Soil Quality Assessment and Management Plans for IITA Research Farms, Nigeria

IITA Ibadan campus, Ikenne and Kano (Minjibir) stations

Authors: E. Jeroen Huising & Samuel A. Mesele

Date: September, 2021

This document contains a summary of the observations and results of the IITA research farms soil assessment. This report also includes the proposed soil management plans for each of the research farms. The field observation data, soil and water laboratory results are presented in the Appendix.

Coverpage photo: Field survey and soil sampling team at Minjibir, Kano station.

Photo credit: Samuel Mesele

Table of Contents

Introduction

Soil management is vital in agronomic and breeding operations to reduce spatial field variability. Poor soil can effectively confound the results of breeding operations as the best of seeds will perform poorly under poor soil conditions. Assessing soil quality to create a soil management plan becomes vital for a proper breeding operation.

Soil quality 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 crops that are grown for research purposes (breeding or testing of agronomic practice, or other). Therefore, it refers to the ability of soil to provide nutrients to plants, maintain and improve water and air within the soil, provide a foothold for plant roots, and provide a healthy environment. 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. On the other hand, the soils are a key element in regulating the effect of experimentally imposed treatments. Treatment effects, including crop varietal effects, are often confounded in poor soils or poor responsive soils.

Soil quality in the research farms may have deteriorated under intensive use, and subsequently, the soil quality may affect the outcome of research projects. The variability between fields and within fields are of particular concern as these may affect the results of the trials. The objective, therefore, must be to determine the soil quality of the various research fields with emphasis on the variability between and within fields. The focus for the quality assessment was on the soil physical-chemical and plant nutritional aspects. We determined the relevant soil parameters to come up with a suggestion for the soil quality indicators to be used for monitoring purposes. This assessment was done for the research farms at;

i. IITA, Ibadan (headquarters), Nigeria
ii. IITA, Ikenne, Nigeria
iii. IITA, Kano, Nigeria.

Methodology

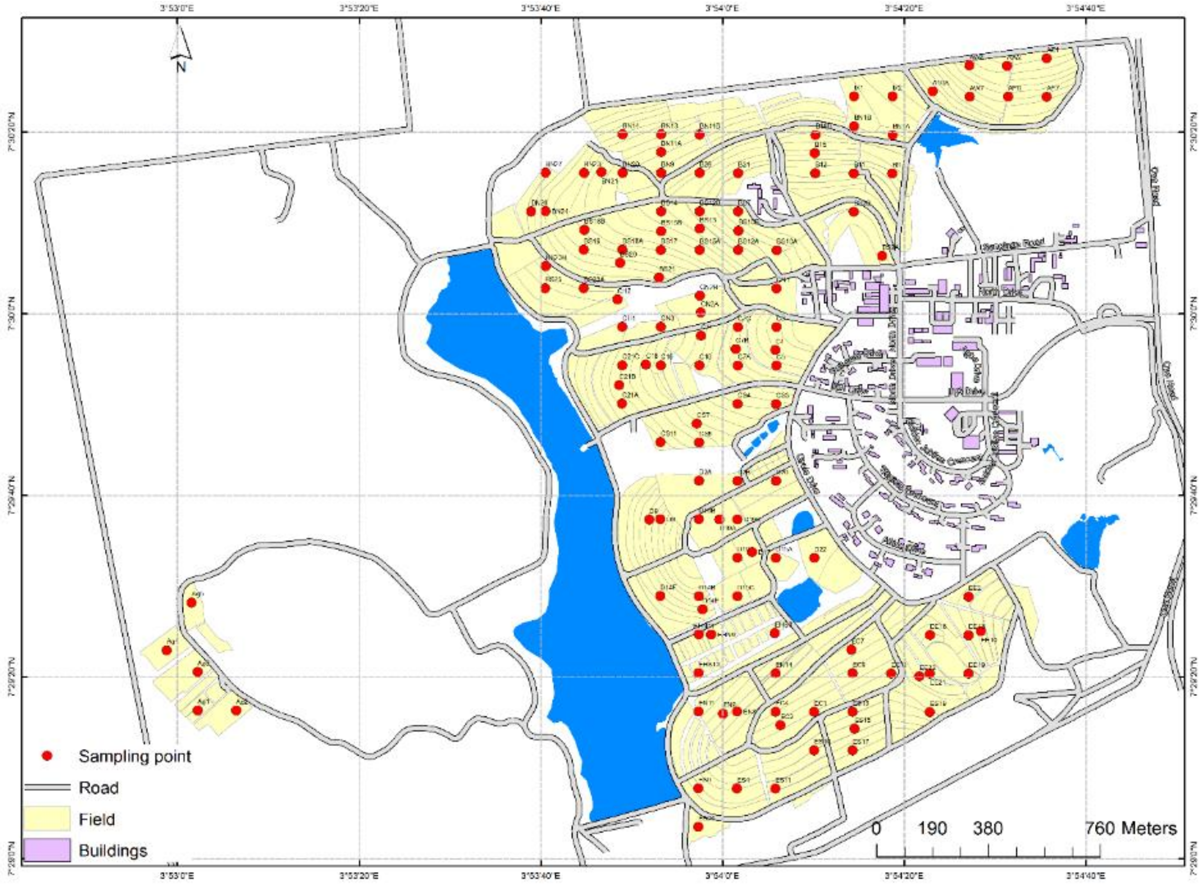
The soil survey was carried out to determine the soil type at each farm and to develop maps characterizing the soil functional properties. The soil and site characteristics were evaluated at specific locations pre-determined by the sampling design. We used a combination of rigid grid design and a nested sampling approach, allowing us to map out the soils (single unit soil maps at 'soil series' level) and assess the spatial variability at each research farm. An average of 50 sampling points per km^2 (100ha) were taken. We took soil samples at each sampling point for laboratory analysis. Samples were taken at 0-20 cm and 20-50 cm depth, where soil depth was not limited. As part of the field survey, information was collected on soil depth restrictions to understand the effective rooting depth. We have also included observations on the drainage conditions at each site. The sampling and data collection were done following standard operating procedures, and for the data recording, we used standard forms implemented in ODK-Collect. This facilitated the use of electronic devices for data recording.

We collected 188 soil samples from 124 sampling points at IITA Ibadan station, 72 soil samples from 36 sampling points at IITA Ikenne station, 52 soil samples from 26 sampling points, and three water samples at Minjibir IITA Kano station. All samples were prepared and analyzed by the IITA Analytical Services Lab (ASL) in Ibadan, using standard wet chemistry analytical procedures.

Results and Recommendations

IITA Ibadan Research Farm

The IITA research farm is approximately 250 hectares in size, located within the IITA Ibadan Campus. Following a general methodology previously described, 124 sampling points were mapped out for observation and soil sample collection (See Map 1).



MAP 1. Soil sampling points at the IITA Ibadan research fields

Land and Soil characteristics and fertility conditions

Soil physical characteristics

The land and soil physical characteristics across the Ibadan research fields show considerable variability. The topography of the Ibadan farm can be subdivided into four: foot-slope, mid-slope, upland, and ridge crest. The southern part of the farm (EHN, CH, CN, EE blocks) is on the foot-slope, and fields on the northern part (B, BN, BS, C, CS, D, AG, AW, AE) are on the mid-slope. The upland and crest occupy the middle part of the research farm. About 67% of the research plots are undulating and slope gently in different directions (See Appendix 1-3). Fields at the foot-slope are flat to almost flat.

Floods are rare but can occur during unusual heavy rainfall events in fields such as BS20, EHS12, EHN11, EHN9, EHS3, M2, and M1. Soil erosion is relatively low due to the conservation measures already in place, like soil bunds and contour ploughing/ ridging.

The soils at the farm are stony, with different size classes of stones distributed across the fields. The stones and pebbles might interfere with tillage operations. Overall, 8% of the fields can be considered extremely stony, 27% are very stony, 44% are stony, and only 21% of the fields do not have stones on the surface.

Overall, the fields (94%) are well drained. A small number of fields, EHS12, EHN11, EHN9, EHS3, and M2 are poorly drained and are used as rice paddy fields. In terms of land use, about 56% of the land was in fallow at the time of this assessment.

The soil colour is primarily dark yellowish-brown with slight colour variation down the soil profile.

Soil depth and texture

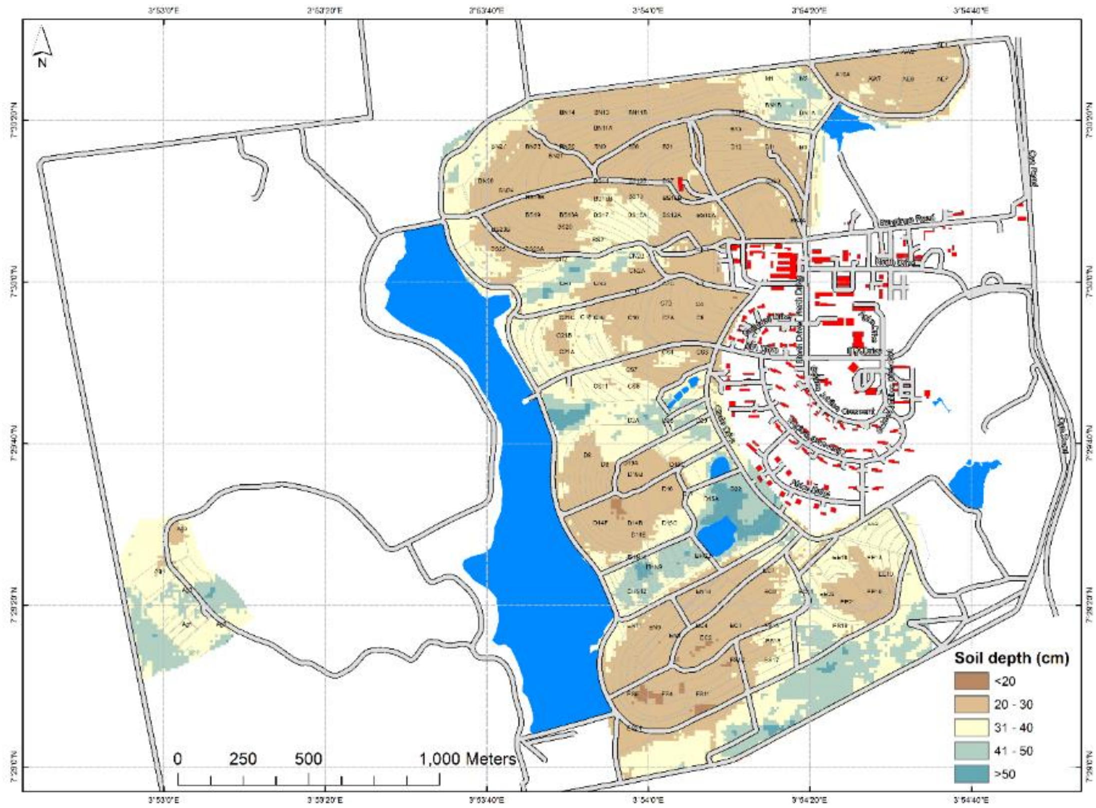
Soils on the farm are derived from the Basement Rock Complex, which generally results in light-textured soils. The soils generally fall within three (3) textural classes, namely: sandy clay loam (9%), sandy loam (90%), and loamy sand (1%). There is a general trend of the clay content increasing with soil depth, but this may not always be apparent as the gravel content increases with depth as well. Some soils have a textural composition that puts them between the loamy sand and sandy loam textural classes. In general, the soils at the farm are sandy.

Soil texture was determined after sieving the soil samples, removing soil particles larger than 2 mm (e.g., gravel and other coarse fragments). We analysed a limited number of the soil samples for gravel content and found all of them to contain a varying degree of gravel. On average, the gravel content was around 20%. This implies that the soils are effectively lighter in texture than indicated by the analysis. As a result, we have to take the effective lower clay and silt percentage into account when interpreting the data for hydrological properties (i.e., water holding capacity, infiltration rate, and drainage). A gravel content of 20% is often taken as the limit for arable cropping. Based on the lab results of the particle size analysis, about 68% of the research fields fall outside the desired soil texture classes, and this is higher when we correct for gravel content. The gravel content is correlated with soil depth, the shallow soils having a higher gravel content.

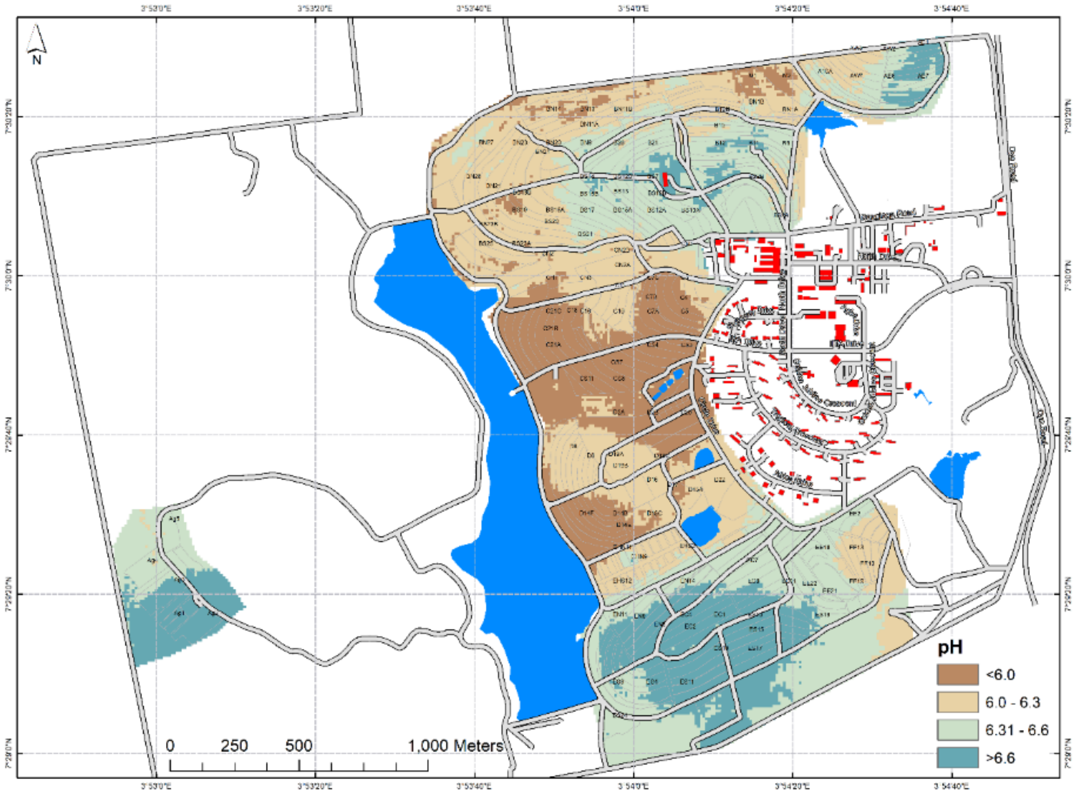
We measured the soil depth restrictions by using the soil auger. The depth restriction was indicated by the depth at which we could not drill further down the soil exerting considerable force even. Depth restriction does not necessarily equate to rooting depth restriction but is a good indicator of effective soil depth. Restrictions at the IITA research farm are generally due to the increase in gravel content with depth and hitting the rotten rock layer. Occasionally, on the more clayey soils, the soils are too firm and compact to dig deeper. Roots would also have difficulty penetrating this soil layer. The soil depth within the research fields varies from very shallow to moderately deep. The soils are generally shallow, with 48% of the areas being very shallow (<25 cm), 50% shallow (between 25 cm and 50 cm depth), and only 2% moderately deep (between 50 cm and 100 cm). Map 2 shows that soil depth restrictions are prevalent at the IITA research farm in Ibadan.

Soil pH

Soil pH is a 'master' 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. Soil pH is generally at an optimum level across the Ibadan research fields, with about 100% of the soils having an optimum pH level of the topsoil (Map 3). There are no management concerns concerning soil pH.



