding.

The observations in the field are made according to standard operating procedure and data was recorded electronically using ODK Collect installed on smartphones. The forms were designed specifically for this study. The data collected were used for ground truthing for the image interpretation and for the validation of data and maps generated.

Leaf assessment

Leaf sampling is used to determine the nutrient content of the palm leaves. This helps to identify possible nutrient deficiencies. We used the critical nutrient levels indicated in IFA's World Fertilizer Use Manual to determine which nutrients are limiting.

For the leaf sample collection, we used the standard protocol described by, amongst others, Thomas Fairhurst (2015) and in AKVOPEDIA.

Equipment and materials required: clean harvesting tool (hook), bush knife, Sharp small knife or scissors, clean plates, microwave, cloth bag, marker pen, paper bags, clean water, and cardboard box.

At each sampling point, two palms were selected and from these their 17th leaf was sampled. These are the same trees as from where the soil samples are collected. The trees are marked so that they can easily be identified when sampling leaf sampling for monitoring purposes is done. Identifying the 17th leaf is done in the following way: The first step is to determine if the spiral is turning left or right by looking at the frond butts on the palm trunk; then locate the last fully opened leaf in the centre of the palm crown. This is Leaf 1. In Leaf 1, the small 'spines' at the bottom of the leaf should already be visible, while in Leaf 0 the leaflets go all the way down into the centre of the leaf. It is easiest to look first for Leaf 0. Leaf 1 is located one-third round away from leaf 0, walking against the direction of the spiral. Following the spiral of Leaf 1 downwards in the canopy: the frond below 1 on the same spiral is 9; the frond below 9 is 17. Cut off Leaf 17 using a clean harvesting tool and place the frond on the weeds or on a plastic sheet, ensuring that it does not touch bare soil, otherwise it can get contaminated with fertilizers. The point (a bit above the middle of the leaf) where the ridge on the upper surface of the rachis tapers to a point is located. Six leaflets on the left side and six on the right side of this point are selected and cut with a knife from the rachis. Of these leaflets, three are in the upper rank and three in the lower rank. The top and the bottom part of the leaflets are cut off so that the middle 15—20 cm remains. The top and the bottom part are discarded while the middle part of the leaflets is put in a clearly marked paper envelope and QR coded. The details of the samples are recorded electronically on the ODK form. The leaflets are later washed in a sterile distilled water; water is allowed to drain out before the leaflets are bagged and place in a microware at a regulated temperature. The leaflet samples are ground when dry and sent to the lab for nutrient analysis.

Sex ratio evaluation

The number of male and female inflorescence may vary strongly from one palm tree to the next, and, therefore, the sex ratio needs to be determined from a large number of trees to get meaningful statistics. The sex ratio is determined for 17 trees at each sampling point. That is for the tree at the centre of the sampling point from where also soil samples have been taken and that has been marked. From the central tree four diagonal transects are marked out, each measuring 45 m (equivalent to the 5th oil palm trees in the line, at a spacing of 9 m between two palms). At the end of each 45 m diagonal transect, the four trees forming a parallelogram of 9 x 9 m^2 are marked out and the number of male and female inflorescence on the palms were counted with the aid of a binocular and recorded. The coordinates of each tree are recorded, and it should therefore be possible to identify the same trees for assessing the sex ratio at later stage for monitoring purposes, it so desired. The sex ratio is determined by the number of female inflorescences divided by the total inflorescence (male plus female inflorescence). The closer the value is to unity the more the dominance of female inflorescence and the higher the productivity of the palm is expected to be.

Laboratory analysis

The soil samples were analysed for particle size, organic carbon, exchangeable acidity, total nitrogen, available phosphorus, exchangeable potassium, exchangeable sodium, exchangeable calcium, exchangeable magnesium, sulphur, manganese, zinc, boron, copper, and iron using wet chemistry standard analysis procedures. Methods of soil analysis and their references are provided below:

1. Organic Carbon by Chromic acid digestion
   Heanes D. L. (1984). Determination of total organic carbon in soils by an improved chromic acid digestion and spectrophotometric procedure. Comm. in Soil Sci., and plant analysis. 15:1191-1213
2. Nitrogen in soil by Kjeldahl digestion and colorimetric determination on Technicon AAII Autoanalyzer.
3. Soil pH. Determined in water on 1:2.5 soil/water ratio.
   Okalebo J.R, Gathua K.W and Woormer P.L. (2002). Laboratory methods of soil and plant anslysis: A working manual. 2nd Edition. TSBF-CIAT 128pp
4. Extractable Phosphorus, Exchangeable Cations and micronutrients in soil are done by Mehlich 3 extraction. Phosphorus is determined colorimetrically using the Technicon AAII Auto-analyser, while the cations are determined using Atomic Absorption Spectrophotometer (Model Buck 211) and /or by ICP-OES (Perkin Elmer Optima 8000). A. Mehlich (1984). Mehlich 3 soil test extractant: A modification of Mehlich 2 extractant. Commun. in Soil Sci. Plant Anal., 15(12), 1409-1416.
5. Exchangeable Acidity is determined by titration method after extraction with 1N KCl.

Anderson. J.M and Ingram J.S (1993). TSBF a handbook of methods. 221p.

6. Bray -1- P in soil. Bray, R. H and L.T Kurtz, 1945. Determination of total and organic and available phosphorous in soils. Soil Sci. 59:39-45.
7. Olsen P in soil. Olsen, S.R, C.V. Cole, F.S Watanabe and L.A Dean (1954). Estimation of available phosphorous in soils by extraction with sodium bicarbonate. U.S.D.A, Circ.939.
8. ECEC is by sum of exchangeable cations and exchangeable Acidity.
9. Soil particle size analysis is done by the hydrometer method.
   Bouyoucos G.H. (1951). A recalibration of the hydrometer for making mechanic analysis of soils. Agron. Jour. 43:434 – 438.

All samples were prepared and analyzed by IITA Laboratory services at Kalambo DRC and supported by CropNuts Lab Services in Kenya. Data quality control was done by IITA-Soil Management unit and the GIS mapping was done by IITA Geospatial Lab.

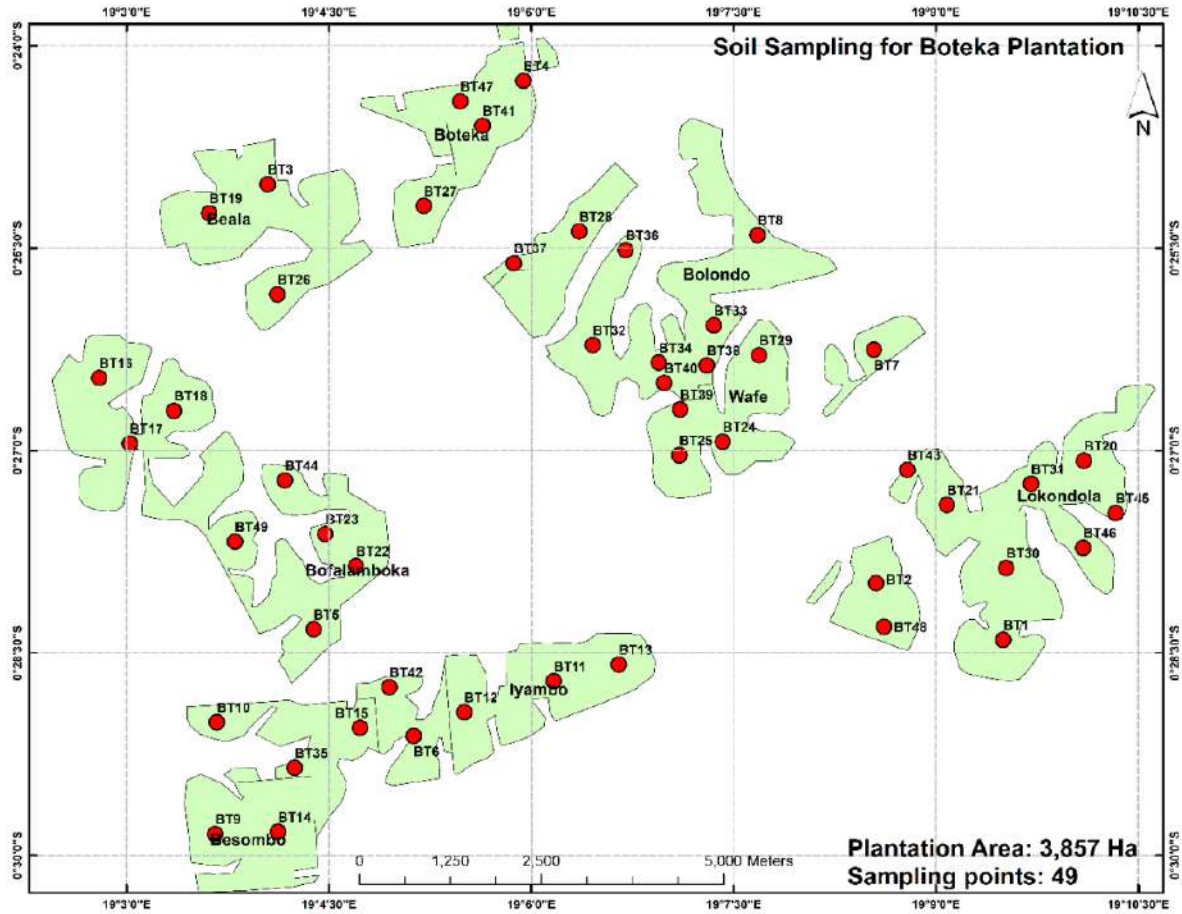
Geospatial analysis

The Empirical Bayesian Regression Kriging (EBRK) was first employed to generate soil property maps. Further analysis indicates that while the semi-variogram model showed some spatial structure, Inverse Distance Weight (IDW) was a more accurate interpolation method for these plantations, given the regular distribution of the sampling points. However, the question was whether meaningful spatial patterns would result, given the relatively little variation in the soil properties in relation to the measurement precision of the soil properties associated with the methods and apparatus used for the analysis. When some meaningful and consistent patterns were observed for the various soil properties the IDW method was subsequently used for generating all the soil property maps. It is noted that IDW is best when data points are evenly distributed and of high density, and when the data in terms of precision of the measurement is of high quality, as in our study. IDW interpolation explicitly assumes that things close to one another are more alike than those farther apart. IDW uses the measured values surrounding the prediction location to predict a value for any unmeasured location. The measured values closest to the prediction location have more influence on the predicted value than those farther away. IDW assumes that each measured point has a local influence that diminishes with distance. It gives greater weights to points closest to the prediction location, and the weights diminish as a function of distance; hence the name inverse distance weighted.

Results and Recommendations

Boteka Plantation

Boteka plantation is the smallest of the three PHC plantation in DRC and it covers approximately 3,857 hectares. It is located north of Kinshasa, close to Mbandaka which is on the Congo River. Following a general methodology previously described, 49 sampling points were mapped out for observation and soil sample collection (See Map 1).



MAP 1. Sampling points at the Boteka plantation

Land and Soil characteristics and fertility conditions

Soil physical characteristics

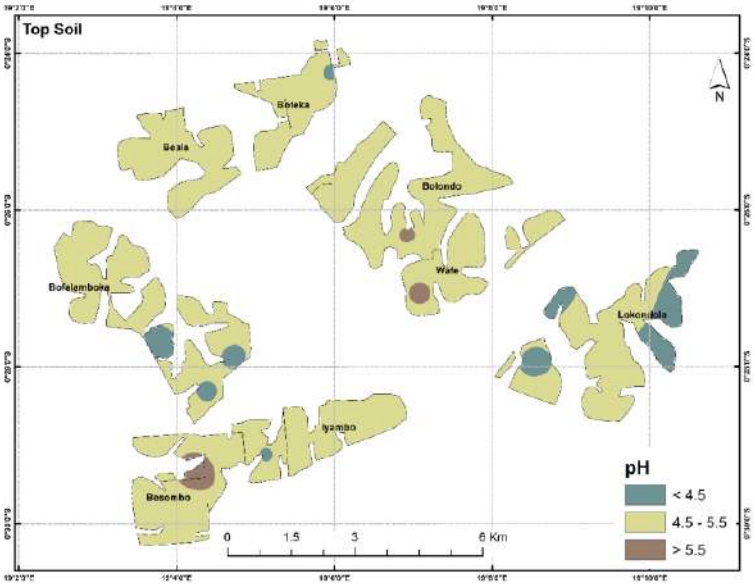
The land is homogenous in terms of soil physical conditions. The general topography of the land is gently undulating terrain, with most of the land being flat or almost flat to gently sloping (See Appendix 2). The soil is very deep with the soil depth generally extending beyond 120 cm and with very little variation. The soil is also well-drained, and with the being very deep there are no rooting restrictions expected. There are no stones large enough to interfere with tillage operations. The soil is essentially a very dark brown sandy loam overlaying a yellowish brown a sandy loam or sandy clay loam subsoil, indicating that there is clay accumulation with depth. This is particularly important for soil moisture retention and proper anchorage of plant roots. There are very little to no variations within the blocks regarding soil depth, colour, drainage condition, and other soil physical conditions. The sand content of the topsoil varies between 74% and 89%; silt content varies from 4 to 16% and the clay content ranges between 2 and 11%. For the subsoil the sand content ranges between 68% and 86%, silt content ranges between 4% and 16% and clay content is in the range of 5% to 24%.

Soil pH

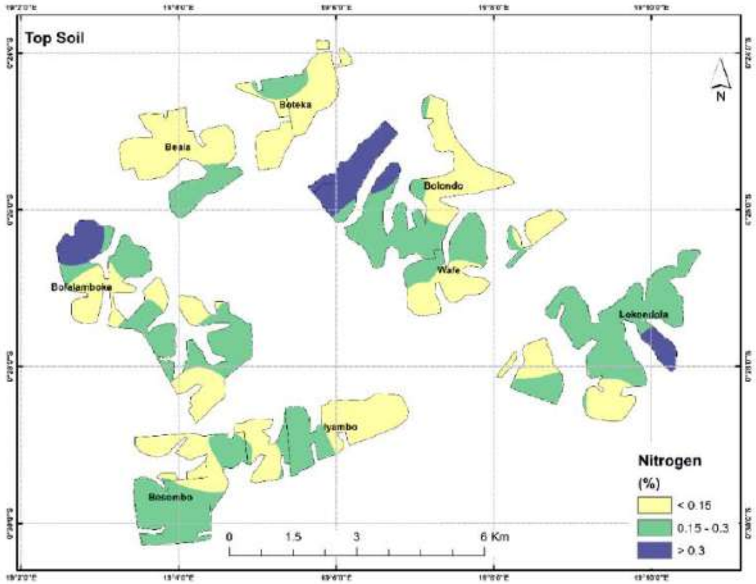
Soil pH is an important variable in soils because it controls many chemical and biochemical processes. It is a measure of the acidity or alkalinity of the soil. Soil pH is critical in crop production because it regulates plant nutrient availability by controlling the chemical form and influences chemical reactions that may make the compound more or less soluble and therefore more or less available for plant uptake. As a result, soil and crop productivity are linked to soil pH values. In terms of spatial variability, Bofamlamboka division and the east of Lokondola division have relatively higher pH values (Map 2). The soil is strongly acid with the soil pH generally below 5.5. This condition is suboptimum for oil palm, and this will affect nutrient availability particularly phosphorus and may also induce micronutrient toxicity. Though palms have good tolerance for acid soils, effort should be made to raise the soil pH through liming.

Soil organic carbon/matter

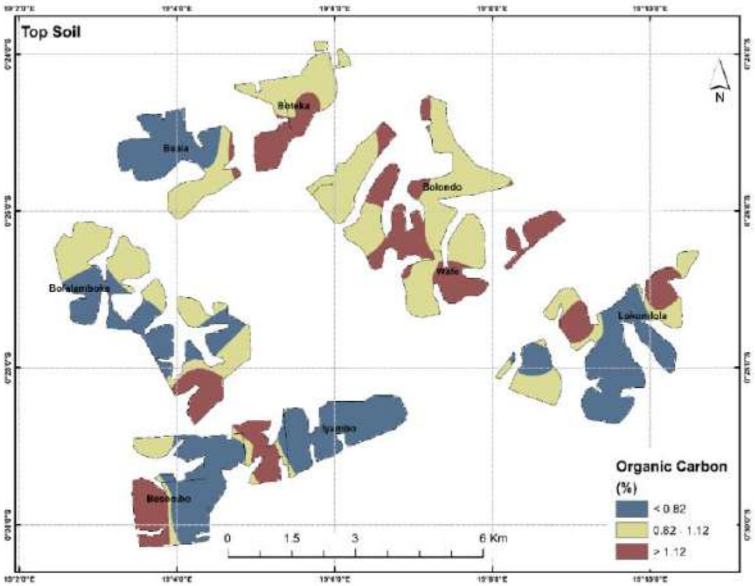
Soil organic matter is a key determinant of soil fertility. Soil organic matter content is a function of organic matter inputs (residues and roots) and litter decomposition. Soil organic matter serves as a reservoir of nutrients for crops, affects soil aggregation, increases nutrient exchange, retains moisture, reduces compaction, reduces surface crusting, and increases water infiltration. Nutrient exchange between organic matter, water, and soil is essential to soil fertility and must be maintained for sustainable production. Land use and management practices affect soil organic matter levels. Soil organic carbon (SOC) is a measurable component of soil organic matter. The soil organic carbon varies between very low and adequate but with a greater proportion of soils with low organic carbon content. Bolondo and Boteka divisions have adequate to high levels of SOC (SOC > 1.2%). Besombo division and northeast of Lokondola are critically low in SOC (SOC < 0.7%, Map 3). In sandy soils such as are found at Boteka, soil fertility is mainly determined by soil organic matter content. This is a significant concern in the soil improvement plans for the plantation. The average SOC is 0.8%, and to bring this to a minimum requirement of 1.2% would require about 12 t/ha of organic carbon (21 t/ha of organic matter) to be added to the soil. This implies that if poultry manure with 30% organic carbon is to be used, 40 t/ha of the poultry manure would be needed, for example. This amount cannot be applied once but should be considered in a space of 3 – 5 years. Rather than applying manure from external sources, compost generated from the waste of bunches after processing or from other organic resources from the plantation should be considered.



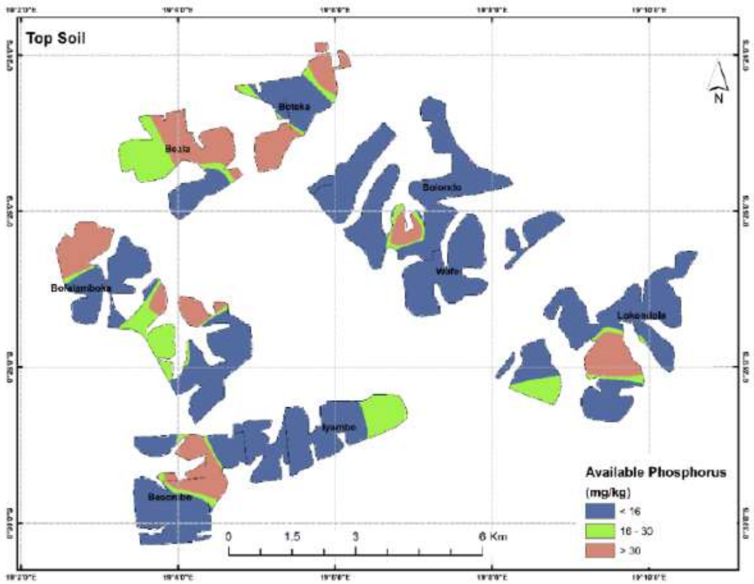
Map 2. Soil pH distribution at Boteka plantation (topsoil)



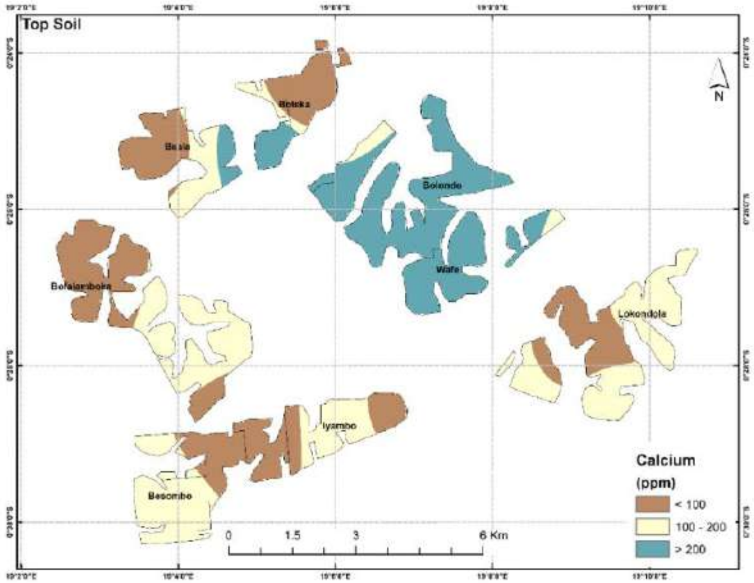
Map 4. Distribution of total soil nitrogen within Boteka plantation



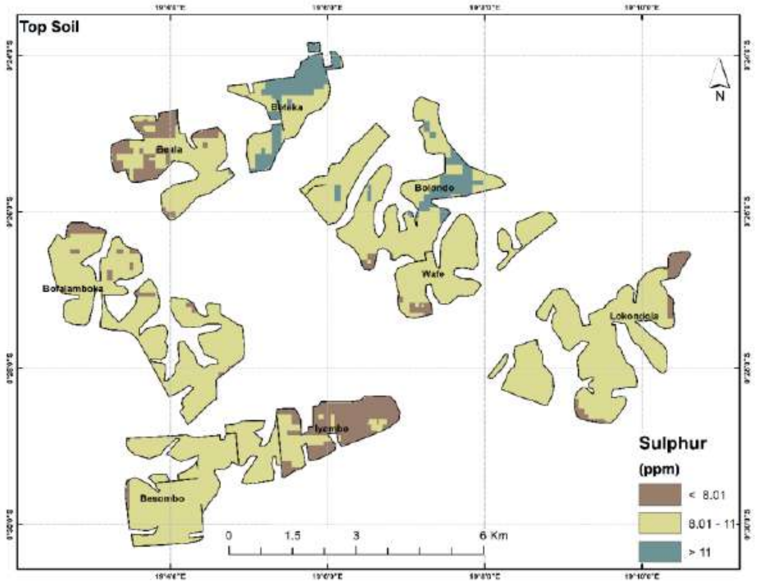
Map 3. Distribution of soil organic carbon within the Boteka plantation



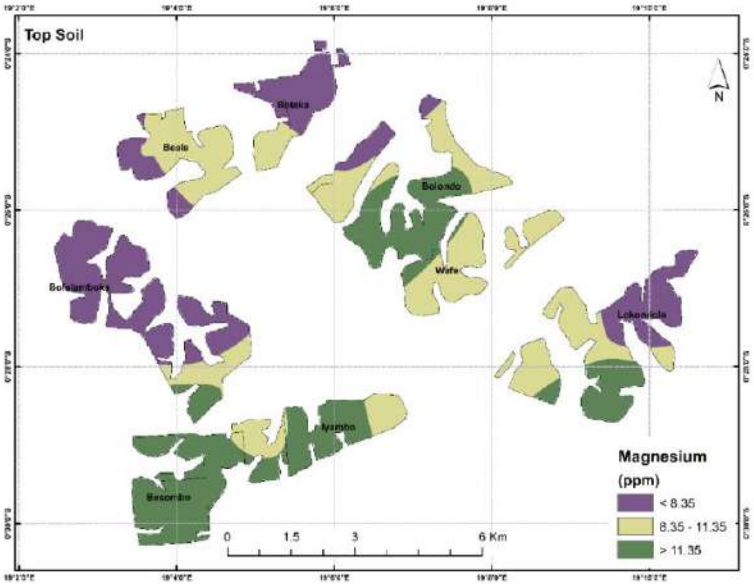
Map 5. Distribution of available phosphorus in the soils of Boteka plantation



Map 6. Distribution of exchangeable calcium in the soils of Boteka plantation



Map 8. Distribution of Sulphur in the soils of Boteka plantation



Map 7. Distribution of exchangeable magnesium in the soils of Boteka plantation

Soil total nitrogen

Nitrogen is an essential primary nutrient for plant growth and development. Soil total nitrogen is closely associated with soil organic matter content in a tropical and highly weathered soils except where intensive management has been imposed. The soils are relatively rich in nitrogen because of the application of nitrogen containing fertilizer. The Besombo southwest, Lokondola, and east and central parts of Bolondo are particularly rich in nitrogen (See Map 4). Beyala section and Bofalamboka division are areas of low nitrogen content in the soil.

Available phosphorus

The concentration of phosphorus in the soil is also related to the amount of soil organic matter. Soils with low organic carbon are also likely to be deficient in phosphorus, except in cases where deliberate actions have been taken to improve the P fertility as in the case of Boteka. The soils are for the larger part low in available phosphorus (<16 ppm). However, there are parts that are adequate and even high in available P. Bofalamboka South, Besombo East and Lokondola Northeast have soils with are high in available phosphorus (Map 5). With depth the available phosphorus varies considerably, and it is critically low in the subsoil (see Appendix 1). This confirms that the high level of phosphorus in the topsoil is because of previous fertilization and not from the soil parent materials.

Exchangeable potassium

Potassium is among the three essential primary nutrients needed for the growth and development of plants and this is particularly needed by oil palm for fruiting among other processes. Exchangeable potassium is critically low, and this condition is uniform across the different divisions and blocks of Boteka plantation. These soils are naturally low in potassium, because of nutrient leaching and because of the low K content of the assumed parent material. Picture 1 provides evidence of potassium deficiency in the palm leaflets at Beala division of the plantation

Exchangeable calcium and magnesium

Calcium is one of the soil essential secondary plant nutrients. Calcium varies between and within the divisions and blocks at Boteka. Bolondo division, Boteka, Besombo and southwest Bofalamboka subdivisions are areas with adequate calcium levels (Map 6). Beala, Iyambo and Lokondola represents areas of low calcium content in the soils.

Magnesium is an essential element for photosynthesis in plants. Magnesium is critically low across the soils of Boteka plantation. There seems to be a clear spatial pattern where Iyambo, Bolondo, and Bofalamboka divisions have relatively higher magnesium content (Map 7) though still within the range of extremely low concentrations. Magnesium is critically low at Lokondola among others with obvious deficiency symptoms (See Picture 2). Magnesium is relevant because it seems to influence the sex ratio in that it increases the number of female inflorescence and herewith the oil production.

Sulphur

Sulphur is one of the secondary essential nutrients. It is especially relevant for oil palm because it is an essential element in the synthesis of oil in the fruit. Sulphur varies between very low and low across Boteka plantation. The areas with very low S are more prevalent and cut across the different divisions of the plantation. Boteka division and the central section of Bolondo division have the highest sulphur concentration in the soil (Map 8) though still within the low threshold.

Picture 1. Palm leaflets showing potassium deficiency at BT19 in Beala division of Boteka plantation

Picture 2. Magnesium deficiency at BT1 (Lokondola south)

Cation exchange capacity

Cation exchange capacity (CEC) is the ability of the soil to hold or store cations. Negatively charged soil particles 'attract' and hold on to cations (positively charged ions), stopping them from being leached down the soil profile. The cations held by the soil particles are called exchangeable cations. As CEC measures a soil's ability to hold and buffer nutrients, it is a crucial determinant of soil fertility. Soils at Boteka plantation are generally low in CEC with values ranging between 2.9 and 6.8 cmol/kg. Soils with low CEC are easily deficient in cations and will impact on recovery rates of nutrients applied. The recommended application rate of soil organic matter would directly impact the capacity of the soil CEC.

Soil micronutrients

Micronutrients such as manganese, iron, boron, copper, and zinc play essential roles in photosynthesis and other processes towards a healthy and productive plant. Manganese, boron, copper and zinc are either low or critically low and with very little spatial variability across the different sections of Boteka plantation. Iron is, however, at high concentrations in the soil (see Appendix 1).

Palm foliage assessment at Boteka

Plant nutrient concentrations

The assessment of nutrient concentrations in the leaves of the oil palms were made at each sampling points within the plantation. Nitrogen concentrations in the leaf ranges from 2.46 to 3.08% with little spatial variation. The nitrogen values are within the adequate threshold with some few points within the high threshold. This implies that nitrogen is not deficient in the palm foliage. The north of Beala, east of Iyambo and south of Lokondola and Bofalaboka have palms with high concentration of nitrogen in the foliage (Map 9).

The concentration of phosphorus in the foliage varies within a narrow range from 0.13 to 0.17%. The critical level for the phosphorus being low is set at 0.15%. The level of phosphorus concentration in the leaves is therefore on the low side, throughout the plantation. The southern and western sections of Lokondola, south of Boteka and Beala, and north of Bolondo have foliage which are low in phosphorus (Map 10). Besombo, western Iyambo, Southern Bofolamboka, north Boteka, and Wafe have palms with just about adequate phosphorus concentrations in the leaves.

Potassium concentration of the foliage varies between 0.53 (low) and 1.01% (adequate) with the majority of points falling in the category of low K than there are with adequate K. One point is ranked as very low (< 0.25 %). West of Bofalamboka, north of Boteka, northwest Beala, central Besombo and west Iyambo have adequate level of potassium in the palm leaves (Map 11).

Calcium varies considerably in the palm foliage at Boteka, being low (brown) at some blocks, adequate (green) in some and high (blue) in others (Map 12). The spatial distribution of calcium concentration in the leaves is patchy and palms with high or low calcium concentration are not concentrated to a particular division of the plantation. Bolondo and Wafe have palm leaves that are either adequate or high in calcium.

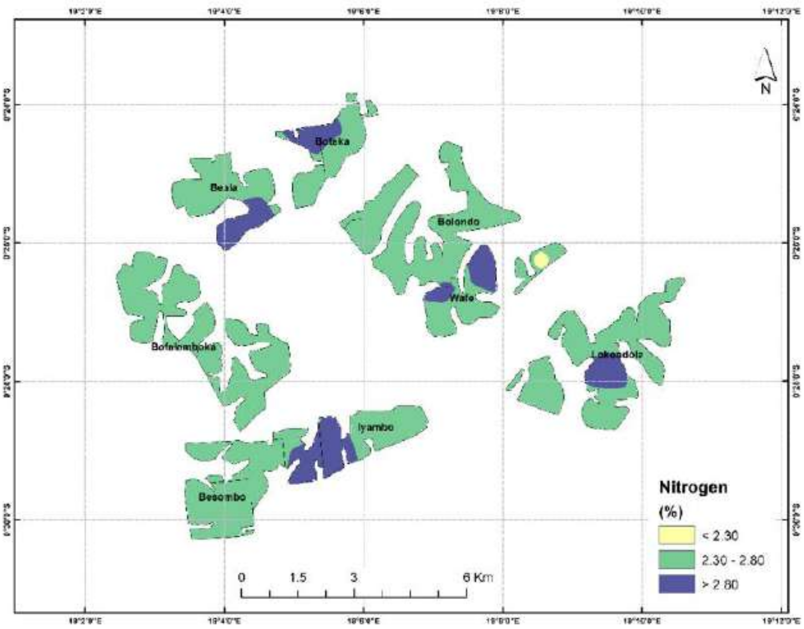
Magnesium on the other hand varies from being very low (< 0.1%) to low and there are no regions of adequate magnesium concentrations in the foliage across the entire Boteka plantation. Bofalamboka, Beala, and Boteka are regions with palms which are critically low in magnesium concentration in the foliage (Map 13).

Sulphur concentration in the foliage is generally low and the situation is more critical at Iyambo, Wafe and Bofalamboka divisions of the plantation (Map 14). Note that the value ranges displayed in the maps are chosen such that the pattern becomes most visible, and the values of the class boundaries do not necessarily coincide with the critical levels used for determining adequacy of the nutrient concentrations

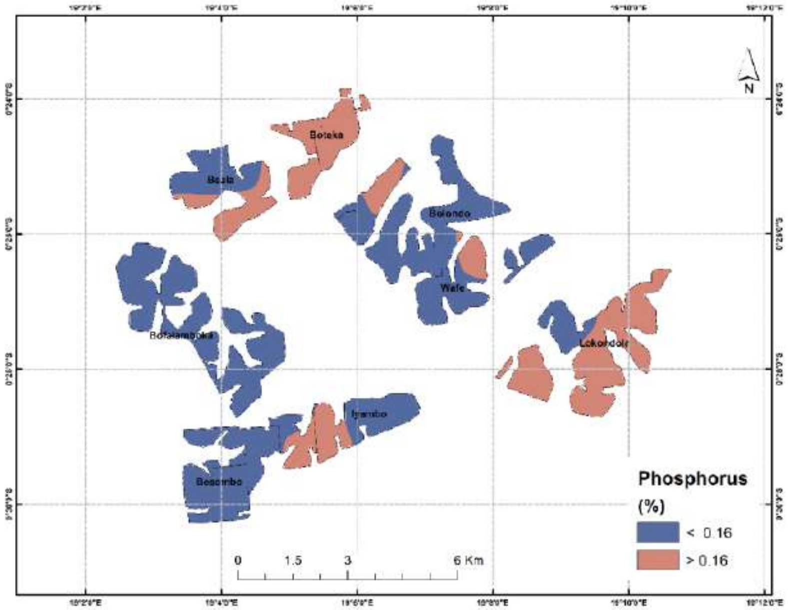
Chlorine concentration is low in 60% of the cases, but not actually deficient anywhere. In the remaining 40% of the cases the chlorine content seems at optimum or adequate levels

Sex ratio

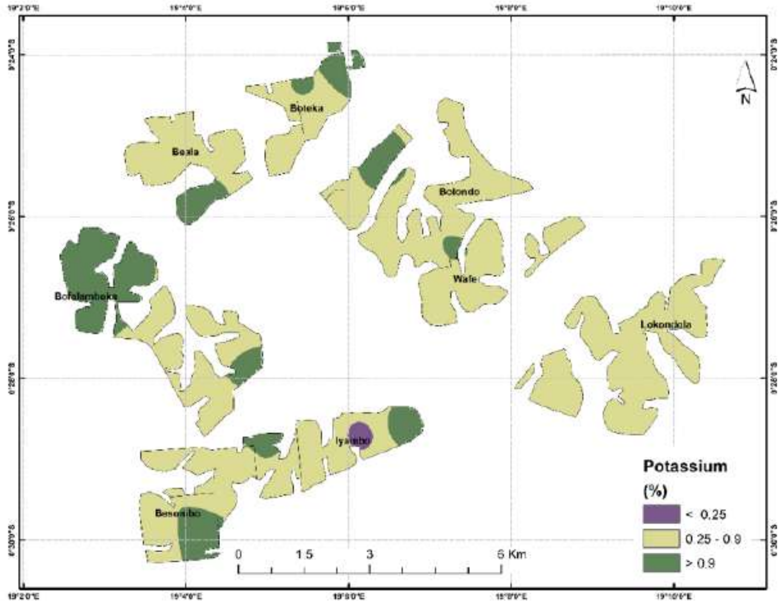
Evaluation of sex ratio was conducted as part of efforts to determine the productivity of the palms. The closer the ratio is to 1 the more the dominance of the female florescence. Generally, the palms are productive with an average sex ratio of around 0.5. For Boteka, we found an average sex ratio for the whole plantation of 0.55. Some parts have a clearly higher sex ratio and some parts a clearly lower sex ratio (see Map 15). Beala, Bofalamboka and Lokondola divisions have the highest sex ratios, greater than 0.6. This implies that female flowers were predominant in the divisions as compared to Bolondo among others. It is for the production manager to find what this is related to (e.g., age of the trees) and whether this is reflected in the production and yield.