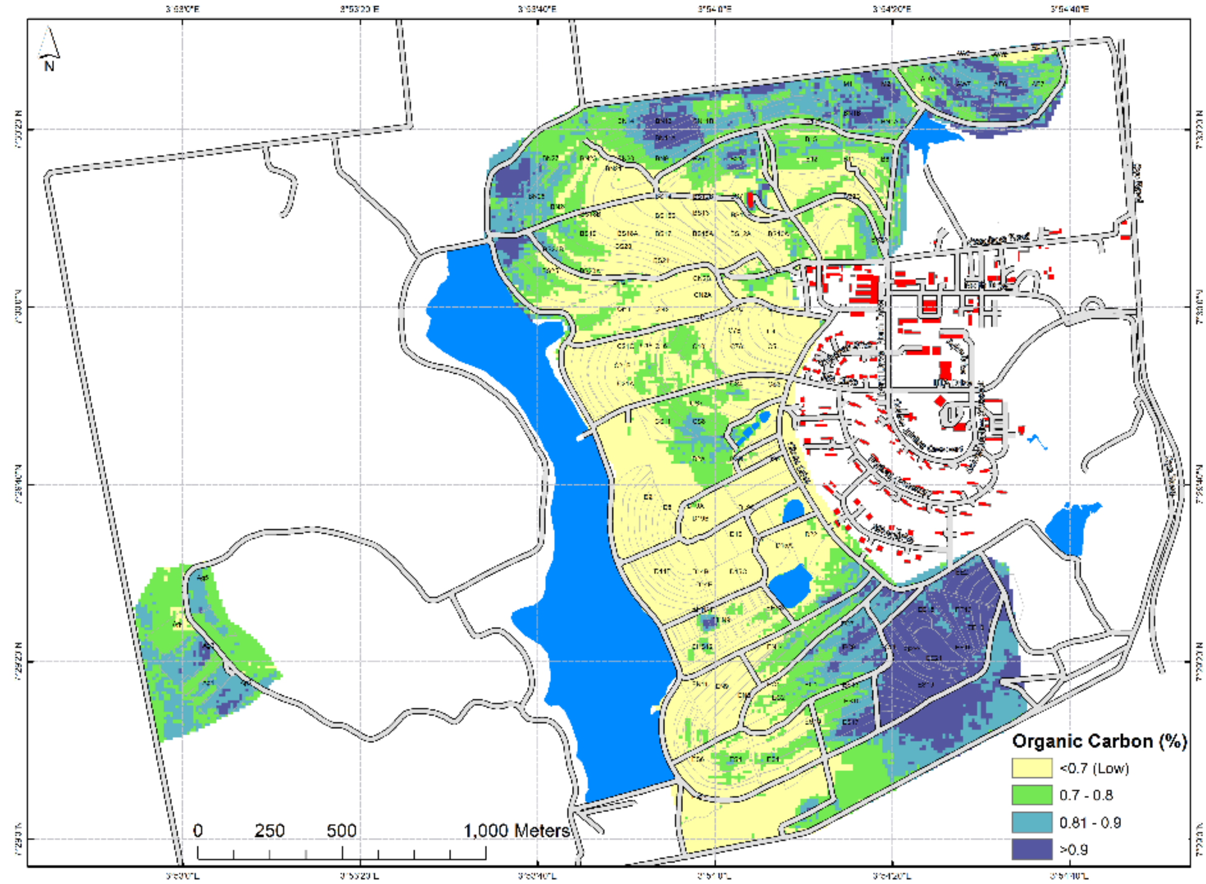
Map 2. Soil depth distribution on Ibadan research fields



Map 3. Soil pH distribution on Ibadan research fields

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 is a measurable component of soil organic matter. The Ibadan research fields generally have low soil organic carbon content, with about 50% of the area having very low SOC (<0.7%), 44% of the land has low SOC, and only about 8% of the fields have an adequate level of SOC (Map 4). In sandy soils such as are found at the Ibadan farm, soil fertility is mainly determined by soil organic matter content. This is a significant concern in any soil improvement plans of the research fields. 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.



Map 4. Distribution of soil organic carbon within the Ibadan research fields

Soil total nitrogen

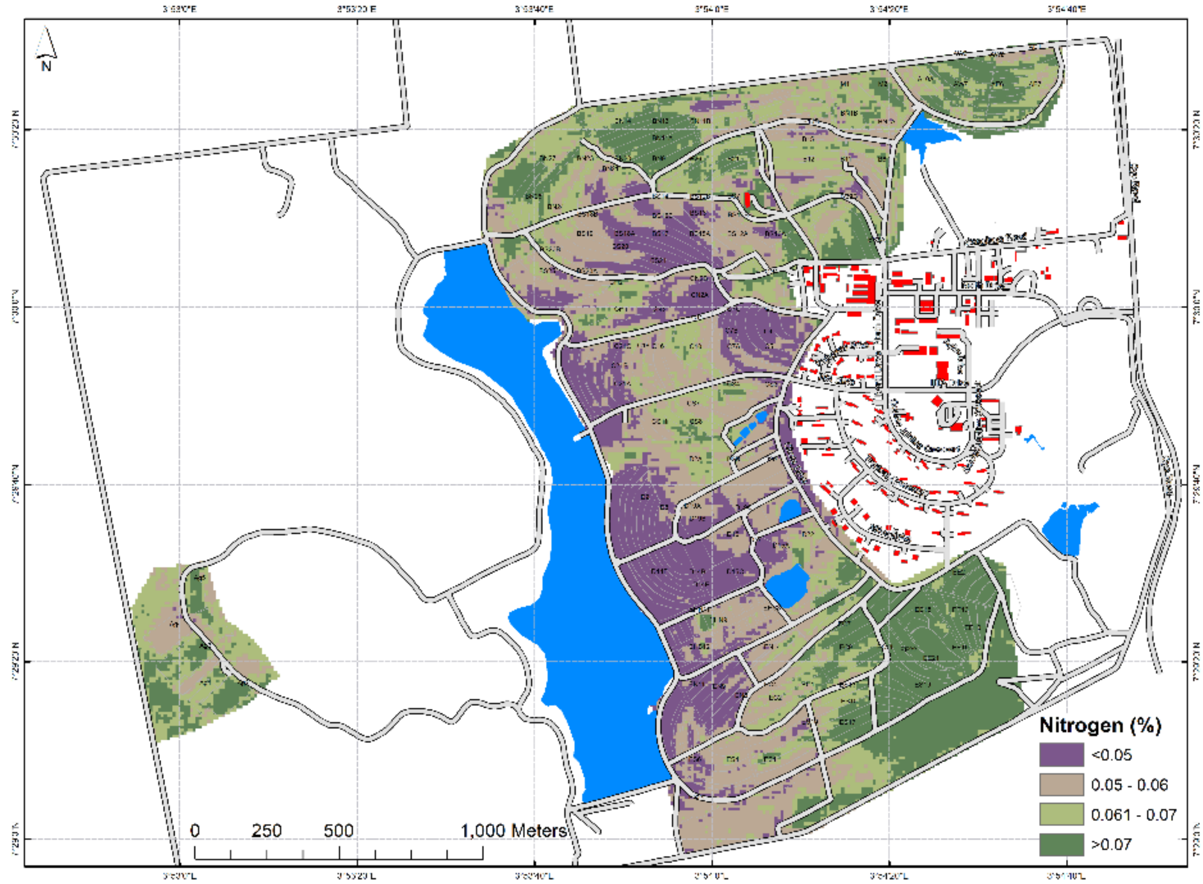
Nitrogen is an essential primary nutrient for plant growth and development. Soil total nitrogen is closely associated with soil organic matter content in a tropical and highly weathered soils such as the soils at IITA Ibadan. The soils are critically low in nitrogen (See Map 5) and must be supplemented by fertilizer to meet crop nutrient demands.

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. About 68% of the soils have very low phosphorus content while others have varying level of P from adequate to high levels (Map 6). Soils adequate or high in P are concentrated in the south and around the northern part of the research farm. We recommend an application rate of 55 kg/ha P_2O_5 to improve the soil P content from the current 8 ppm to a minimum requirement of 16 ppm. This is just for recapitalization of P in the soil, additional P needs to be applied to satisfy crop demand.

Exchangeable potassium

Potassium is among the three essential primary nutrients needed for the growth and development of plants. We found potassium at adequate levels in about 57% of the soils at the Ibadan research farm (Map 7).



Map 5. Distribution of total soil nitrogen within the Ibadan research fields

About 43% of the farm, covering the central parts of the research farm and down to the southwestern part, have low potassium content. To amend the low K levels in the soil, 298 kg/ha of K_2O is needed.

Exchangeable calcium

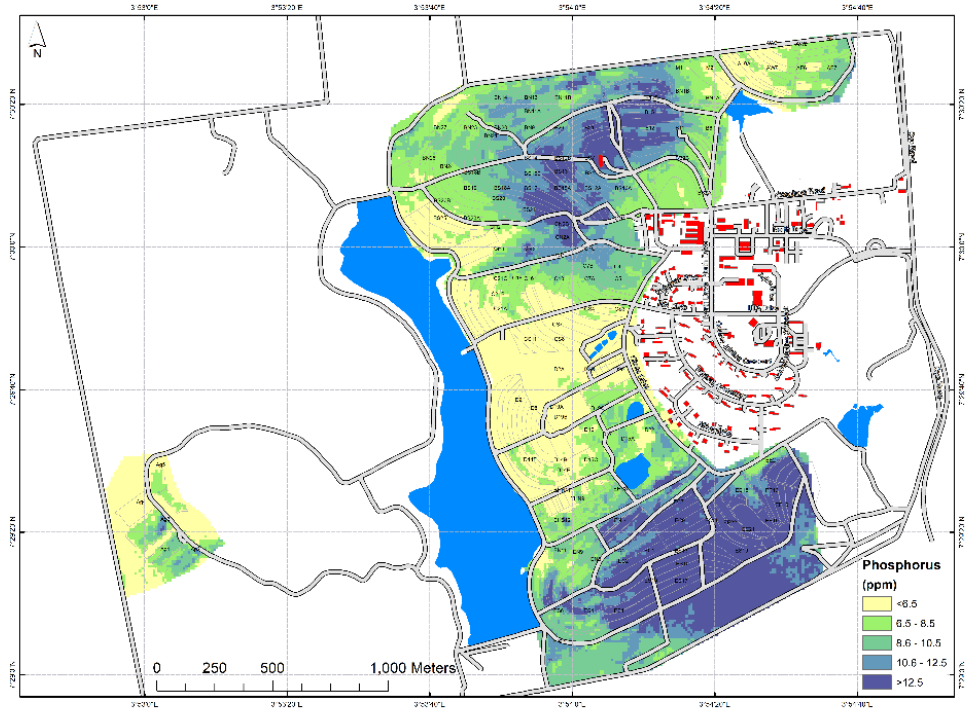
Calcium is one of the soil essential secondary plant nutrients. There are no significant concerns with calcium content in the Ibadan research fields. Calcium was found to be at adequate levels in 92% of the fields. Only 8% of the soils have calcium content that falls below the minimum requirement of 200 ppm. The low calcium soils are found at the extreme west end bordering the lake (Map 8). This area could be improved with an application of 529 kg CaO per hectare.

Exchangeable magnesium

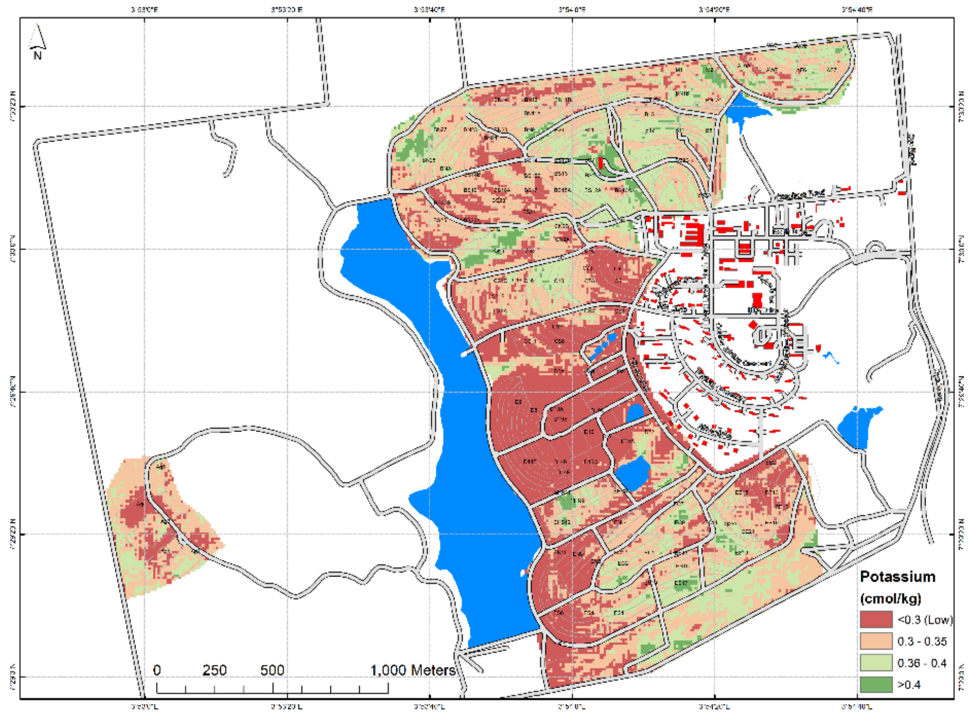
Magnesium is an essential element for photosynthesis in plants. Magnesium is low in over 73% of the research fields (Map 9). The middle sections of the farm are particularly low in magnesium. Only 27% of the soils in the extreme northeast (A block), southwest (ES block), and the west end (Ag block) have adequate Magnesium levels. To raise the Mg levels to the minimum level would need an application of 342 kg/ha of MgO fertilizer.

Exchangeable sodium

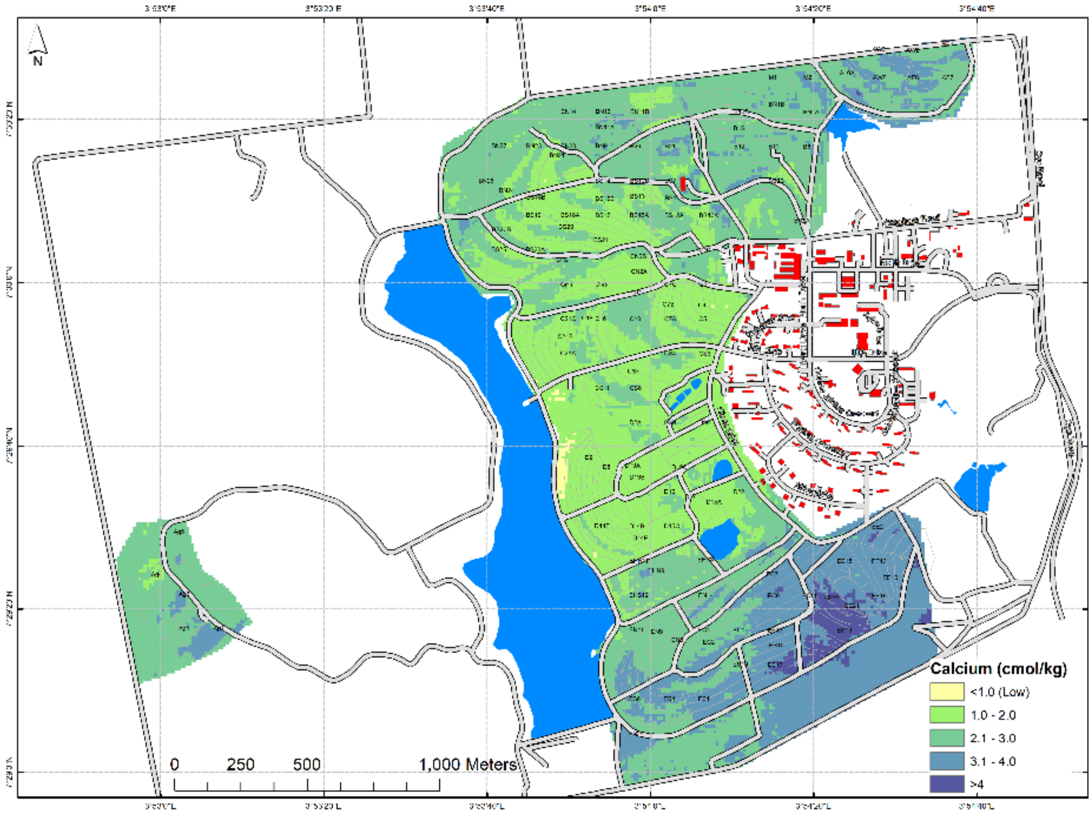
There are no problems with the sodium content of the soils at Ibadan research farm as sodium concentration is already at the optimum level having concentrations less than 0.7 cmol+/kg (Map 10).



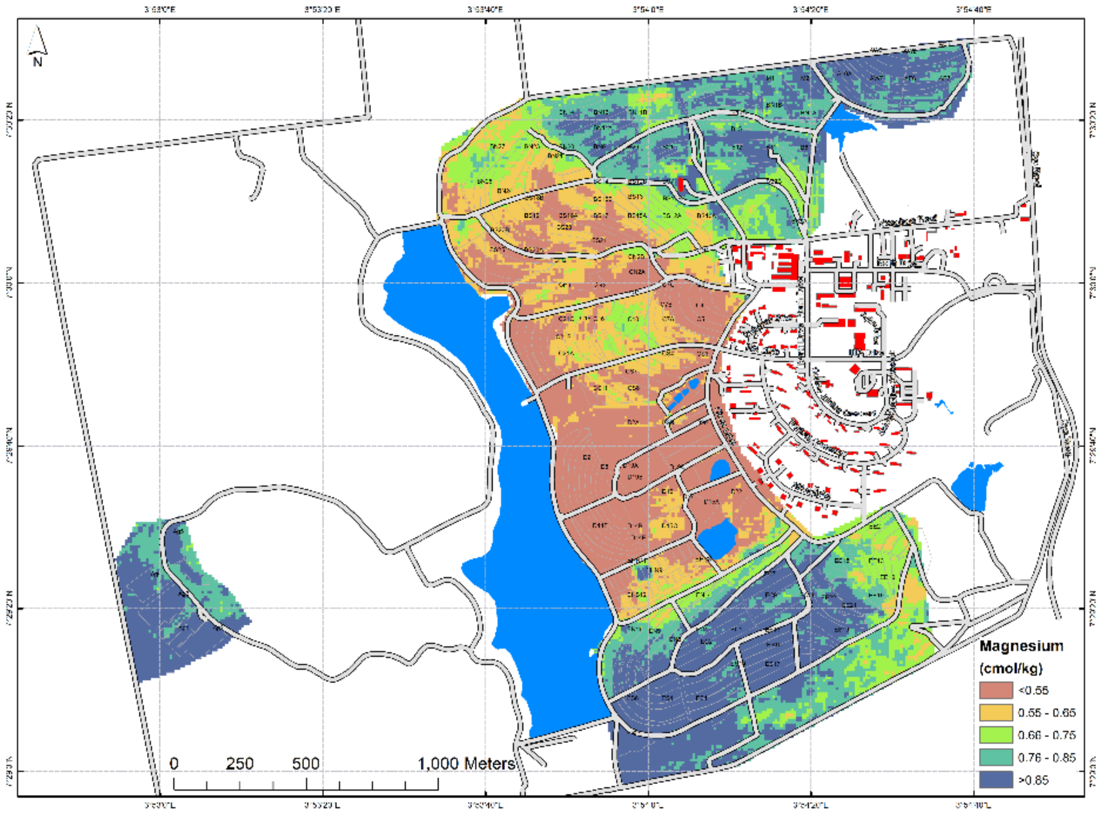
Map 6. Distribution of available soil phosphorus within the Ibadan research fields



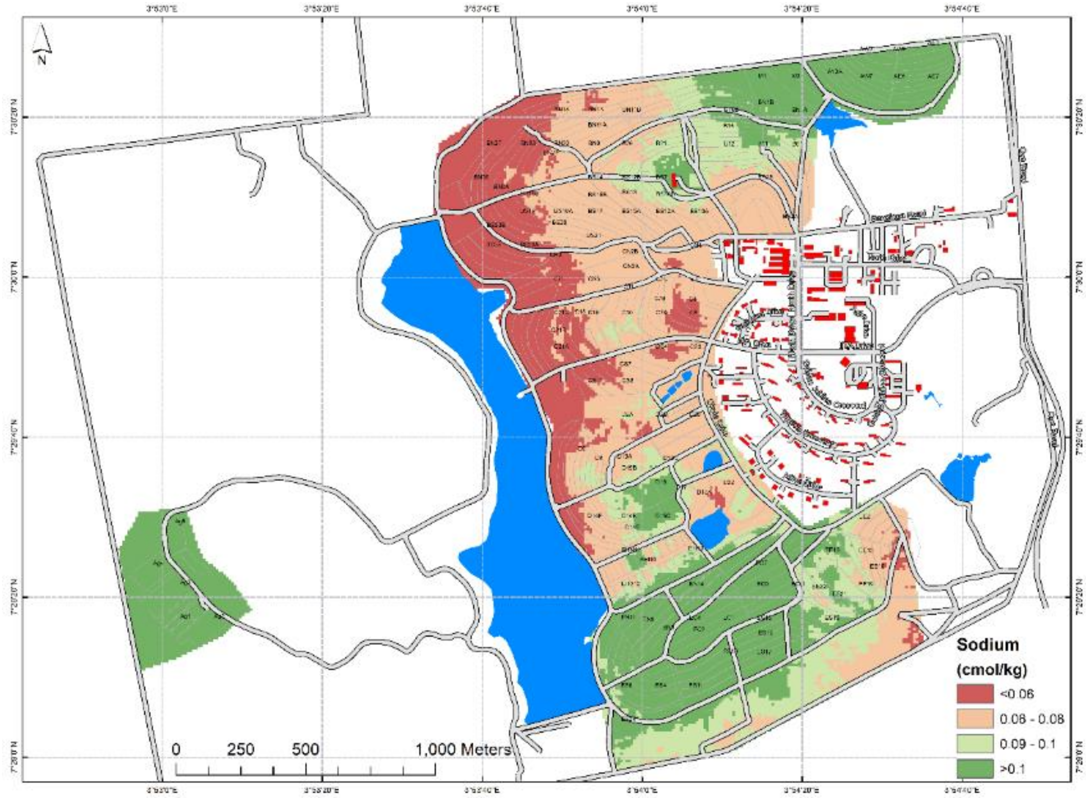
Map 7. Distribution of exchangeable soil potassium within the Ibadan research fields



Map 8. Distribution of exchangeable soil calcium within the Ibadan research fields



Map 9. Distribution of soil exchangeable magnesium within the Ibadan research fields



Map 10. Distribution of soil exchangeable sodium within the Ibadan research fields

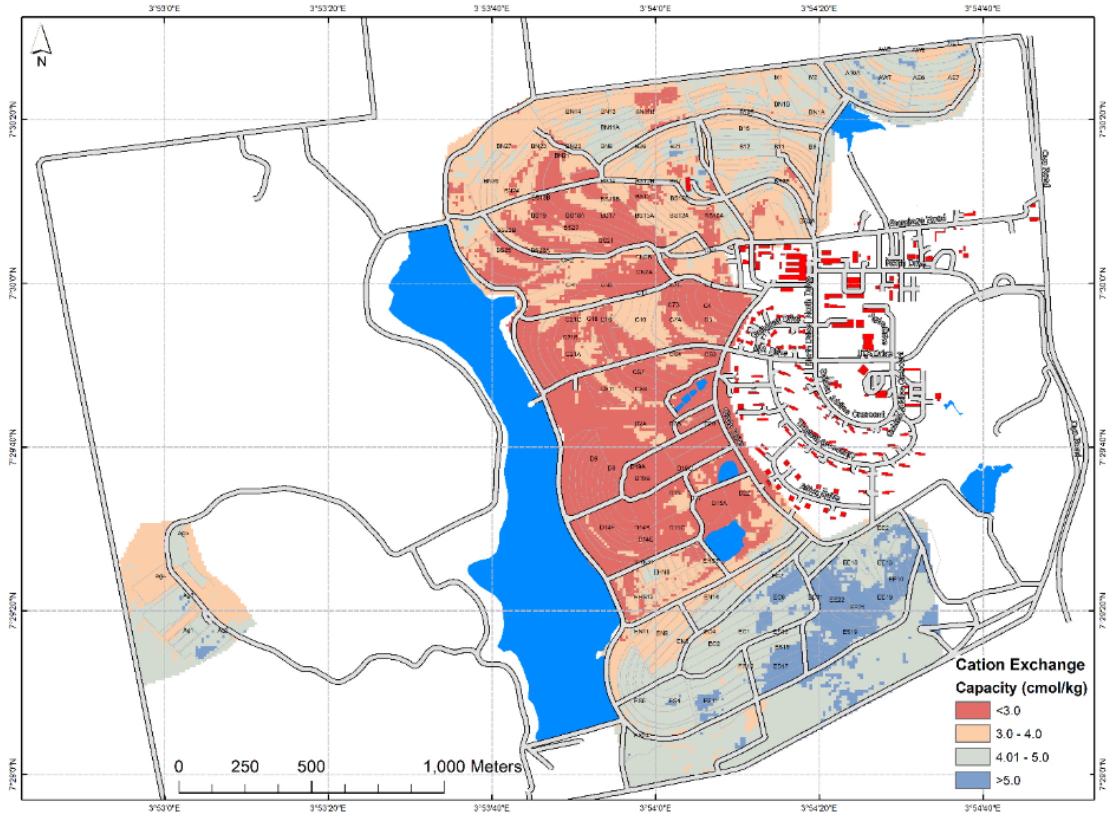
Cation exchange capacity

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. The summation of the exchangeable cations and the exchangeable acidity is referred to as the effective cation exchange capacity (ECEC). As CEC measures a soil's ability to hold and buffer nutrients, it is a crucial determinant of soil fertility. Soils with high CEC can hold more cations and release them gradually for plant uptake at time of demand, however dependent on base saturation and influenced by soil pH.

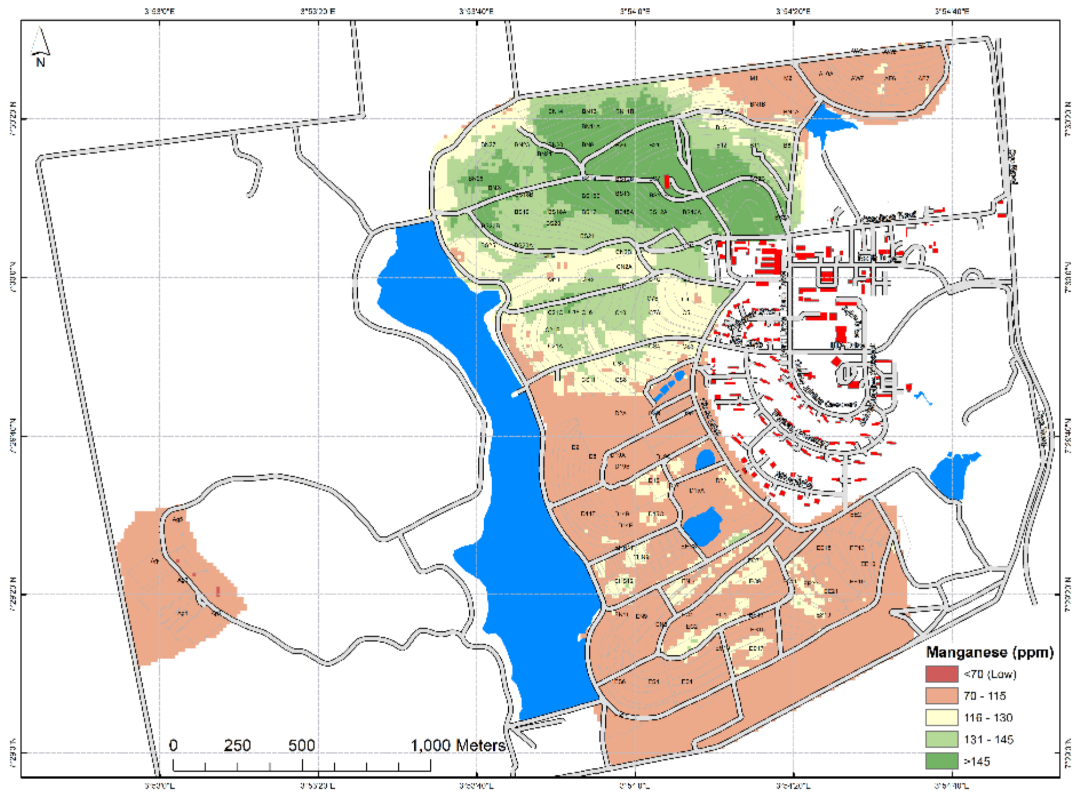
On the contrary, soils with low CEC are easily deficient in cations and will impact on recovery rates of nutrients applied. Generally, the soils at the Ibadan research farm are low in ECEC (Map 11). Soils in the central sections (BS, C, CN CS, D, and EHN blocks), representing 80% of the farm, have extremely low ECEC levels. The recommended application rate of soil organic matter would directly impact the capacity of the soil CEC. The southern and parts of the west end have relatively higher ECEC even though it is still far below the minimum requirement of 16 $cmol^{(+)}$/kg.

Soil micronutrients

Manganese is one of the main plant micronutrients with an essential role in plant growth as a component of enzymes involved in photosynthesis and other processes. Manganese is at an adequate level in 92% and 100% of the topsoil and subsoil across the research fields (Map 12).