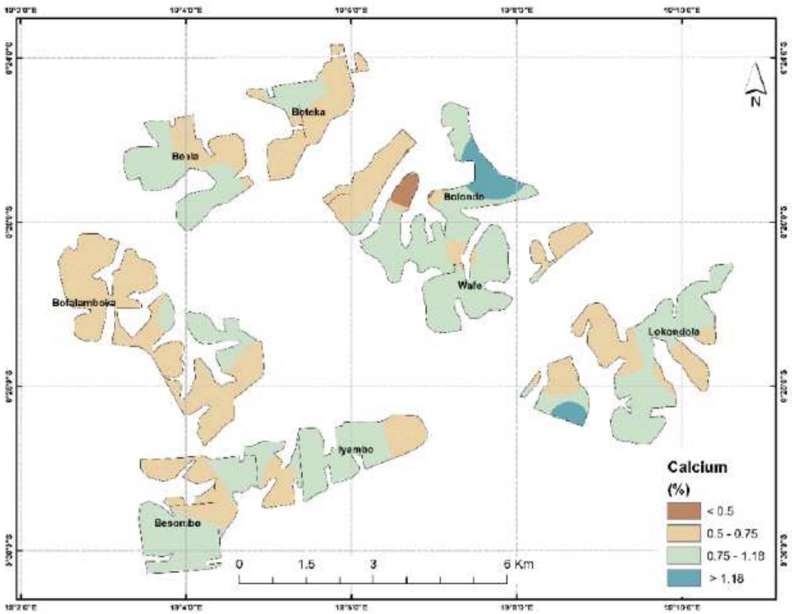
Map 9. Nitrogen concentration in palm foliage at Boteka plantation



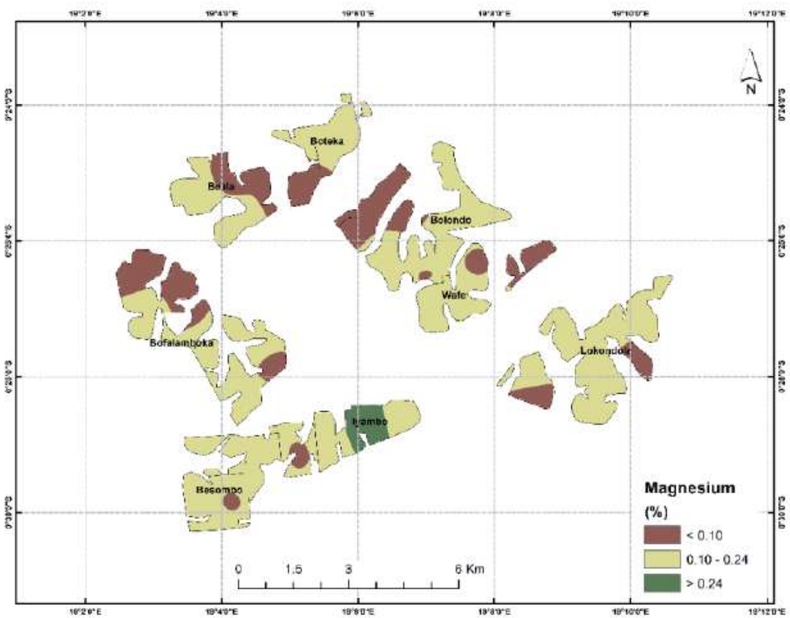
Map 10. Phosphorus concentration in palm foliage at Boteka plantation



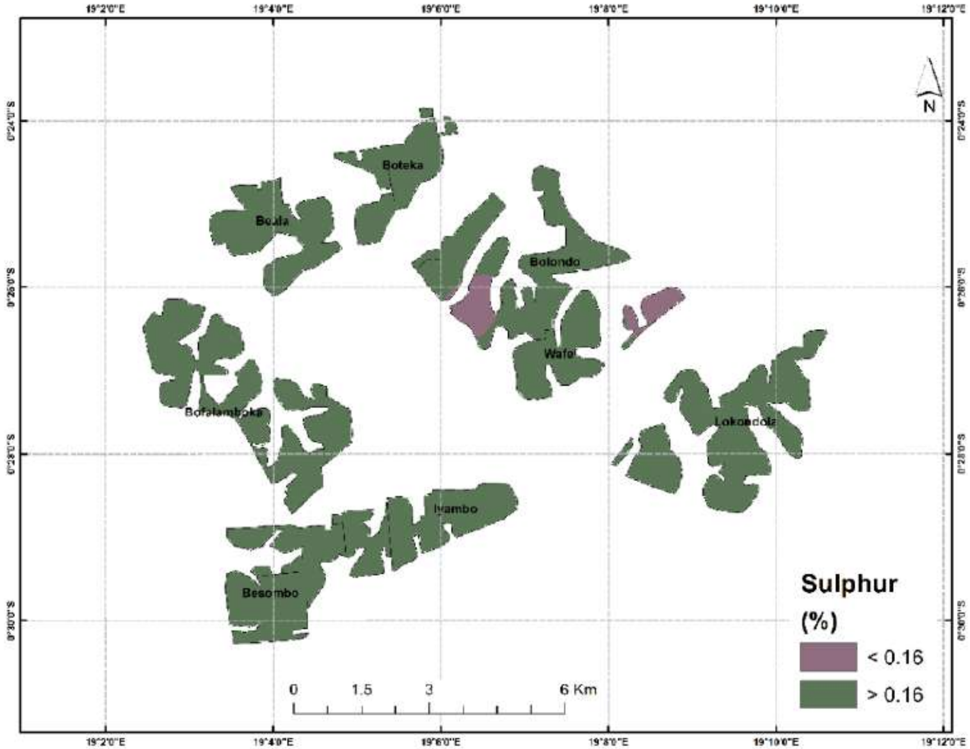
Map 11. Potassium concentration in palm foliage at Boteka plantation



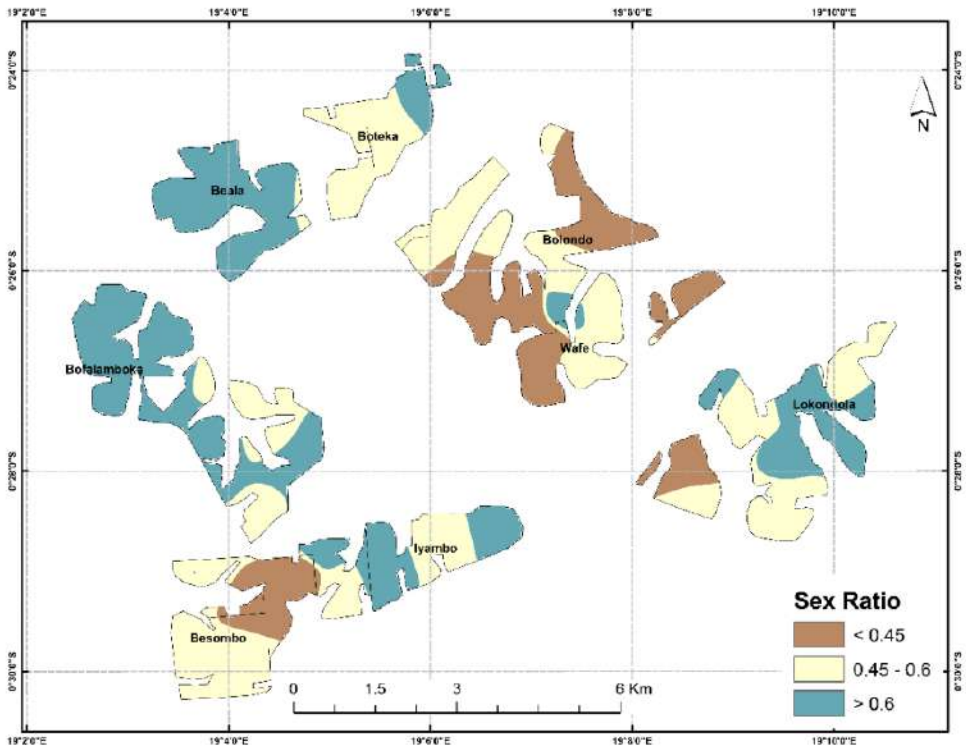
Map 12. Calcium concentration in palm foliage at Boteka plantation



Map 13. Magnesium concentration in palm foliage at Boteka plantation



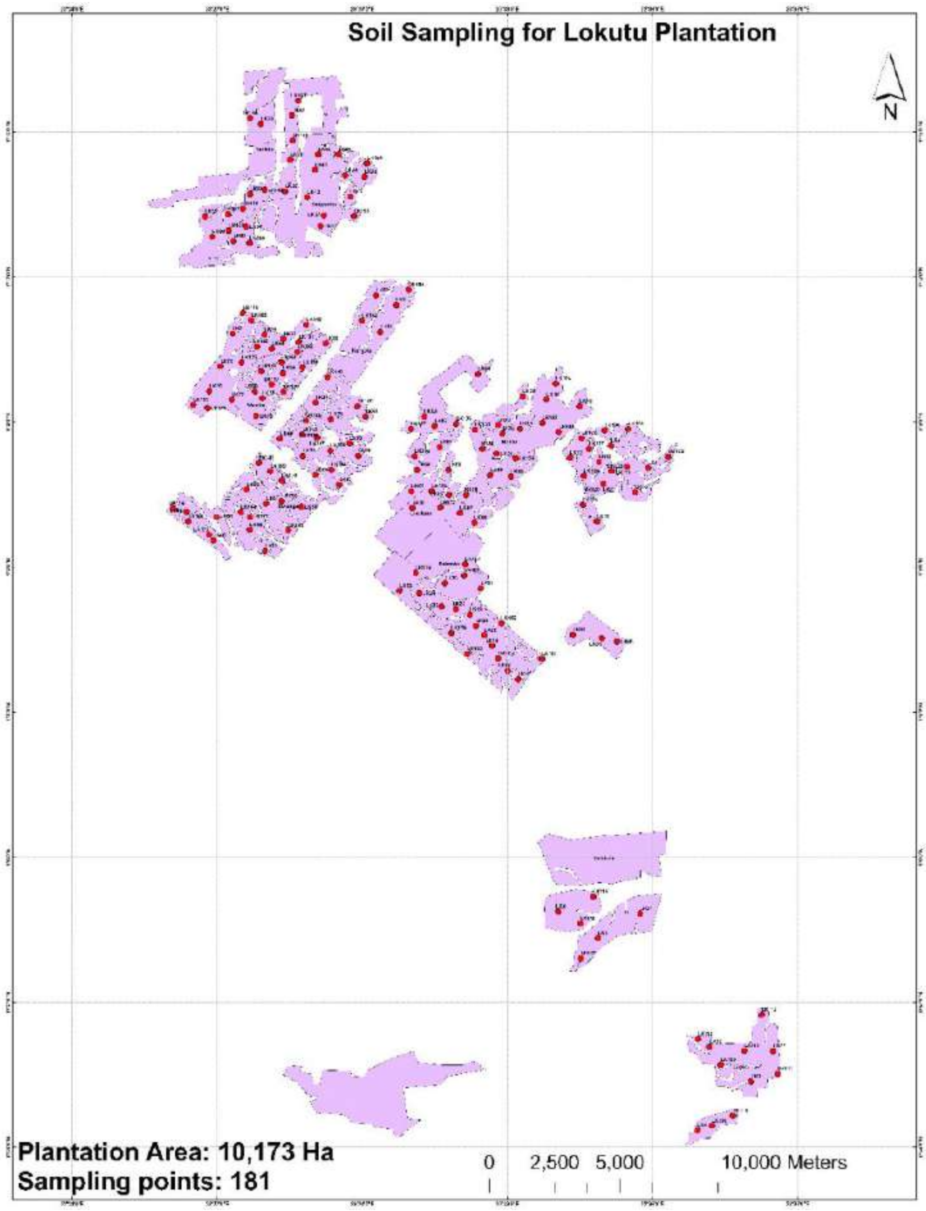
Map 14. Sulphur concentration in palm foliage at Boteka plantation



Map 15. Distribution of sex ratio at Boteka plantation

Lokutu Plantation

Lokutu plantation is the largest of the three PHC plantation in DRC and it covers approximately 10,173 hectares, excluding old plantations. It is located at about 261 km northwest of Kisangani, DR Congo. Following a general methodology previously described, 181 sampling points were mapped out for observation and soil sample collection (See Map 16) and of these 174 sampling points were surveyed. Some parts of the plantation could not be reached because of the poor condition on the road.



MAP 16. Sampling points at Lokutu plantation

Land and Soil characteristics and fertility conditions, Lokutu

Soil physical characteristics

The land is homogenous in terms of soil physical conditions. The general topography of the land is gently undulating terrain, with the majority of the land being flat or almost flat to gently sloping (See Appendix 4) but with higher proportion of flat than sloping lands. The soil is very deep with the soil depth generally extending beyond 120 cm with no spatial variations. The soil is also well-drained and with the deep nature of the soil, there are no rooting restrictions expected. Stones either on the surface or within the profile considerably limited or absent in most cases. Generally, the soil is typical a dark brown sandy clay loam with some little colour and textural variations.

The sand content, and consequently the clay content, varies both in the topsoil and in the subsoil. The percentage sand varies between 51% to 92% for the topsoil with similar variation for the subsoil. Likakasa, Bolanga, Kangala and Wamba north divisions have lower sand content of less than 72%. Locumete estate, Makav division, Wamba south are areas with high sand content greater than 76%. The silt content of the soil is very low and does not vary significantly. Yambula division has relatively higher silt content among others. Consequently, the sand and clay content are inversely related, implying that divisions or blocks with higher sand content have lower clay content and vice versa. In all, the soil falls within 3 textural classes, namely: sandy clay loam, sandy loam and loamy sand. About 70% of the soils fall within the sandy clay loam. The maps of the soil particle sizes are presented in the Appendix 4. The soil has a good level of clay varying between 7 and 43% clay content, important for soil moisture retention and proper anchorage of plant roots. There is generally an increase of clay content with depth for the individual soil profile because of clay illuviation.

The soil is strongly acid with the soil pH values varying between 4.9 and 5.2. Yalikito estate and Wamba division are zones with relatively higher pH values. Mosite estate and Bolembo division are zones with the lowest pH values (Map 17). The pH condition of the entire plantation at Lokutu is suboptimum for palms and this will affect nutrient availability particularly phosphorus and may also induce micronutrient toxicity. As already noted, palms have good tolerance for acid soils though symptoms of hyperacidity has started to show at LK77 (See Picture 3). Effort should be made to raise the soil pH through liming.

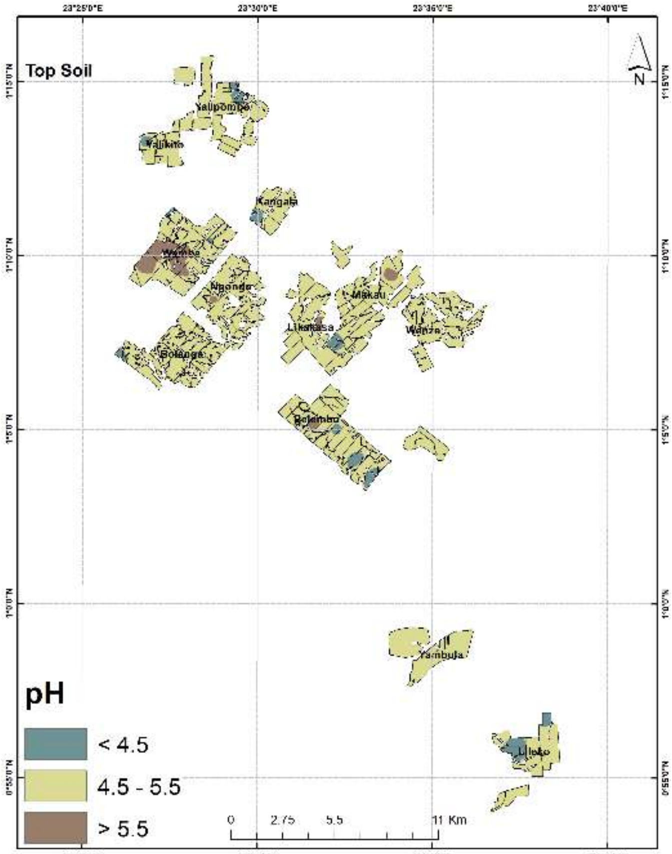
Soil organic carbon/matter

Soil organic carbon varies between very low and low but with a greater proportion of soils which are very low organic carbon. Soil organic carbon is very low across the entire Irumu estate (Map 18). Bolanga division within the Ugungu estate and Wamba north have soils with relatively high SOC though still within the low threshold (SOC<1.2%).

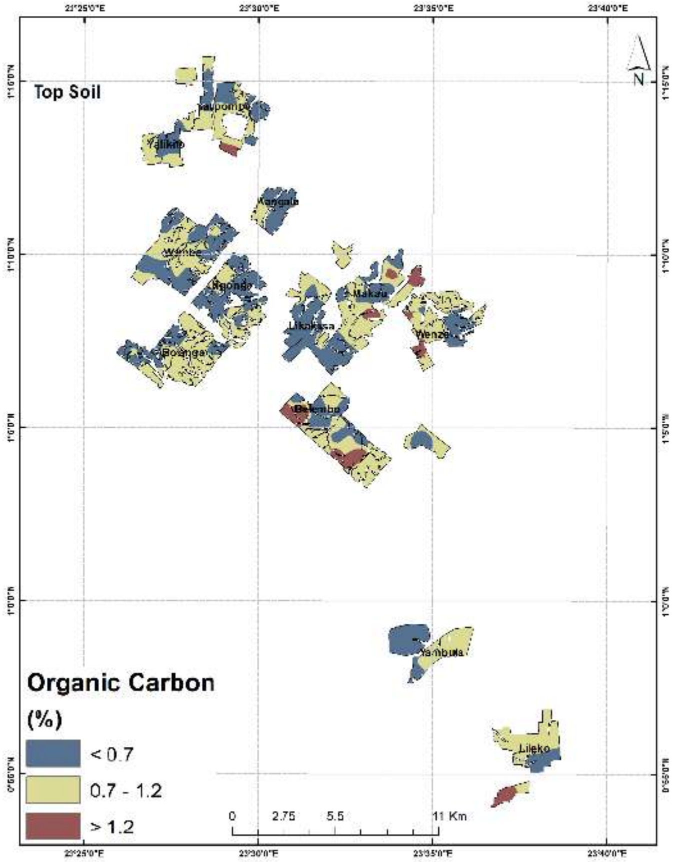
Soil total nitrogen, available phosphorus and exchangeable potassium

The soils are relatively rich in nitrogen and varies from being low to adequate within and between the different blocks. Bolanga and Bolembo divisions, Mosite estate, south of Wamba and north of Yalipombo divsions have soils with adequate nitrogen level. Soils of Makav among others are low in nitrogen (See Map 19). There is some correlation between the SOC and Total Nitrogen distribution patterns, as you would expect in natural situations, but in this case the pattern is mainly explained by nutrient management, and especially with application of N-based fertilizer.

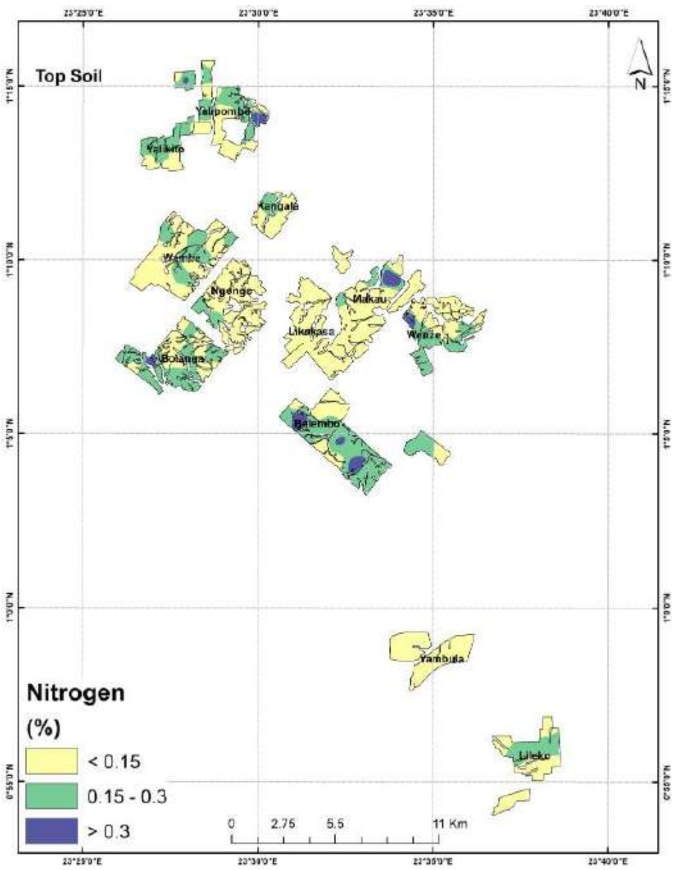
The soils are very poor in phosphorus concentration, which is consistent with the general low pH levels. Ugungu and mosite estates are among the poorest in phosphorus content of the soils (Map 20).



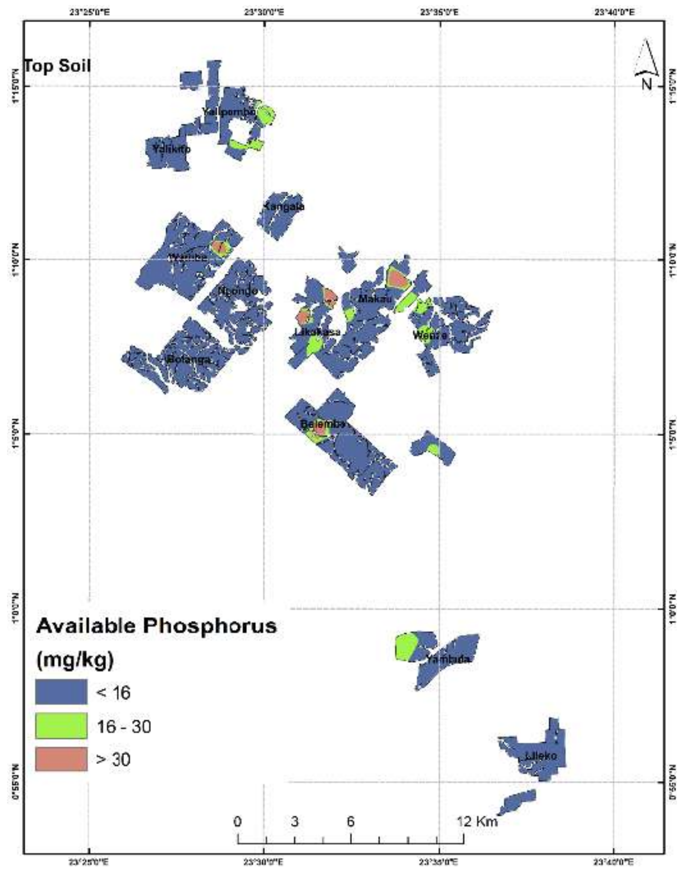
Map 17. Soil pH distribution at Lokutu plantation



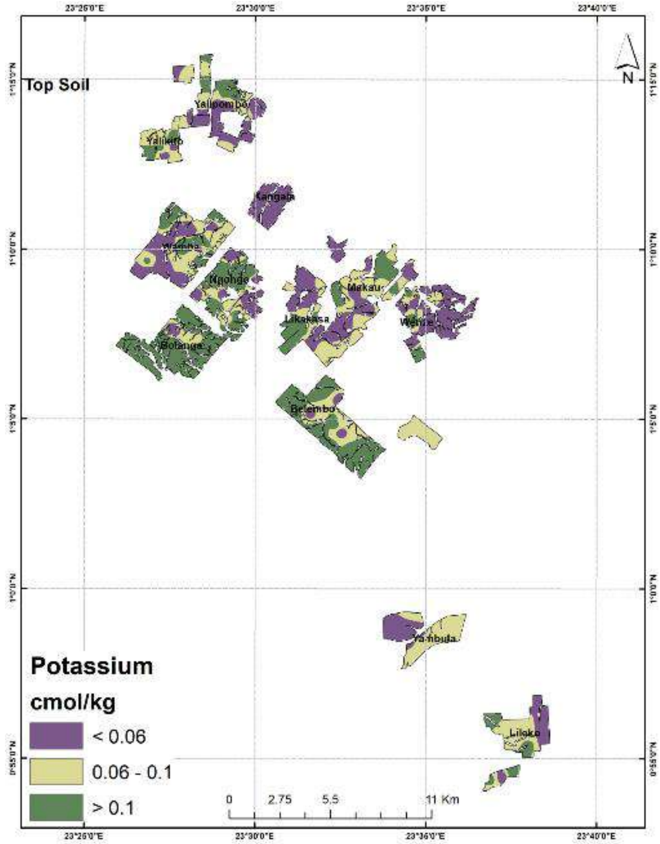
Map 18. Soil organic carbon at Lokutu



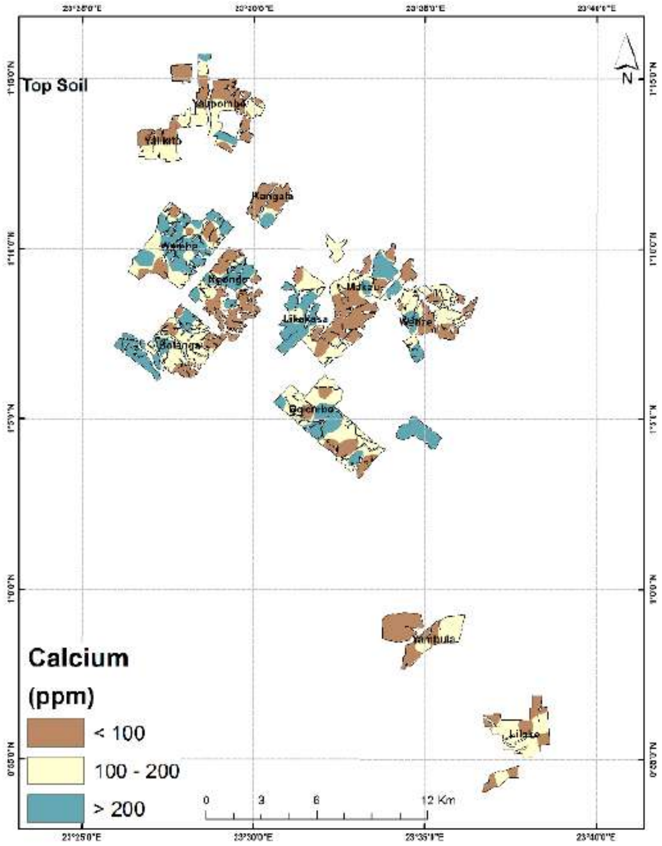
Map 19. Soil nitrogen distribution at Lokutu



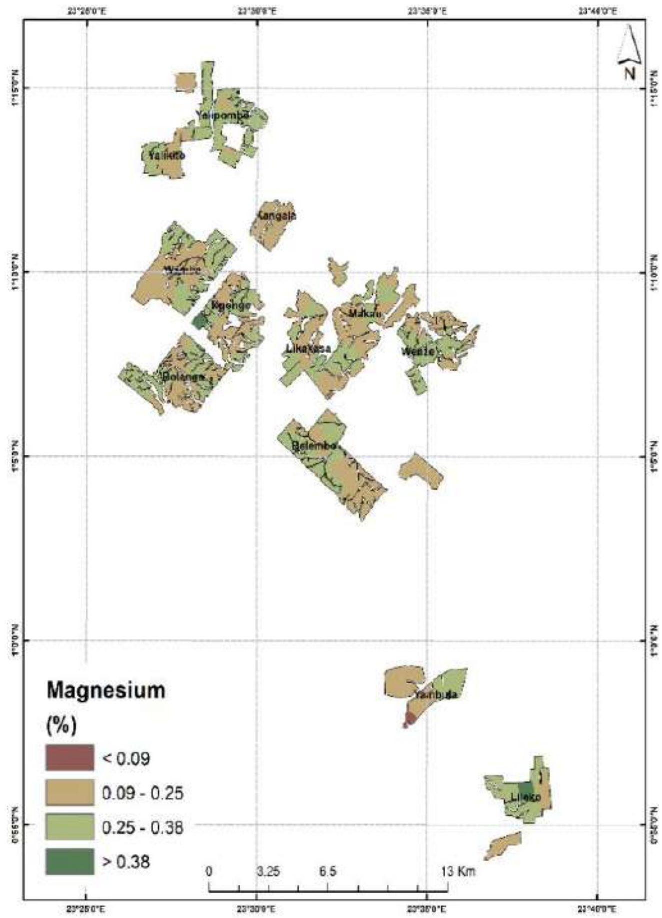
Map 20. Soil available phosphorus distribution



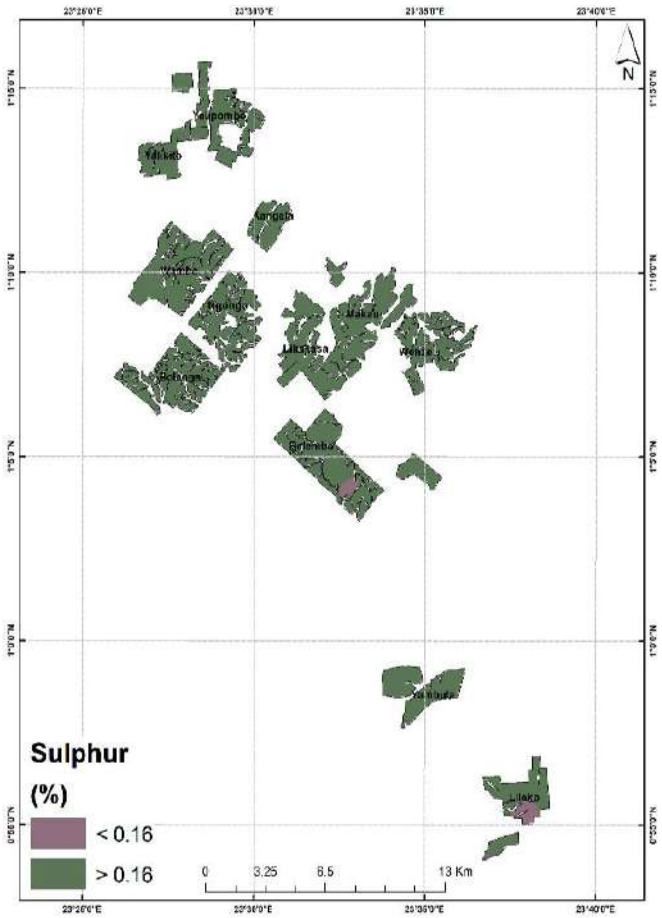
Map 21. Distribution of soil exchangeable potassium



Map 22. Exchangeable calcium



Map 23. Exchangeable magnesium



Map 24. Sulphur distribution

Picture 3. Symptoms of hyperacidity or oil palm wilt disease caused by Fusarium oxysporum

Exchangeable potassium is critically low in the soils at Lokutu and the values are generally below 0.30 cmol/kg. This shows the palms are likely to suffer K deficiencies if enough applications of K fertilizers are not applied (See Picture 4). There is a mall spatial variability of K within the subdivisions of the estates. Mosite estate, Yalikito division and most parts of Ugungu estate have higher potassium concentrations relative to the other zones (See Map 21).

Picture 4. Potassium deficiency in palm leaflets at LK100 –Likakasa division

Calcium, magnesium and sulphur

There is little variability with respect to calcium distribution in the soils at Lokutu (Map 22). The soils are generally low in calcium content. Similar to calcium is the magnesium concentrations in the soils. The soils are critically low in magnesium and shows little variability across the plantation (Map 23). Sulphur is also low in the soils of Lokutu and Sulphur is also low in the soils of Lokutu and vary slightly across the estates (Map 24). The soils of Mosite estate, Bolembo and Bolanga divisions are relatively high in Sulphur though within the low threshold.

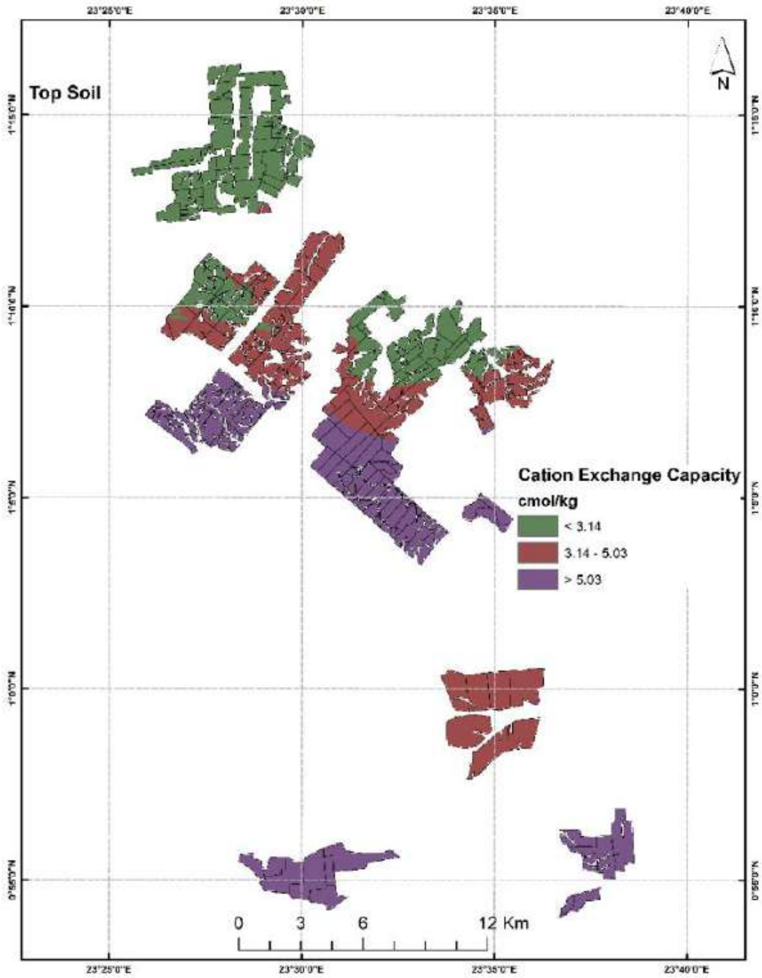
Cation exchange capacity

The capacity of the soils to hold nutrients is considerably low across Lokutu plantation. There is clear spatial pattern in the distribution though irrespective of the values being low throughout. Bolanga, Bolembo and Lileko divisions have slightly higher CEC (Map 25). The low CEC of the soil is a complete reflection of the low organic matter content of the soils.

Soil micronutrients

Micronutrients such as manganese, iron, boron, copper, and zinc play essential roles in plant metabolism. Manganese and boron are generally low in the soils of Lokutu with the deficiency of boron being the most critical. Picture 5 shows crinkled leaves -evidence of boron deficiency in the leaflets at Wamba division of Lokutu plantation. Iron is adequate across the plantation. Copper and Zinc are also low but with some zones of adequate level of the nutrients. Copper is adequate in the soils of Bolanga, Kangala and Wenze divisions while Ugungu estate have soils which are adequate in zinc concentration (See Appendix 1).

Picture 5. Crinkled leaflets indicating boron deficiency at LK77 in Wamba division of Lokutu



Map 25. Distribution of cation exchange capacity of the soils

Palm foliage assessment at Lokutu

Plant nutrient concentrations

The assessment of nutrient concentrations in the leaves of the oil palms were made at each sampling points within Lokutu plantation. Nitrogen concentrations in the leaves range from 2.63 to 2.74% with little spatial variations. Nitrogen concentration in the palm foliage at Lokutu is slightly lower and less variable compared to Boteka. The nitrogen values are within the adequate threshold with some few points within the high range. Palm leaves at Locumete estate have the highest nitrogen and this is followed by Ugungu estate (Map 26).

The concentrations of phosphorus in the leaves across Lokutu plantation is low but not critically low, and rather tending more towards adequate level. The range within which the phosphorus content varies is very small and there is also very little spatial variation in phosphorus concentration in the foliage. The pattern visible in Map 27 is just because the critical level for low phosphorus content is set at 15.5%.

Potassium concentration in the palm leaves varies being low (< 0.9%) and being adequate, and with a few points even falling in the high range (> 1.20%). Bolembo and the north of Locumete estate as well as Mosite estate have palms with adequate potassium concentration in the leaves (Map 28). Wenze, Kanga and Ngongo divisions have low K concentrations in the palm foliage.

Calcium is generally not limiting in the palm leaves across Lokutu plantation. Ungungu estate and some parts of Yalikito and Yalipombo show a high calcium concentration in the palm leaves (Map 29).