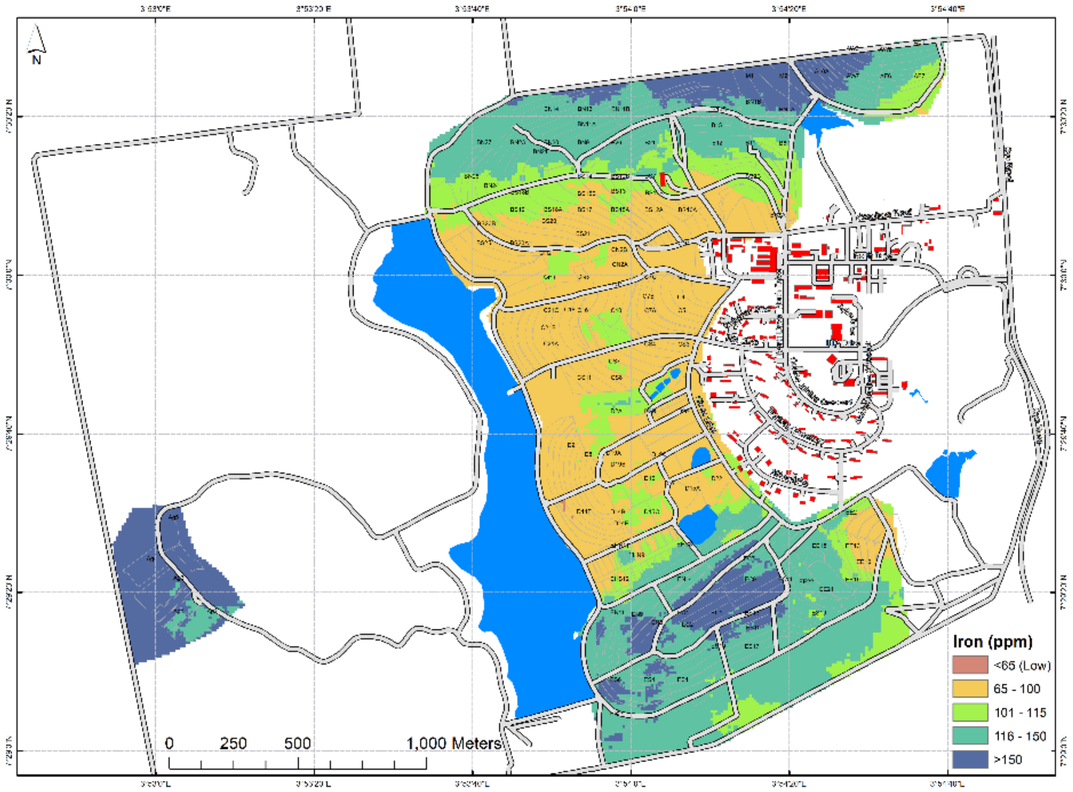


Map 11. Distribution of soil effective cation exchange capacity within the Ibadan research fields



Map 12. Distribution of soil manganese within the Ibadan research fields

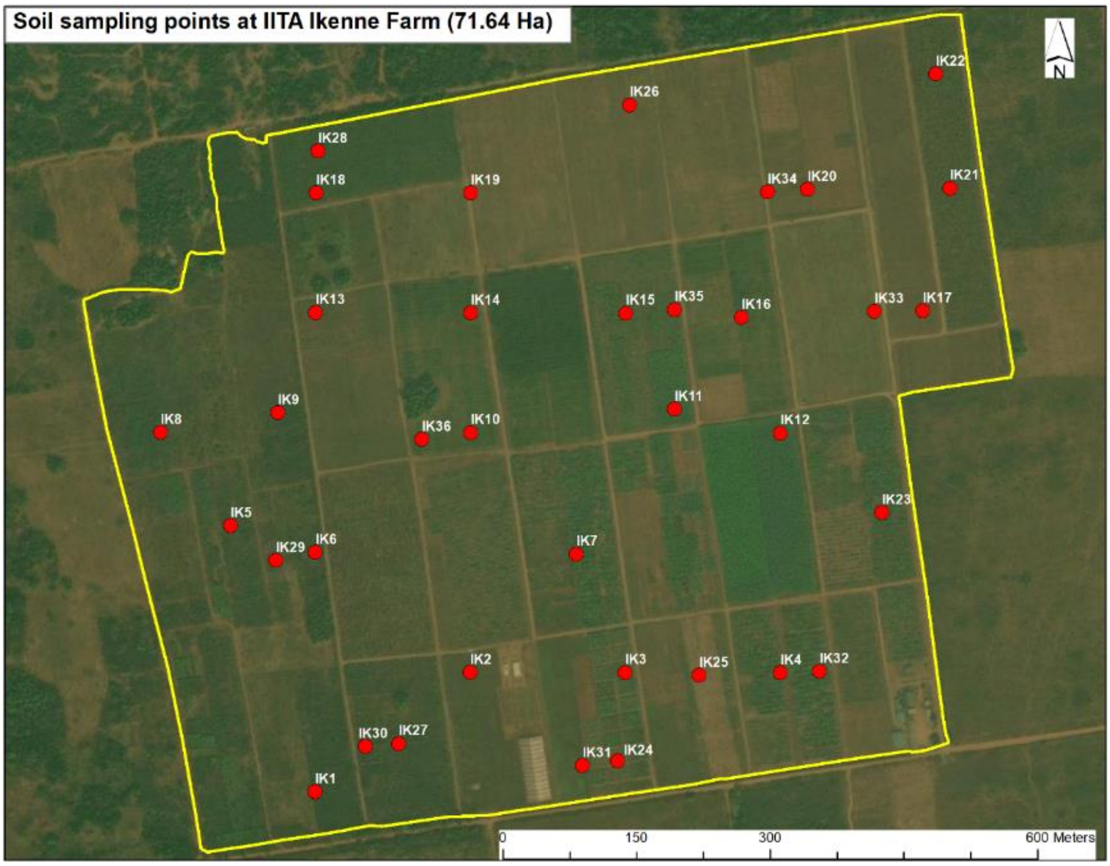
Iron is involved in the synthesis of chlorophyll and is essential for maintaining chloroplast structure and function. Generally, iron was found to be adequate in about 90% of the research fields. However, about 6% of the fields, mainly in the A block, have high levels of iron in the topsoil (Map 13).



Map 13. Distribution of soil iron within the Ibadan research fields

IITA Ikenne Research Farm

The 71 hectares IITA research station at Ikenne, located in Ogun state, about 100 km from Ibadan, is primarily used for breeding and agronomic research for cassava, maize, yam, soybeans, and cowpeas. Following the general methodology previously described, 36 sampling points were mapped out for soil assessment (Map 14).



MAP 14. Soil sampling points of the IITA Ikenne station

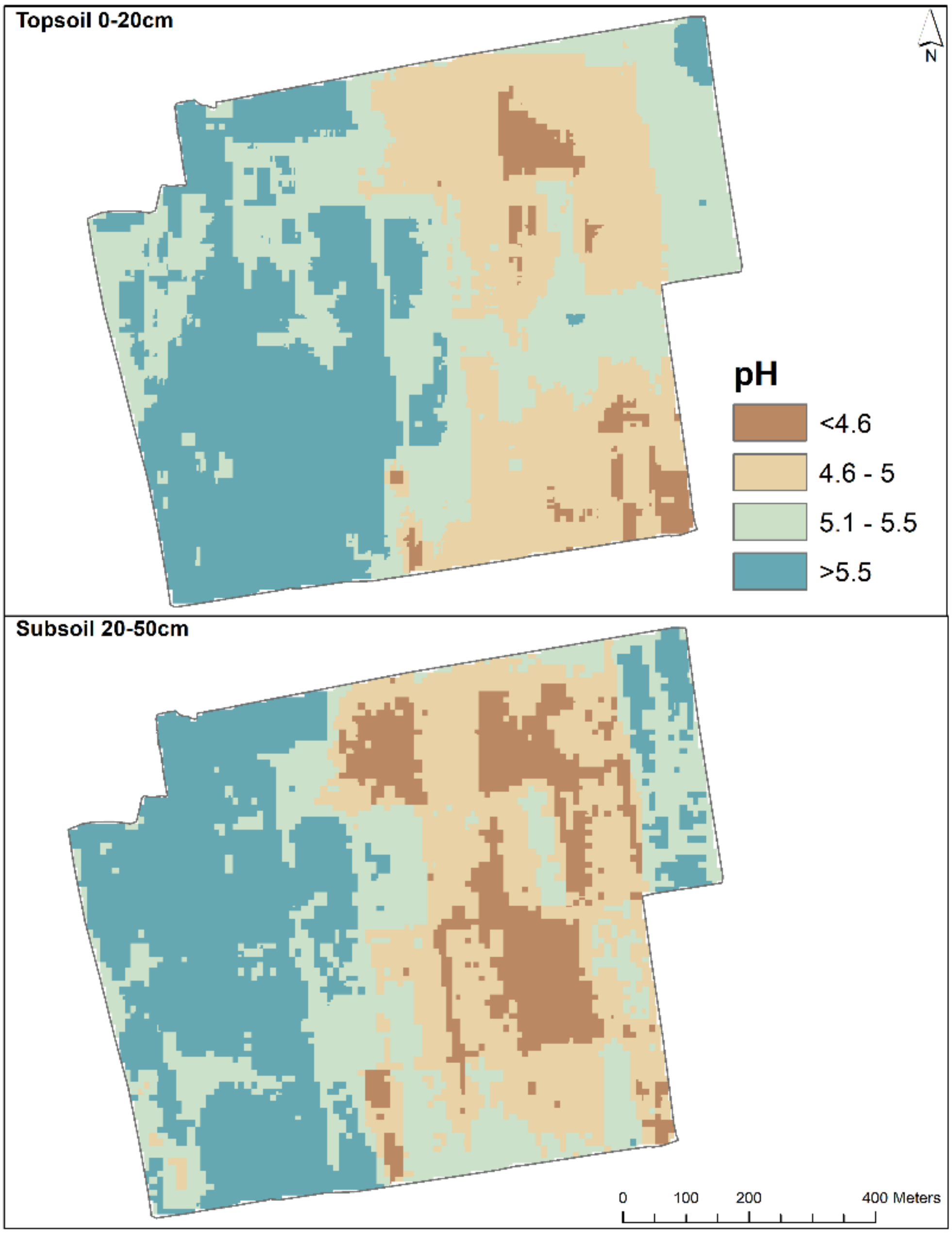
Land and Soil characteristics and Fertility conditions

Soil physical characteristics

The land is homogenous in terms of soil physical conditions. The general topography of the land is gently undulating terrain, with the majority of the land being flat or almost flat to gently sloping (See Appendix 3 - 6). The soil is deep (> 100 cm depth) and well-drained with no possible rooting restrictions. There is little variation in soil depth. There are no stones that might interfere with tillage operations. Over 60% of the land was in fallow at the time of this assessment. The area in use was planted with cassava with very few plots for maize. Apart from these fields, no other crops (Soybeans and cowpeas are grown at Ikenne) were planted. The topsoil colour mainly falls into three categories: very dark brown, dark brown, and dark yellowish-brown. There are very little to no variations within fields regarding soil depth, color, drainage condition, and other soil physical conditions. The sand content varies between 68 and 78% in the topsoil and between 50 and 72% in the subsoil. The silt content varies from 4 to 15% and 2 to 8% in the top and subsoil, respectively, while the clay content ranges from 15 to 23% and 25 to 45% in the top and subsoil, respectively. The topsoil is predominantly sandy loam, with about 54% falling within the desirable and suitable textural range for crop production. The subsoil varies in its textural class between sand clay loam (33%) and sandy clay (67%).

Soil pH

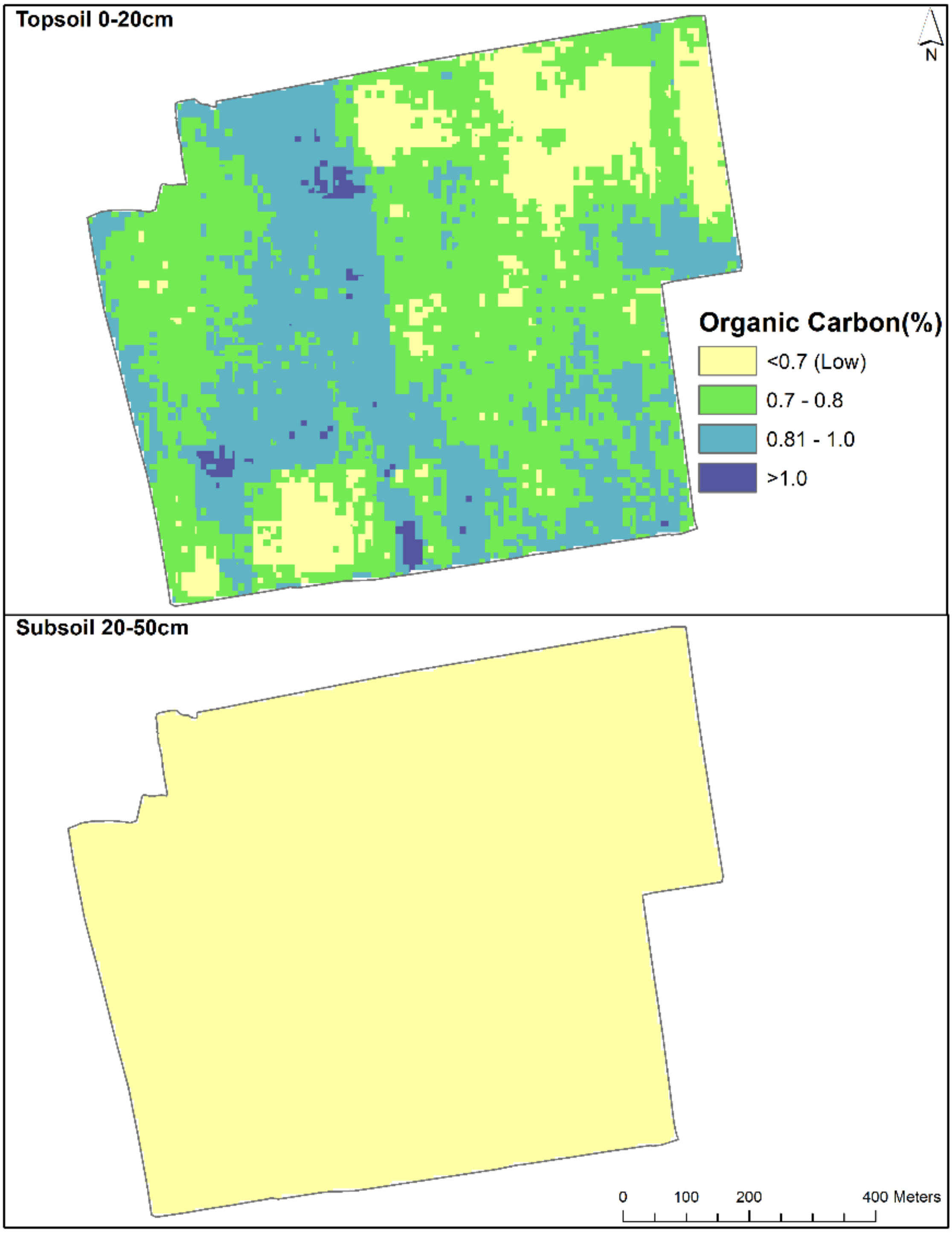
The soil pH values vary between 4.2 and 6.4, from strongly acidic to slightly acidic. The soils at the research farm fall within the two categories of low and optimum pH. About 54% of the fields have low soil pH, while 46% have optimum pH levels (between pH 5.5. and 6.5). Variations in pH follow the West-East divide, with the western part of the fields having optimum soil pH and the eastern parts being low in soil pH (Map 15). Areas with pH values lower than 5.5 will require lime application to amend soil acidity. About 1.0 t/ha of lime is needed to raise the pH by 1 unit. The quantity of lime required will depend on the actual soil pH of the field, among other factors.