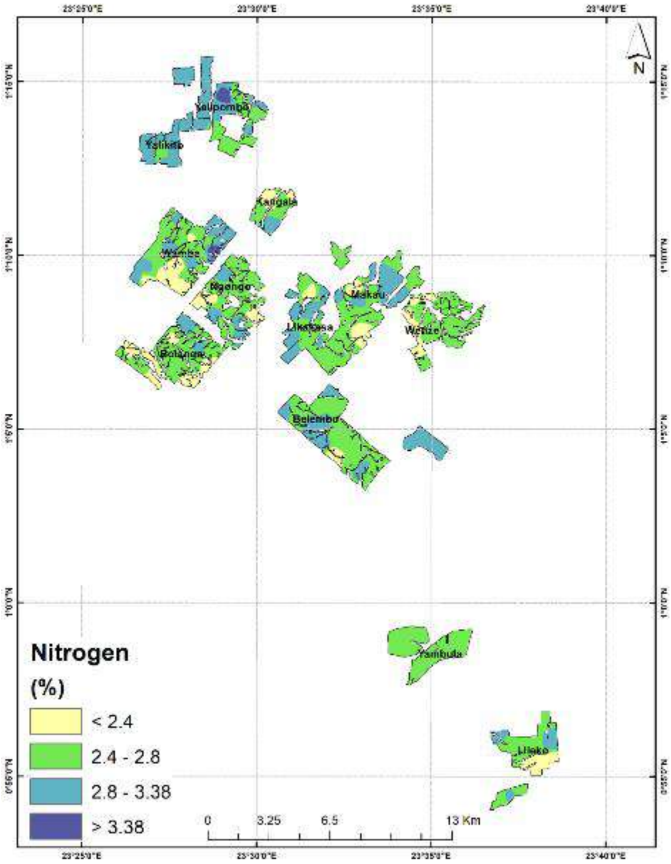
Magnesium varies across the different subdivisions of the plantation. About 50% of the plantation has palms with adequate magnesium level in the foliage. This magnesium rich foliage is found in south Likakasa, west Bolembo, Yalipombo and Yambula divisions of the plantation (Map 30). Wenze, Makau, Kangala, Yalikito and Wamba divisions are areas of concern with respect to possibility of magnesium limitation in the palms.

Sulphur concentration in the foliage is generally low and the situation is more critical at Wenze division (Map 31).

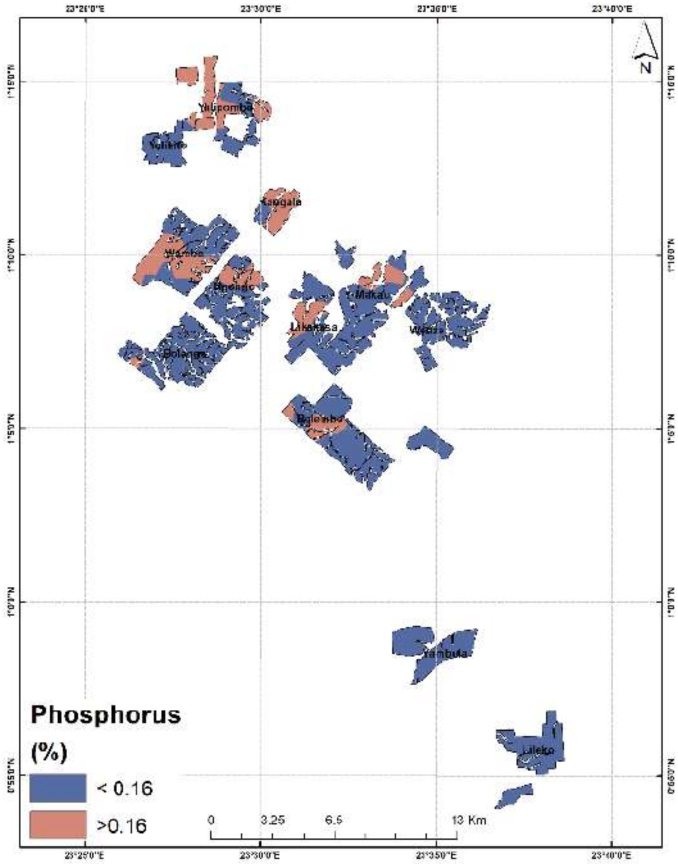
Clorine plays a role in photosynthesis and water use efficiency and is of specific important to oil palm. The concentration in the leaves varies from ‘extremely low’ (<0.10%) to ‘adequate’ (>0.50%; highest value recorded is 0.68%), but for the major part rates as ‘low’. Fourteen (14) percent qualifies as adequate, 4% as extremely low and 10% of the observations show clearly deficient levels.

Sex ratio

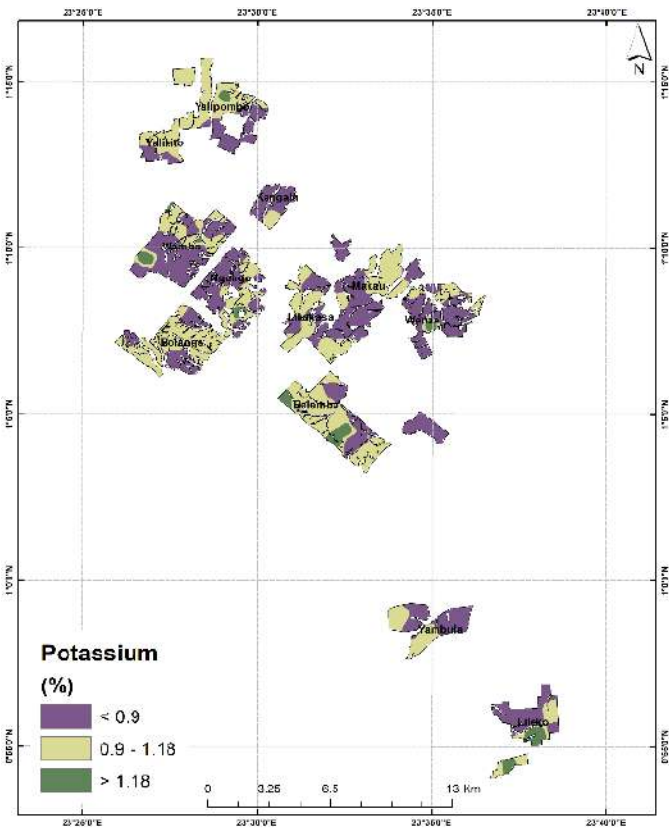
The number of male and female flowers were counted to determine the sex ratio at each sampling point. The palms at Lokutu have an average sex ratio of 0.47, which is lower than that of Boteka. We found one site (LK3) with a sex ratio of 0.0, but this was from a single observation (11 male, 0 male). We found one site (LK30) with a sex ratio of 1.0, but this was likewise from a single observation. Otherwise, lowest sex ratio found was 0.14 and the highest was 0.99. The later was found at LK51, a 3-year-old plantation completely overgrown with weeds. The spread is considerable with a standard deviation of 0.14.



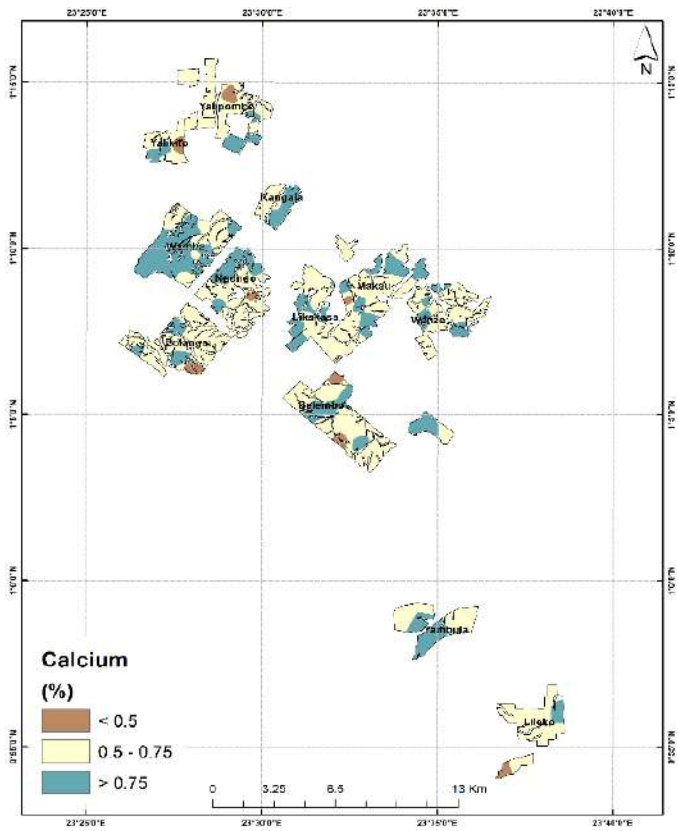
Map 26. Nitrogen concentration in palm leaves



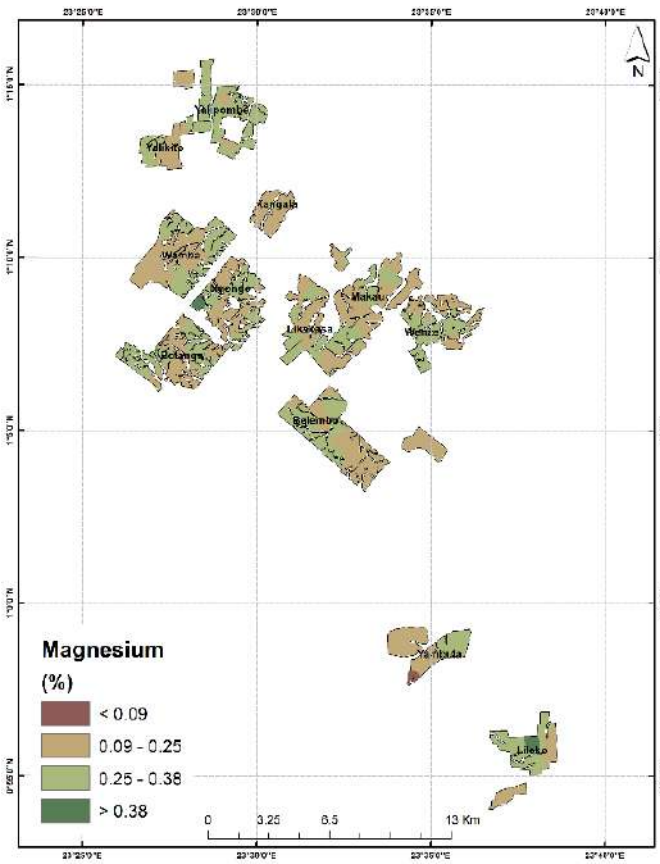
Map 27. Phosphorus concentration in palm leaves



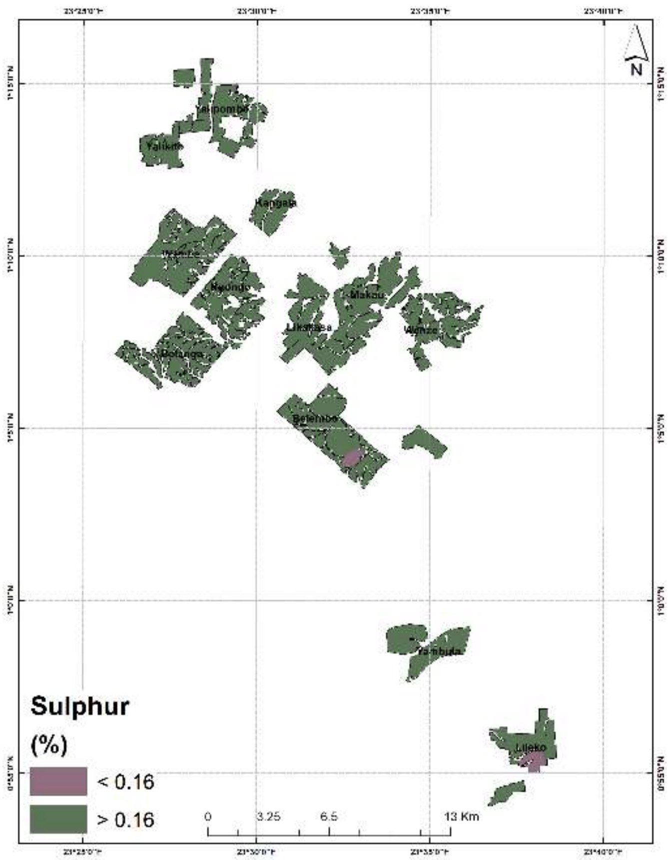
Map 28. Potassium concentration in palm leaves



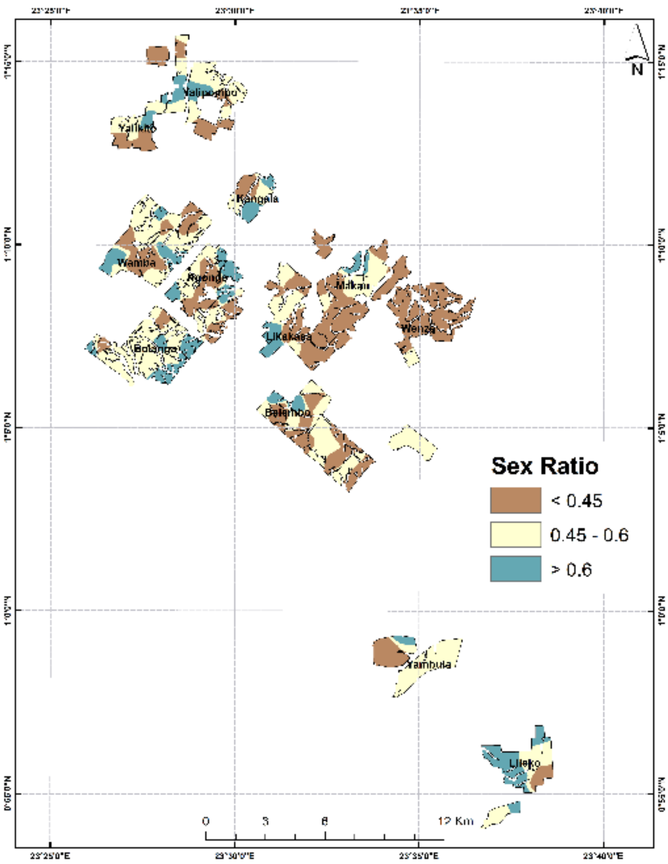
Map 29. Calcium concentration in palm



Map 30. Magnesium concentration in palm leaves



Map 31. Sulphur concentration in palm leaves

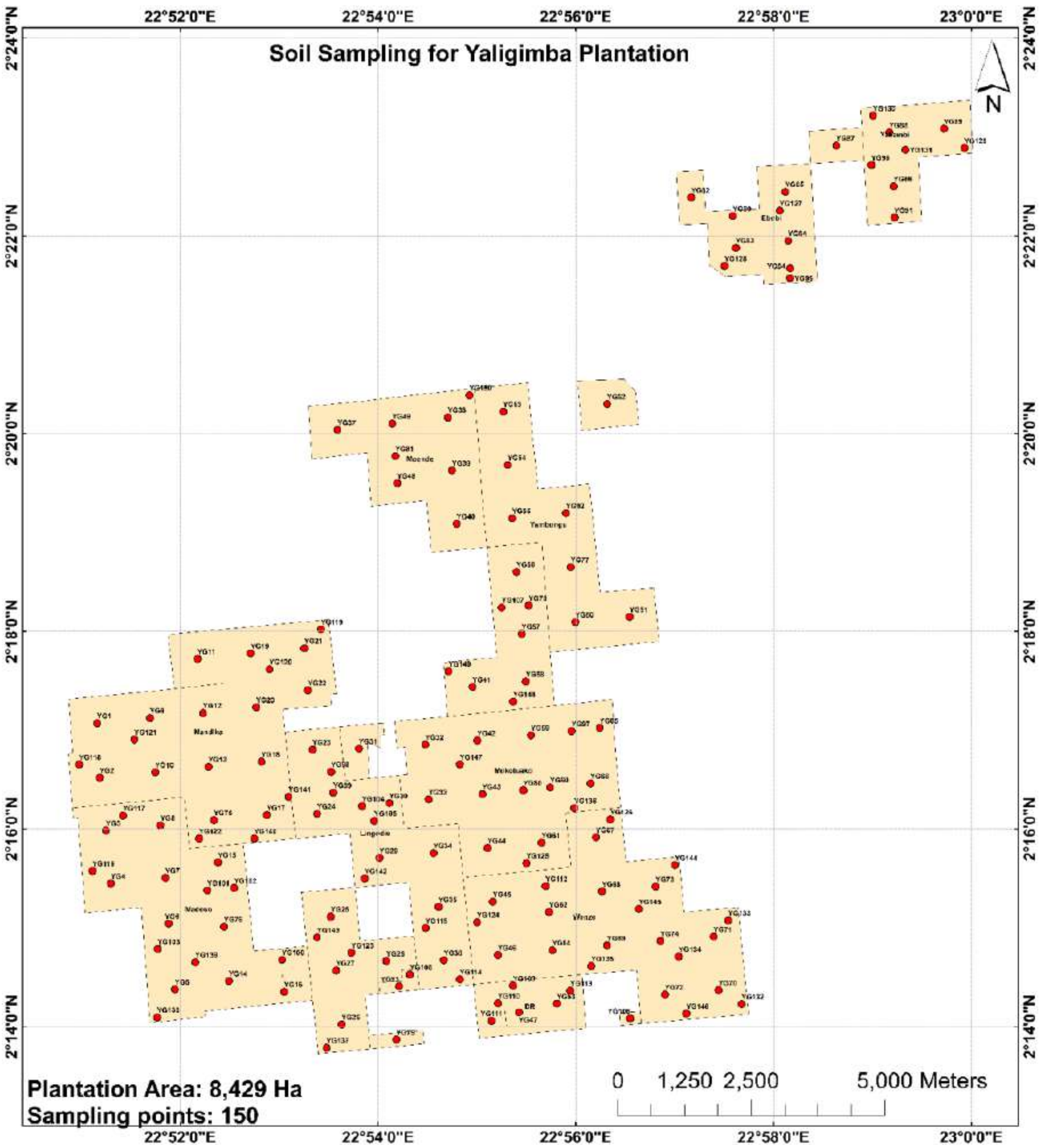


Map 32 shows the blocks within the divisions of the estate where highly productive palms are found (sex ratio > 0.6). Bolanga and Kangala divisions seem to have the most productive palms. We find a clear geographical spread between the sites with high and low sex ratio, which we will leave to management to investigate and explain

Map 32. Sex ratio of the palms at Lokutu

Yaligimba Plantation

Yaligimba plantation is the largest of the three PHC plantation in DRC and it covers approximately 8,429 hectares, excluding old plantations. It is located at about 581 km northwest of Kisangani. Following a general methodology previously described, 150 sampling points were mapped out for observation and soil sample collection (See Map 33) and of these 144 sampling points were actually surveyed and sampled, because some points could not be accessed due to the road condition



Map 33. Sampling points at Yaligimba plantation

Land and Soil characteristics and fertility conditions, Yaligimba

Soil physical characteristics

The land is homogenous in terms of soil physical conditions. The terrain is generally flat to almost flat and there are really no sloping lands within the plantation. (See Appendix 6). The soil is very deep with the soil depth generally extending beyond 120 cm and there is no spatial variability in soil depth. The soil is also well-drained and there are no stones on the surface or within the profile. Generally, the soil is typical a dark brown sandy clay loam topsoil overlying a reddish-brown sandy clay loam subsoil with little colour and textural variations.

The sand content varies both in the topsoil and in the subsoil with higher sand percentage in the topsoil. Division Wenze and west of Nonde have sand content greater than 71%. The silt content of the soil is generally very low, indicating that the soils are highly weathered. The entire Bokombe estate has slightly higher silt content. The soil has a clay content varying from 8 to 31% and 11 to 45% in the topsoil and subsoil respectively. There is an increase in clay content with soil depth generally within the profile. The sand and clay content are inversely related, implying that divisions or blocks with higher sand content have lower clay content and vice versa. In all, the soil falls within 3 textural classes, namely: sandy clay, sandy clay loam, and sandy loam, like in Lokutu. Over 80% of the soils fall within the sandy clay loam textural class. The maps of the soil particle sizes are presented in the Appendix 6.

Soil pH

The soil is strongly acid with the soil pH of 4.95 on average and with little spatial variation in pH (standard deviation = 0.27; Map 34). The pH condition of the entire plantation at Yaligimba is suboptimum for palms and this will affect nutrient availability particularly phosphorus and may also induce micronutrient toxicity. As already noted, palms have good tolerance for acid soils, but effort should still be made to raise the soil pH through liming.

Soil organic carbon, total nitrogen, available phosphorus, and exchangeable potassium

Soil organic carbon ranges from 'very low' to 'high' (> 1.7%) and varies strongly from one part to the other in the plantation (Map 35). Maximum values reach up to 3%.

The soils are likewise varying in nitrogen content and range from low 'low' to 'adequate' (Map 36). The C/N ratio varies strongly from one point to the other, indicating that the N content is not that much related with the soil organic matter content in the soil, but is rather the effect of management. It would suggest that management differs from one block to the other or for the different parts of the map. If management has been uniform, the strong variation in the N content remain to be explained.

Available phosphorus is low on average and in the major parts of the land, such as Noende, Wenze and Ebobi divisions. We find 20% of the points showing adequate levels of phosphorus, in Bokombe division and west of Wenze for example. We have a few points with quite extreme levels of P concentrations, like YG128 (99 ppm) in the northern section, YG17 (127 ppm), YG2 (91 ppm), and YG6 all in the western section of the plantation. (Map 37).

Exchangeable potassium is generally 'extremely low' with 120 out of the 144 points showing a value of less than 0.2 cmol/kg. Values from 0.2 to 0.3 cmol/kg are still considered 'low', but somehow still manageable for oil palm. The east and south sections of Ebobi and southern Madoso divisions have relatively higher potassium in the soils among others (Map 38).

Calcium, magnesium, and sulphur

There is little variability with respect to calcium distribution in the soils at Yaligimba (Map 39). The soils are generally low in calcium content. Thirty-three out of the 145 points show adequate concentration. The magnesium concentration in the soils of Yaligimba are critically low and shows little variability across the plantation (Map 40). There are no points with adequate magnesium concentration. Sulphur varies from 'extremely low' to 'low' and varies slightly across the estates (See Appendix 1).

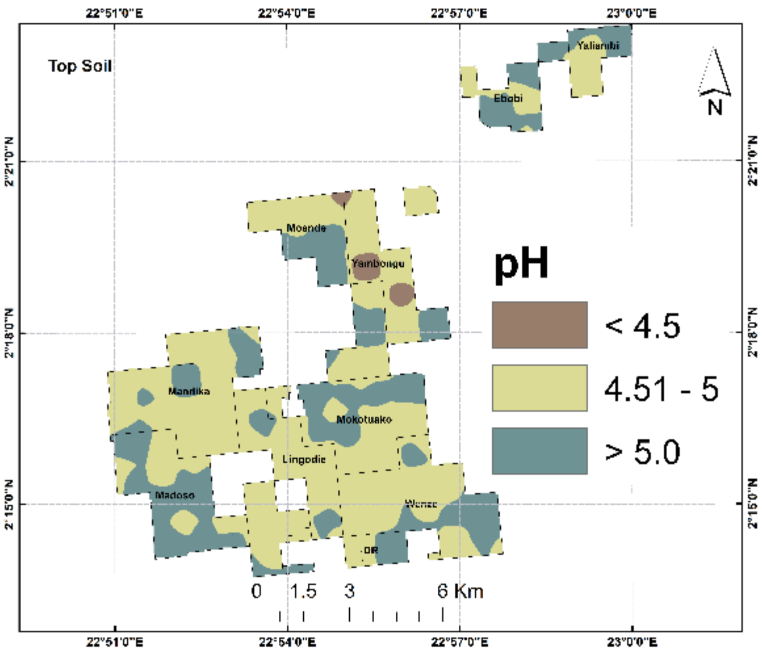
Cation exchange capacity

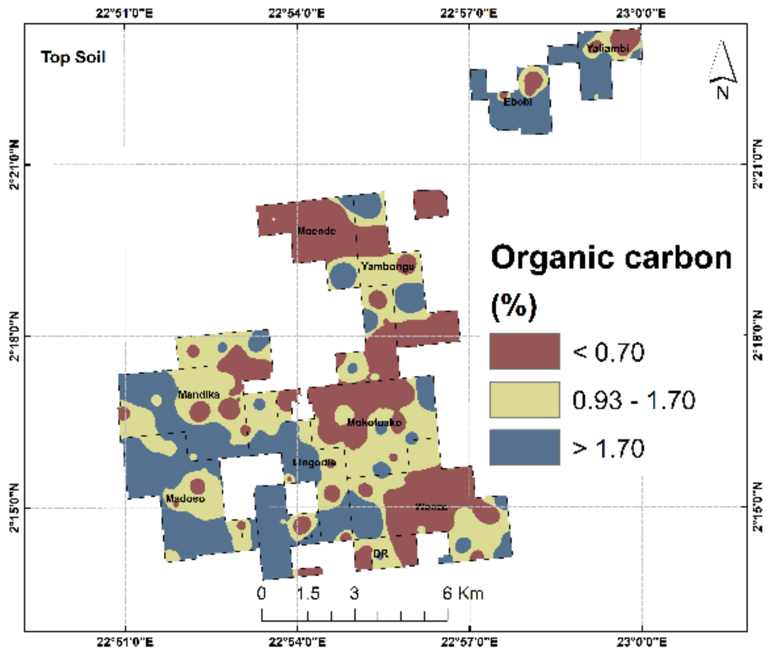
The capacity of the soils to hold nutrients is critically low across Yaligimba plantation. Generally, the plantation could be divided into two based on the CEC values. Ebobi division has the highest CEC values with value CEC above 5 .0 cmol/kg and can be considered 'low' in CEC whereas the rest of the plantations have CEC values below 5.0 cmol/kg and is considered extremely low (Map 41).

Soil micronutrients

Micronutrients such as manganese, iron, boron, copper, and zinc play essential roles in plant metabolism. Apart from iron, the soil is very low in micronutrients. The soil micronutrient profile is presented in Appendix 1.

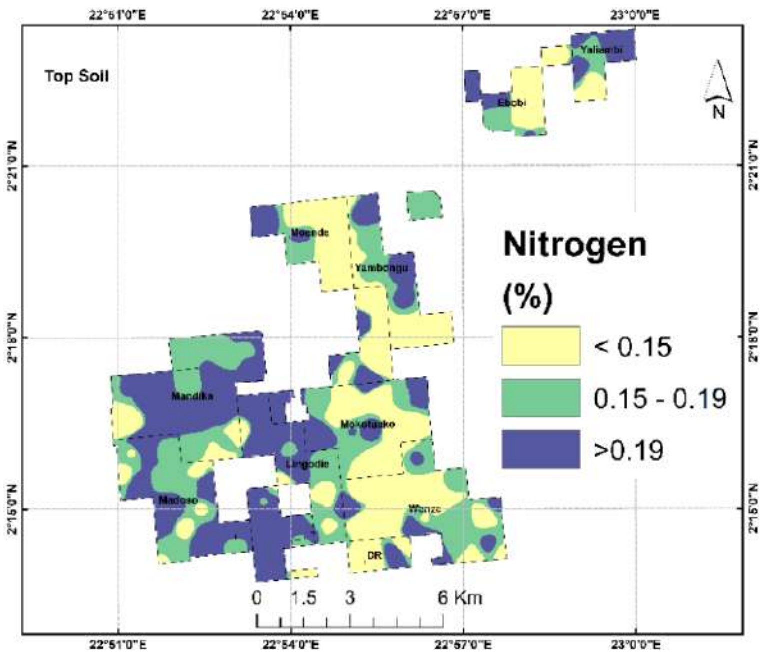
Picutre 6. Magnesium deficiency at YG86 (N2.3750, E22.9869) within Yaliambi division of Yaligimba plantation

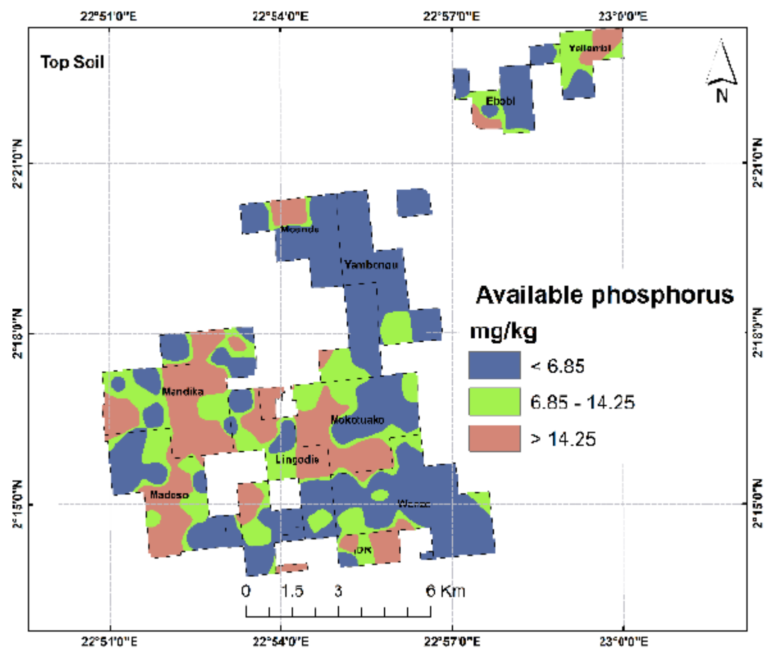




Map 34. Soil pH distribution

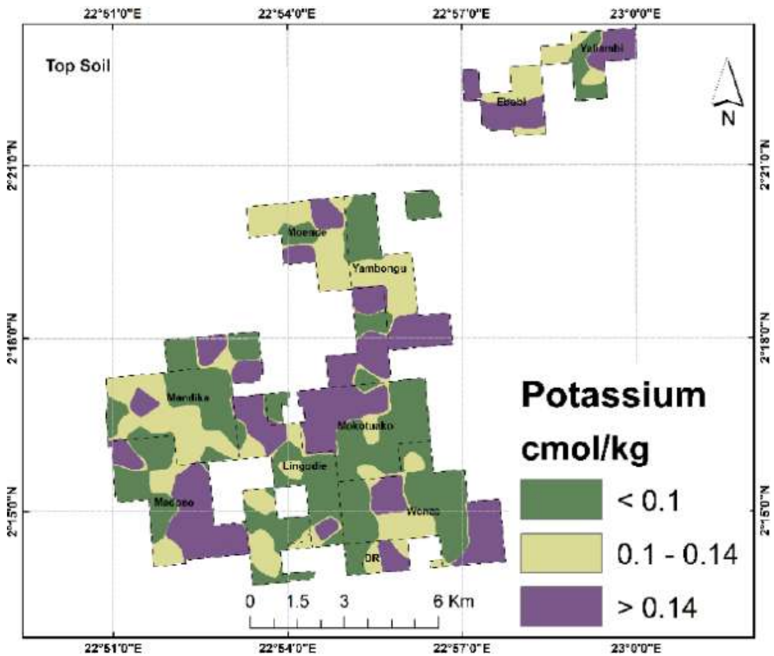
Map 35. Soil organic carbon at Yaligimba

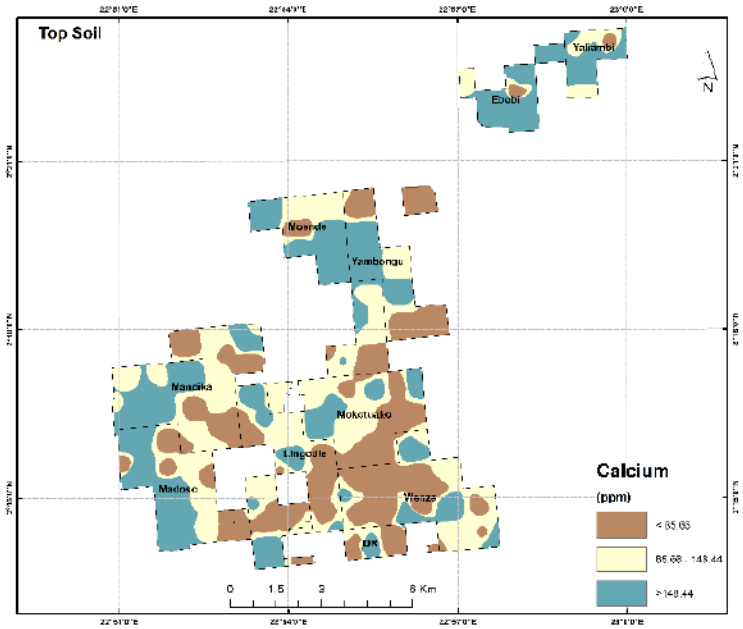




Map 36. Total soil nitrogen

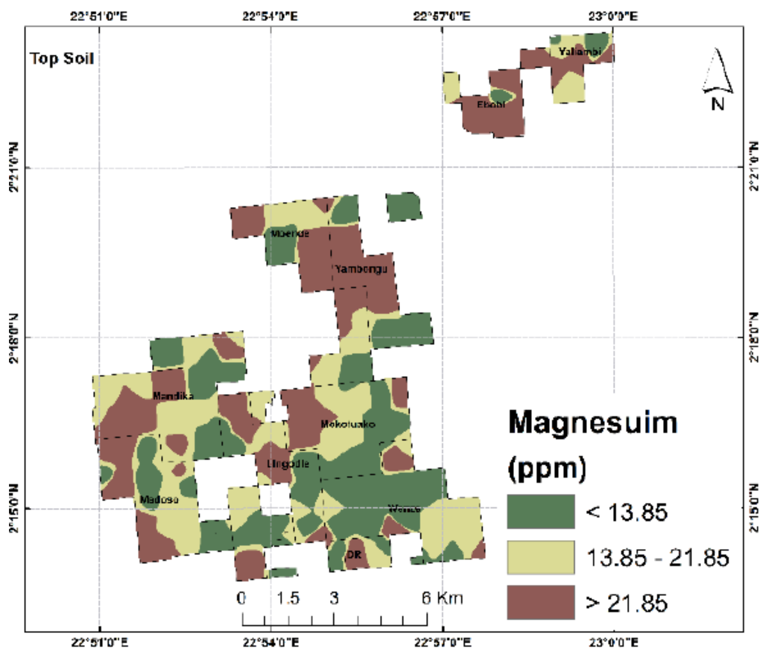
Map 37. Available soil phosphorus

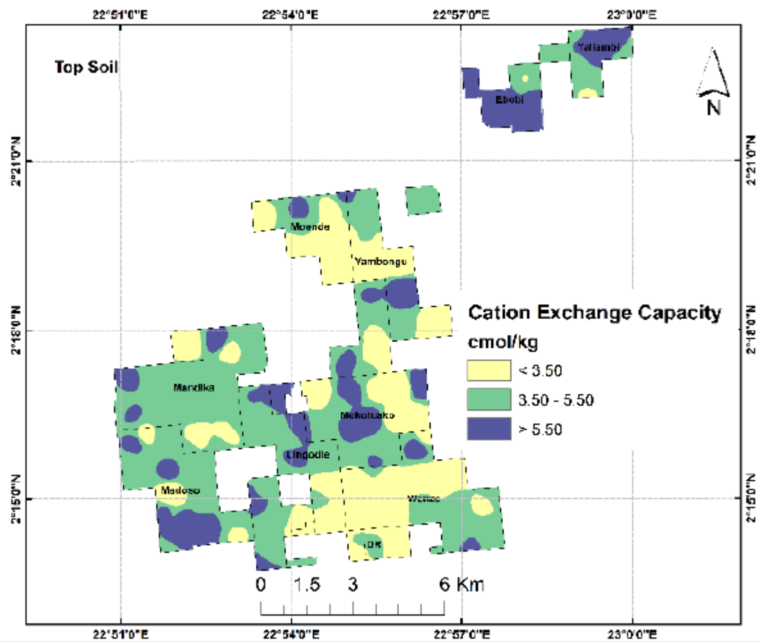




Map 38. Exchangeable potassium

Map 39. Exchangeable calcium





Map 40. Exchangeable magnesium

Map 41. Cation exchange capacity of the soils

Palm foliage assessment at Yaligimba

Plant nutrient concentrations

We made an assessment of nutrient concentrations in the palm foliage at each sampling point within Yaligimba plantation. We observed nitrogen concentrations in the leaf ranges from 2.39 to 3.15% with little spatial variations. Nitrogen concentration in the palm foliage at Yaligimba is comparable to those of Boteka. The nitrogen values are within the range of 'adequate' to 'high' levels of N in the foliage. Palm leaves at Mokotuako, Wenze north Mandika and north Yaliambi are the spots of high nitrogen concentration in the leaves (Map 42).