Map 15. Soil pH distribution on Ikenne research fields

Soil organic carbon

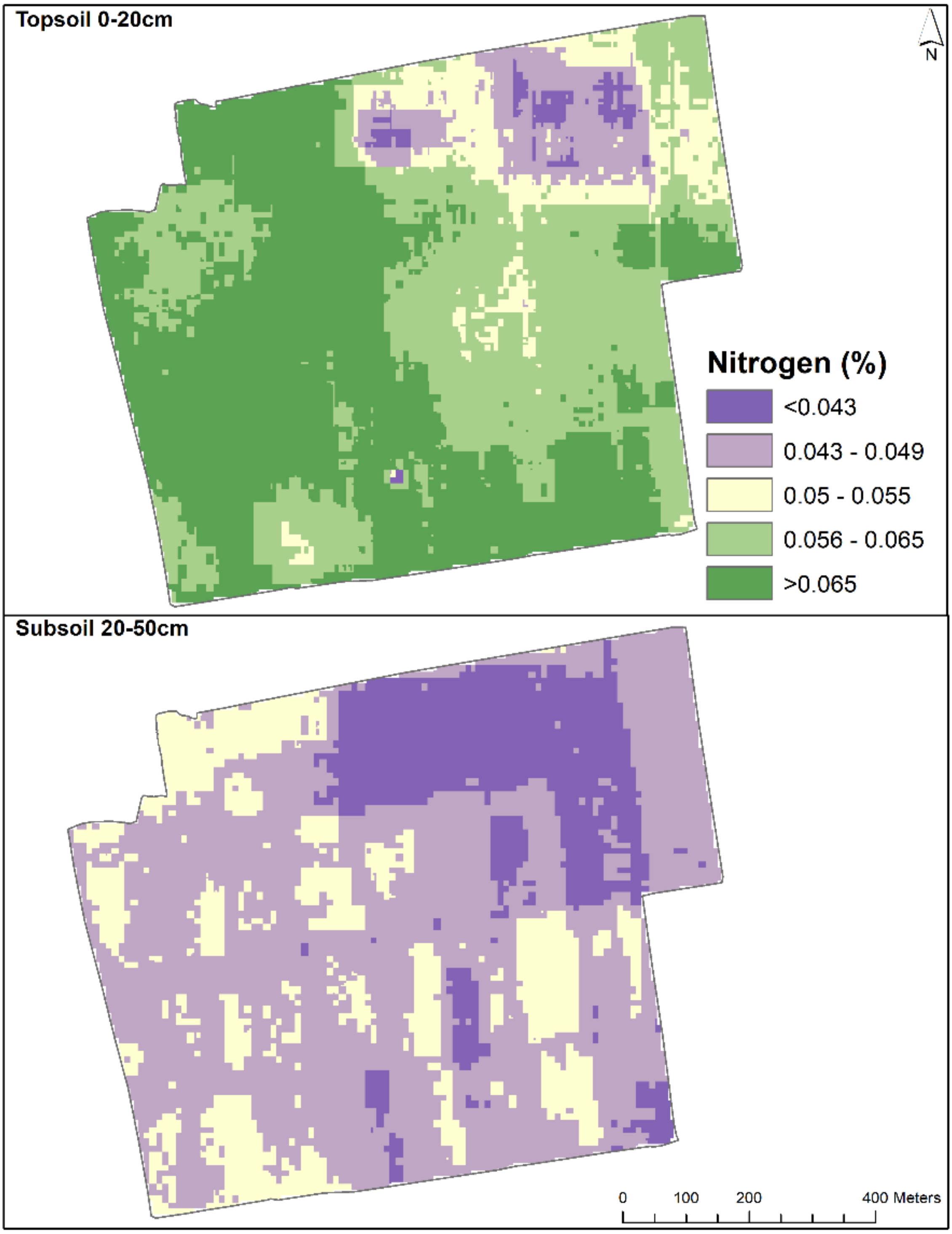
The organic carbon content of the soil varies from 0.58 to 1.22%, which is from very low to adequate levels. About 60% of the fields are very low in SOC; 39% are low, and only 1% have acceptable SOC levels. The northeast section is particularly very low in soil organic carbon level (Map 16). To improve the soil organic carbon from an average SOC of 0.78% to 1.2%, an application of about 12.6 t/ha of organic carbon, equivalent to 21.7 t/ha of organic matter, is needed, in theory. One needs to consider that only a fraction of the organic matter applied will be transformed into stable carbon (humus components). Equivalent rates of manure will very much depend on the quality of the manure and then especially the ash content.



Map 16. Soil organic carbon distribution on Ikenne research fields

Soil total nitrogen

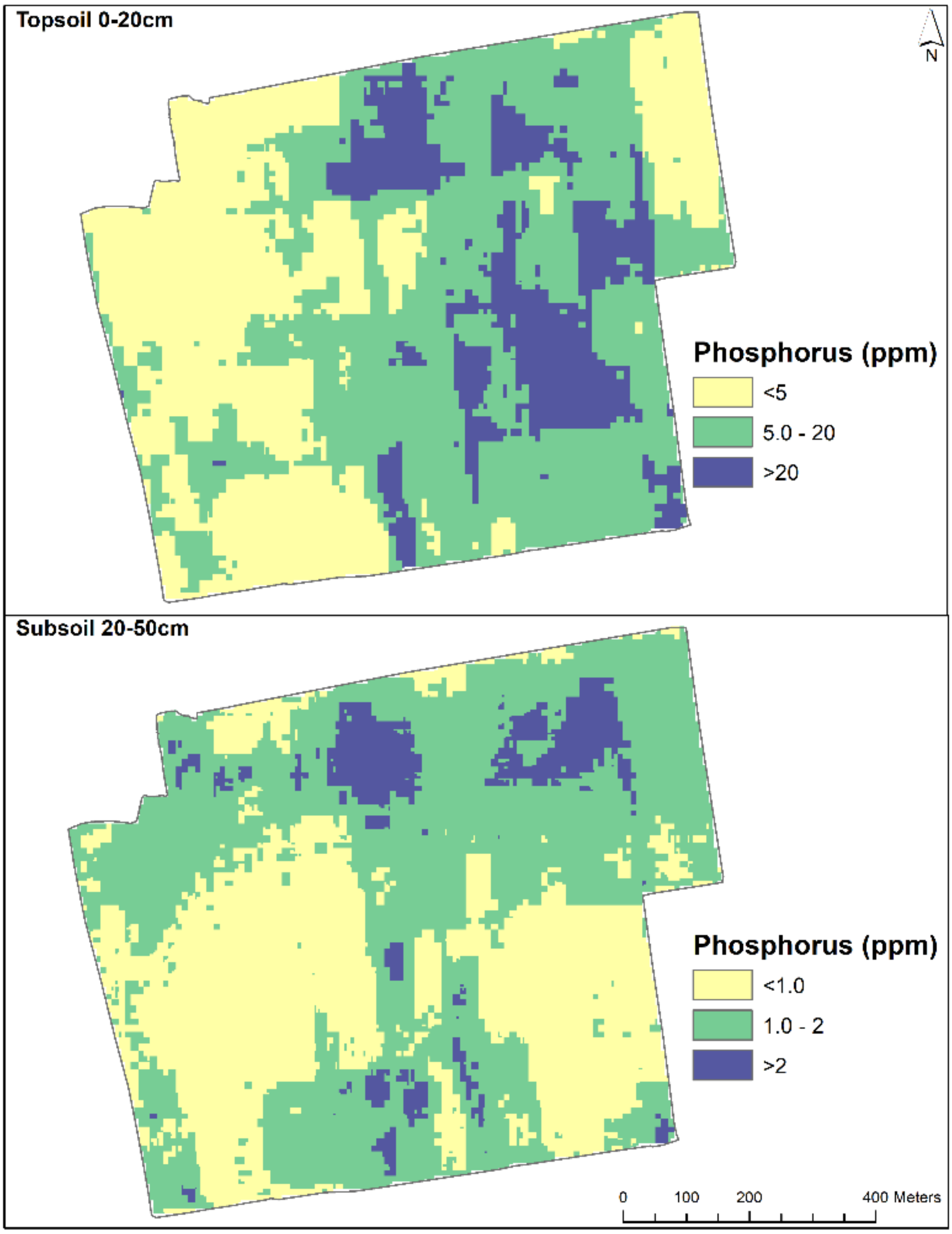
The total soil nitrogen ranges between 0.043 and 0.115% in fields IK19 and IK6, respectively. Total soil nitrogen is deficient across all the research fields (Map 17). The total N spatial variability follows the same pattern as the soil organic carbon. Improvement of the soil organic matter will contribute substantially towards recapitalizing the total soil nitrogen. Application of mineral N to crops should follow the 4 Rs principle of fertilizer application (right amount, right time, right placement and right timing)



Map 17. Soil total nitrogen distribution on Ikenne research fields

Available phosphorus

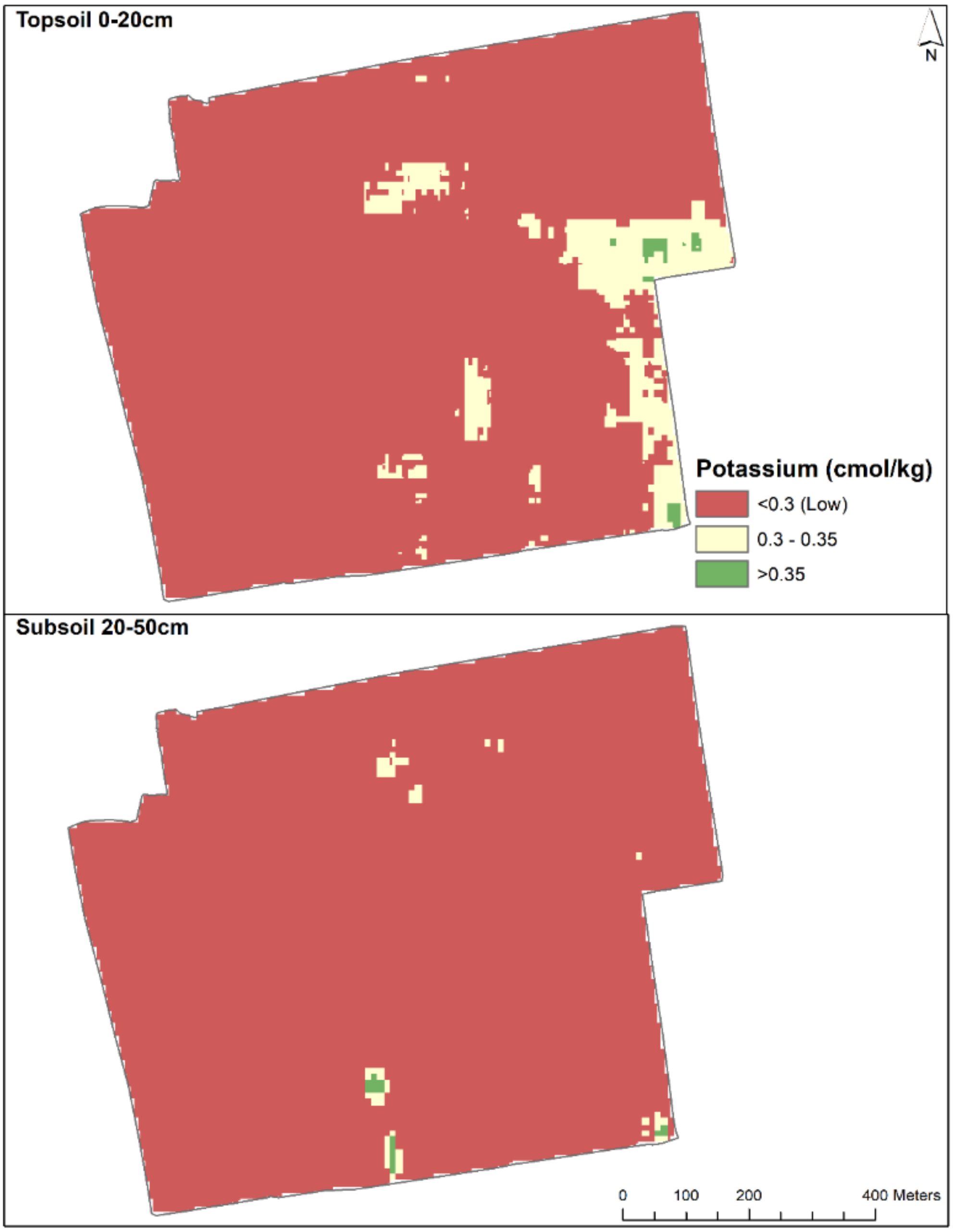
The available soil phosphorus varies considerably across the farm, with values ranging between 0.2 and 95.53 mg/kg on IK12 and IK15, respectively. The available phosphorus on these fields is generally low, and this is true for about 92% of the research fields. The entire western section of the farm is extremely low in phosphorus (Map 18). The spatial variation follows the same trend as the soil pH. There are spots of adequate and high phosphorus levels in the fields found around the eastern and northern parts of the farm, which is about 8% of the farm. Application of 76 kg/ha P_2O_5 phosphorus fertilizer is required to raise the phosphorus level from a mean of 5 ppm to the 16 ppm minimum requirement.



Map 18. Soil available distribution on Ikenne research fields

Exchangeable potassium

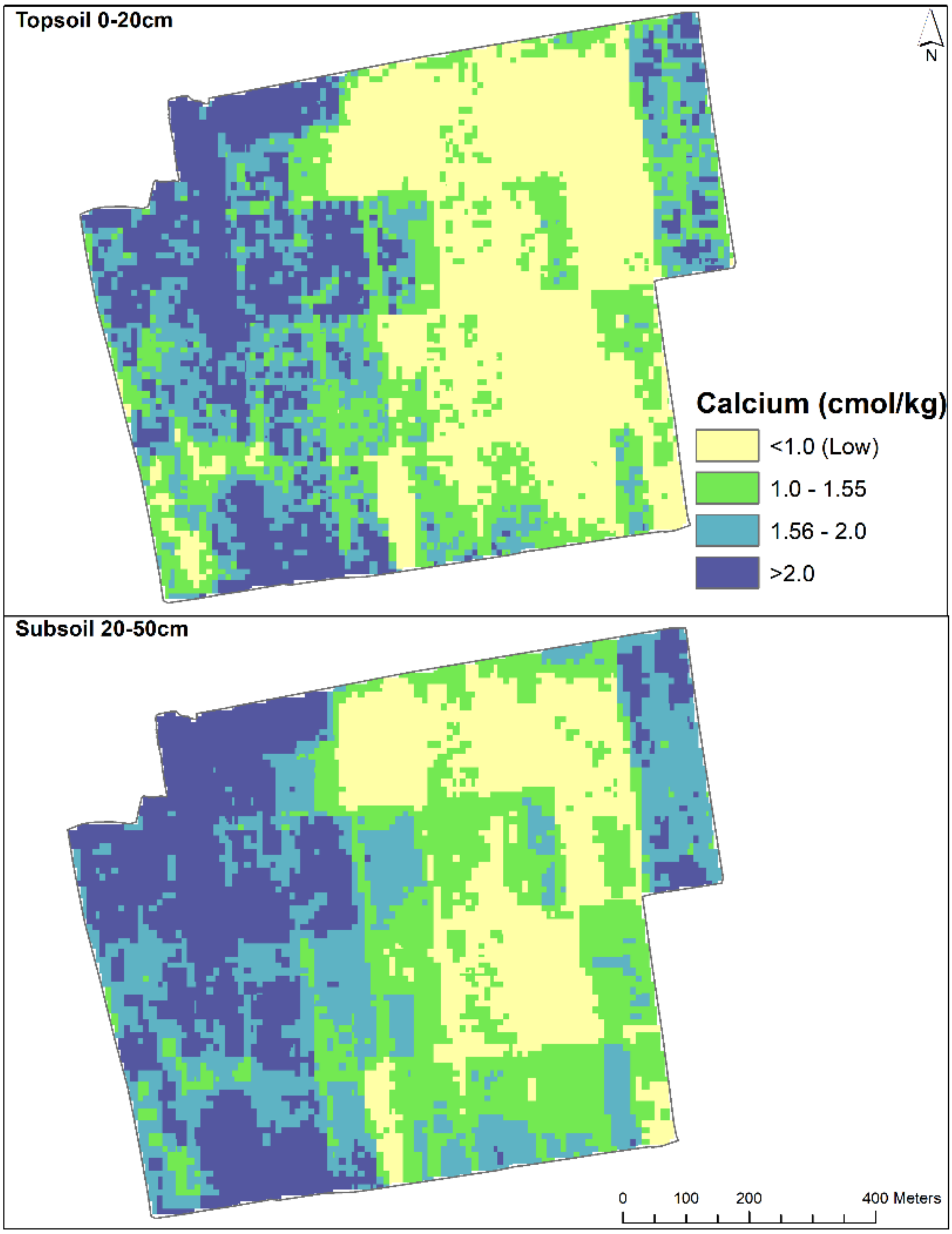
Potassium concentration in the soils varies between 0.09 cmol/kg in fields IK2 and 0.39 cmol/kg in IK 33. The soils are generally low in potassium, which is true in 90% of the research fields. The whole western section and north-eastern part are very low in potassium (Map 19). The extreme eastern sections have adequate potassium concentrations, accounting for about 10% of the entire research farm. The subsoil is generally deficient in potassium except for a few spots in the northern section. Improvement of the potassium concentration of this soil will require an application of 99 kg/ha of K_2O fertilizer.



Map 19. Distribution of exchangeable soil potassium within the Ikenne research fields

Exchangeable calcium

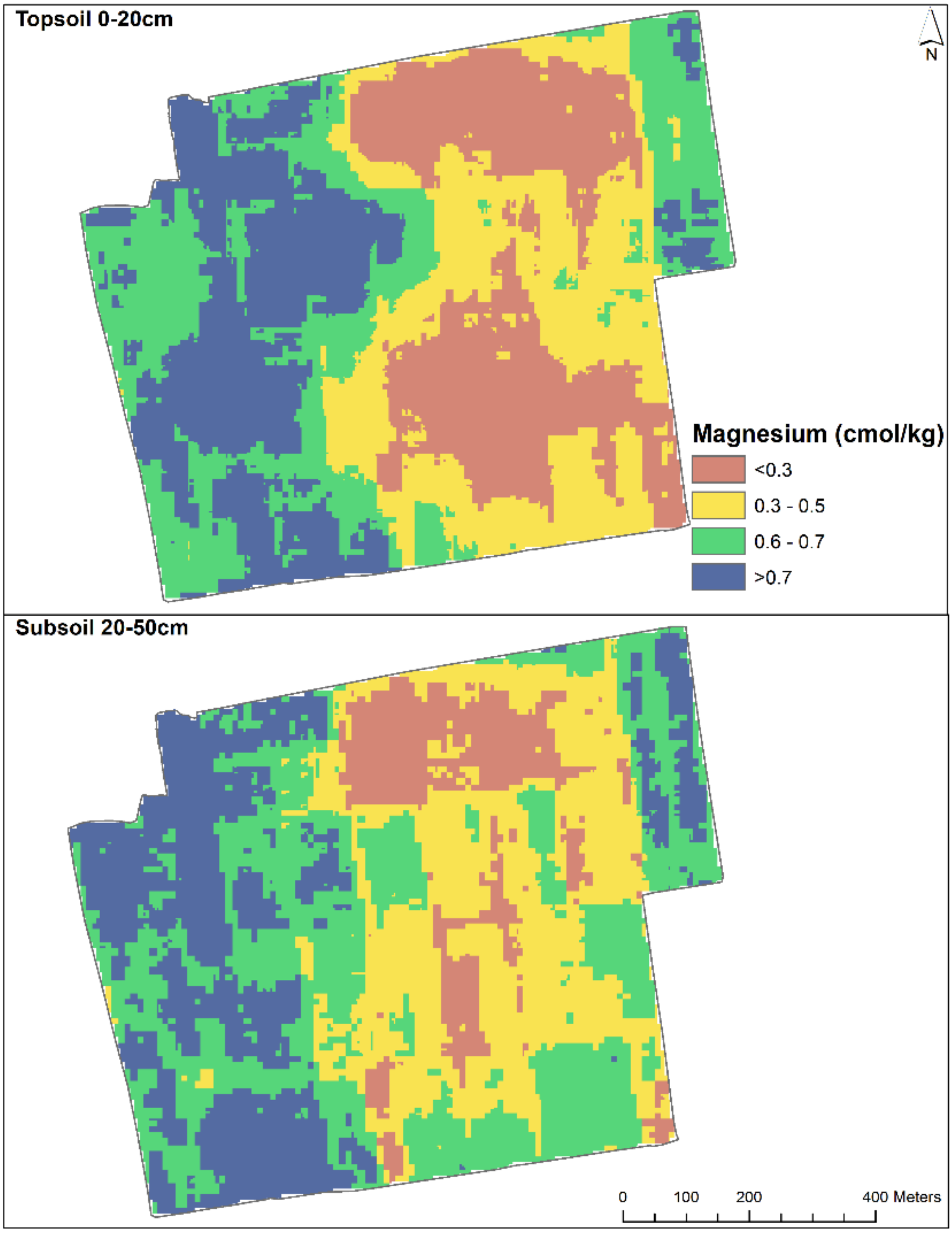
The calcium content of the soils varies between 0.18 to 10.30 cmol/kg in IK7 and IK31, respectively. About 32% of the research fields are low in calcium, 67% are adequate, and 1 % can be classified as high. Areas of acceptable calcium content are located in the western part of the farm (Map 20). The spatial variation of calcium follows the same trend as that of the soil pH and available phosphorus. Still, there are no significant concerns with the calcium level of the soil.



Map 20. Distribution of exchangeable soil calcium within the Ikenne research fields

Exchangeable magnesium

Magnesium concentrations vary between 0.12 and 1.23 cmol/kg in IK7 and IK14, respectively. The soils at the farm (93% of the fields) are generally low in magnesium (Map 21). This means that the soil magnesium concentration is less than 1.0 cmol/kg. Though magnesium is low, there are still spatial patterns across the farm with the western section having relatively more magnesium than the eastern part. About 184 kg/ha of MgO would be needed in the form of fertilizers to improve the magnesium level of the soil.



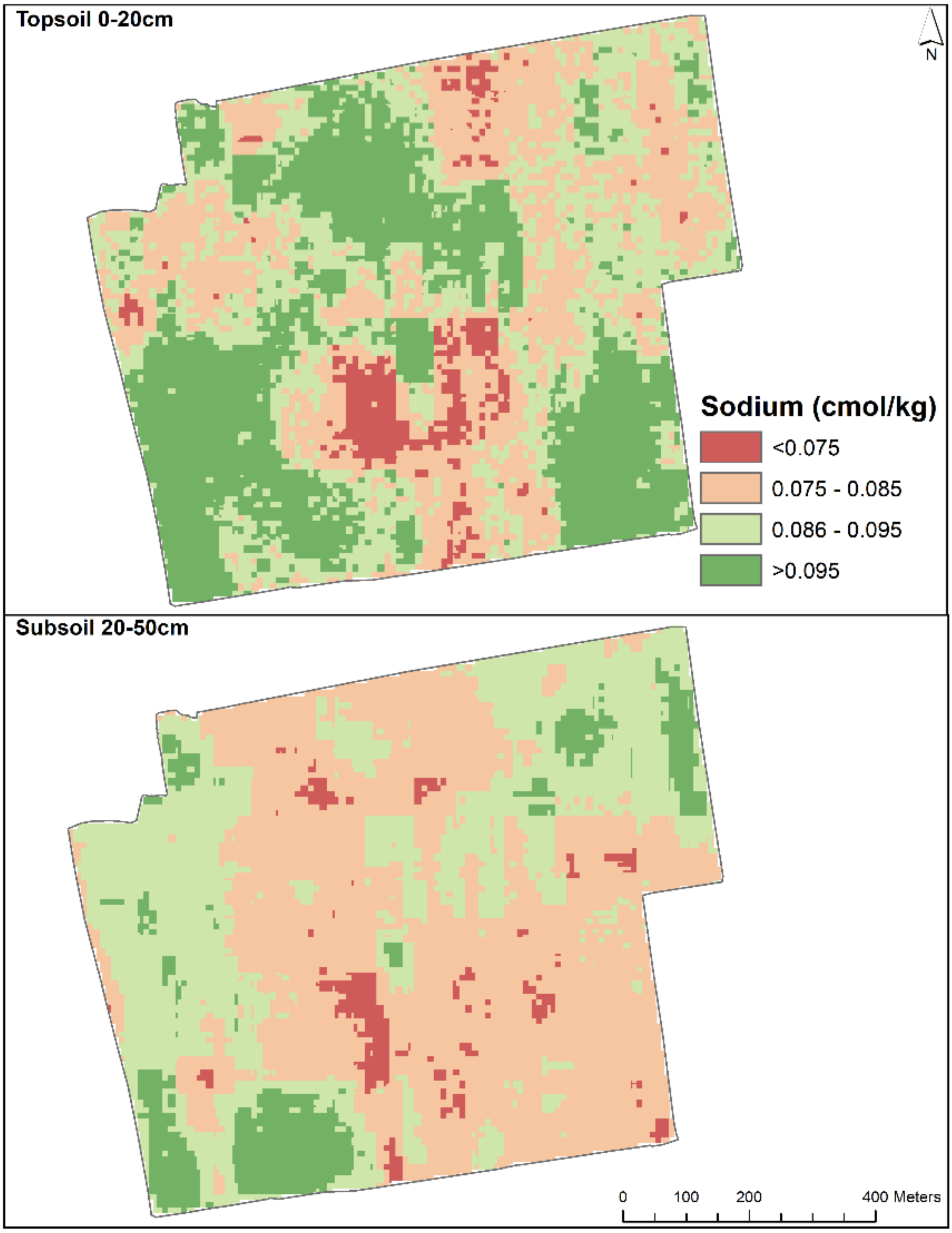
Map 21. Distribution of exchangeable soil magnesium within the Ikenne research fields

Exchangeable sodium

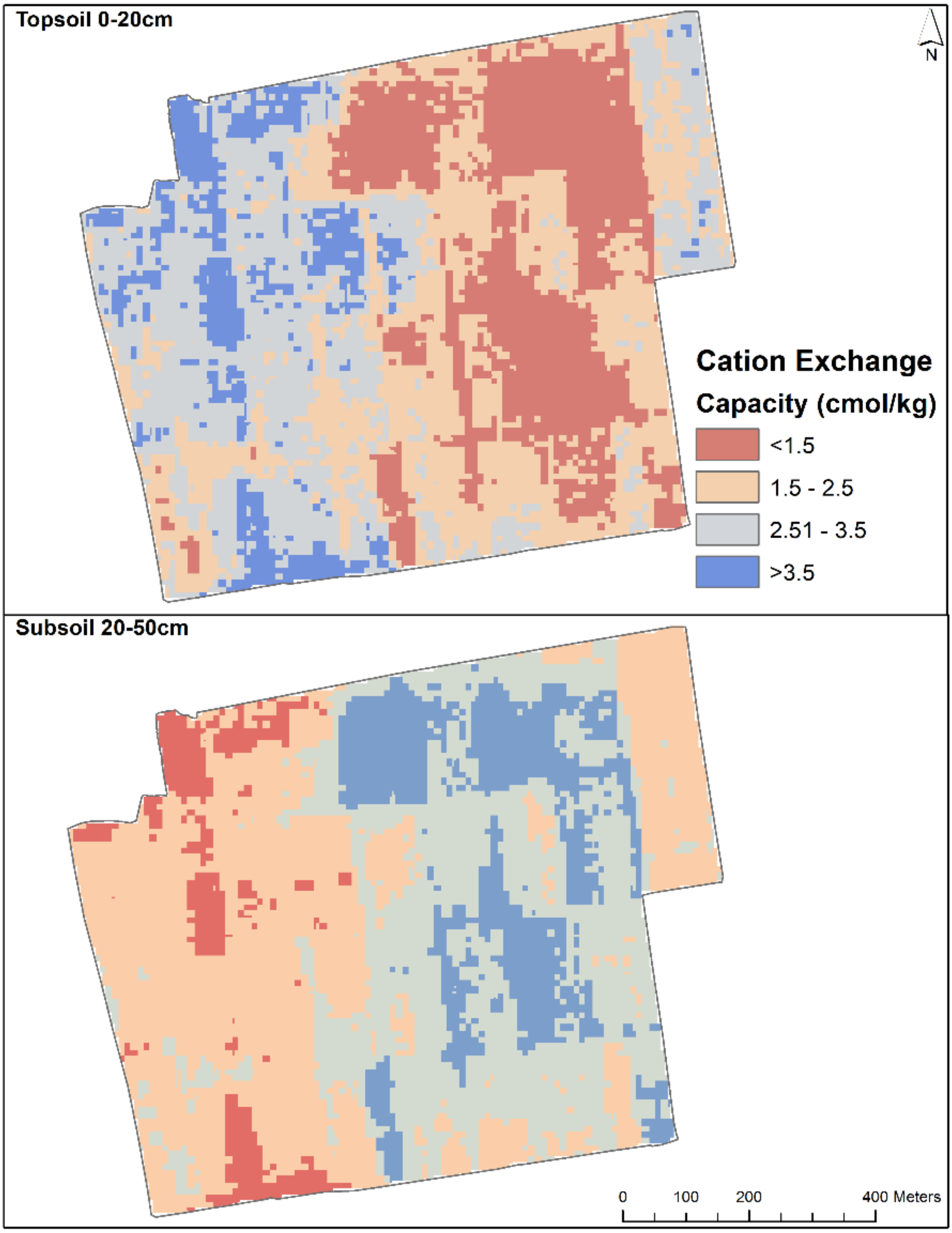
There is minimal variation in the sodium content of the soils at Ikenne. The soils generally have adequate levels of sodium (Map 22). Therefore, there are no concerns with the sodium content of the research fields at Ikenne.

Effective cation exchange capacity

The effective cation exchange capacity of the soils is generally very low and does not show any significant spatial variations (Map 23), though a spatial distribution pattern is clearly visible.



Map 22. Distribution of soil exchangeable sodium within the Ikenne research fields

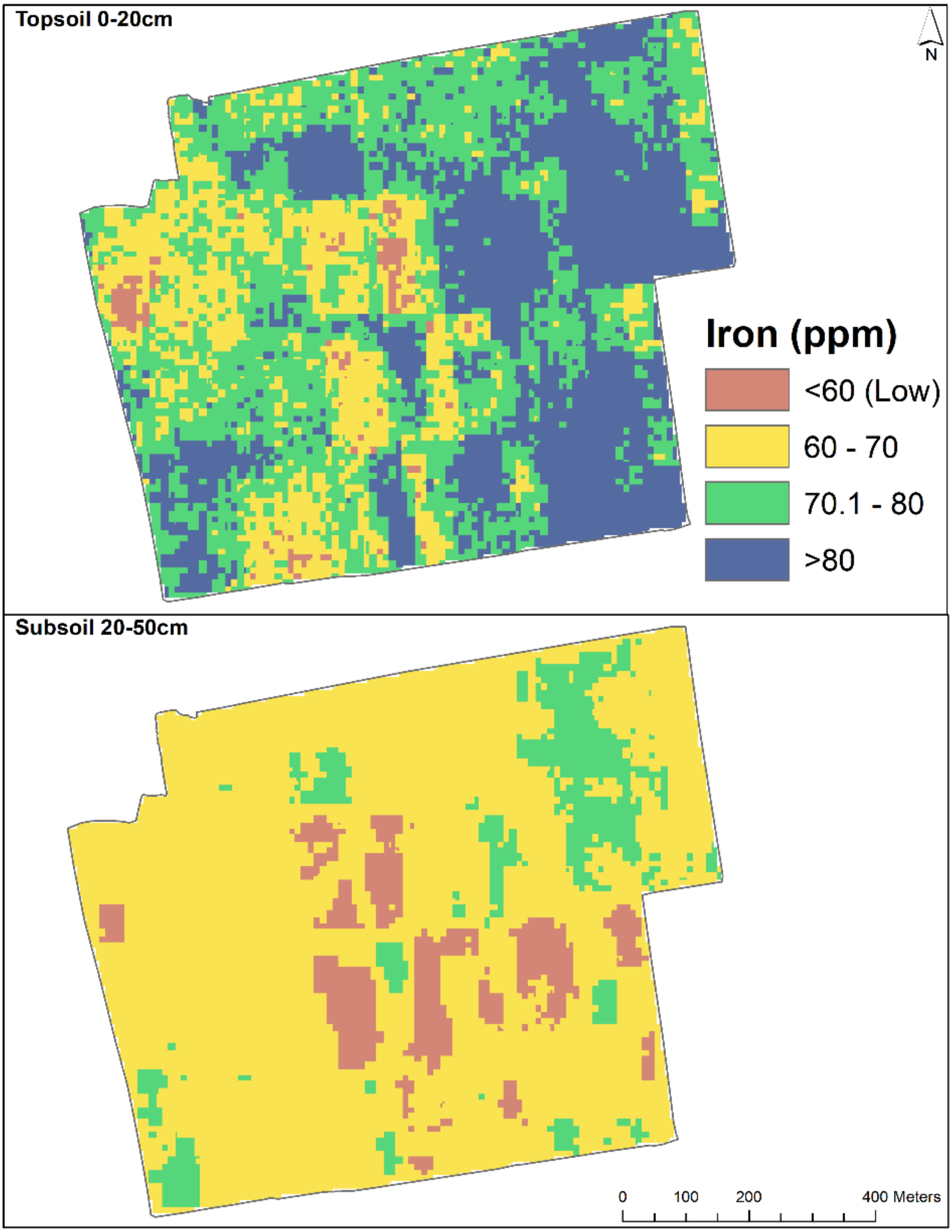


Map 23. Distribution of soil effective cation exchange capacity within the Ikenne research fields

Soil micronutrients

Manganese levels vary between 25 and 95 mg/kg at the IK3 and 1K18 sampling points, respectively. We found the soils to be low in manganese in 49% of the research fields, around the middle section stretching towards the north –southern sections of the farm (Map 24). And approximately 51% of the fields have adequate manganese content. This area is in the western section of the farm from north to south. Manganese is considered low when it falls below the minimum requirement of 60 mg/kg. On the other hand, iron varies between 47 and 114 mg/kg at IK3 and IK33, with about 80% of the fields having adequate concentrations (Map 25). Iron concentrations decrease slightly down the soil profile.