The concentration of phosphorus in the leaves varies across the Yaligimba plantation from 'low', to 'high'. Eighty (80) of the 141 points are rated as 'low', there are 58 points rated as 'adequate' and 3 points are rated as having a high concentration. Map 43 shows the spatial distribution of phosphorus concentration in the plant tissue (leaf) within the plantation.

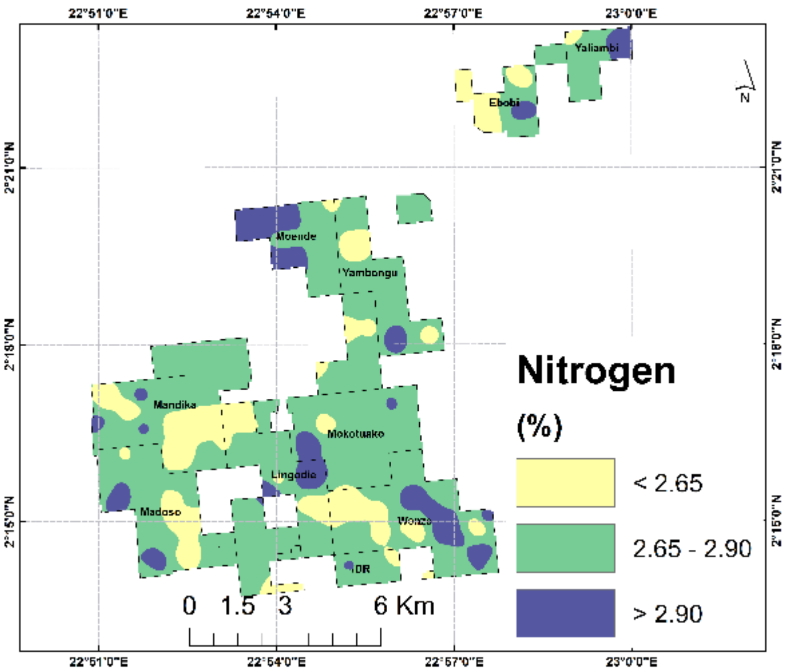
Potassium concentration in the palm leaves varies from being deficient (<0.75%) to being in excess. In 31 out of the 141 points K is considered deficient. This is applying the criteria for older palms (over 6 years in age). (For younger palm trees the criterion for deficiency is set at 1.00%. being low and being adequate.) For another 56 points the concentration is considered low, but not deficient. Only in 49 sites the concentration is adequate and in 5 sites the concentration is considered to be in excess. Together that represents 38% of the total sample. Again, the individual points are not representative of the block since it is only from two palm trees the leaf sample is taken for a particular sampling point. But it provides reliable statistical information on the spread of the values within the plantation. Potassium concentrations in the palm leaves are at adequate level in Yambongu, Moende, Ebobi and Yaliambi divisions while Wenze and Mandika, among other divisions of the plantation, have a low level of potassium in their palm tissues (K <0.90%, Map 44).

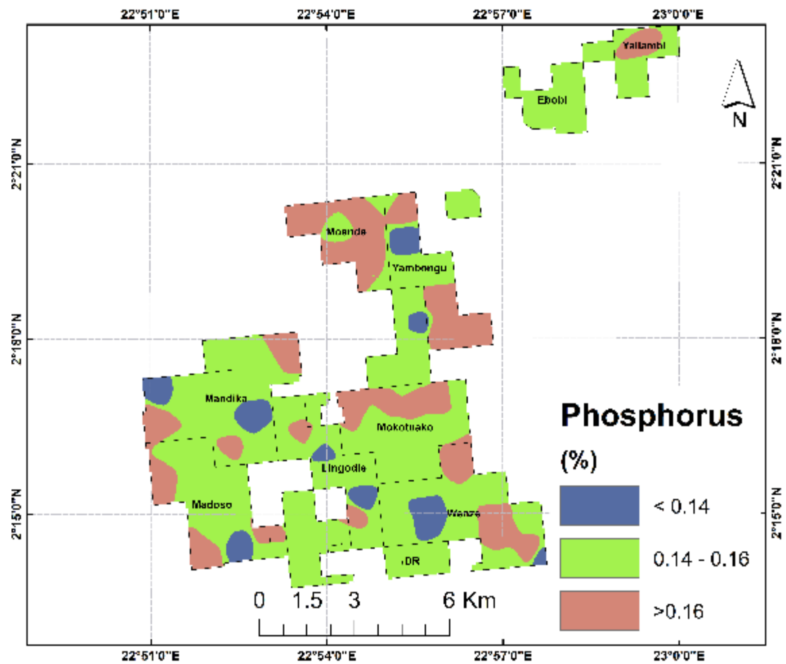
Calcium is generally not limiting in the palm leaves across Yaligimba plantation. Out of the 141 points, 63 points are rates as high, with a few points even being considered having Ca in excess. Seventy-seven (77) points are rated as having optimum Ca concentration. Wenze and Mandika including Madoso divisions have relatively high concentration of calcium in their palm tissues (Map 45).

Magnesium varies across the different subdivisions of the plantation. Yaligambi, east Ebobi and south Moende divisions have adequate level of magnesium in the foliage (Mg >=0.26%; Map 46). Of the 141 sampling points 117 have 'low' Mg concentrations in the leaves. Of these 117 points, 63 are considered deficient and of these 6 points are rats as critically low. Palms at Lingodie and its environs have low Mg concentration in the leaves.

Sulphur concentration in the foliage is generally low and the situation is more critical at Mandika division (Map 47). Ninety-two (92) points are considered to have clearly deficient levels of S concentration.

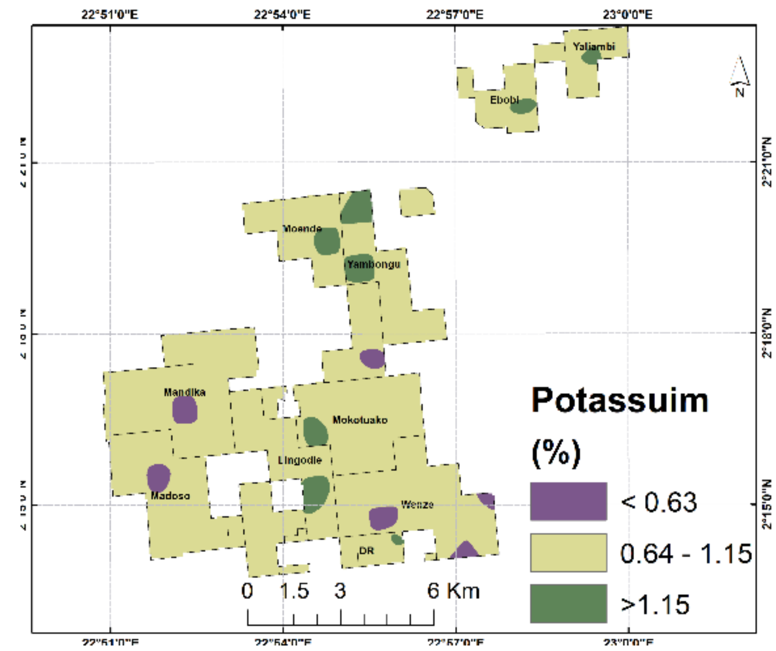
Clorine is in 'low' concentration in 44% of the cases and 5% of the points show deficiency levels

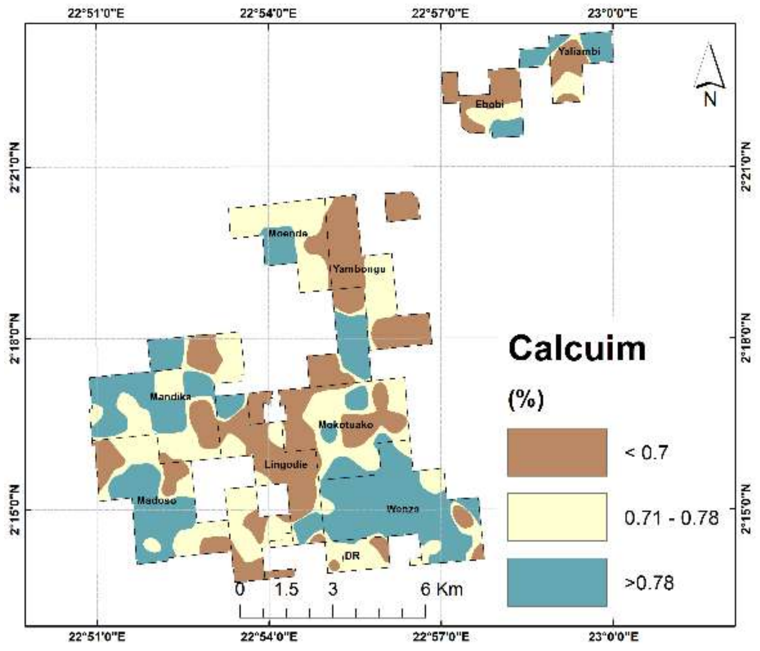




Map 42. Nitrogen concentration in the leaves

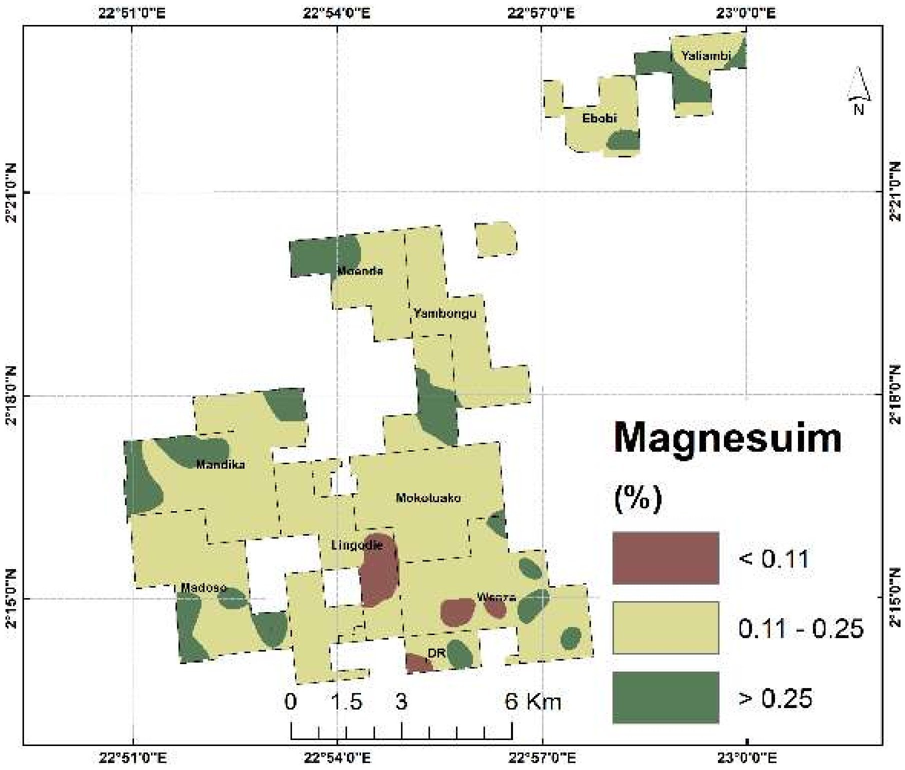
Map 43 Phosphorus in the leaves



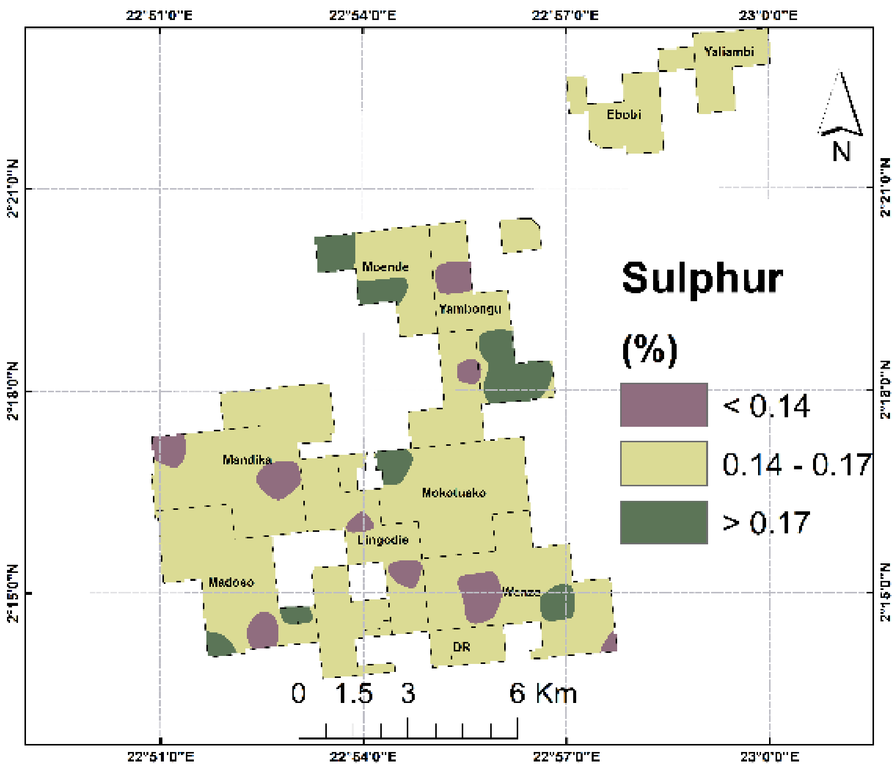


Map 44. Potassium in palm leaves

Map 45. Calcium in palm leaves



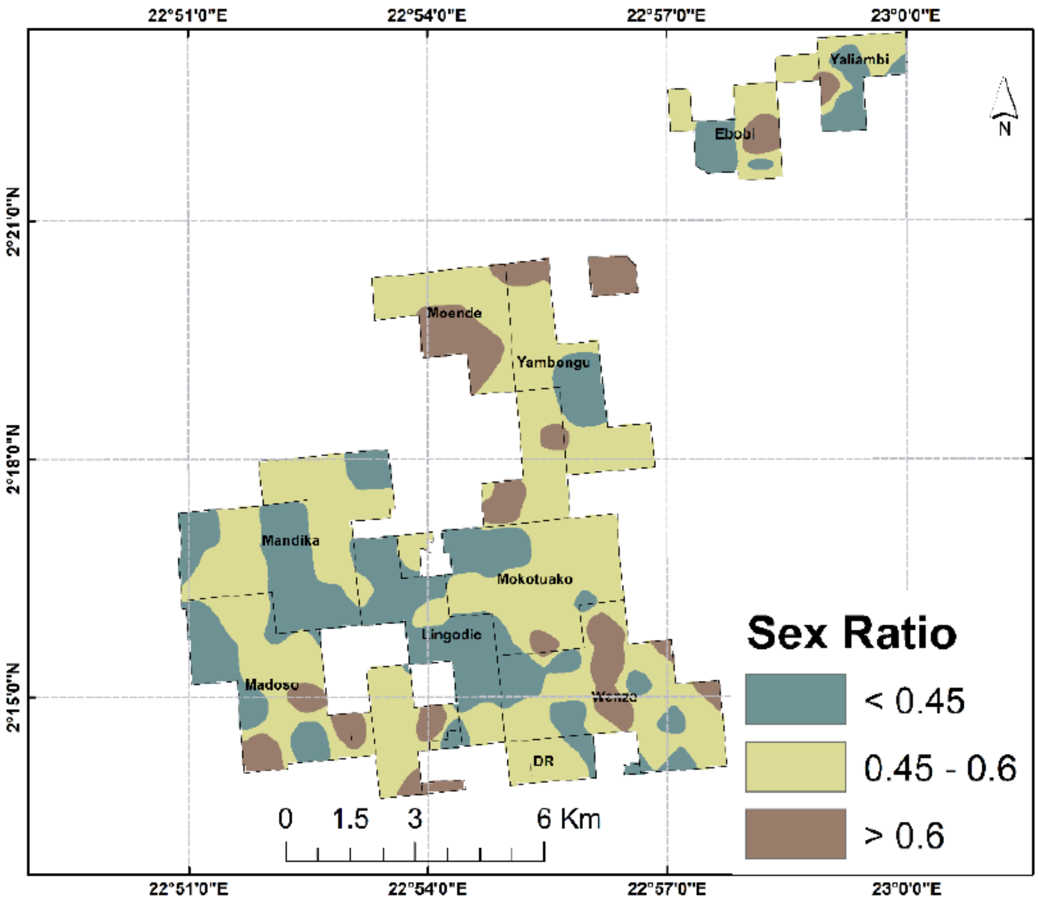
Map 46. Magnesium concentration in leaves



Map 47. Sulphur in palm leaves

Sex ratio

We counted the number of male and female flowers to determine the sex ratio at each sampling point. The sex ratio was calculated as number of female flowers divided by the sum of the female and male inflorescence. The average sex ratio for the whole plantation is at 0.49; the lowest value is 0.22 and the highest average (average of 17 observations per sampling point) sex ratio found is 0.78. The standard deviation is 0.10, indicating there is quite some variations between one point and the other. There is not a clear spatial distribution pattern, though the areas with low sex ratio seem somehow concentrated. Lingodie and northeast of Yaliambi divisions have the lowest sex ratio while Moende, east Ebobi and south Yaliambi have the highest sex ratio exceeding 0.6 (Map 48) and these locations also coincides with areas where the number of female flowers per palm stand exceeds 7 (See Appendix).



Map 48. Sex ratio

Conclusions and recommendations

The patterns we observe for Boteka, Lokutu and Yaligimba with respect to the condition of the soil as well as the condition of the oil palms is largely comparable, which might also not be that surprising given that the parent material on which the soils have developed are largely the same (unconsolidated sedimentary rock), all three plantations fall within the same agroecological zone and experience the same agroclimatic conditions and the management has been largely the same, though the age of the plantations is different.

The most important difference between the plantation the soil texture, with Boteka having the lighter textured soils (less clay and higher sand content) with some important implications. In In general, the physical characteristics are comparable. The soils of Lokutu and Yaligimba are generally of medium texture with good potential to retain moisture in the subsoil layer for plant uptake while Boteka has light-textured soils. This notwithstanding, moisture deficit is unlikely to occur either because of the favourable climatic condition with possibility of rains throughout the year at Boteka. There are no stones to interfere with tillage operations and there is also no gravel in the soil profile that might impede root development. The soils are generally well drained and very deep with no restriction to root development. The clay fraction is likely to consist of less active clay minerals. Soils might become compact and hard with higher clay percentage and difficult to penetrate for the roots. Oil palm is not a deep rooting tree and does not seem to be affected, especially not in Lokutu and Yalimgimba plantations which have the higher clay percentage in the sub-soil. On the other hand, the sandier texture in Boteka might result in stronger leaching of nutrients from the soil. And this is reflected in extremely low Mg concentration in the soils of Boteka compared to the soils of Yaligimba and Lokutu (highest though still very low on average). Also, the exchangeable K is lowest in Boteka on average. In Boteka we see the extremely low Mg and K concentrations also reflected in the nutrient content of the leaf tissue, which is critically low in the oil palm trees in Boteka. Most of the soil properties are rather uniform, especially when soil nutrient concentrations are concerned. Where they vary, like for nitrogen, it is usually the direct consequence of past agronomic management of the plantations (fertilizer application). Soil pH is very low, with average pH level below 5 for all plantations, but again lowest for Boteka. It is generally within the tolerable limit for oil palm, but nevertheless affects soil fertility. Application of dolomite lime is recommended for all plantations in sufficient quantities to raise the pH with 0.5 units at least.

The soil organic carbon varies considerable within each of the plantations, is on average highest in Yaligimba, followed by Boteka and is lowest in Lokutu (0.77% on average). Especially Lokutu would deserve improved soil organic matter management. The application of compost could help boost the soil organic carbon of the plantations particularly Lokutu. Improvement in soil organic matter does not only improve soil fertility but also productive soils through better water and nutrient holding capacities. And it will stimulate soil life which will improve soil quality considerably.

Soil nitrogen is within the adequate level across most subdivisions of the plantations, relating to previous fertilization effort. The other soil nutrients are not in balance with the soil nitrogen content as result of past fertilization efforts mainly focused on application of nitrogenous fertilizers. Especially Mg and K concentrations are (quite) low in all three plantations. Likewise, sulphur concentrations are low in all plantations, which is also reflected in the low S concentrations in the leaf tissue. These three nutrients are of special relevance to oil palm and that these are limiting throughout will have direct implications for the yield and production.

Available phosphorus content of the soil varies considerably within and between the plantations. The Boteka plantation has an adequate phosphorus level on average but varying across the different estates of the plantation will require attention. Yaligimba plantation has soils which are low in phosphorus content on average but has several sampling points with high available P concentrations as well. Is not clear whether these are individual points or representative of the whole block. Most points/blocks that have low avail. P requires attention. Lokutu plantation has the lowest average avail. P concentration; quite low for a large majority of points with a few isolated points having a rather high available P, which we cannot explain. The phosphorus content of these soils also has to do with previous fertilization efforts but can also be explained by the low pH levels in the soils. Deliberate attempt should be made to increase the P content of Yaligimba and Lokutu soils especially. The application of phosphorus containing mineral fertilizers offers immediate solution while the application of compost provides medium to long-term benefits in phosphorus build up in the soils.

Potassium is the most important nutrient in oil palm nutrition, playing crucial role in oil palm metabolism, photosynthesis, stomatal opening (control entry of carbon dioxide for photosynthesis and regulating the water balance in the plant), enzyme activation, and oil synthesis. K-deficient palms are, therefore, more susceptible to drought conditions and may lead to lower oil content of the fruit. The soils are critically low in K and K deficient palms are widespread across the 3 plantations, Boteka most of all. Potassium appears to have been neglected or not applied in adequate amounts in previous fertilization of the plantations. Conscious effort is urgently required to increase the K concentrations in the soils of the different plantations.

Other essential soil macronutrients are calcium, magnesium, and sulphur. Mg and S are considerably low in most cases across the plantation. Ca may vary. Of these, magnesium and sulphur are the most critical due to their importance for oil synthesis. Efforts to raise the soil pH through dolomite or agricultural lime application will also improve these nutrients particularly calcium and magnesium while additional efforts should be made for sulphur application.

Due to the low exchangeable bases coupled with the low soil organic carbon, the CEC (soil capacity to hold nutrients) is low. Application of organic fertilizers or well composted organic material would help to raise the soil cation exchange capacity and herewith the overall soil fertility. It is not easy to adequately address, but one can adapt by applying the fertiliser in small quantities but with higher frequency.

The micronutrient profile of the soils is low across the different estates of the plantations. Boron, among the deficient soil micronutrients, is the most critical for oil palm. Available B seems to be critically low in the Boteka plantation, though varies somewhat. It is also in this plantation that we find symptoms of B deficiency in the leaves. Likewise, for Lokutu and Yaligimba, B is very low, but not to the extreme as it is in Boteka. It is important to include zinc, copper, and boron in the fertilizer application program for the plantations. Foliage application or compost application offers the best-bet to raising the micronutrient profile of the soils in a gradual and consistent manner. B-fertilizer should be applied with caution because it easily becomes toxic when applied too much.

Nutrient concentrations in palm tissues vary widely per plantation based on the concentration of the nutrients in the soil among other factors. Notably, nitrogen is not deficient in any of the palms. Phosphorus, potassium, and sulphur concentration in the tissue are also seen to be adequate in major parts of the plantations. However, potassium and magnesium appear to be limiting among others. There is a good correlation in nutrient availability in the soils and the nutrient concentrations in palm foliage.

The sex ratio in part gives an indication of the potential productivity of the palms. We found oil palms at Boteka to be the most potentially ‘productive’ among the plantations having an average sex ratio of 0.55, which is associated with the age of the plantation (being the youngest). Yaligimba follows with an average sex ratio just below 0.5 (*viz*. 0.49) being young and better maintained. Lokutu, being the oldest plantation, has the lowest average sex ratio of 0.47. In all subdivisions of the plantations, where the female inflorescence predominates the male, there is a potential higher economic return.

In all, efforts to increase the productivity of the plantations should focus principally on soil fertility and proper weed management of the plantations.

References:

D.J. Halliday, M.E. Trenkel, (1992), World fertilizer use manual, International Fertilizer Industry Association, Paris

T. Fairhurst, (2015), Minimization of error in leaf analysis sampling and analysis, Extension Bulletin TCCL-001, Tropical Crop Consultants Limited (TCCL), Kent, UK

AKVOPEDIA, Sustainable Oil Palm Farming / Leaf sampling, created: October 2016, latest revision: January 2018, accessed October 2021, (https://akvopedia.org/wiki/Sustainable_Oil_Palm_Farming_/_Leaf_sampling#:~:text=Leaf%20sampling%20is%20used%20to,help%20to%20track%20nutrient%20deficiencies)

Appendix 1: PHC soil and leaf assessment dataset and their description

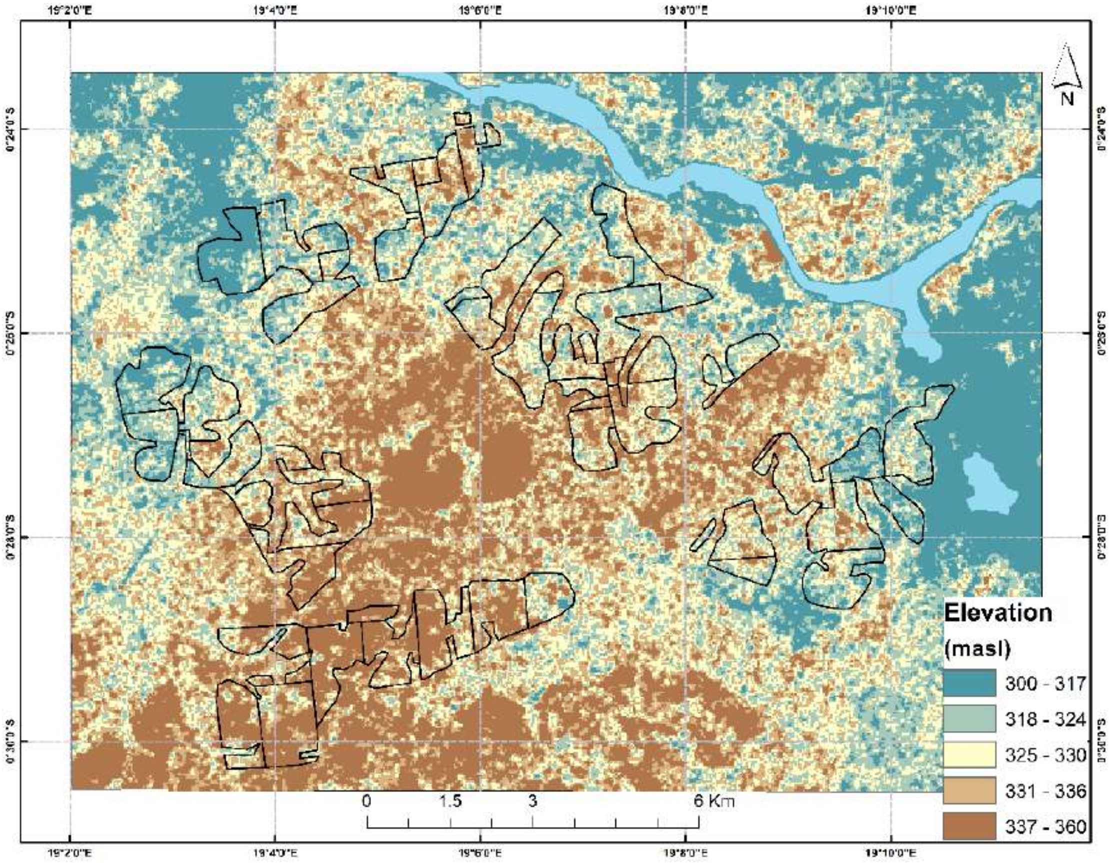
All the data generated in this study can be accessed here. The folder (PHC soil and leaf assessment2022) contains the data files from the observations in the field (the data recorded using the ODK forms), with result from the wet chemistry soil analysis, leaf nutrient analysis and sex ratio data. Table 1 gives the description of these files.

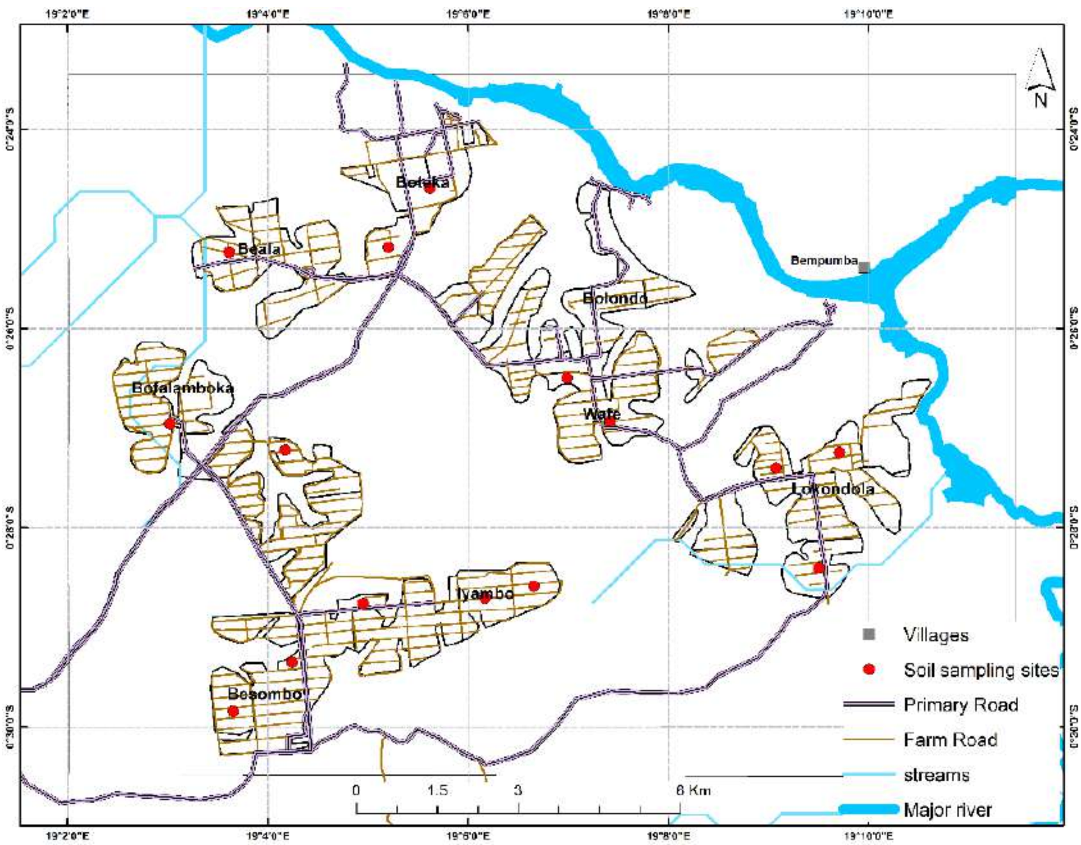
Table 1 Overview of the data files that can be accessed through the link provided

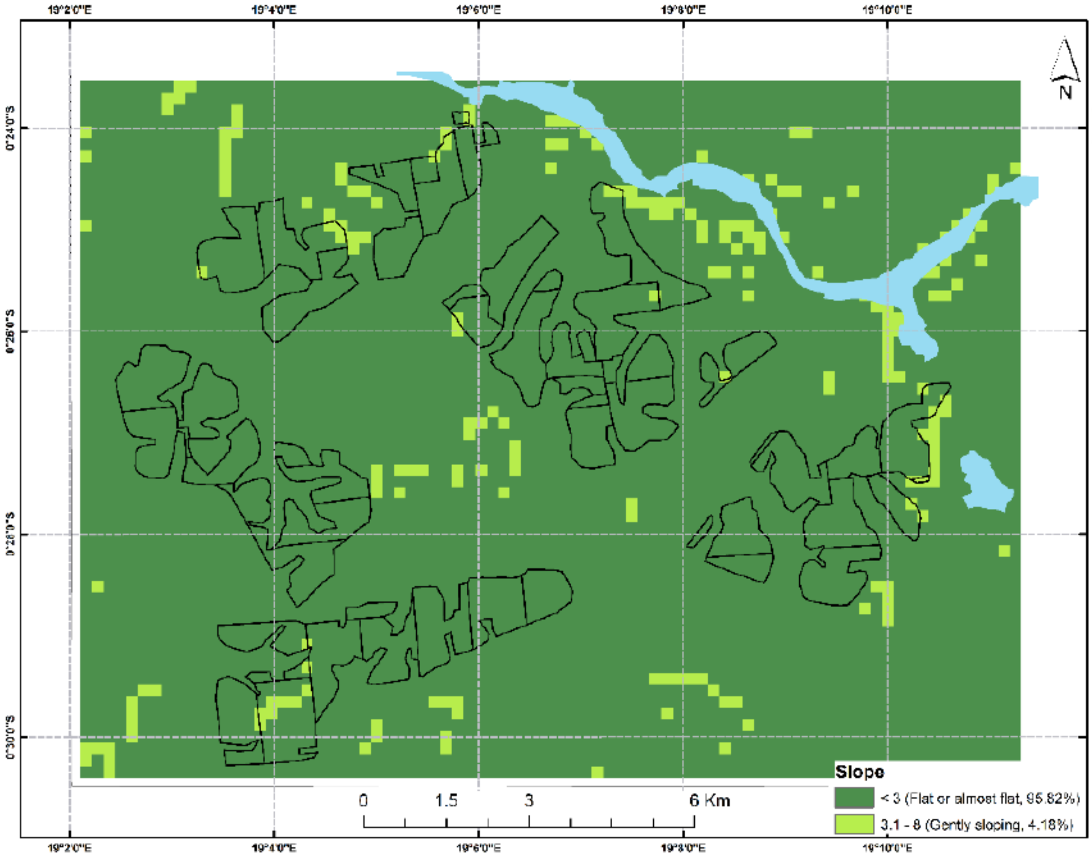
File name	Extension/File type	Description/content
Boteka_all_soil&plant&sex	xlsx	Contains PHC Boteka soil analysis data, leaf nutrient concentrations and sex ratio. The file contains 4 spreadsheets, 'topsoil' contains the soil analysis results of the topsoil samples, 'subsoil' contains the soil analysis results of the subsoil samples, 'leaf' contains the nutrient concentrations in the leaves (highlighted in different colours based on the sufficiency levels of each of the nutrients), 'sex_ratio' contains the number of male and female flowers and the calculated sex ratio per sampling point.
Field data_all plantations	xls	Contains PHC land and soil survey information including GPS coordinates of the sample points, vegetation assessment data, land and soil characteristics data of Boteka, Lokutu and Yaligimba plantations. This file also contains the link to all the pictures taken at the sampling points. Some of the pictures show the deficiency symptoms observed on the palm foliage across the plantations
Lokutu_all_soil&plant&sex	xlsx	Contains PHC Lokutu soil analysis data, leaf nutrient concentrations and sex ratio. The file contains 4 spreadsheets, topsoil contains the soil analysis results of the topsoil samples, 'subsoil' contains the soil analysis results of the subsoil samples, 'leaf' contains the nutrient concentrations in the leaves (highlighted in different colours based on the sufficiency levels of each of the nutrients), 'sex_ratio' contains the number of male and female flowers and the calculated sex ratio per sampling point.

Yaligimba_soil&plant&sex	xlsx	Contains PHC Yaligimba soil analysis data, leaf nutrient concentrations and sex ratio. The file contains 4 spreadsheets, topsoil contains the soil analysis results of the topsoil samples, 'subsoil' contains the soil analysis results of the subsoil samples, 'leaf' contains the nutrient concentrations in the leaves (highlighted in different colours based on the sufficiency levels of each of the nutrients), 'sex_ratio' contains the number of male and female flowers and the calculated sex ratio per sampling point.

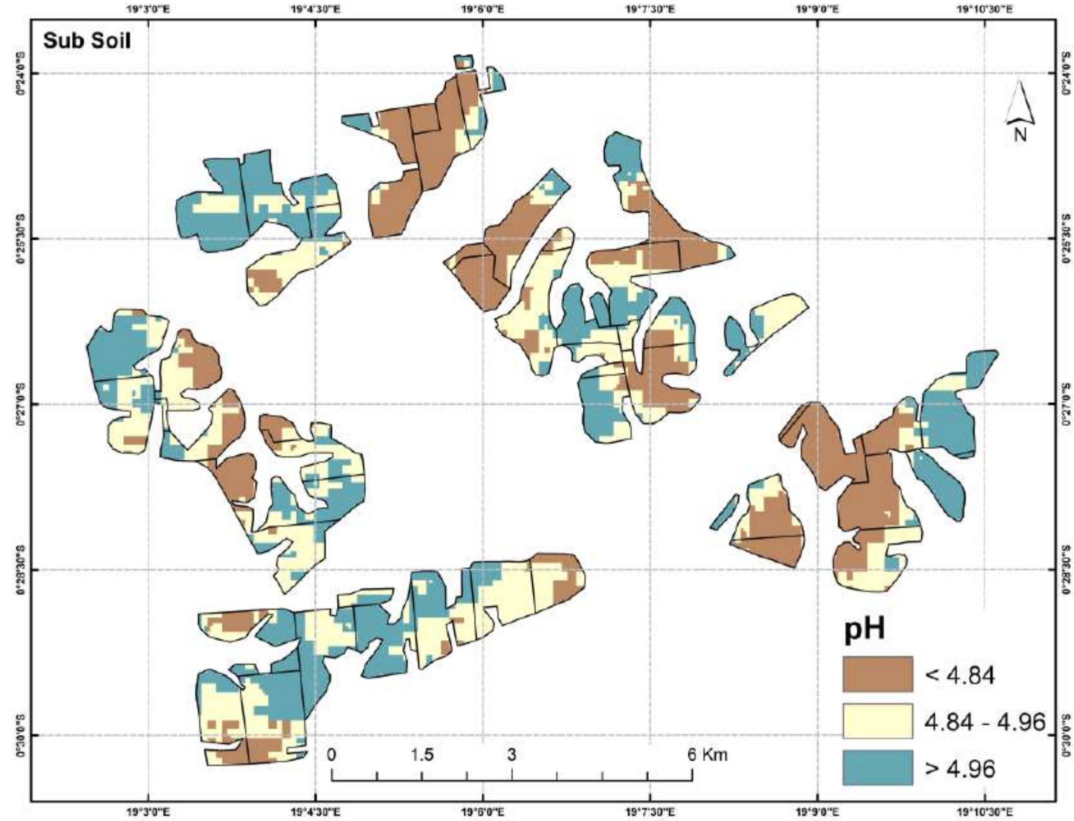
Appendix 2: Land and soil maps of Boteka plantation

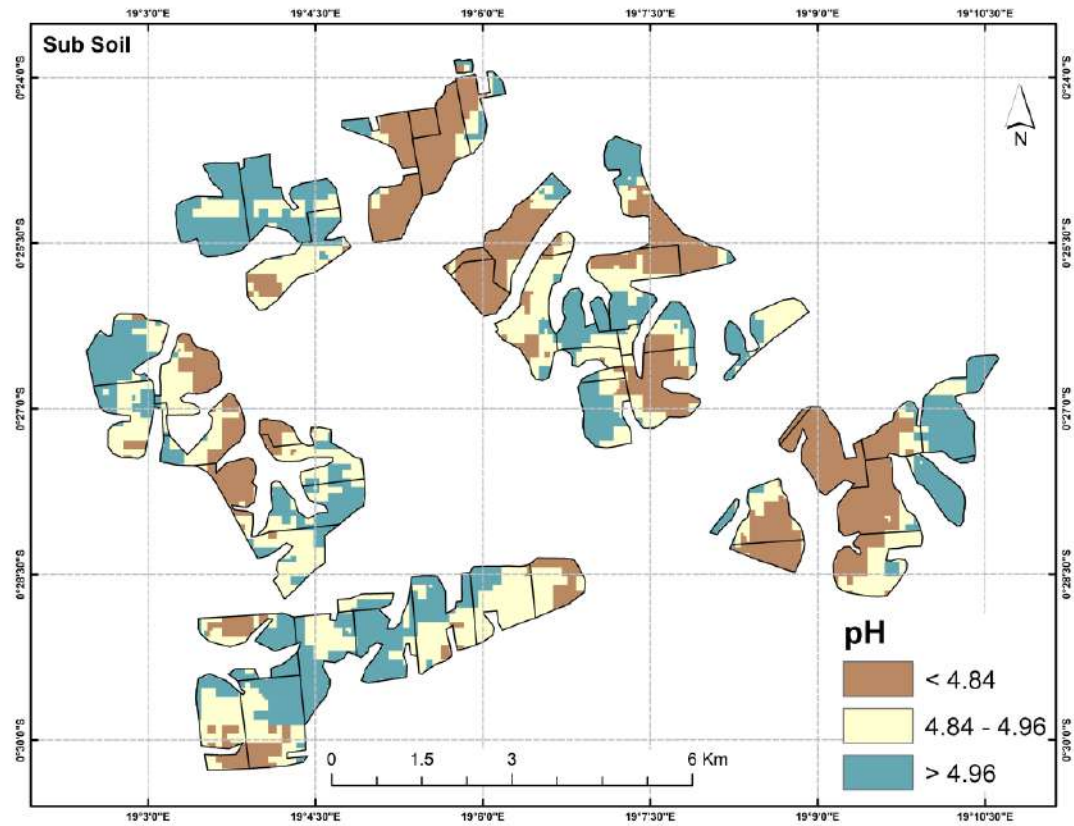


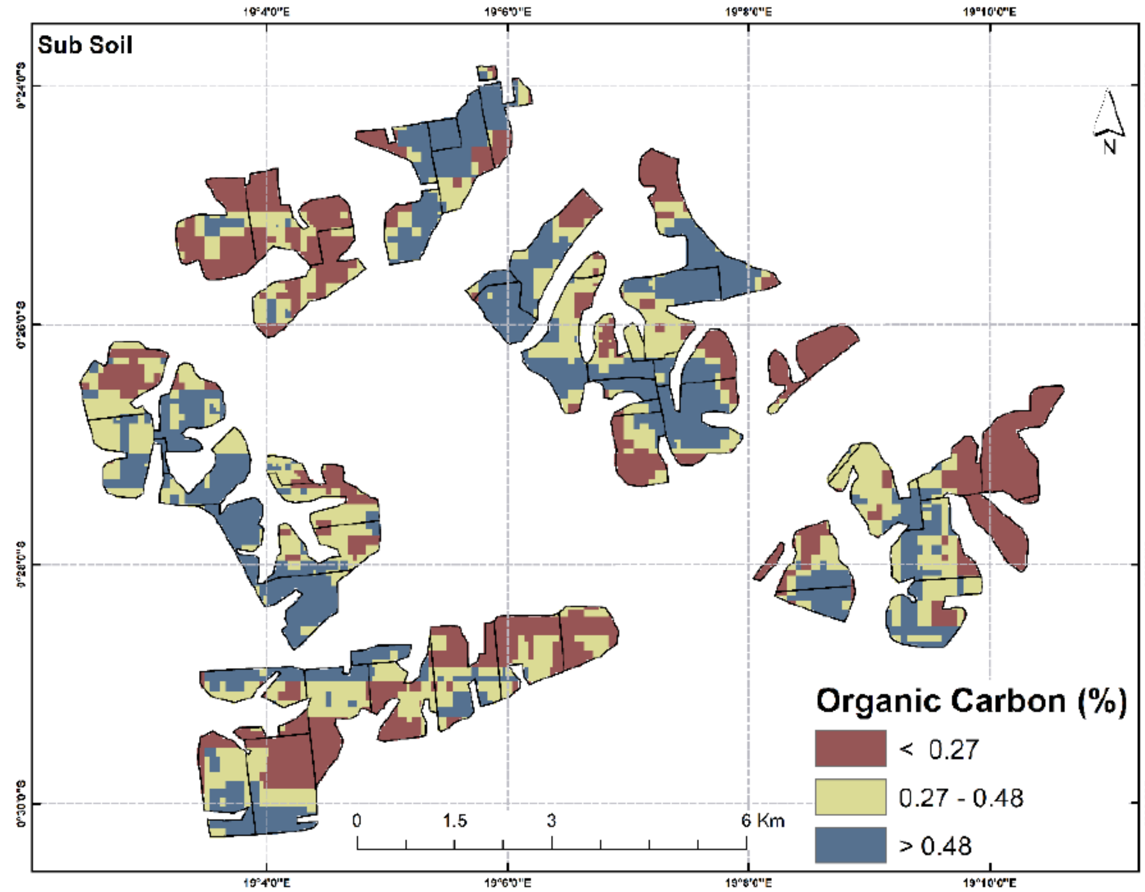


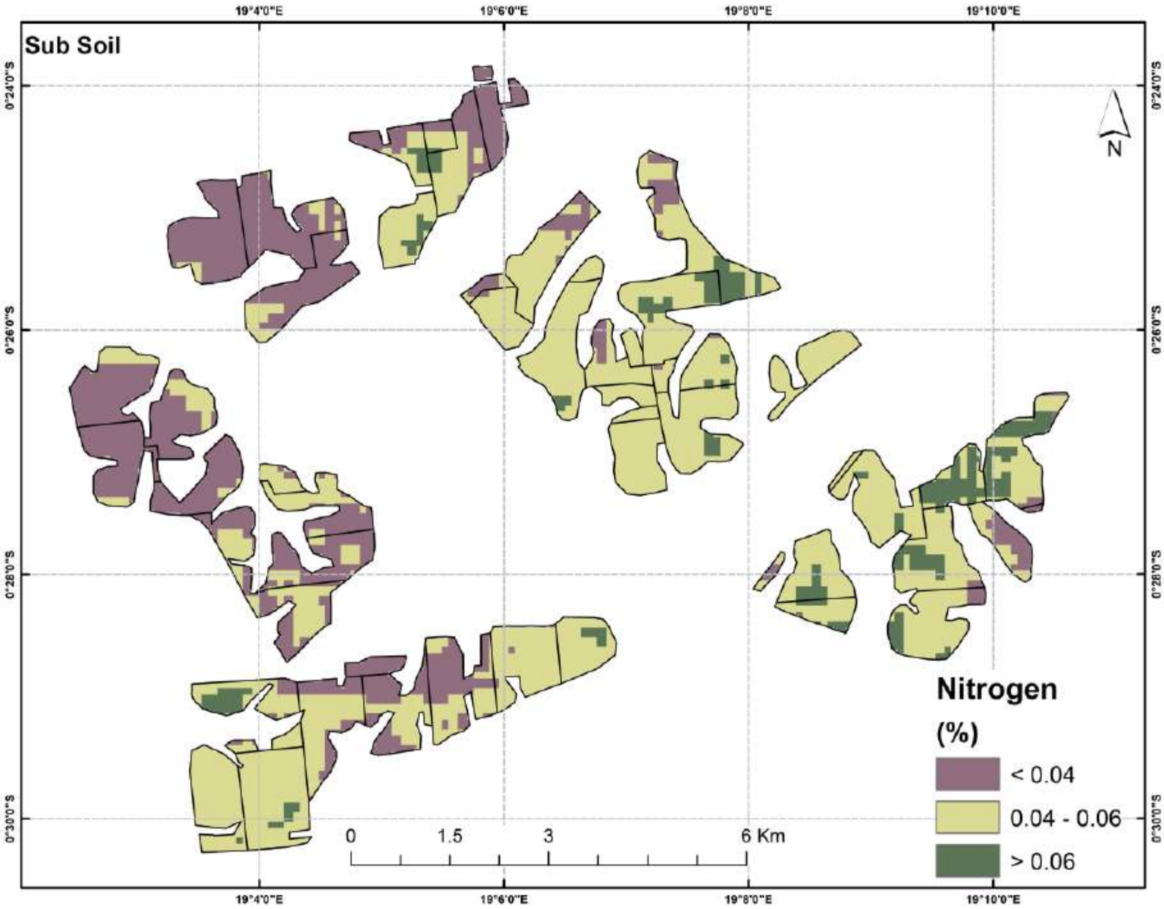


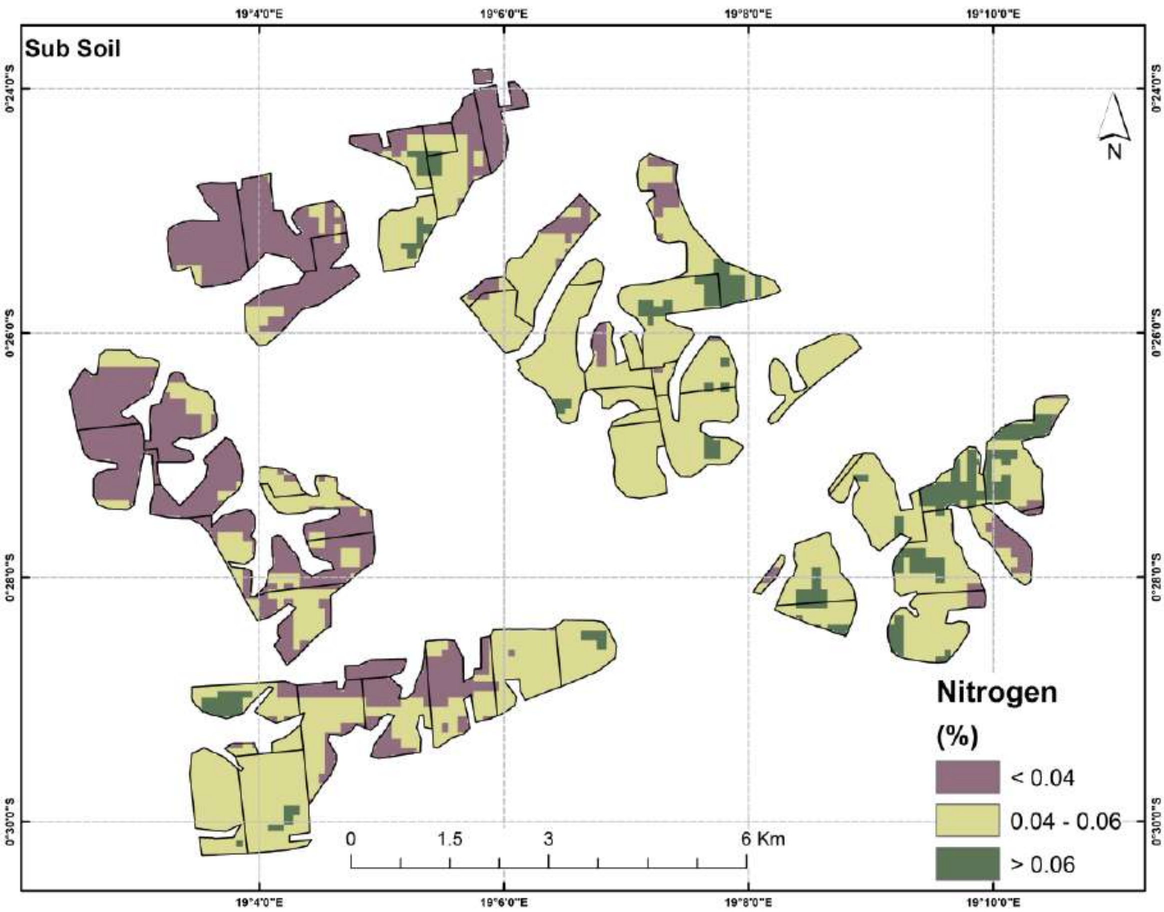
19°2'0"E
19°4'0"E
19°6'0"E
19°8'0"E
19°10'0"E
0°24'0"S
0°26'0"S
0°28'0"S
0°30'0"S
N
0
1.5
3
6 Km
Slope
< 3 (Flat or almost flat, 95.82%)
3.1 - 8 (Gently sloping, 4.18%)

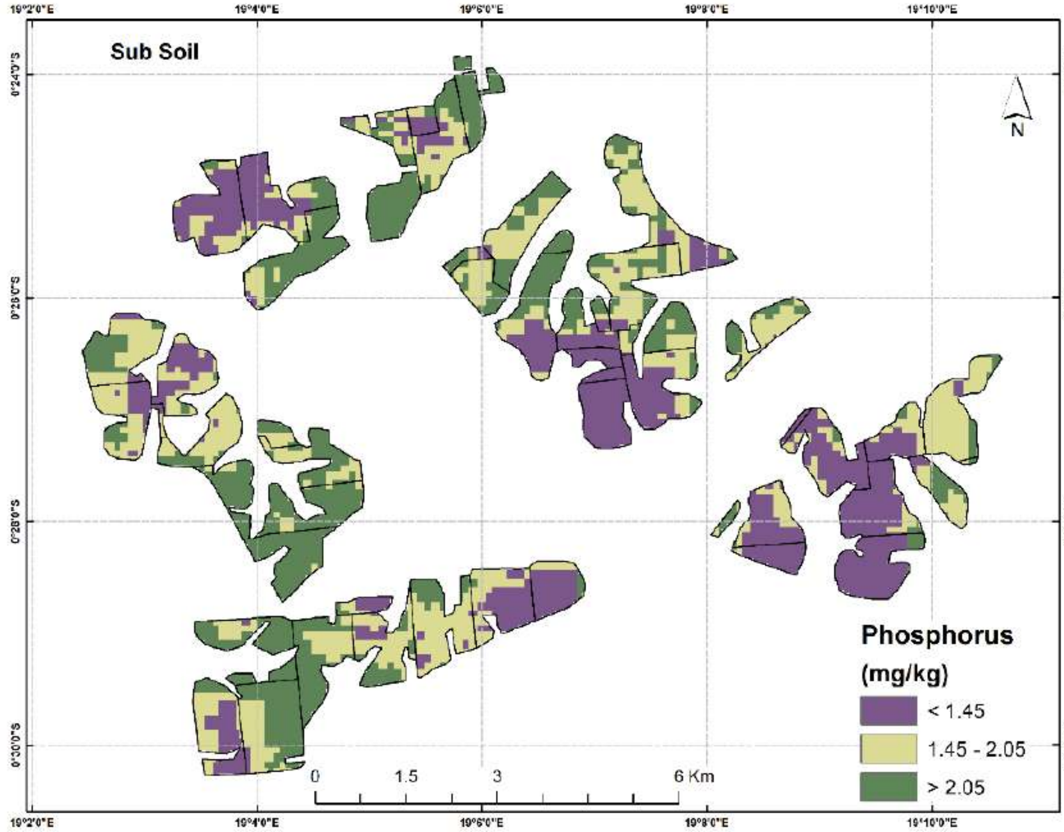

Sub Soil
pH
< 4.84
4.84 - 4.96
> 4.96
0
1.5
3
6 Km
N
19°3'0"E
19°4'30"E
19°6'0"E
19°7'30"E
19°9'0"E
19°10'30"E
0°24'0"S
0°25'30"S
0°27'0"S
0°28'30"S
0°30'0"S

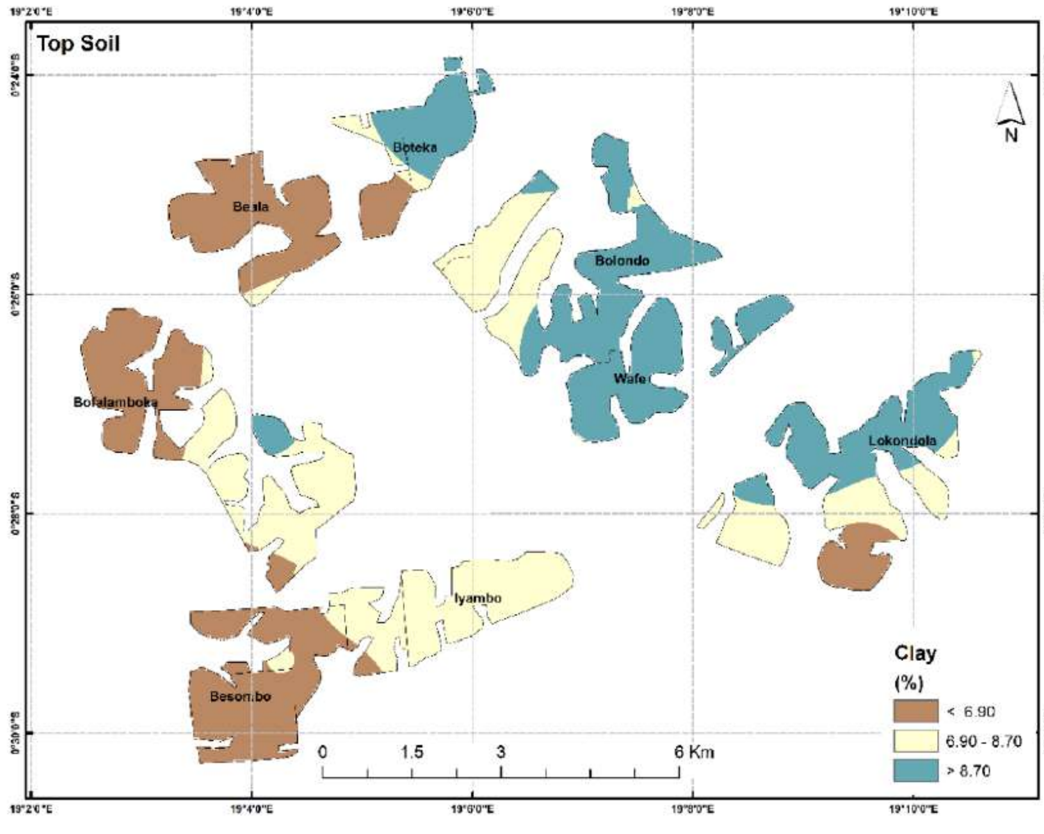

Sub Soil
pH
< 4.84
4.84 - 4.96
> 4.96
0
1.5
3
6 Km
N
19°3'0"E
19°4'30"E
19°6'0"E
19°7'30"E
19°9'0"E
19°10'30"E
0°24'0"S
0°25'30"S
0°27'0"S
0°28'30"S
0°30'0"S

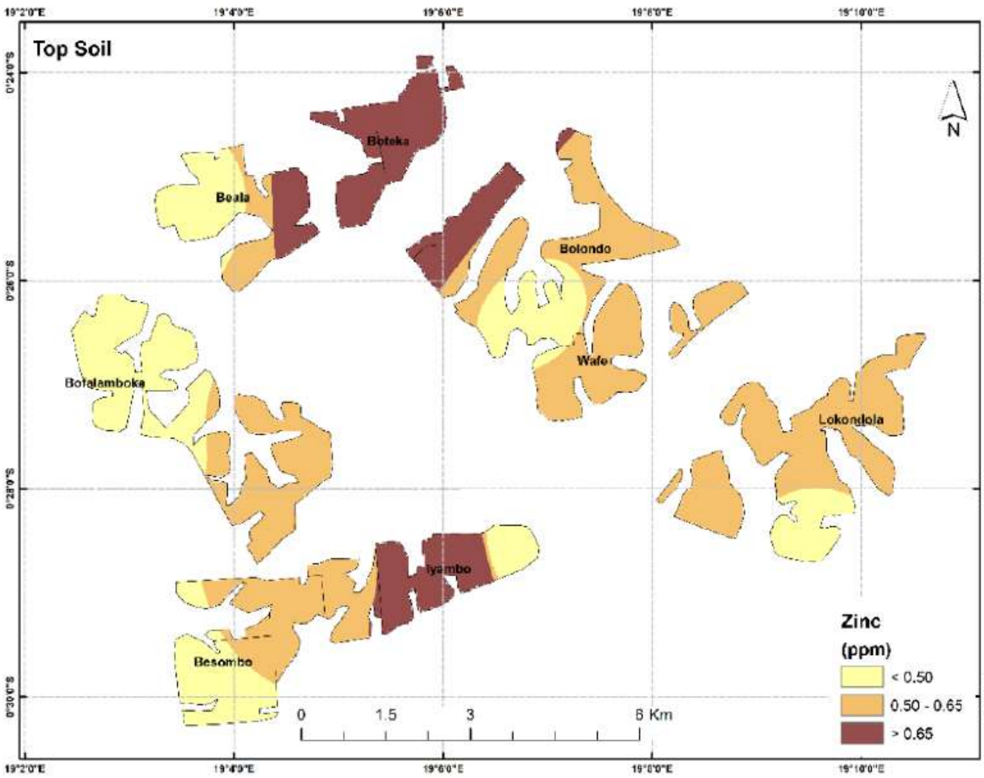

Sub Soil
19°4'0"E
19°6'0"E
19°8'0"E
19°10'0"E
0°24'0"S
0°26'0"S
0°28'0"S
0°30'0"S
N
Organic Carbon (%)
< 0.27
0.27 - 0.48
> 0.48
0
1.5
3
6 Km

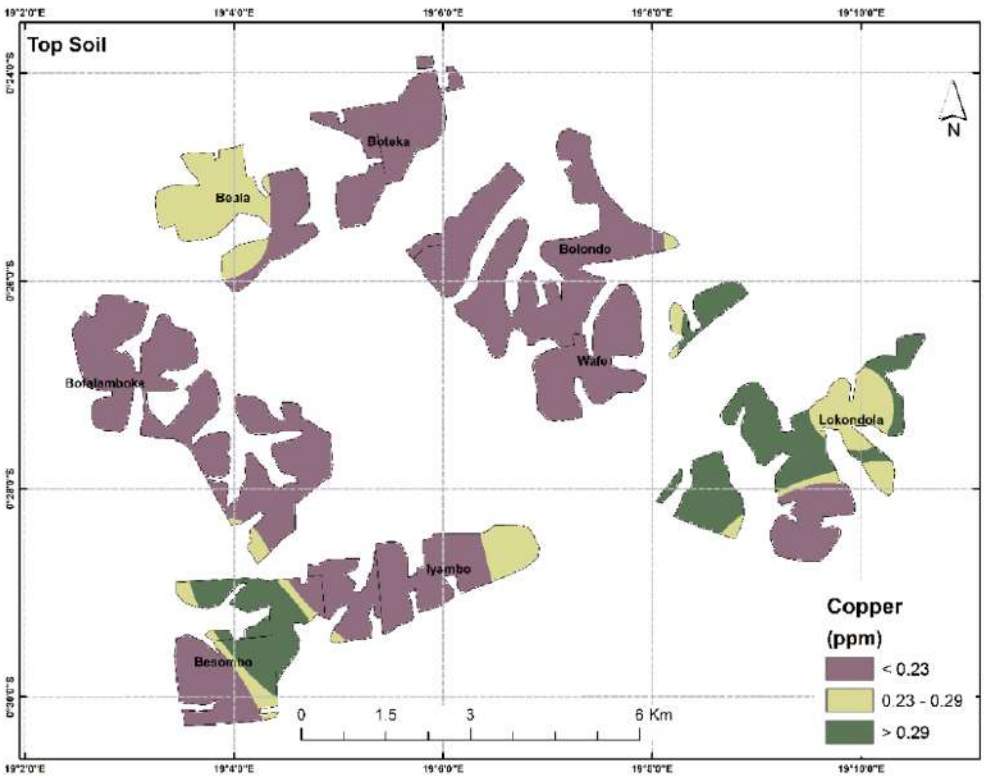

Sub Soil
Nitrogen
(%)
< 0.04
0.04 - 0.06
> 0.06
0 1.5 3 6 Km
19°4'0"E
19°6'0"E
19°8'0"E
19°10'0"E
0°24'0"S
0°26'0"S
0°28'0"S
0°30'0"S
N


Sub Soil
Nitrogen
(%)
< 0.04
0.04 - 0.06
> 0.06
0 1.5 3 6 Km
19°4'0"E
19°6'0"E
19°8'0"E
19°10'0"E
0°24'0"S
0°26'0"S
0°28'0"S
0°30'0"S
N

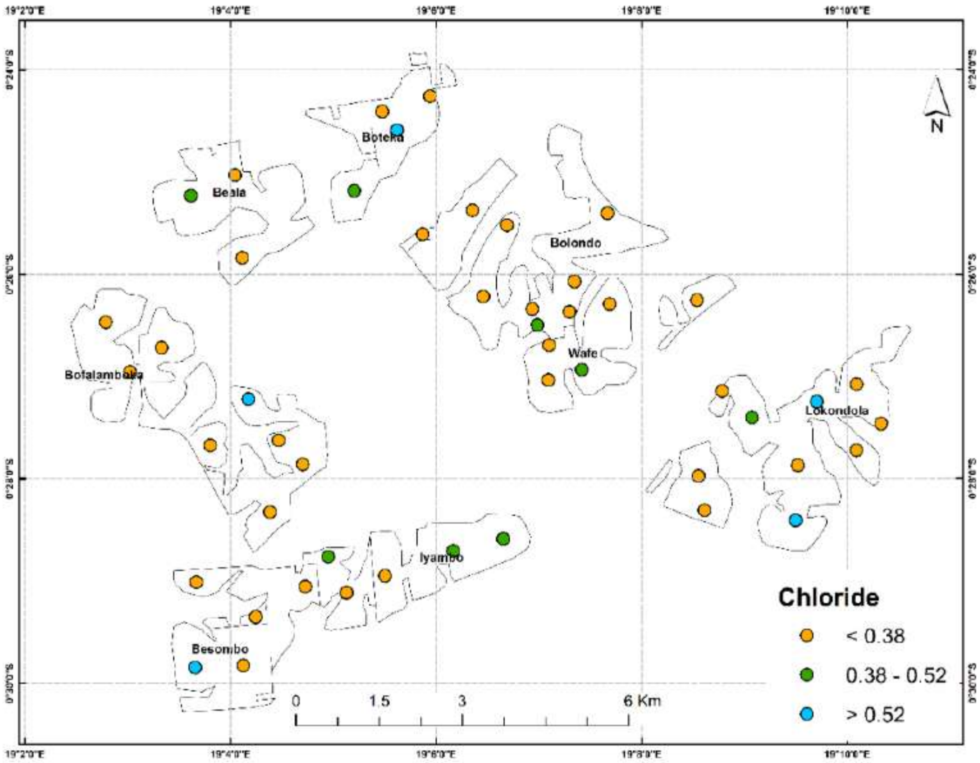

Sub Soil
Phosphorus
(mg/kg)
< 1.45
1.45 - 2.05
> 2.05
0
1.5
3
6 Km
N
19°2'0"E
19°4'0"E
19°6'0"E
19°8'0"E
19°10'0"E
0°24'0"S
0°26'0"S
0°28'0"S
0°30'0"S

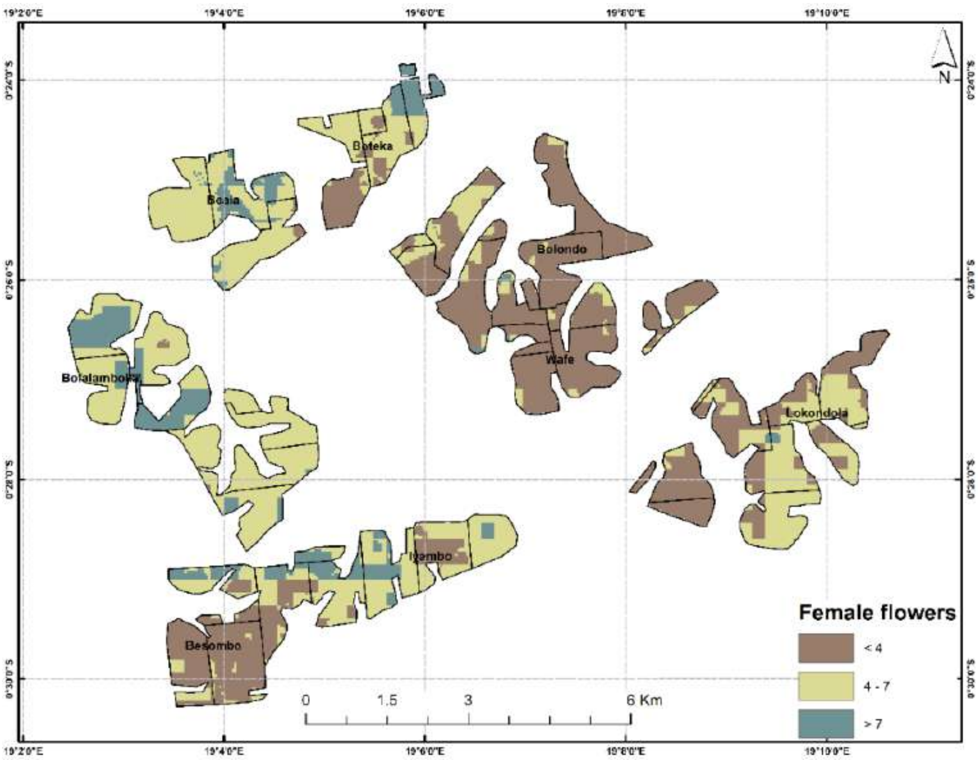

Top Soil
Boteka
Beala
Bolondo
Bofalamboka
Wafe
Lokondola
Iyambo
Besombo
Clay
(%)
< 6.90
6.90 - 8.70
> 8.70
0
1.5
3
6 Km
N
19°2'0"E
19°4'0"E
19°6'0"E
19°8'0"E
19°10'0"E
0°24'0"S
0°26'0"S
0°28'0"S
0°30'0"S


Top Soil
Boteka
Beala
Bolondo
Wafe
Bofalamboke
Lokondola
Iyambo
Besombo
Zinc
(ppm)
< 0.50
0.50 - 0.65
> 0.65
0
1.5
3
6 Km
N

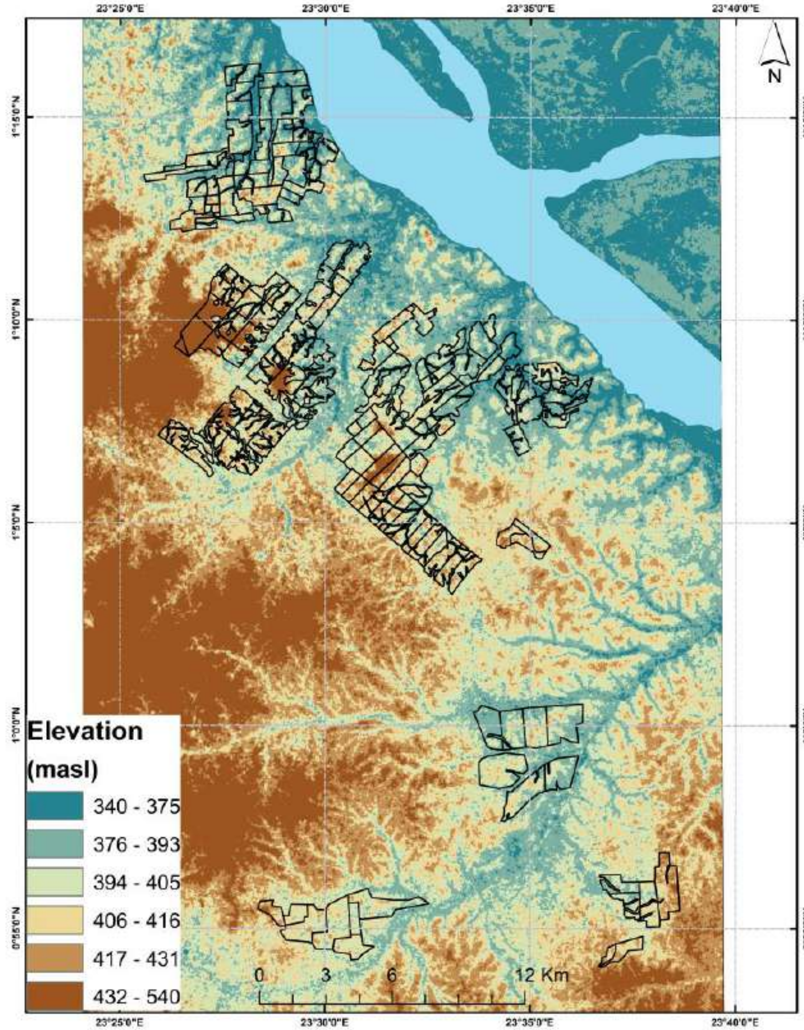

Top Soil
Boteka
Beala
Bolondo
Wafe
Bofalamboke
Lokondola
Iyambo
Besombo
Copper
(ppm)
< 0.23
0.23 - 0.29
> 0.29
0
1.5
3
6 Km
N