Map 24. Distribution of soil manganese within the Ikenne research fields



Map 25. Distribution of soil iron within the Ikenne research fields

IITA Kano Research Farm

The IITA Minjibir research station near Kano has 45 hectares of land used for agronomy and breeding research. Following the general methodology already described, 26 sampling points were mapped out for the soil assessment (Map 26).

MAP 26. Soil sampling points of the IITA Kano station

Land and Soil characteristics and fertility conditions

Soil physical conditions

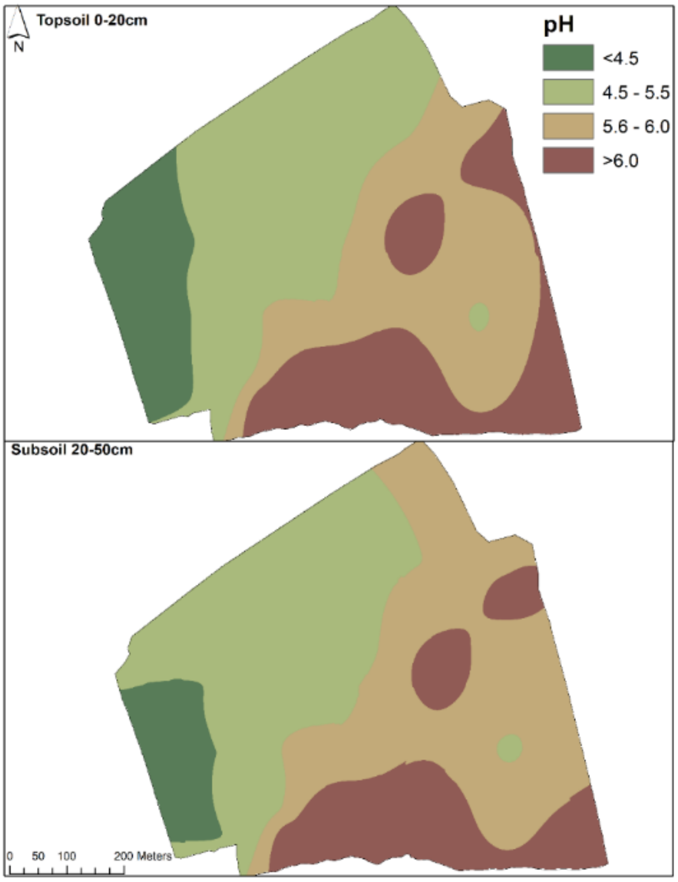
There are few variations in the soil physical characteristics of this land. The land is level to almost level in most parts (See Appendix 7 – 9). The soil is deep (that means beyond a depth of 100 cm), and gravel is limited to a few spots around the farm. Generally, soil depth restriction is not an issue, and there are no stones that may interfere with tillage operations. Due to the very gentle undulating terrain, there are no severe risks of erosion. All areas close to the reservoir are susceptible to flooding, with the possibility of flooding in some places during high rain events, while in some areas, flooding is somewhat frequent and but irregular. There are three drainage classes within the research farm: poor, moderate, and well drained. Plots around the lake are either poorly or moderately drained, with mottles occurring in the topsoil in some areas. The closer the plot is to the lake, the more poorly drained the soil is. Fields beyond the area that is periodically flooded outside are well drained, and these account for over 75% of the total research field area. Over 70% of the land was in fallow at the time of this assessment. Areas in use were seeded to cowpeas at the time.

The soil colour tends to vary considerably, with about eight different shades of brown of the topsoil, while the colour of the subsoil varied between shades of brown to different shades of red (according to the Munsell colour chart) and with no clear spatial pattern observed.

There are variations in the soil particle size distribution across the fields. Sand content varied between 70 and 84%, silt between 3 and 10%, and clay content between 10 and 27% within the topsoil. In the subsoil, sand content ranges from 64 to 84%, silt content is from 5 to 14%, and clay content ranges between 8 and 22%. The soils fall within two textural classes; loamy sand and sandy loam. About 83% of the soils are sandy loam both in the top and subsoil. There is a minimal textural variation with soil depth.

Soil pH

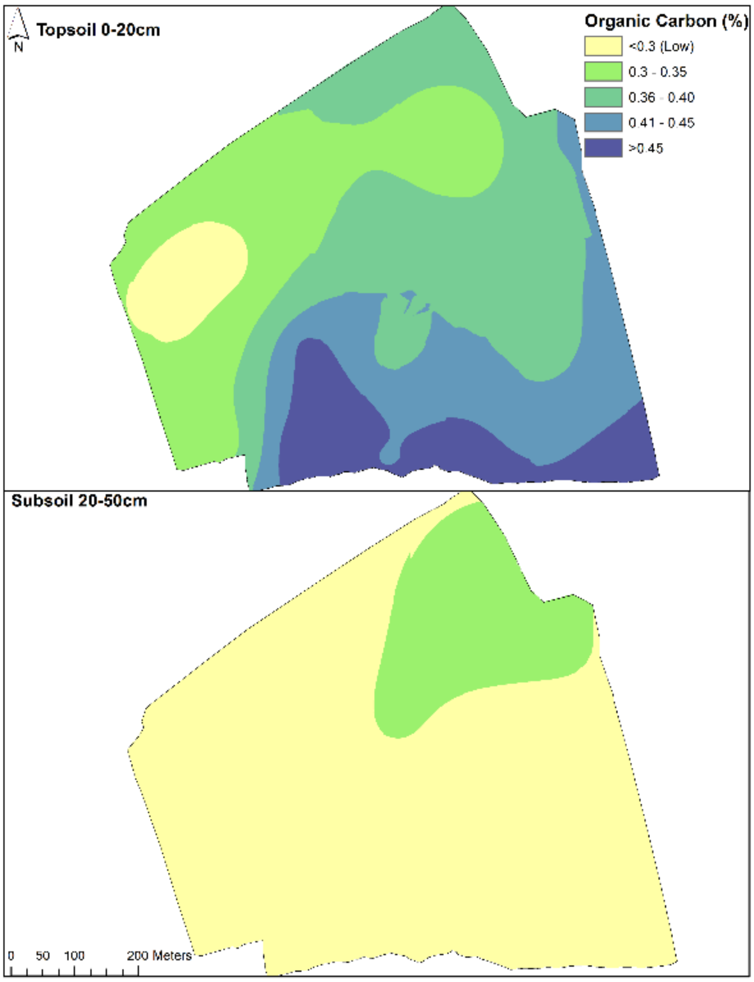
Soil pH is one of the critical soil functional properties, and it affects nutrient availability in soils. Soil nutrients are unavailable for plant uptake at very low and high pH levels. At the Minjibir farm, soil pH is low (below 5.5) in about 44% of the land. The extreme western section is predominantly very low in pH (less than 4.5). The entire western section stretching to the north of the land (See Map 27) are areas that need to be corrected because the pH of these soils is below 5.5, a threshold at which growth of acid intolerant crops is affected. To restore the pH levels in these fields, a minimum of 2.0 t/ha of lime is required. However, the soil pH is at the optimum level in about 56% of the area, which is found around the south and eastern section of the land. There are no variations in the pattern of pH in the top and subsoils.



Map 27. Distribution of soil pH within the Kano research fields

Soil organic carbon

Soil organic carbon is a vital soil quality indicator as it supplies plant nutrients and regulates many other soil properties. We found 98% of the soils to be very low (OC < 0.7%) in soil organic carbon, representing more or less the entire farm. However, plots close to the dam have slightly more soil organic carbon (See Map 28). The subsoils are likewise very low in soil organic carbon, mostly below 0.3%. Low soil organic carbon is a significant concern for any soil improvement plans for the farm. Raising the soil organic carbon would require an application rate of 46.5t/ha of organic matter.



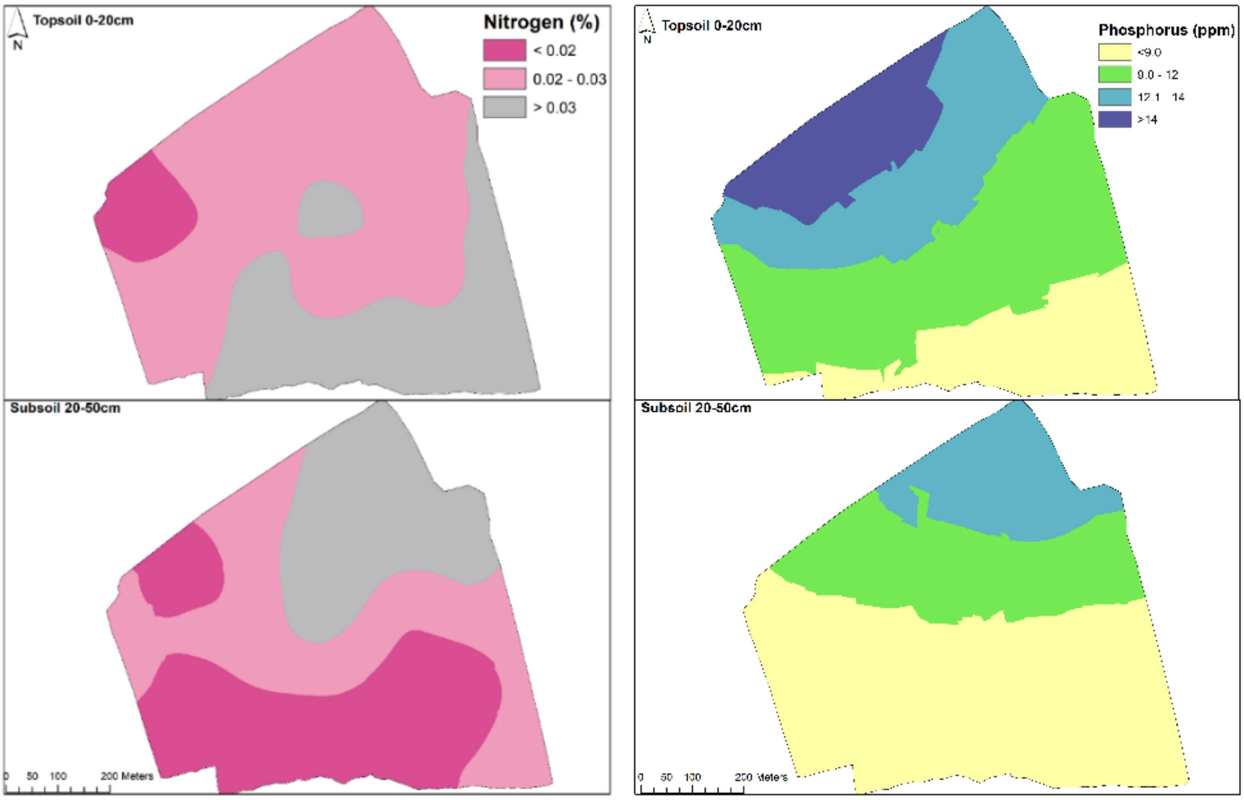
Map 28. Distribution of soil organic carbon within the Kano research fields

Soil total nitrogen

Nitrogen is an essential macronutrient for plant function and is a key component of amino acids, which form the building blocks of plant proteins and enzymes. It is the primary limiting nutrient to sustain crop yields and quality. Nitrogen is deficient in all research fields. Areas close to the lake seem to be slightly better, but the nitrogen concentration still falls below the minimum requirement of 1.5 g/kg (Map 29). The continuous and judicious use of nitrogen fertilizers is key to the sustainable use of the research fields. The amount of nitrogen needed to raise the nitrogen level to the minimum standard is high (3.7 t N /ha), for which there is no practical solution except through improvement of the soil organic matter.

Available phosphorus

A major source of available phosphorus is soil organic matter, and in natural terrestrial ecosystems it may result from from the weathering of minerals in the parent rock material. It is usually the second most limiting nutrient for crop production (after nitrogen). About 90% of the farm has low phosphorus concentration, and the remaining 10% only being adequate in phosphorus levels. Variations of soil available phosphorus follow a gradient from south to north (Map 29). The southern part is extremely low in phosphorus, which is followed by the middle section. The northern section has higher phosphorus levels, with some spots reaching the threshold for adequate phosphorus levels of 16 mg/kg. To Improve the phosphorus content of these soils (recapitalization) would require about 55 kg/ha of P_2O_5 application.



Map 29. Distribution of total soil nitrogen and available phosphorus within the Kano research fields

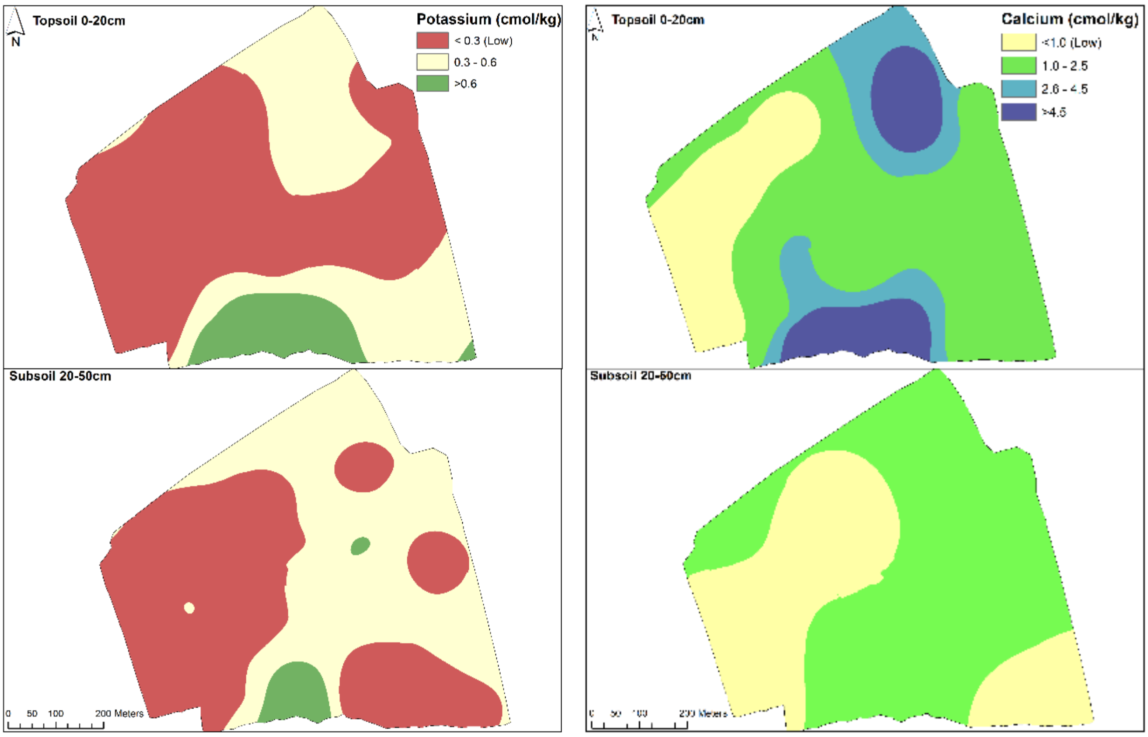
Exchangeable potassium

Among the three primary essential nutrients, potassium is the most abundant at the research farm. Potassium concentration is above the minimum requirement of 0.3 cmol/kg in about 40% of the farm, while the remaining 60% of the land is low in potassium concentration. The central part of the farm stretching to the entire western section of the land are particularly low in potassium (See Map 30) and will need to be corrected through fertilizer input at an application rate of 142 kg K_2O per hectare.