Appendix 3: Plant nutrient and sex ratio maps at Boteka plantation

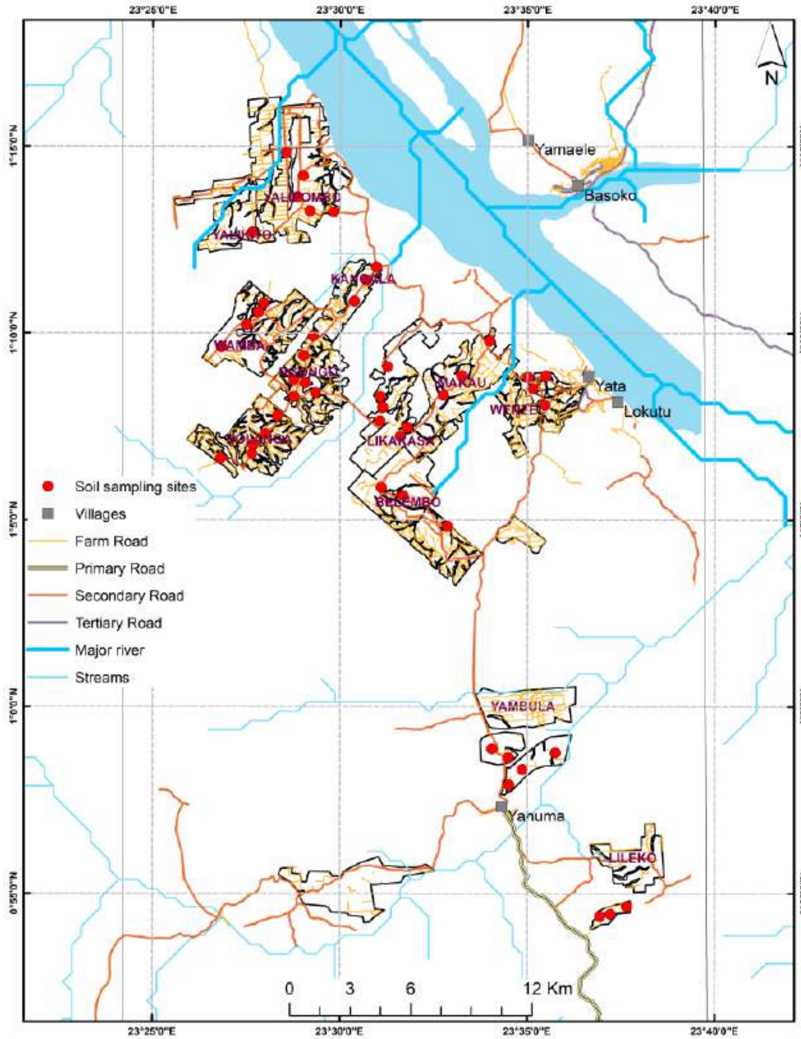




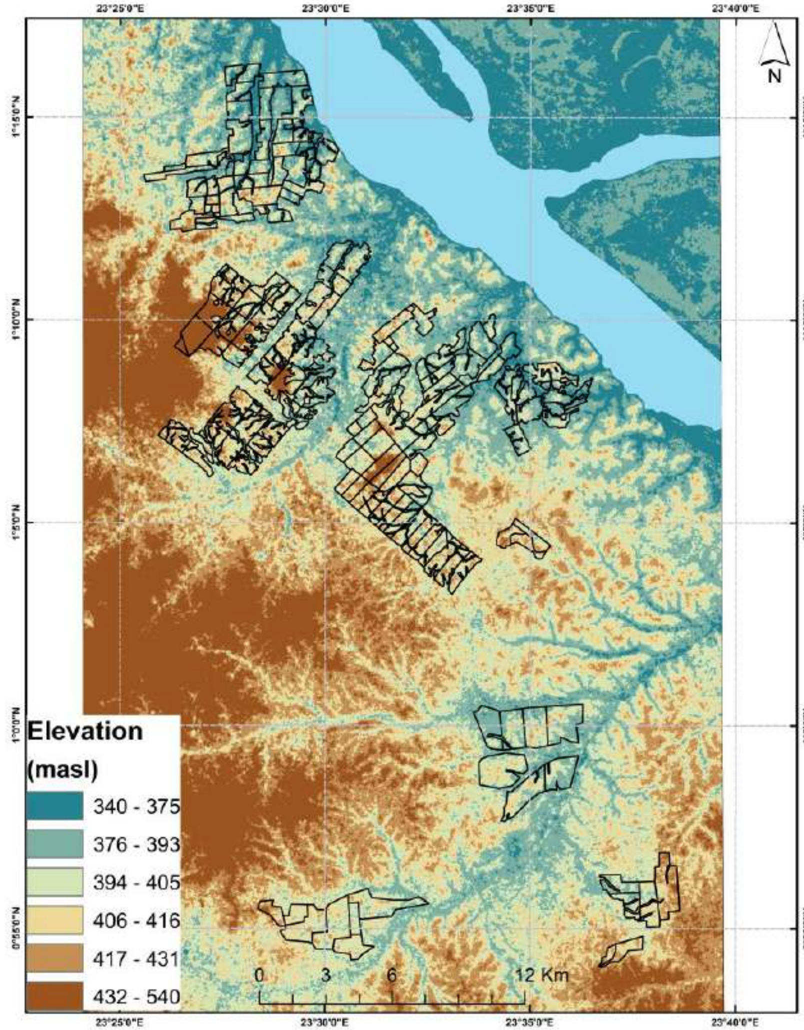
Appendix 4: Land and soil maps of Lokutu plantation



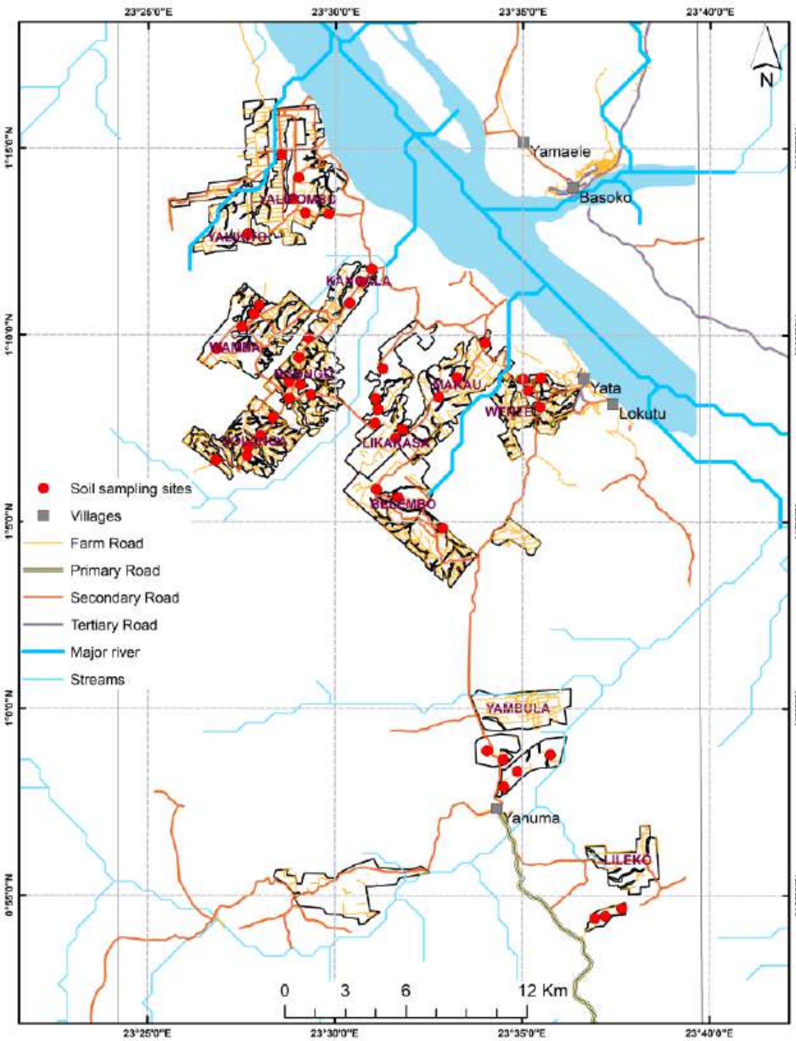
23°25'0"E
23°30'0"E
23°35'0"E
23°40'0"E
N
Elevation
(masl)
340 - 375
376 - 393
394 - 405
406 - 416
417 - 431
432 - 540
0
3
6
12 Km



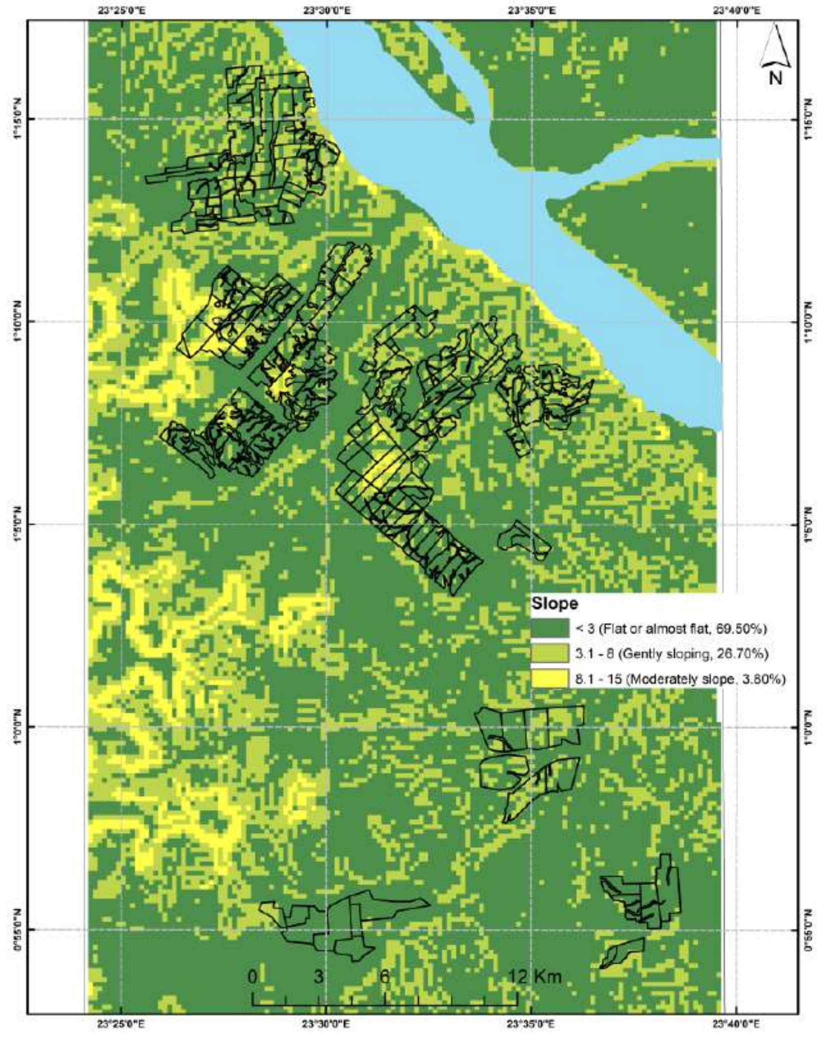
23°25'0"E
23°30'0"E
23°35'0"E
23°40'0"E
N
Yamaele
Basoko
Yata
Lokutu
Yahuma
YAMBULA
LILEKO
Soil sampling sites
Villages
Farm Road
Primary Road
Secondary Road
Tertiary Road
Major river
Streams
0
3
6
12 Km



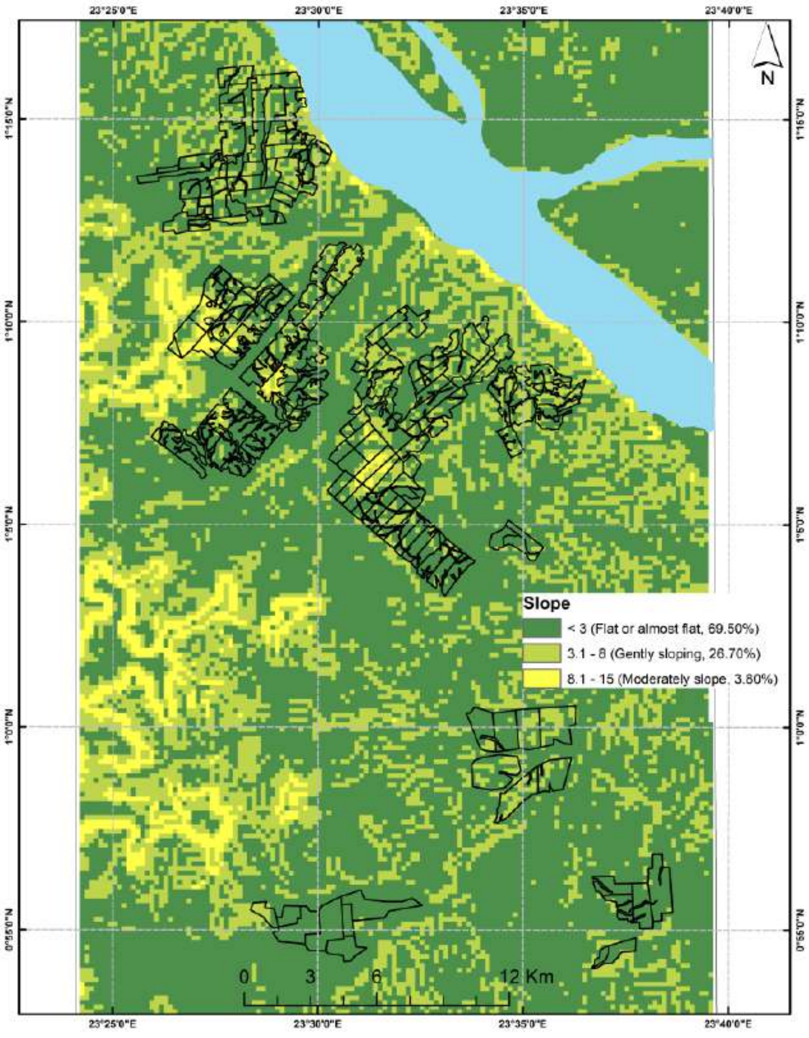
Elevation
(masl)
340 - 375
376 - 393
394 - 405
406 - 416
417 - 431
432 - 540
0 3 6 12 Km
N
23°25'0"E
23°30'0"E
23°35'0"E
23°40'0"E
1°15'0"N
1°10'0"N
1°5'0"N
1°0'0"N
0°55'0"N



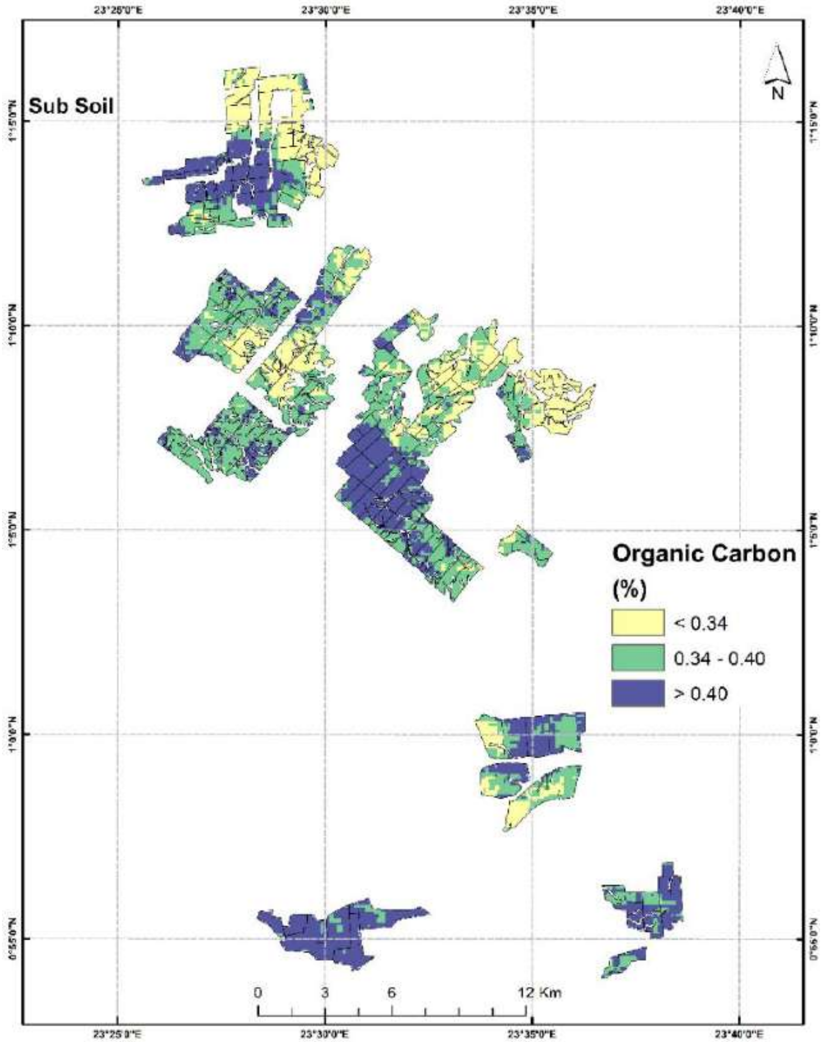
N
Yamaele
Basoko
Yata
Lokutu
Yanuma
YAMBULA
LILEKO
WAMBA
LIKAKASA
Soil sampling sites
Villages
Farm Road
Primary Road
Secondary Road
Tertiary Road
Major river
Streams
0 3 6 12 Km
23°25'0"E
23°30'0"E
23°35'0"E
23°40'0"E
1°15'0"N
1°10'0"N
1°5'0"N
1°0'0"N
0°55'0"N

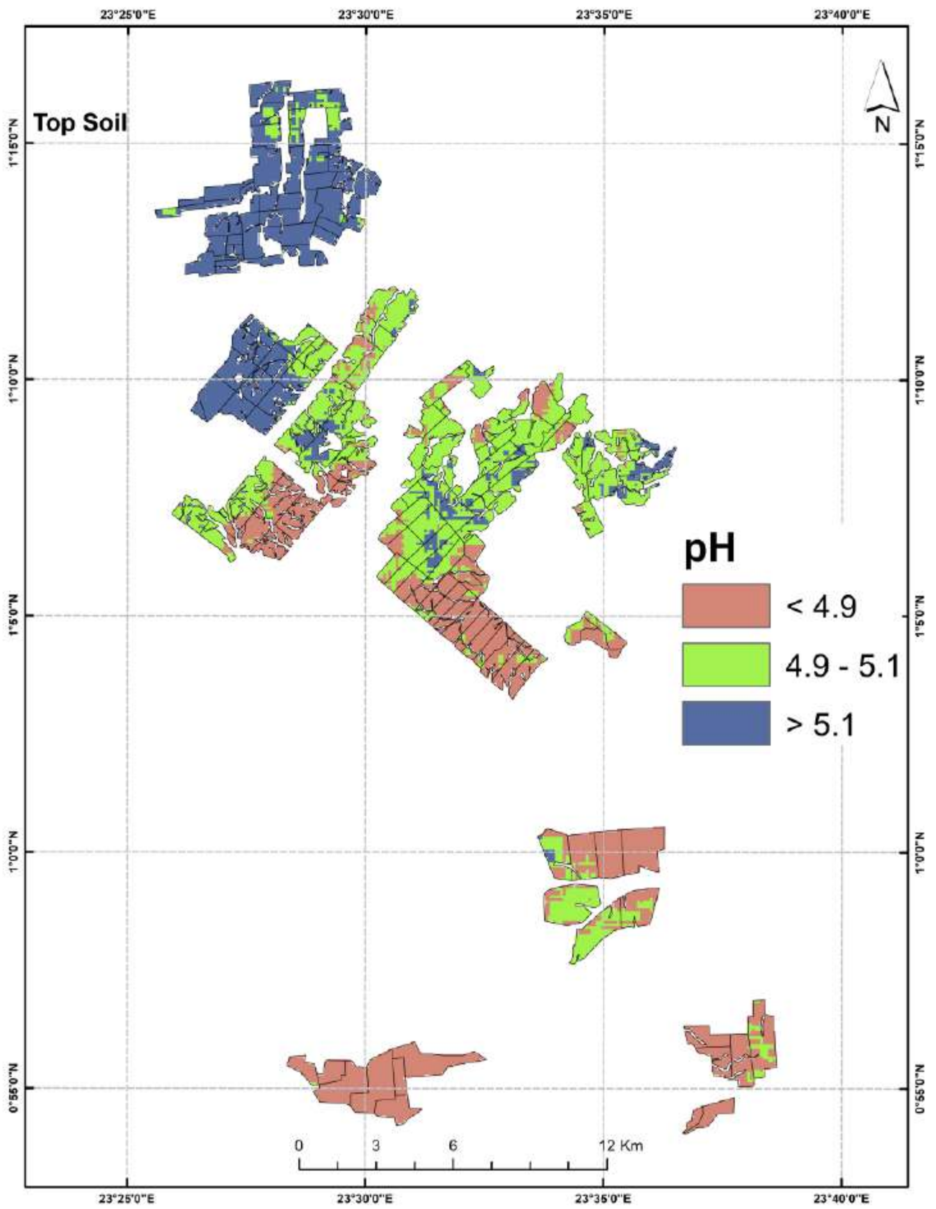


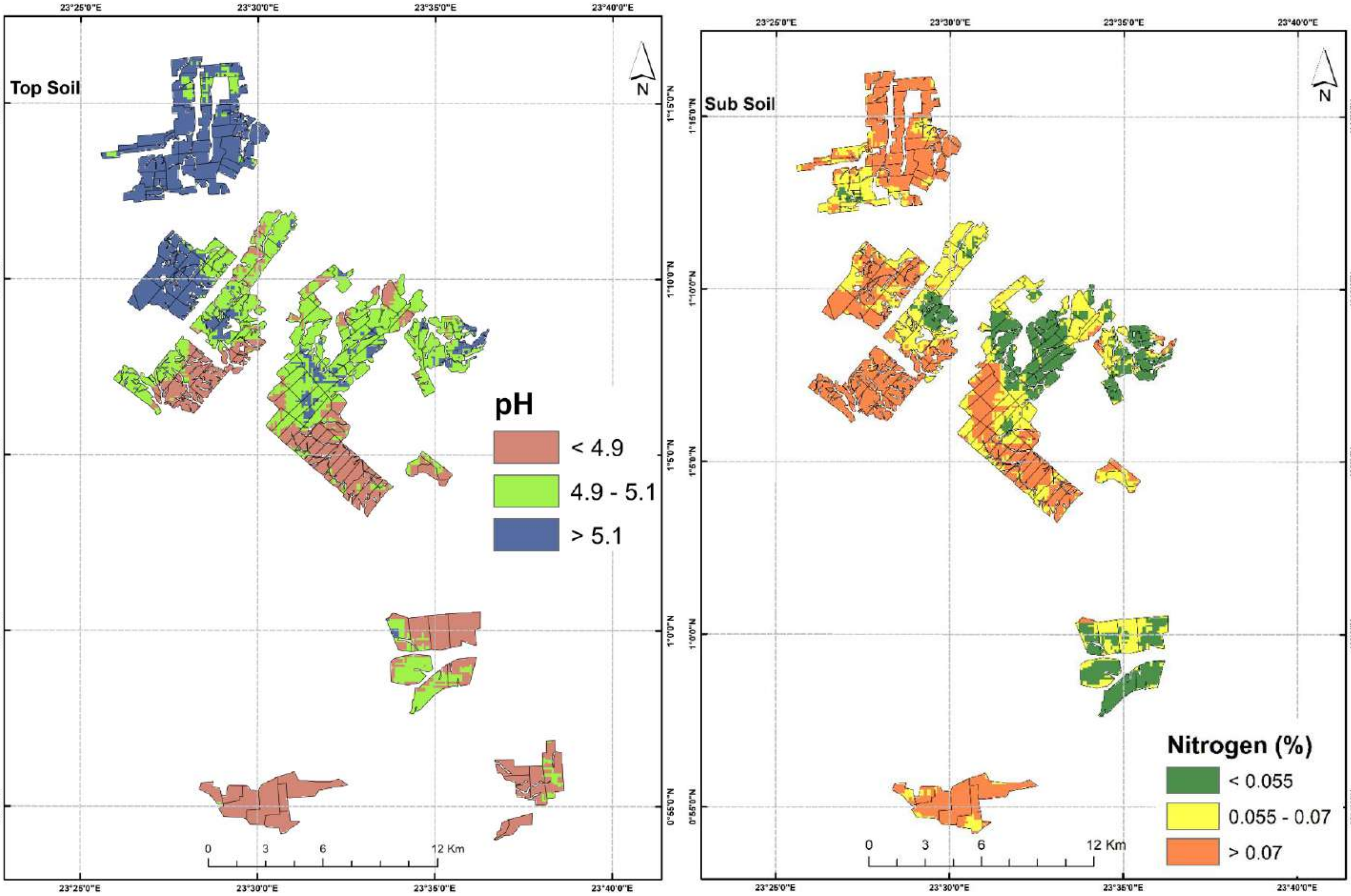
23°25'0"E
23°30'0"E
23°35'0"E
23°40'0"E
1°15'0"N
1°10'0"N
1°5'0"N
1°0'0"N
0°55'0"N
N
Slope
< 3 (Flat or almost flat, 69.50%)
3.1 - 8 (Gently sloping, 26.70%)
8.1 - 15 (Moderately slope, 3.80%)
0 3 6 12 Km

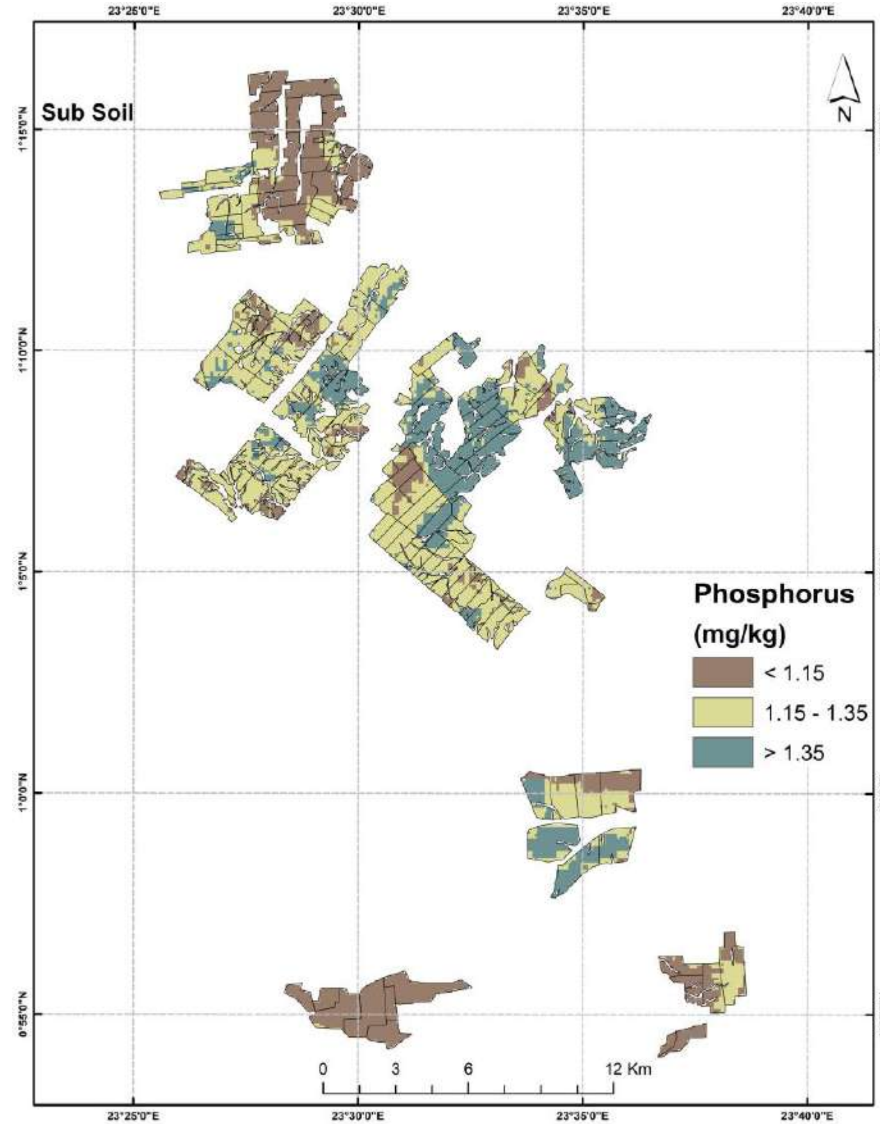


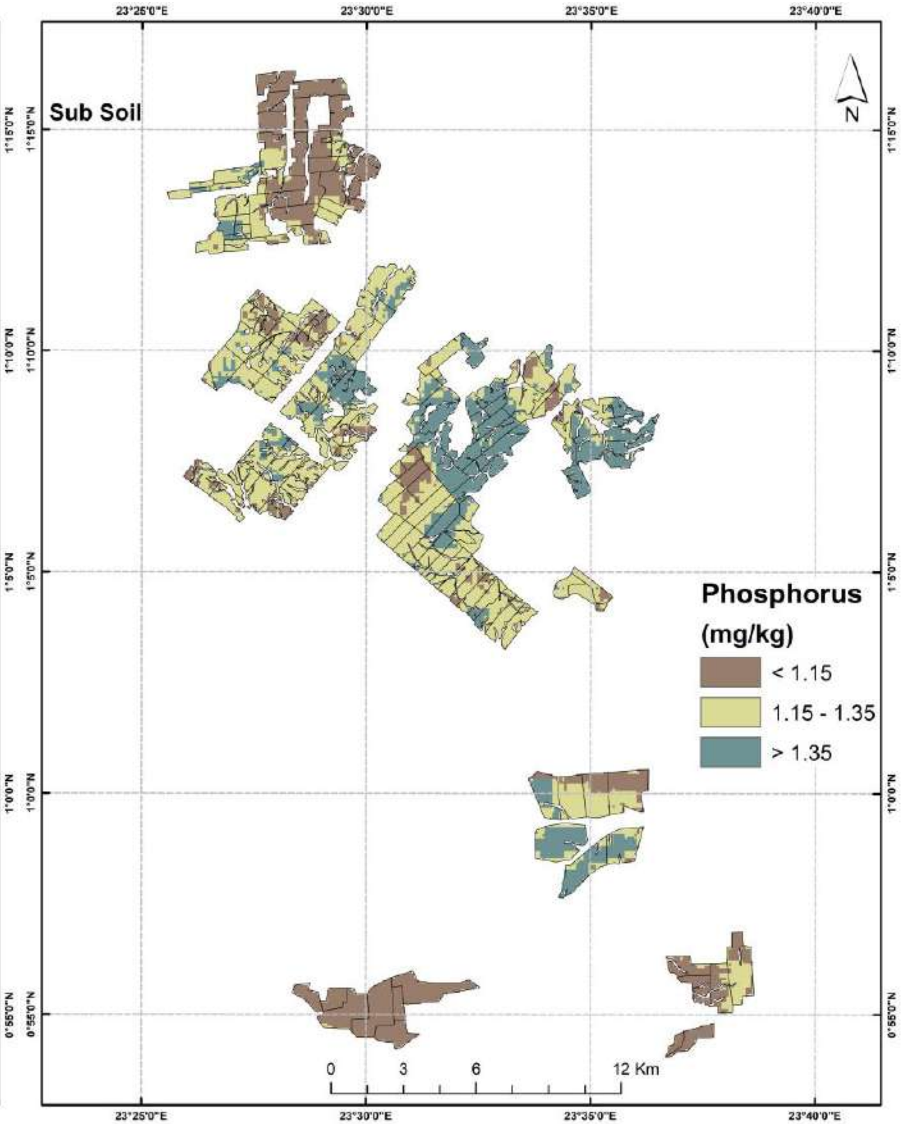
23°25'0"E
23°30'0"E
23°35'0"E
23°40'0"E
1°15'0"N
1°10'0"N
1°5'0"N
1°0'0"N
0°55'0"N
N
Slope
< 3 (Flat or almost flat, 69.50%)
3.1 - 8 (Gently sloping, 26.70%)
8.1 - 15 (Moderately slope, 3.80%)
0 3 6 12 Km

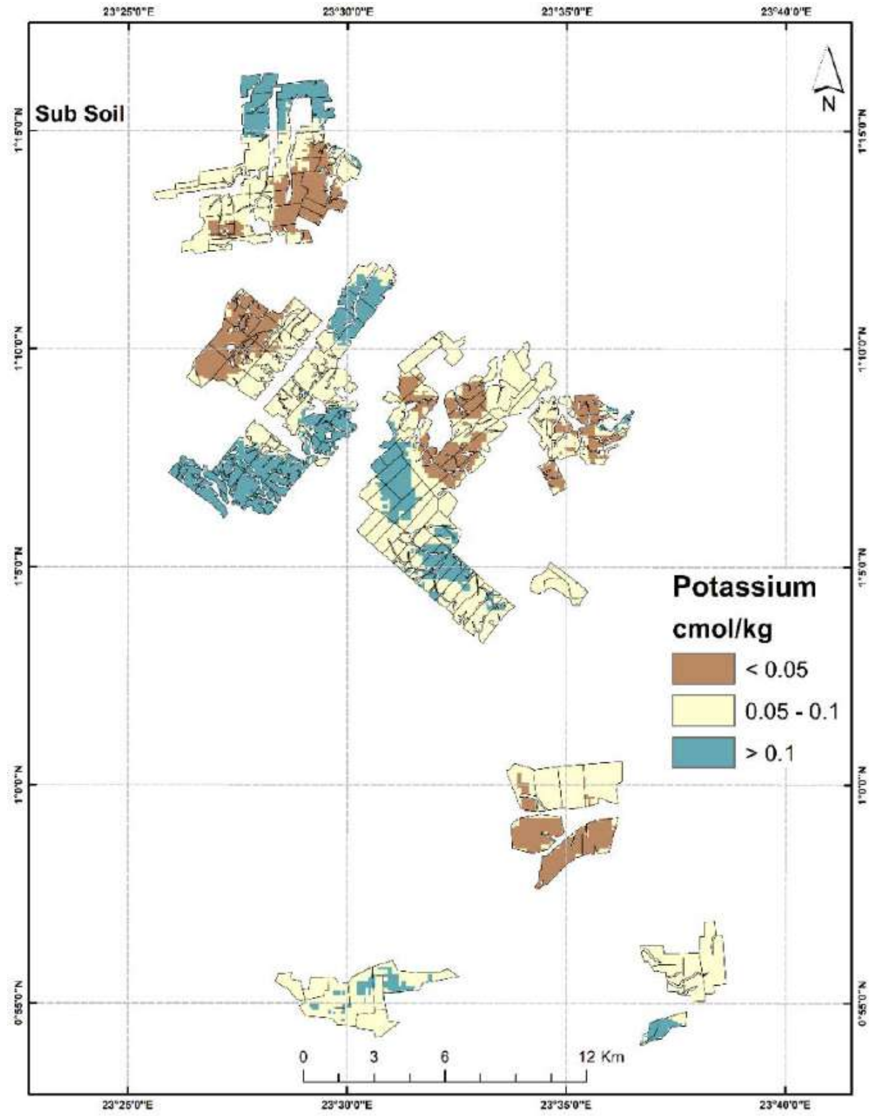

Sub Soil
N
Organic Carbon
(%)
< 0.34
0.34 - 0.40
> 0.40
0
3
6
12 Km
23°25'0"E
23°30'0"E
23°35'0"E
23°40'0"E


Top Soil
N
pH
< 4.9
4.9 - 5.1
> 5.1
0
3
6
12 Km
23°25'0"E
23°30'0"E
23°35'0"E
23°40'0"E
1°15'0"N
1°10'0"N
1°5'0"N
1°0'0"N
0°55'0"N

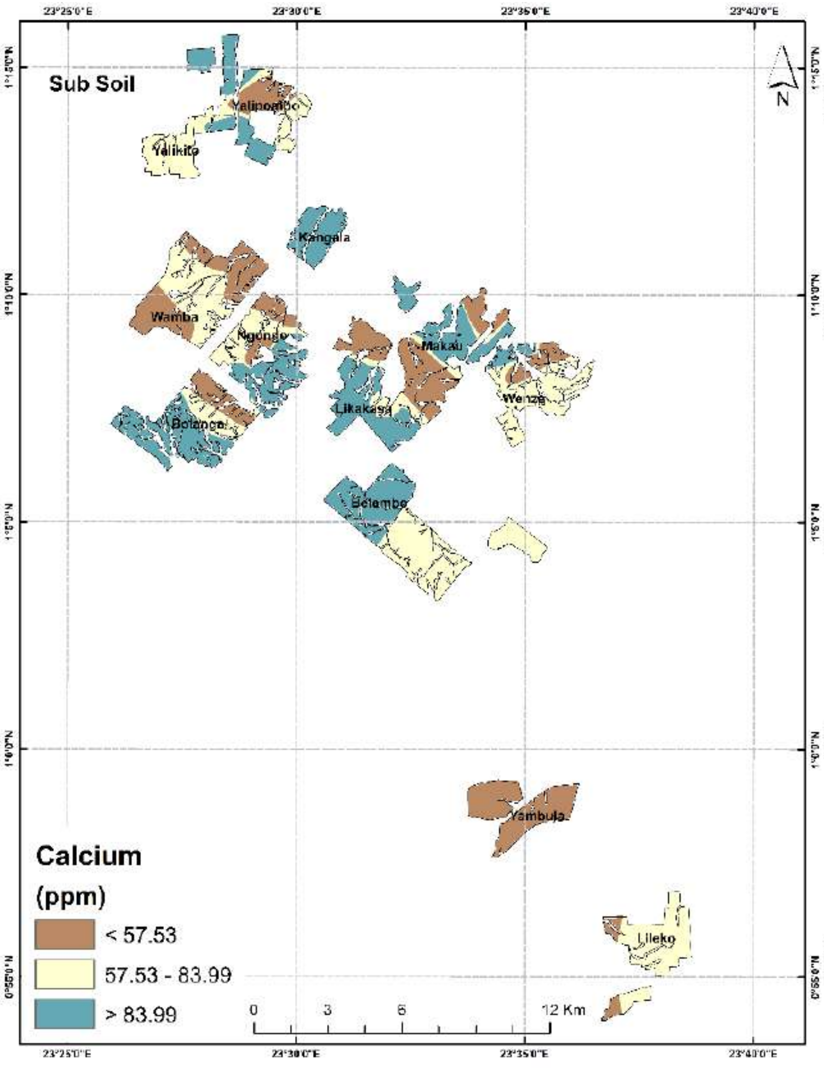

Top Soil
pH
< 4.9
4.9 - 5.1
> 5.1
Sub Soil
Nitrogen (%)
< 0.055
0.055 - 0.07
> 0.07
0
3
6
12 Km
N

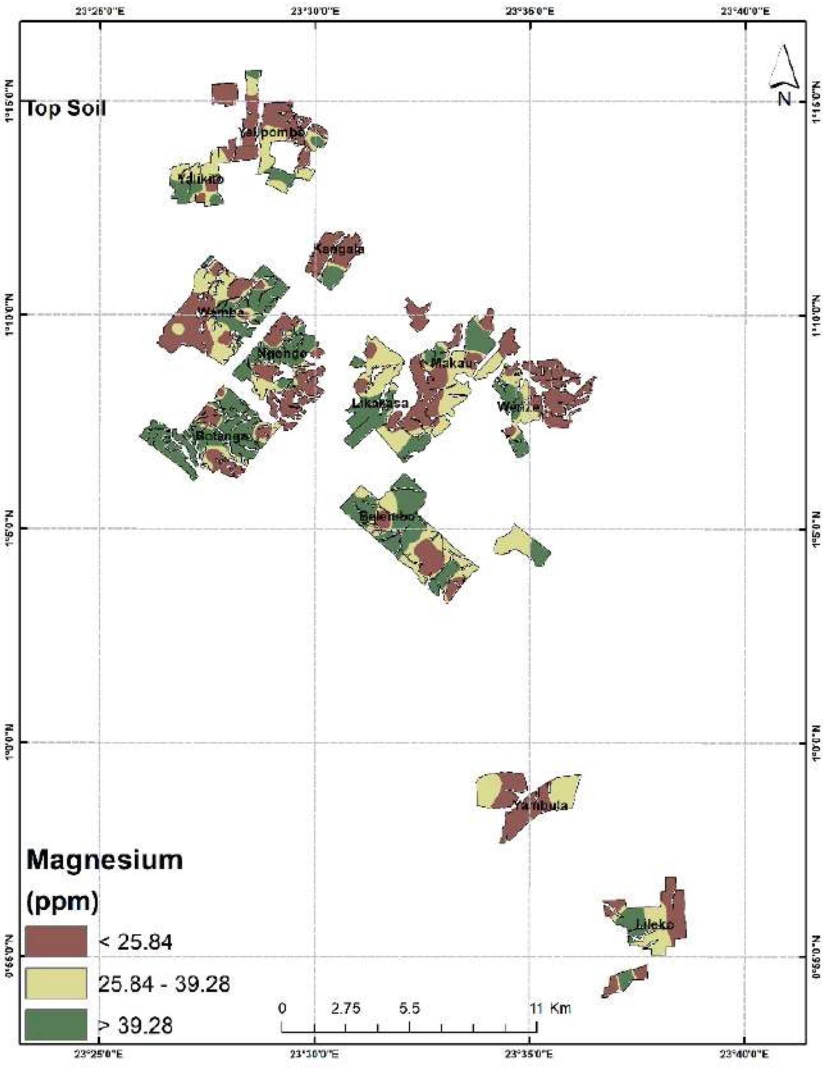

23°25'0"E
23°30'0"E
23°35'0"E
23°40'0"E
1°15'0"N
1°10'0"N
1°5'0"N
1°0'0"N
0°55'0"N
Sub Soil
N
Phosphorus
(mg/kg)
< 1.15
1.15 - 1.35
> 1.35
0 3 6 12 Km

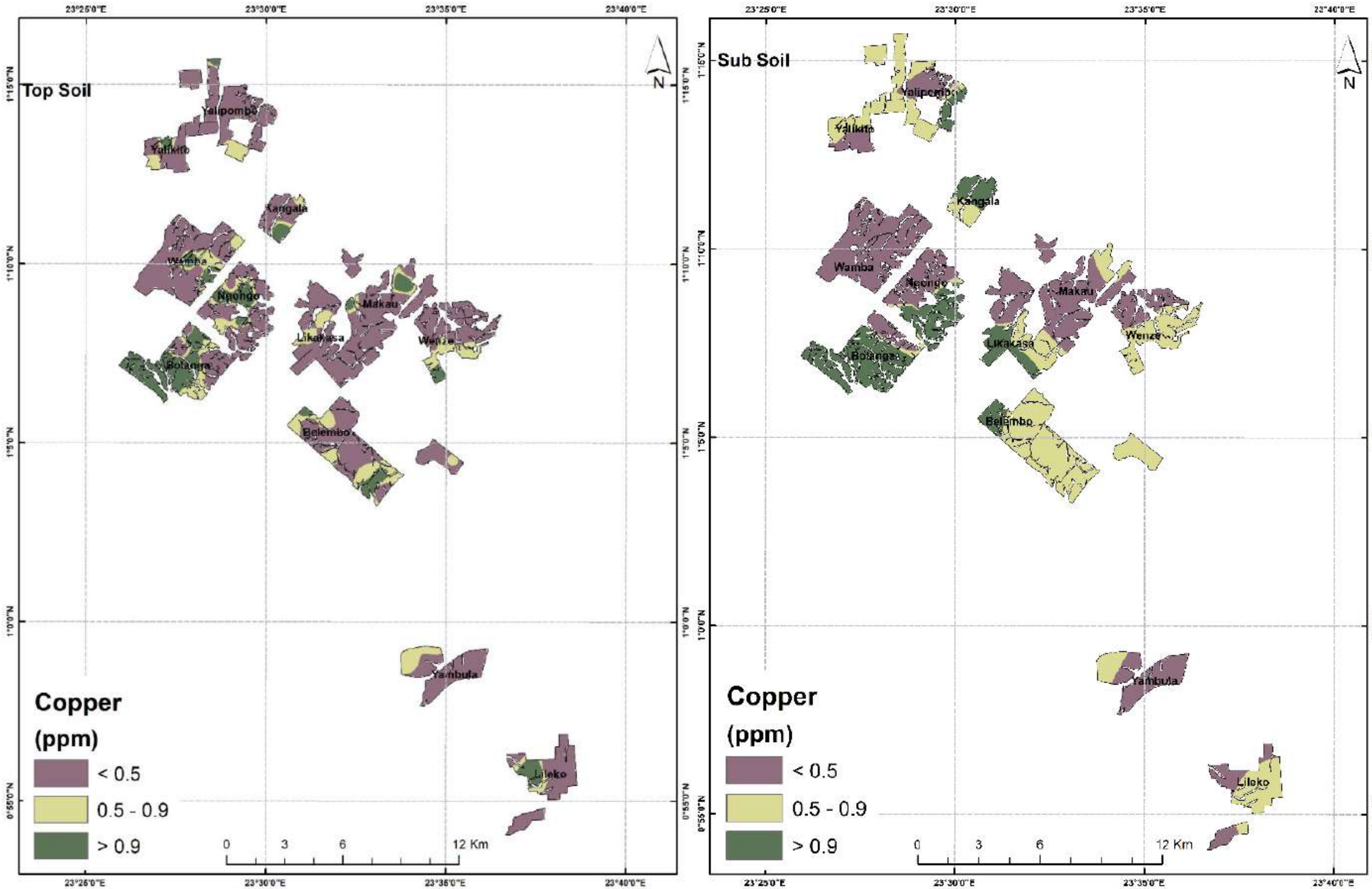

23°25'0"E
23°30'0"E
23°35'0"E
23°40'0"E
1°15'0"N
1°10'0"N
1°5'0"N
1°0'0"N
0°55'0"N
Sub Soil
N
Phosphorus
(mg/kg)
< 1.15
1.15 - 1.35
> 1.35
0 3 6 12 Km



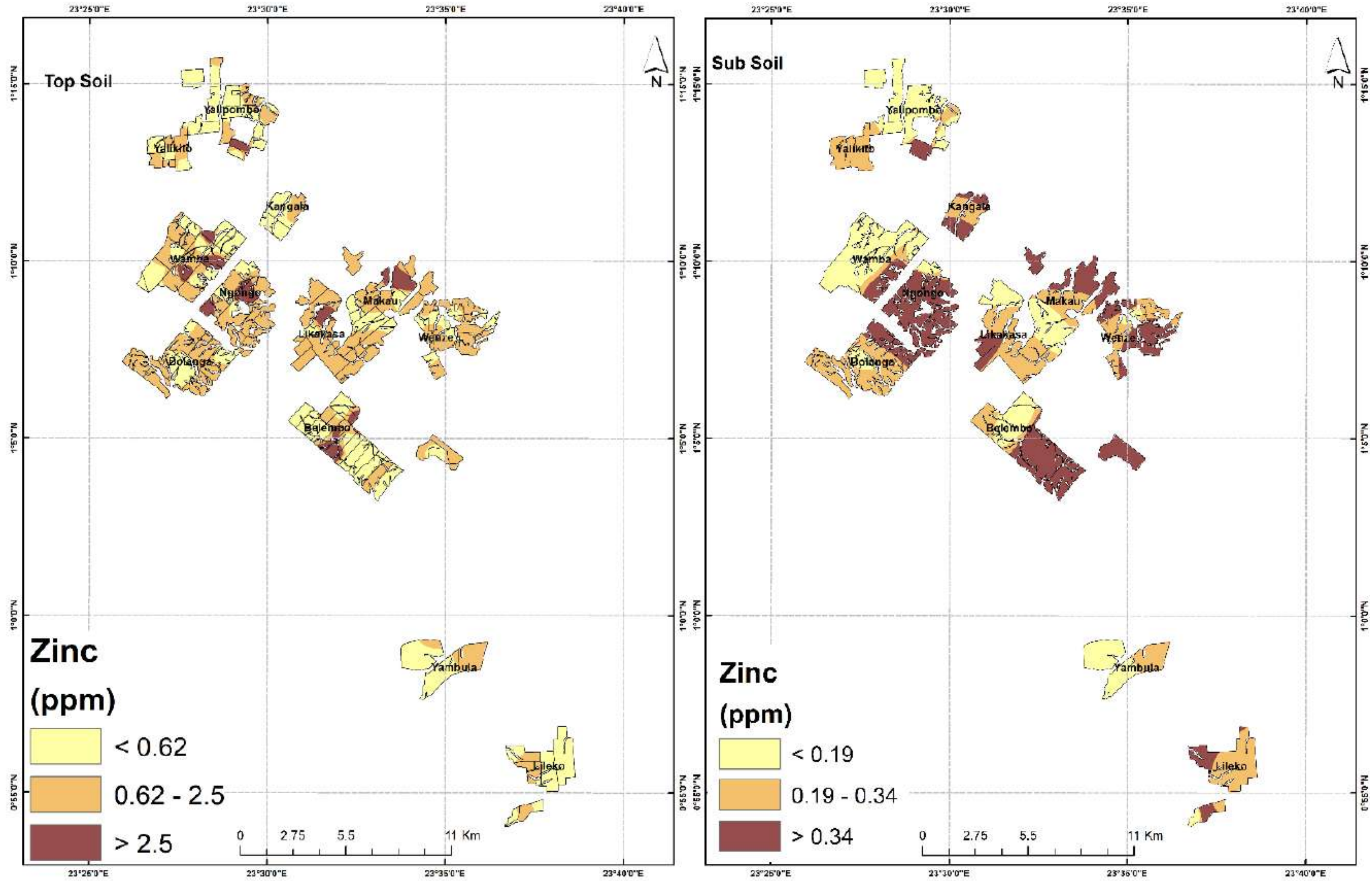
Sub Soil
N
23°25'0"E
23°30'0"E
23°35'0"E
23°40'0"E
1°15'0"N
1°10'0"N
1°5'0"N
1°0'0"N
0°55'0"N
Potassium
cmol/kg
< 0.05
0.05 - 0.1
> 0.1
0 3 6 12 Km

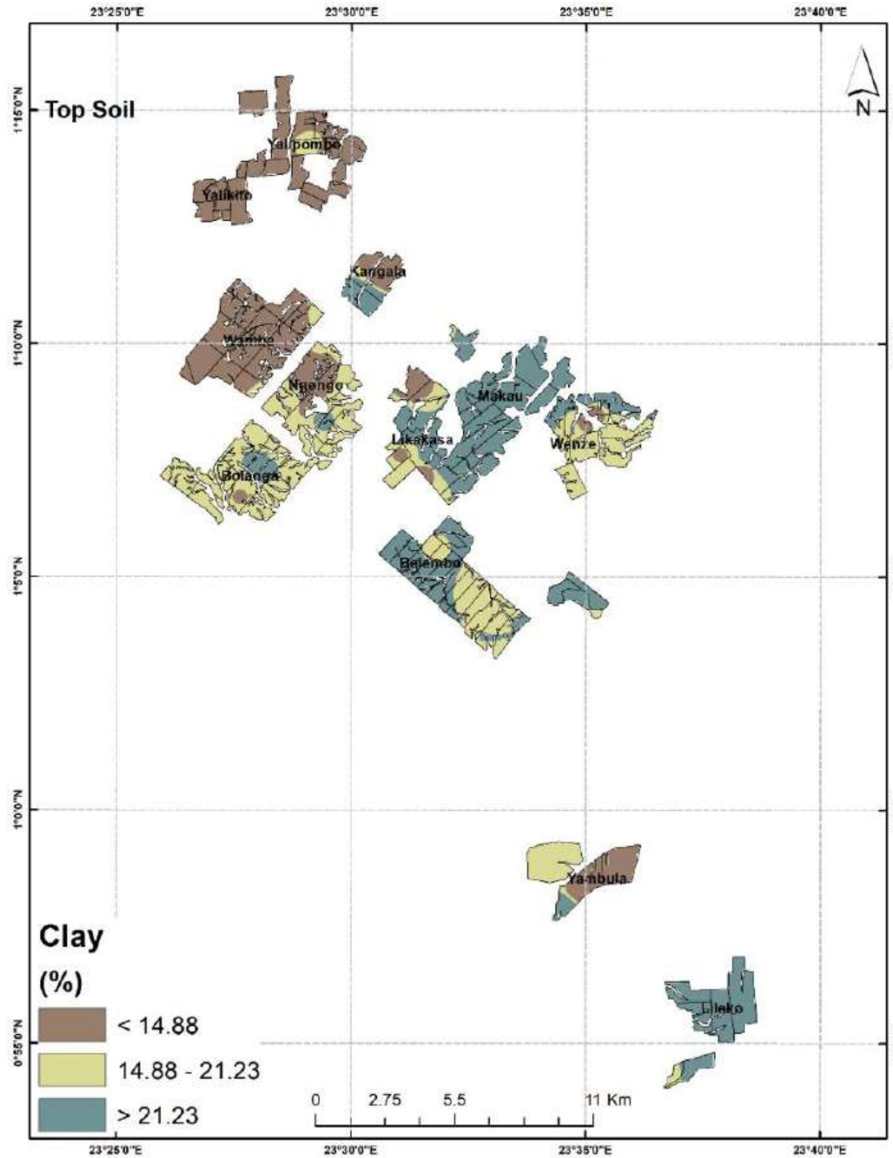

Sub Soil
Yalipombo
Yalikito
Kangala
Wamba
Ngongo
Makau
Likakasa
Wenze
Botanga
Belembo
Yambula
Lileko
Calcium
(ppm)
< 57.53
57.53 - 83.99
> 83.99
0 3 6 12 Km
N

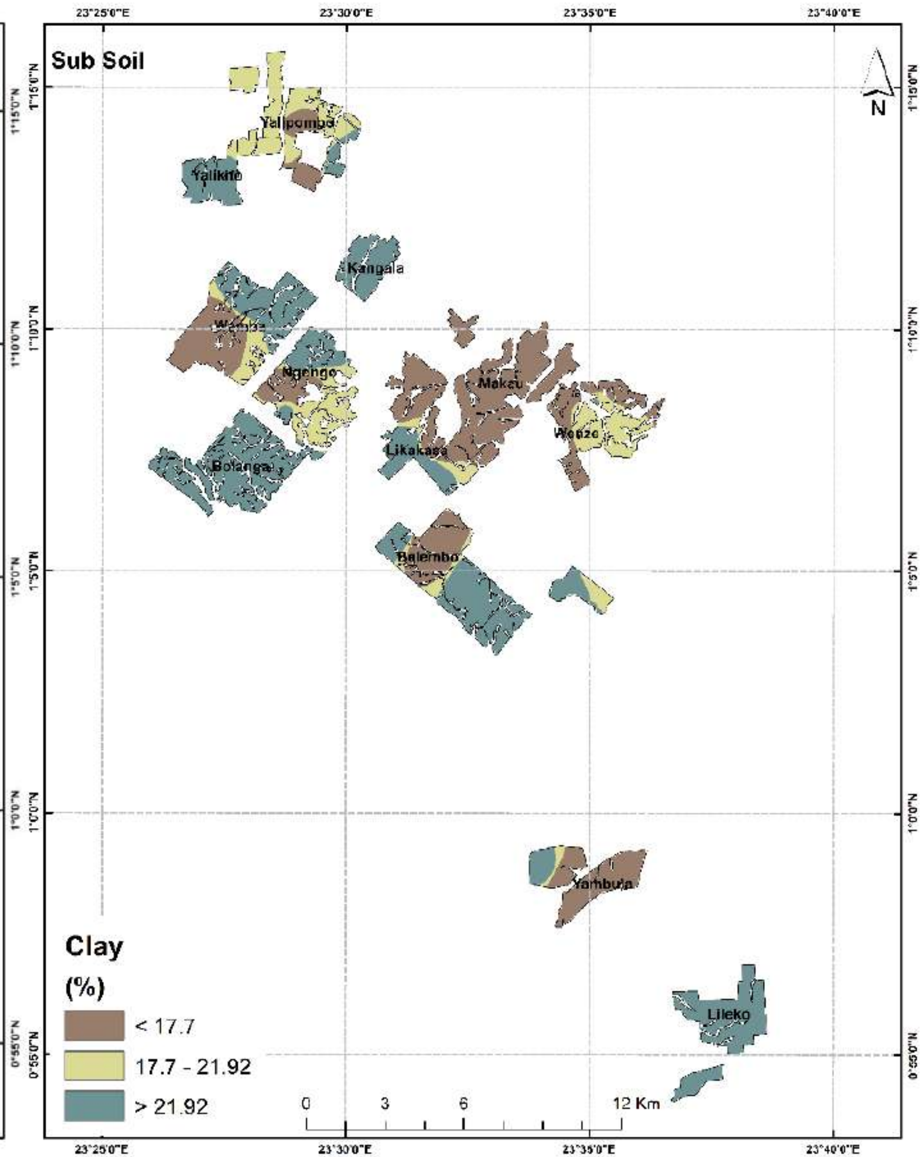

Top Soil
Yalipombo
Yalikito
Kangala
Wamba
Ngongo
Makau
Likakasa
Wenze
Botanga
Belembo
Yambula
Lileko
Magnesium
(ppm)
< 25.84
25.84 - 39.28
> 39.28
0 2.75 5.5 11 Km
N



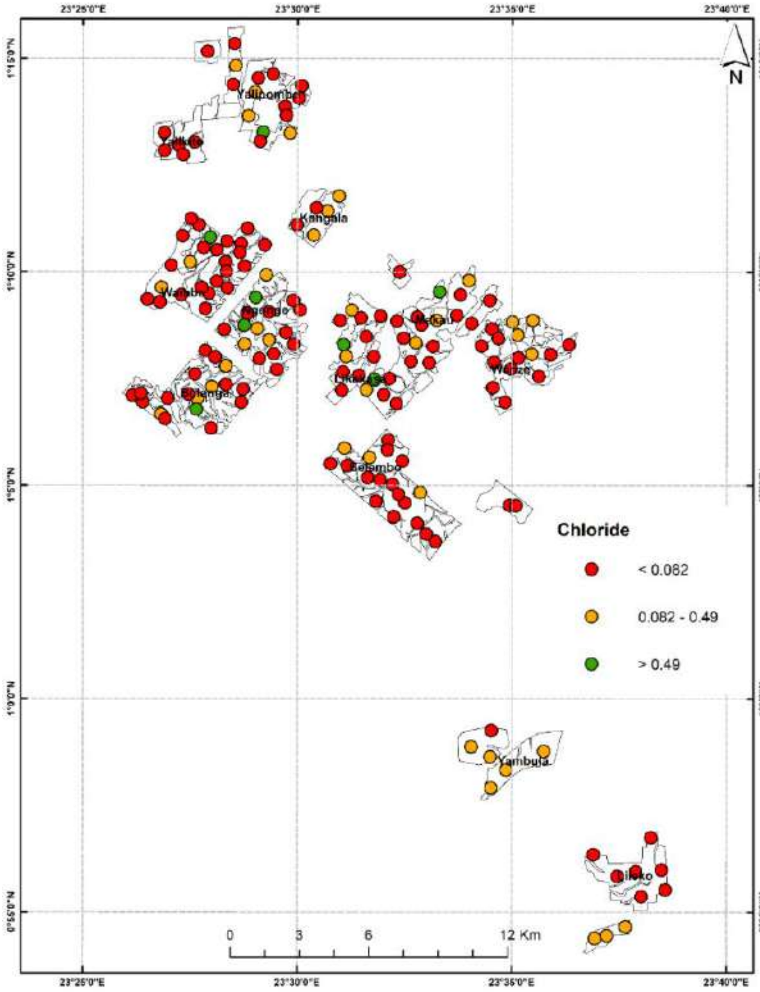
Top Soil
Yalipombo
Yalikito
Kangala
Wamba
Ngongo
Makau
Likakasa
Wenze
Botanga
Belembo
Yambula
Lileko
Copper
(ppm)
< 0.5
0.5 - 0.9
> 0.9
0
3
6
12 Km
Sub Soil

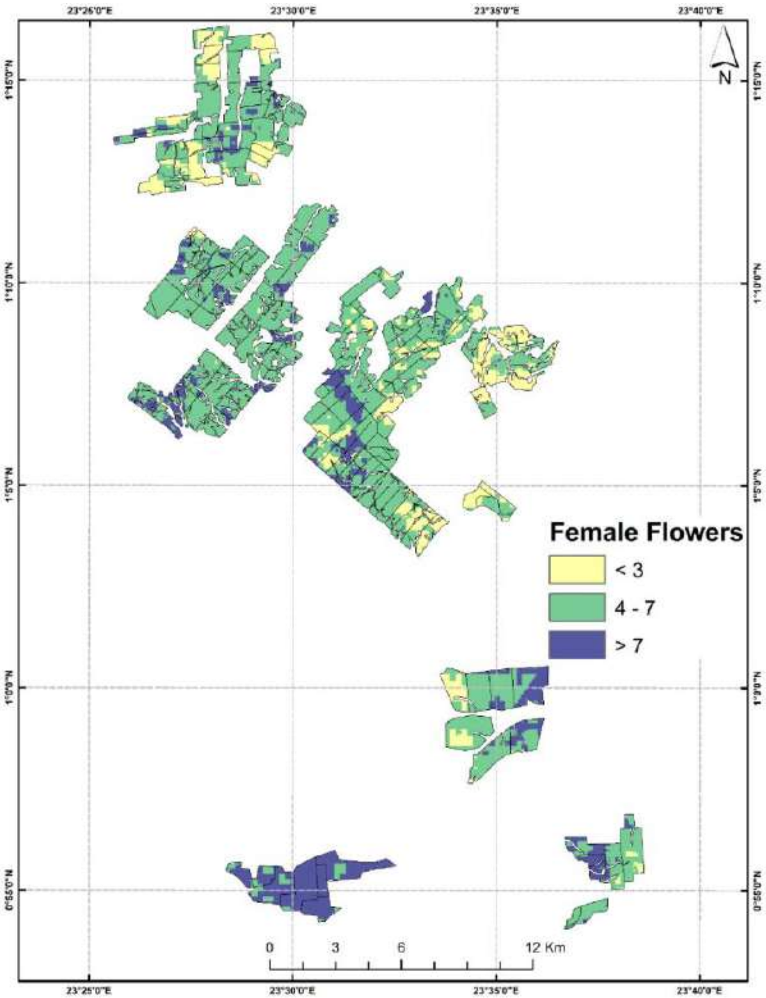

Top Soil
Yalipombe
Yalikito
Kangala
Wamba
Ngongo
Makau
Likakasa
Wenze
Bolongo
Belembo
Yambula
Lileko
Zinc
(ppm)
< 0.62
0.62 - 2.5
> 2.5
0 2.75 5.5 11 Km
Sub Soil
Zinc
(ppm)
< 0.19
0.19 - 0.34
> 0.34
0 2.75 5.5 11 Km
N


Top Soil
N
Yalipombo
Yalikito
Kangala
Wamba
Ngongo
Makau
Likakasa
Wenze
Bolanga
Belembo
Yambula
Lileko
Clay
(%)
< 14.88
14.88 - 21.23
> 21.23
0
2.75
5.5
11 Km

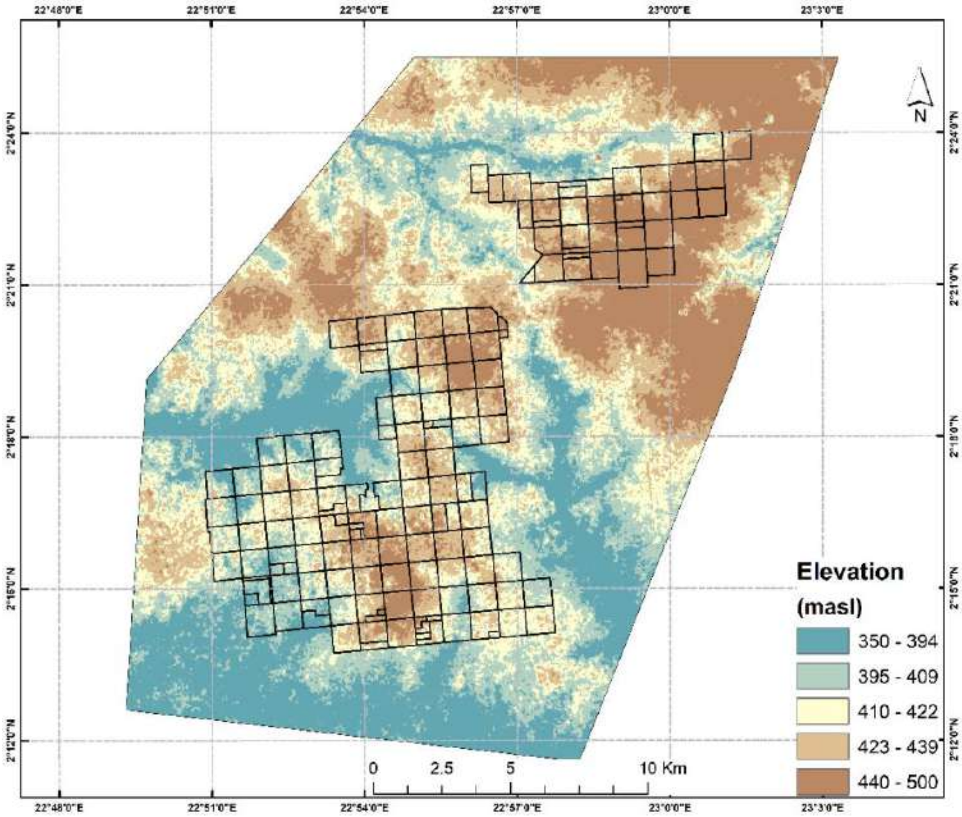

Sub Soil
N
Yalipombo
Yalikito
Kangala
Ngongo
Makau
Wenze
Likakasa
Bolanga
Belembo
Yambula
Lileko
Clay
(%)
< 17.7
17.7 - 21.92
> 21.92
0
3
6
12 Km

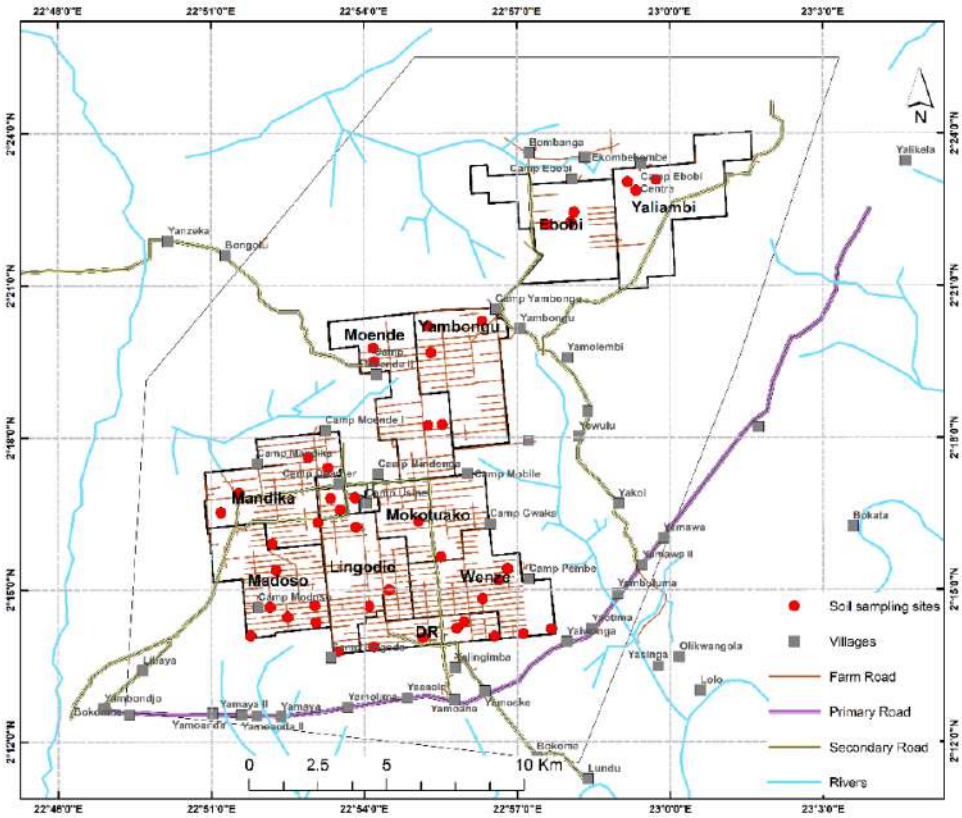
Appendix 5: Plant nutrients and sex ratio maps of Lokutu

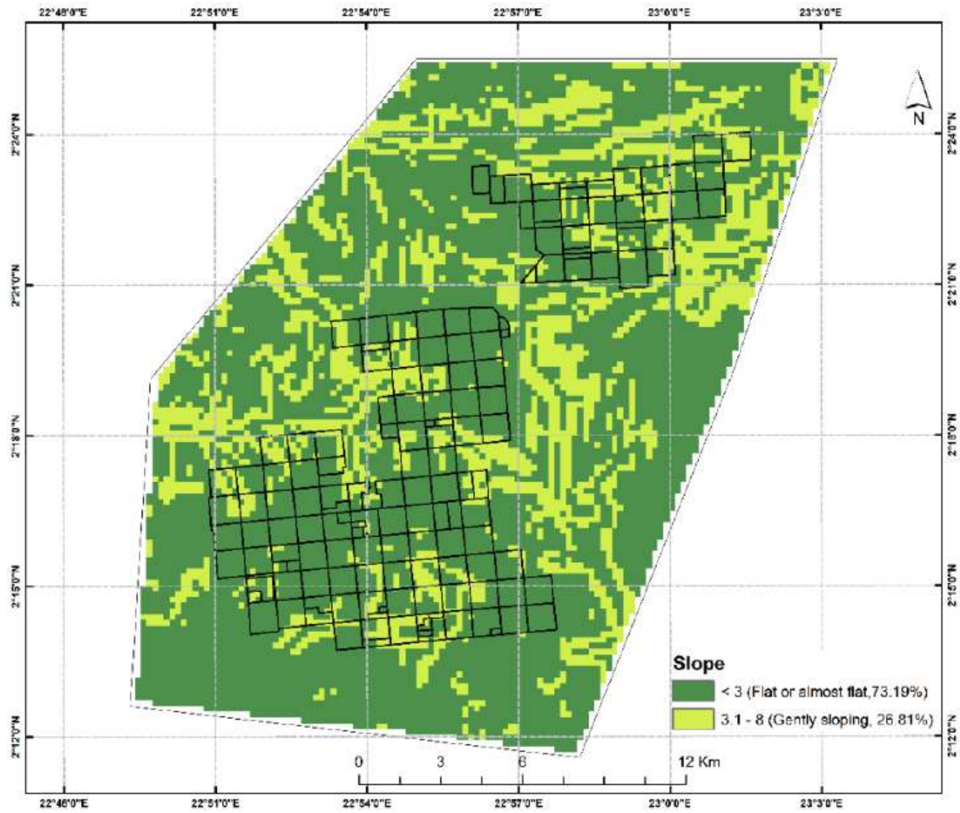


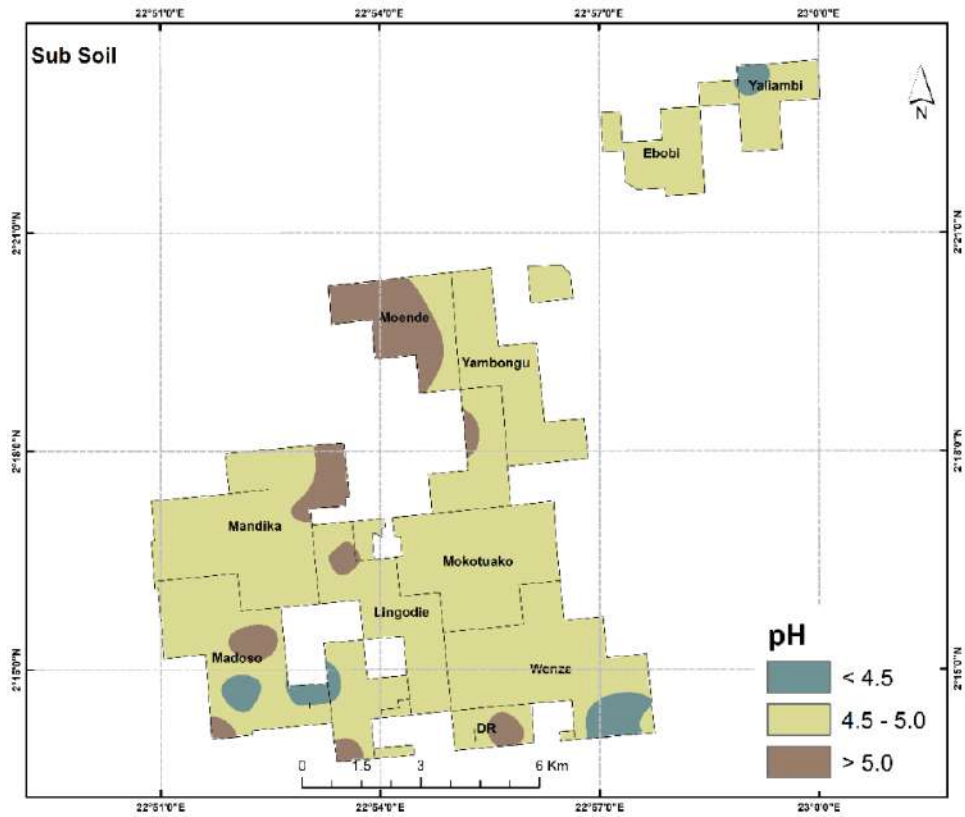


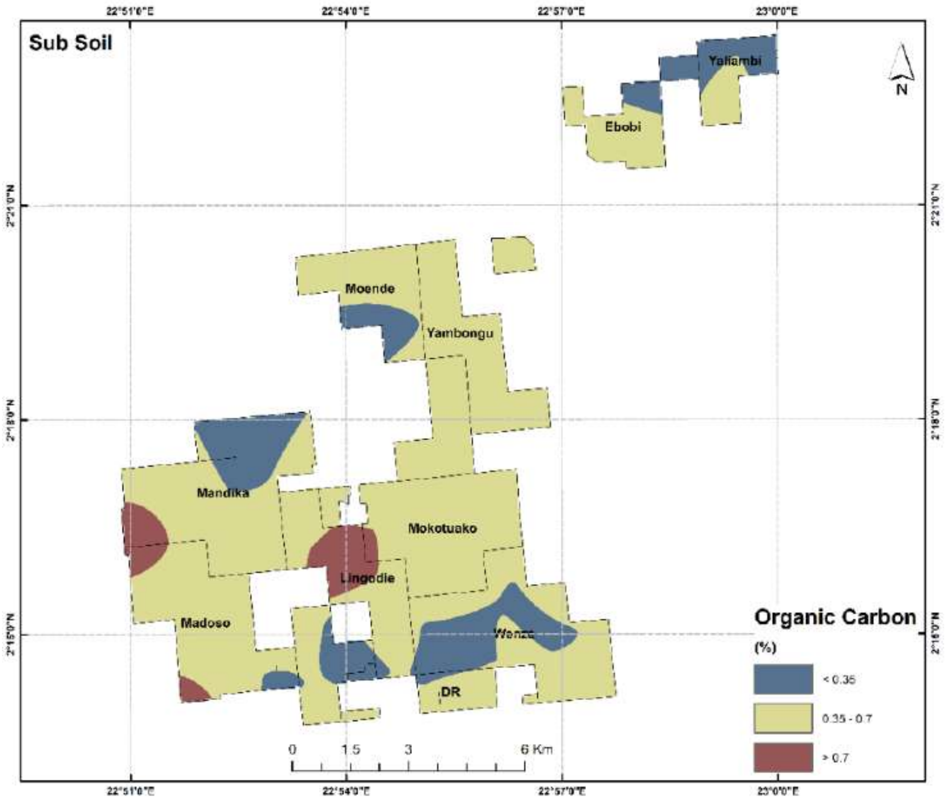
Appendix 6: Land and soil maps of Yaligimba plantation

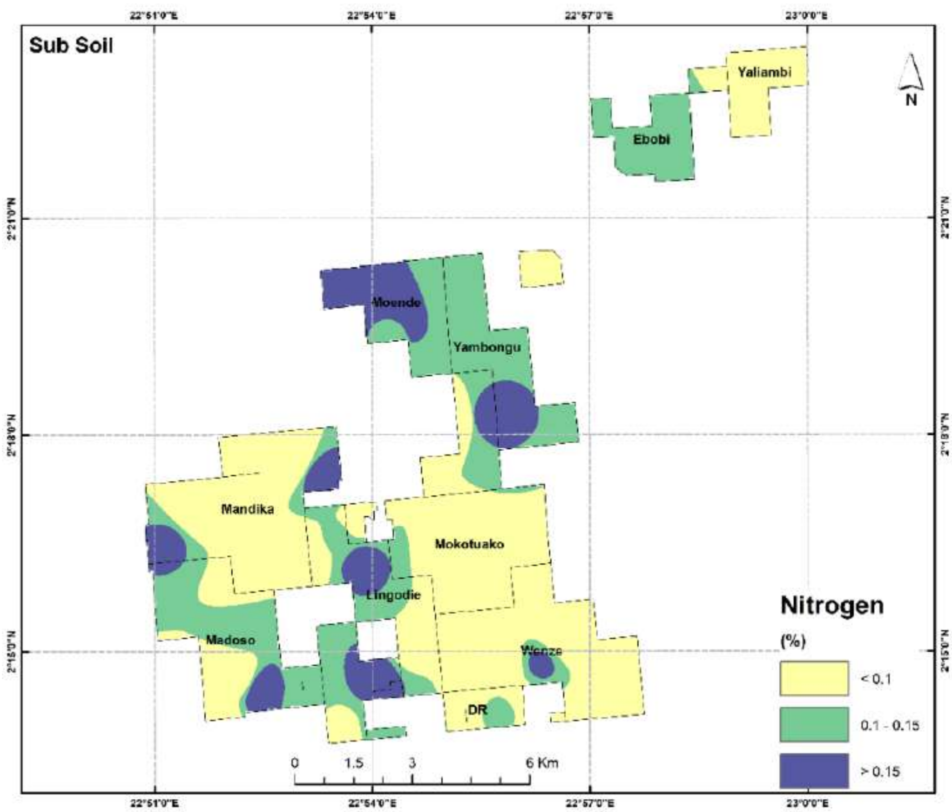


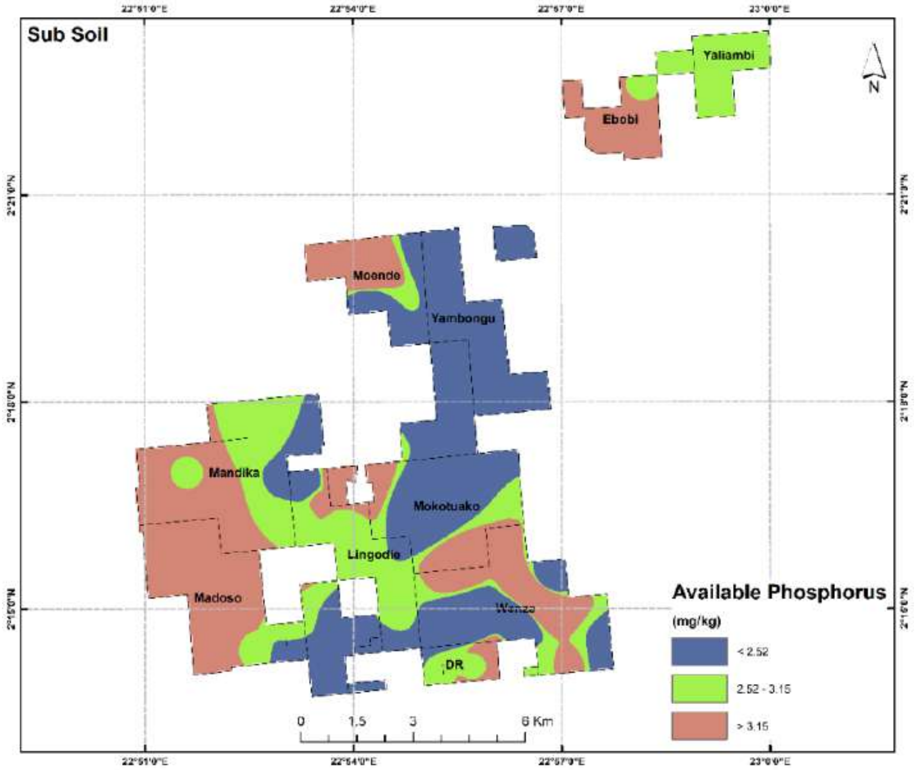


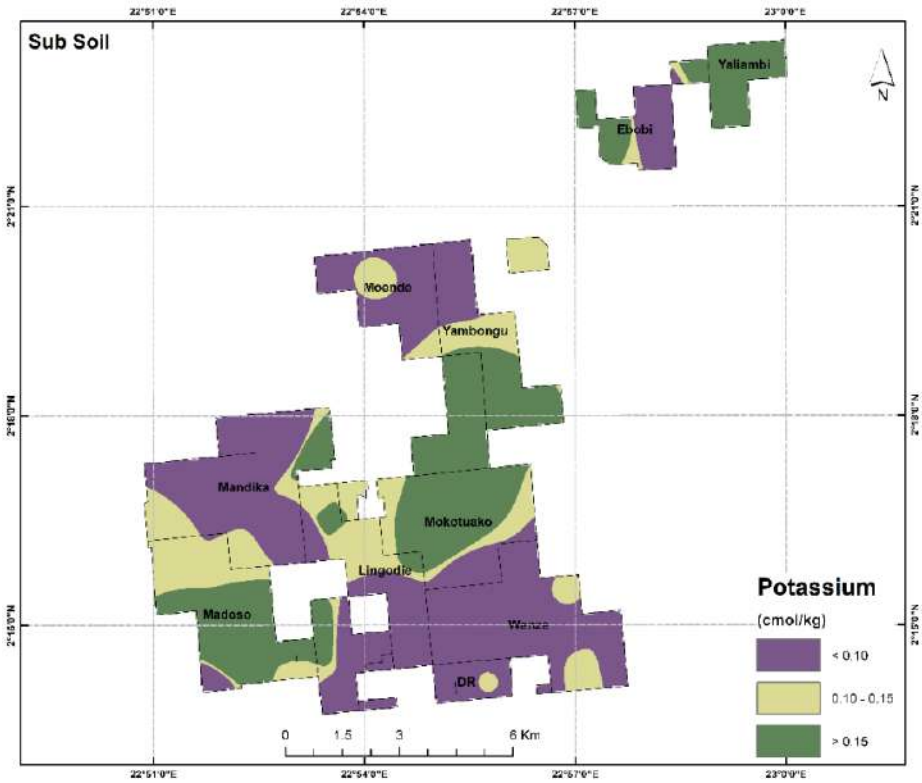

Slope
< 3 (Flat or almost flat,73.19%)
3.1 - 8 (Gently sloping, 26.81%)
0 3 6 12 Km
N

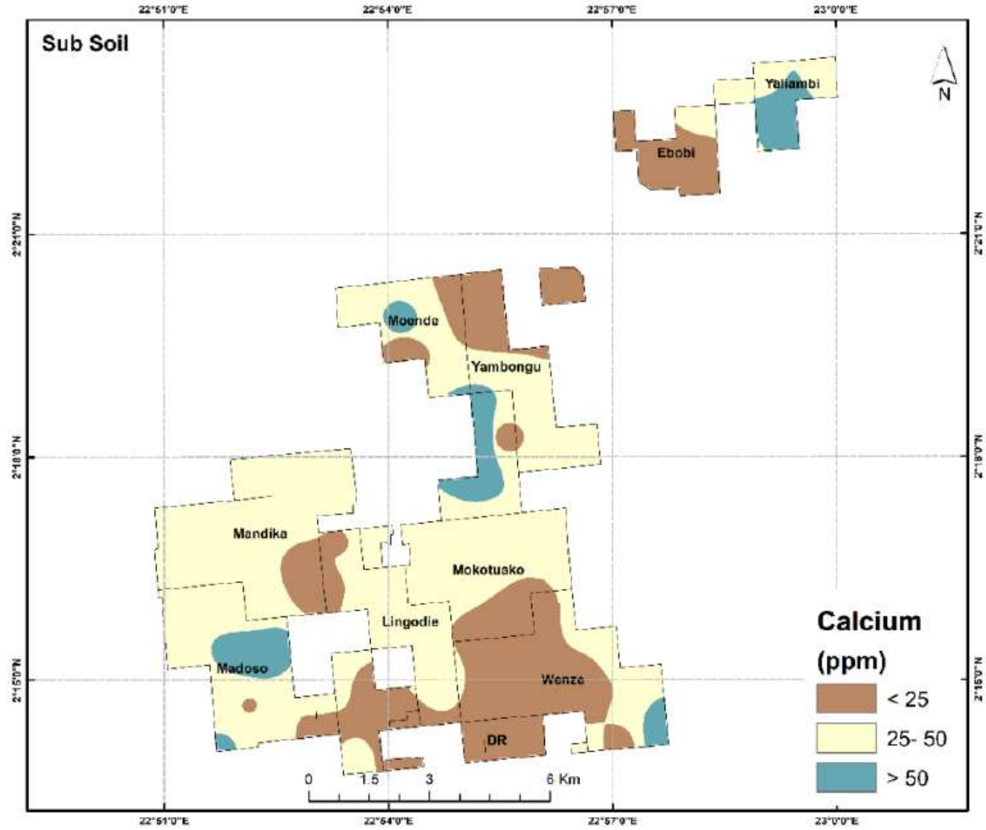

Sub Soil
Yaliambi
Ebobi
Moende
Yambongu
Mandika
Mokotuako
Lingodie
Madoso
Wenze
DR
pH
< 4.5
4.5 - 5.0
> 5.0
0 1.5 3 6 Km
N

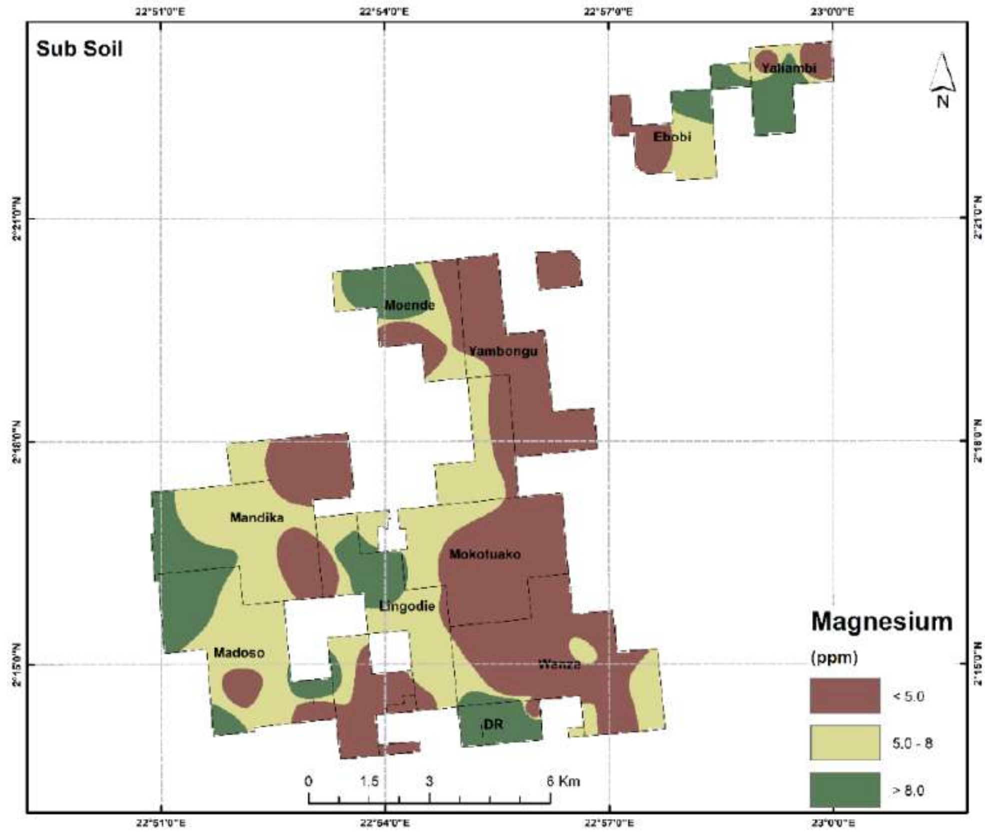

Sub Soil
Yaliambi
Ebobi
Moende
Yambongu
Mandika
Mokotuako
Lingodie
Madoso
Wenze
DR
Organic Carbon
(%)
< 0.35
0.35 - 0.7
> 0.7
0
1.5
3
6 Km
N

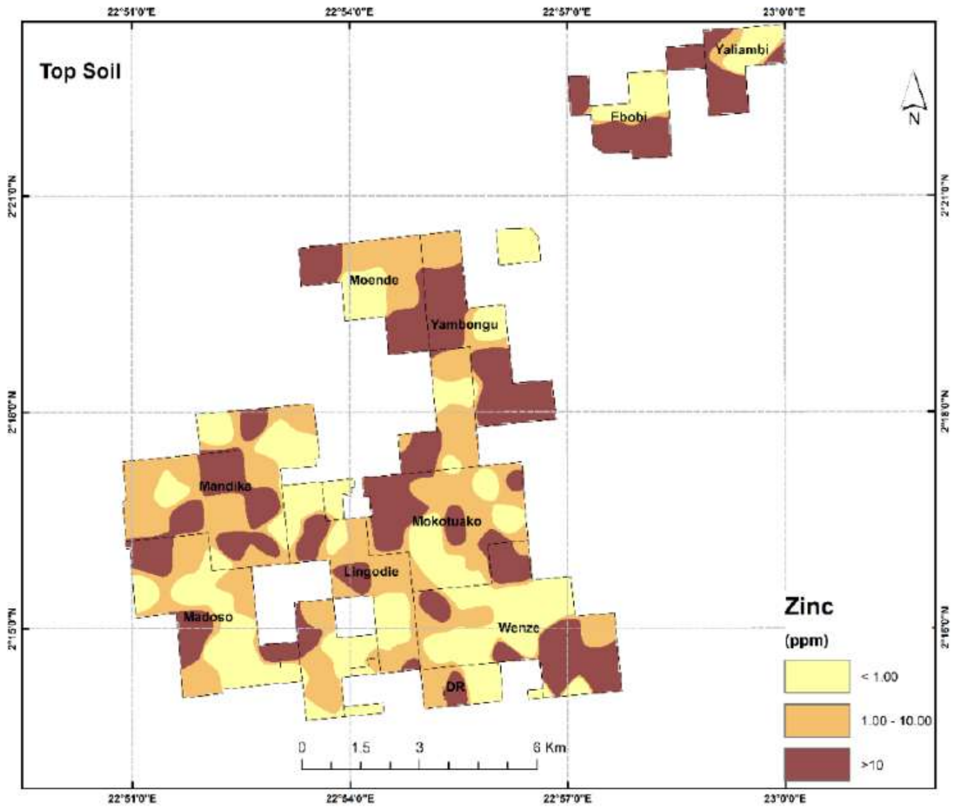

Sub Soil
Yaliambi
Ebobi
Moende
Yambongu
Mandika
Mokotuako
Lingodie
Madoso
Wenze
DR
Nitrogen
(%)
< 0.1
0.1 - 0.15
> 0.15
0
1.5
3
6 Km
N

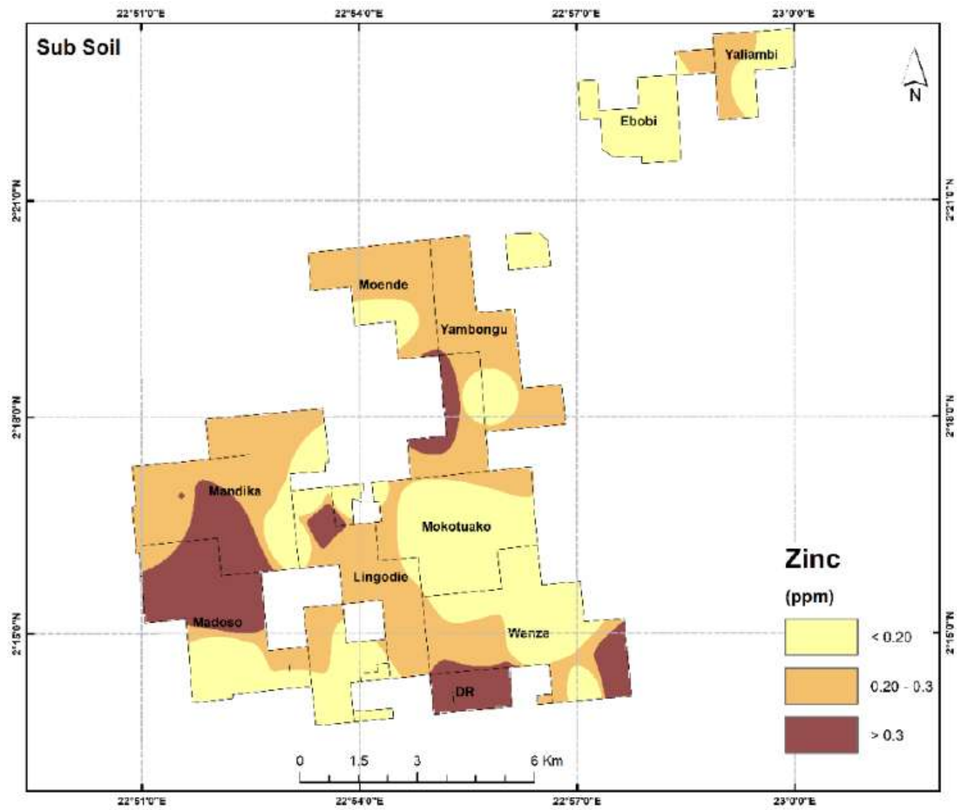

Sub Soil
Yaliambi
Ebobi
Moondo
Yambongu
Mandika
Mokotuako
Lingodie
Madoso
Wenze
DR
Available Phosphorus
(mg/kg)
< 2.52
2.52 - 3.15
> 3.15
0 1.5 3 6 Km
22°51'0"E
22°54'0"E
22°57'0"E
23°0'0"E

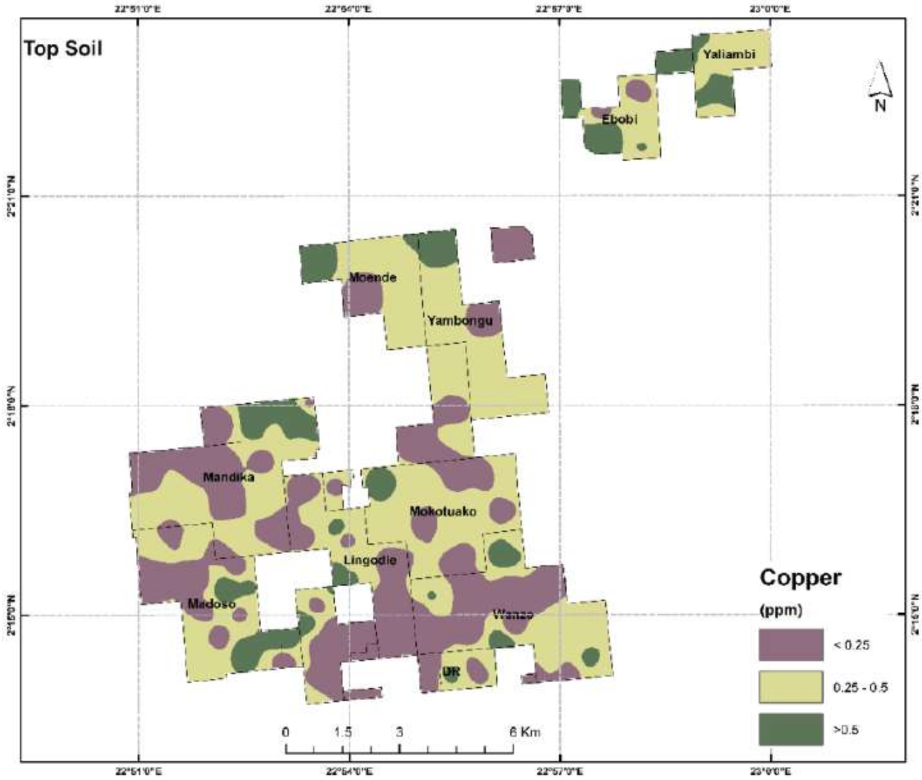

Sub Soil
Yaliambi
Ebobi
Moondo
Yambongu
Mandika
Mokotuako
Lingodie
Madoso
Wenze
DR
Potassium
(cmol/kg)
< 0.10
0.10 - 0.15
> 0.15
0 1.5 3 6 Km
22°51'0"E
22°54'0"E
22°57'0"E
23°0'0"E


Sub Soil
22°51'0"E
22°54'0"E
22°57'0"E
23°0'0"E
2°21'0"N
2°18'0"N
2°15'0"N
N
Yaliambi
Ebobi
Moende
Yambongu
Mandika
Mokotuako
Lingodie
Madoso
Wenze
DR
0
1.5
3
6 Km
Calcium
(ppm)
< 25
25- 50
> 50

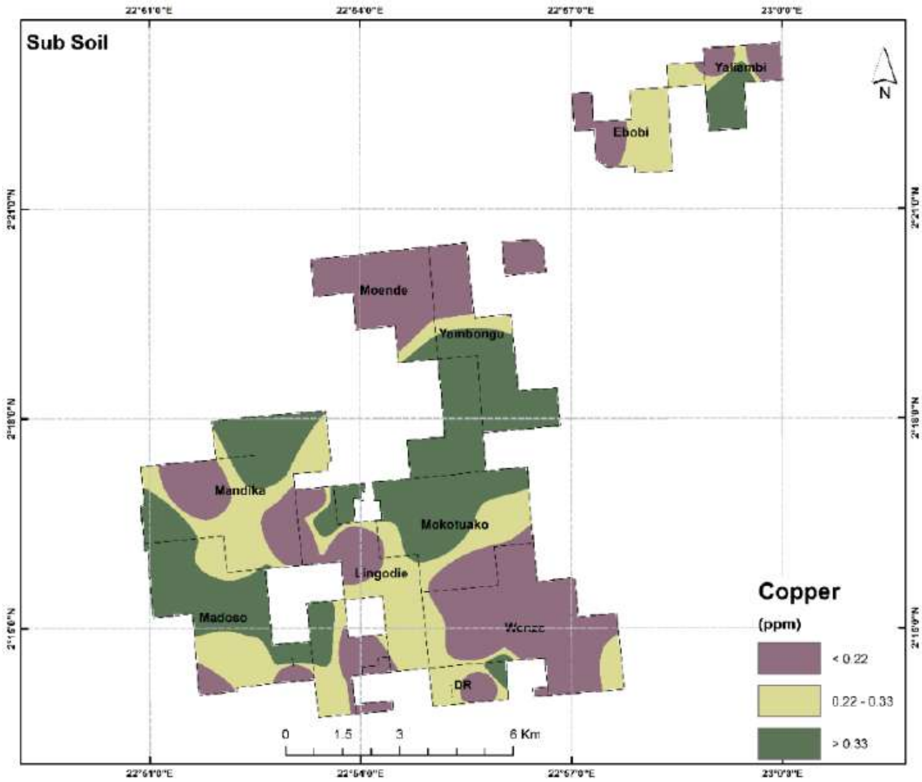

Sub Soil
22°51'0"E
22°54'0"E
22°57'0"E
23°0'0"E
2°21'0"N
2°18'0"N
2°15'0"N
N
Yaliambi
Ebobi
Moende
Yambongu
Mandika
Mokotuako
Lingodie
Madoso
Wenze
DR
0
1.5
3
6 Km
Magnesium
(ppm)
< 5.0
5.0 - 8
> 8.0


Top Soil
Yaliambi
Ebobi
Moende
Yambongu
Mandika
Mokotuako
Lingodie
Madoso
Wenze
DR
Zinc
(ppm)
< 1.00
1.00 - 10.00
>10
0 1.5 3 6 Km
22°51'0"E
22°54'0"E
22°57'0"E
23°0'0"E
2°21'0"N
2°18'0"N
2°15'0"N
N

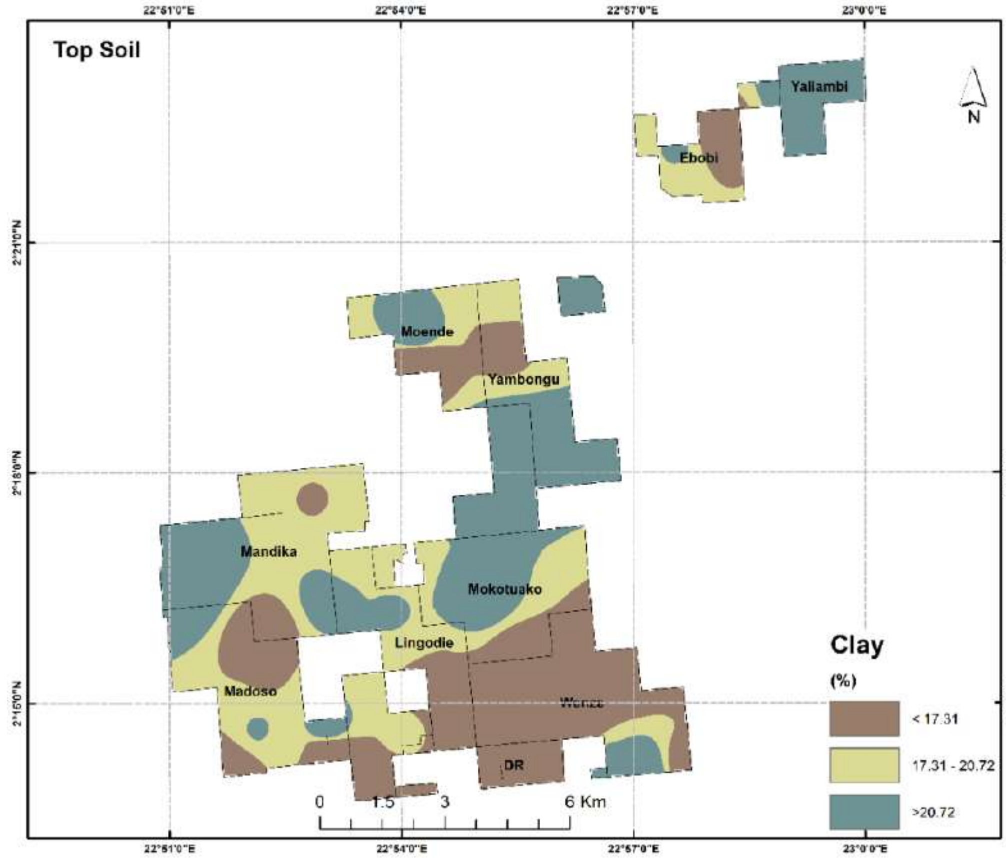

Sub Soil
Yaliambi
Ebobi
Moende
Yambongu
Mandika
Mokotuako
Lingodie
Madoso
Wenze
DR
Zinc
(ppm)
< 0.20
0.20 - 0.3
> 0.3
0 1.5 3 6 Km
22°51'0"E
22°54'0"E
22°57'0"E
23°0'0"E
2°21'0"N
2°18'0"N
2°15'0"N
N



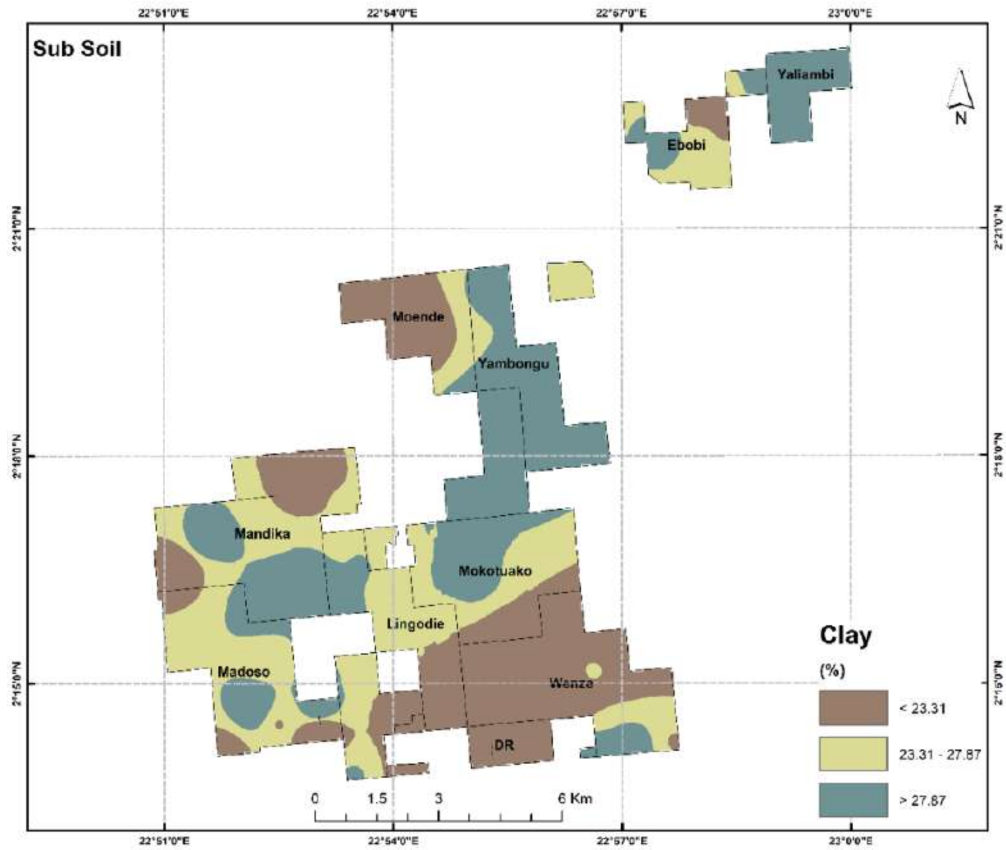
Top Soil
22°51'0"E
22°54'0"E
22°57'0"E
23°0'0"E
2°21'0"N
2°18'0"N
2°15'0"N
N
Yaliambi
Ebobi
Moende
Yambongu
Mandika
Mokotuako
Lingodie
Madoso
Wanzo
DR
Copper
(ppm)
< 0.25
0.25 - 0.5
>0.5
0 1.5 3 6 Km



Sub Soil
22°51'0"E
22°54'0"E
22°57'0"E
23°0'0"E
2°21'0"N
2°18'0"N
2°15'0"N
N
Yaliambi
Ebobi
Moende
Yambongu
Mandika
Mokotuako
Lingodie
Madoso
Wenze
DR
Copper
(ppm)
< 0.22
0.22 - 0.33
> 0.33
0 1.5 3 6 Km



Top Soil
Yaliambi
Ebobi
Moende
Yambongu
Mandika
Mokotuako
Lingodie
Madoso
Wenze
DR
N
Clay
(%)
< 17.31
17.31 - 20.72
>20.72
0 1.5 3 6 Km



Sub Soil
Yaliambi
Ebobi
Moende
Yambongu
Mandika
Mokotuako
Lingodie
Madoso
Wenze
DR
N
Clay
(%)
< 23.31
23.31 - 27.87
> 27.87
0 1.5 3 6 Km

Appendix 7: Plant nutrients and sex ratio maps of Yaligimba