Exchangeable Calcium

Calcium is one of the secondary essential macronutrients needed for the proper growth and development of crops. About 33% of the Minjibri soils are low in calcium in the extreme west

(Map 30). The soil has adequate calcium levels in 60% of the land, and there are some spots of high calcium concentration in about 5% of the area near the northeast and extreme south of the farm. Thus there is little concern with regards to the soil calcium content in terms of management practices.



Map 30. Distribution of soil exchangeable potassium and calcium within the Kano research fields

Exchangeable Magnesium

Magnesium is also a secondary macro-nutrient essential for sustainable crop production. The soil is considerably low in potassium in over 90% of the research fields. We still see a spatial pattern in the variation of Magnesium concentrations, even though concentrations are low. The southern section (areas close to the lake) has relatively higher magnesium content, while the western section towards the central part has the lowest magnesium concentration (Map 31).

Exchangeable sodium

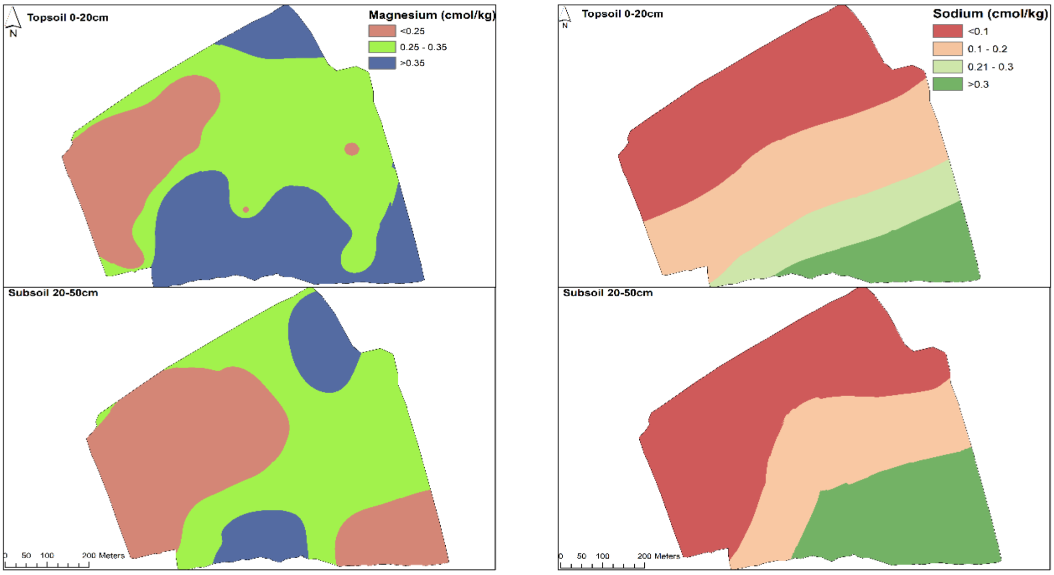
There is minimal variation in soil sodium content in the fields. It was noted that the sodium concentration declines with distance away from the lake (Map 31). The soils generally have an adequate level of sodium. Therefore, there are no concerns with the sodium content in the Kano research fields.

Cation exchange capacity (CEC)

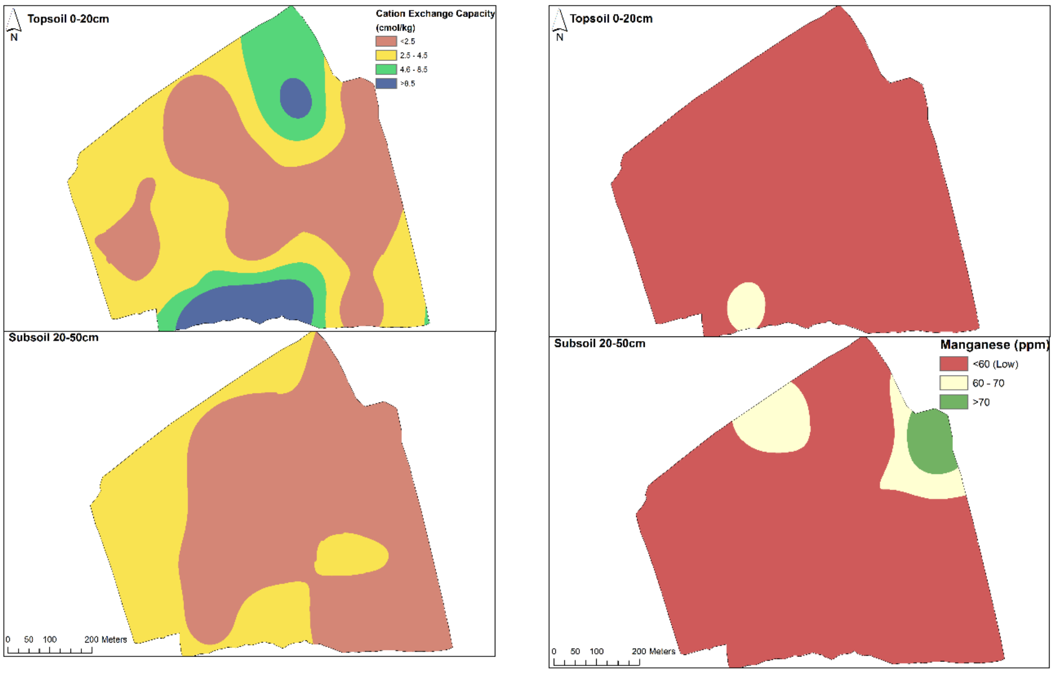
As CEC measures the soil's ability to hold nutrients, it is a key determinant of soil fertility. The ECEC is very low in 90%, low in 6%, and adequate in 4% of the fields. The center-south and the northeastern corner of the land show low to acceptable levels of ECEC in their soils (Map 32). Soils with low CEC become acidic very quickly and need liming more frequently than soils with high CEC. Soils with high CEC have a higher ability to hold water, while soils with low CEC have a low capacity to hold water. Low CEC may result in low nutrient recovery efficiency for applied granular fertilizer.

Soil micronutrients

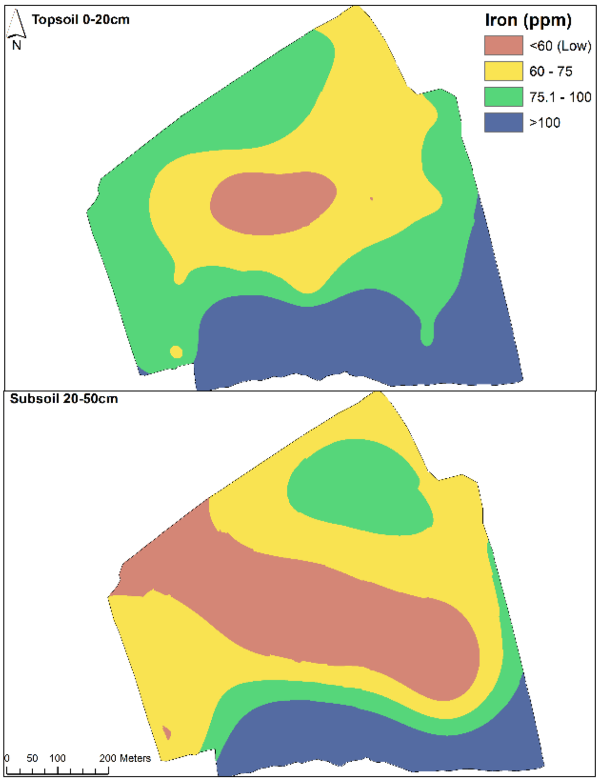
Soil micronutrients are critical components in soil quality assessment. The soils at Minjibir are low in manganese content in about 71% of the land, while the remaining areas have adequate manganese levels. Areas very low in Mn are around the northwest and a spot in the southeast (Map 32). On the other hand, as a micronutrient, iron is adequate in 71% and slightly high in about 8% of the land, and the remaining 21% of the soils have low iron concentration (See Map 33).



Map 31. Distribution of soil exchangeable magnesium and sodium within the Kano research fields



Map 32. Distribution of soil effective cation exchange capacity and manganese within the Kano research fields



Map 33. Distribution of soil iron within the Kano research fields

Ibadan research farm – soil management plan

Field layout and design

From the point of view of erosion control there does not seem to be a need to change the layout of the fields on the farm. The current design/layout is dictated by the undulating topography of the terrain and the wish to control erosion. The fields are oriented along the contour lines, and the plots are elongated along the contours. The width of the fields is along the downslope direction and kept at a minimum. The width of the plots seems to be adjusted to, and in agreement with, the slope, according to the current guidelines and calculation methods. It means that there are hardly any opportunities to increase the width of the fields or change the layout without increasing the risk of erosion, because there seem to be hardly any alternative erosion control measures for this type of slopes and on this type of soils (see further details in the section on erosion control and water conservation).

There might be a desire to change the field layout for operational reasons, to make the design more efficient. Possible change in the field layout should be restricted to flat to almost flat terrain, however. On sloping land the possibilities will be determined by soil characteristics like soil depth, soil texture, and depth of the A-horizon and other.

We observed only a slight variation in soil properties across the farm and within the fields. There is no need for further division of the plots, or for another layout of the plots, to increase the homogeneity of the soil conditions within the plots.

There is an extensive road network on the farm, and access to the individual plots is good and does not give a reason to change the layout of the fields to improve accessibility. The roads and tracks do seem to take up a relatively large proportion of the land

The map of the research farm needs to be updated to reflect the changes in land use. For example, there are plots along the east bank of the lake where trees have been planted, but that are still mapped as research fields.

Erosion control and water conservation

Erosion control is essential, especially for the Ibadan research farm, because of the undulating topography. At Ibadan, about 44% of the field varies in steepness between gentle and moderate slopes (see Appendix 3). On slopes of 2 – 6% in intermediate to high rainfall zones, that the IITA research farm of Ibadan is part of, graded bunds are the appropriate technique to control erosion. At the IITA research farm, graded bunds are laid out with grass strips on the sloping fields, which seems adequate under prevailing conditions. The vertical interval (VI) between the bunds and the horizontal distance (HD) between the bunds seems to have the right measure (VI around 1 meter to 1.5 meters and a HD ranging between 20 and 30 to 35 meters, (http://ecoursesonline.iasri.res.in/mod/page/view.php?id=2101). Ploughing is done along the contour lines. These measures seem to be adequate.

Terracing (bench terraces) is generally considered for steeper slopes. But it would not be suitable even when considered for the Ibadan research farm. The soils are too shallow to allow for terracing, and it would cause a substantial variation in soil condition within the field because of the subsoil being exposed on the 'upper' part of the terrace.

Soil tillage

Conservation tillage is often recommended for erosion control (Bergtold and Sailius, 2020). Still, it may not be needed for the IITA Ibadan research farm, given the light-textured soils and high infiltration capacity generally associated with it and considering that measures are already taken to control erosion. However, to conserve soil organic carbon and soil moisture. Conservation tillage or agriculture might be considered.

Currently, a (offset) disc plough is being used for land preparation at the research farm. The disc plough is often used and suited for lighter soils, as in the case of the IITA research farm. Disc ploughs break up soil aggregates into smaller particles. Frequent use of the disc plough may produce a compacted layer (plough pan). Still, the impact is less on the sandy soils with high gravel content at the IITA Ibadan research farm, in which we found only very poorly developed aggregate structures. However, a disc plough does invert and herewith disturbs the soil structure with possible adverse effects on soil life (soil organisms) and increased rate of decomposition and mineralization of soil organic matter, for example. As such, non-inversion tillage techniques, like a ripper or chisel plough, may be considered (see the section on soil fertility management)

No-till or minimum-till operations may also be problematic because of the sandy texture and the possible restriction to root penetration consequently. The plasticity of the soil is significantly reduced with high sand and gravel content. Moreover, there are other complexities associated with no- and minimum tillage (see next section).

The mouldboard turns the soil over and buries surface residue more effectively than a disc plough, for example. It is not suited for the shallow soils and shallow topsoil of the research farm because it brings up the less fertile subsoil and even the gravel that we find at shallow depth in the soil. A possible alternative is the 'eco-plough' that works the soil less deep (less than 20cm). It is done by running the tractor on top of the land rather than in the furrows (Prinsen, 2017). In Africa, in practice the ploughing is done to less than 20 cm depth generally.

Alternatives like subsoiling, or ripping, are likewise not feasible at the research farm because of the shallow soils, apart from maybe the section in the forest area west of the lake (fields Ag1 to Ag5)

Soil fertility management and soil moisture management

Soil organic matter management

The Ibadan research farm is by and large extremely low in soil organic carbon (SOC). That is, most of the fields have extremely low SOC percentages (SOC < 0.7%). Only the fields in the northern fringe of the farm, the southeast section, and the section within the forest area on the western part of the farm have slightly higher SOC percentages, though still classified as low (less than 1.2%). There are only a few isolated points that have a SOC percentage of higher than 1.2%. When we correct for the gravel content, the average SOC% is even below 0.5% for the area mapped as extremely low SOC content.

The SOC has a strong influence on other soil properties, especially on sandy soils that we find on the farm. The SOC affects the soil hydrologic, chemical, and biological properties of the soil. Therefore, managing SOC is crucial component of managing soil water, to increase the water availability to crops, and managing soil fertility to improve nutrient availability to the crop, and in the management of soil biological quality for the reduction in soil-borne pests and diseases.

To increase the SOC in the topsoil (0-20 cm) with 0.6% about 25 tons of organic matter per ha needs to be applied. For the areas classified as low SOC% (effective SOC% of around 0.08% to 0.09%), half of this amount would suffice. This is in theory the amount of OM needed to provide the required amount of organic carbon. In practice much larger volumes would be required because only part of the supplied organic matter will be transformed into the stable humus component of the soil, whereas the larger part will be used as food for the microbial population in the soil (and therefore growth of the microbial population). Moreover, we are referring here to the dry matter content of well-composted organic resources. The amount of fresh weight required will depend on the moisture content of the organic resource.

Such amounts cannot be applied at once, and a plan needs to be developed for increasing SOC levels systematically over the years. The organic resource, when applied, needs to be worked into the soil to prevent loss of the organic matter. At the same time, measures need to be taken to maintain the soil organic carbon levels, including proper crop residue management and crop rotation. The crop rotation should include a crop that helps build soil organic matter, and improved grassland would probably be the most efficient. And at the same time, land should be set aside for biomass production to provide for the needed organic resources.

Soil nutrient management

Soil fertility management should aim to bring and maintain the crop nutrient levels in the soil to a minimum that does not limit crop production and in which fertilizer application for crop production should aim only to satisfy nutrient demand and to maintain the soil nutrient concentration at sufficiency levels. That is, nutrient concentrations should be brought up to levels that are considered critical and below which the nutrient concentrations are considered low or very low. Another aspect is the capacity of the soil to hold the nutrients and release them for uptake by the plant at the time of demand. This is measured by the Cation Exchange Capacity (CEC) as far as the cation are concerned. Still, another aspect of soil fertility management concerns the pH of the soil because the pH influences the availability of nutrients. Nitrogen (N), Potassium (K), and Sulphur (S) appear to be less affected by soil pH. However, Phosphorus (P) is directly affected by low and high pH values by changing the form of P and making it less soluble. Soil pH levels affect the availability of micronutrients (Fe, Mn, Bo, Cu, and Zn). The pH also affects the CEC and the form of the organic compounds in the soil and the microbial composition and is, therefore, an essential aspect in managing soil fertility.

Map 6 shows that the whole research farmland is very low in available P (P_{avail} < 16 ppm). When considering the individual sampling points, 68% of the points are very low in available P, and 16% of the points show adequate levels of available P. To recapitalize soil P for those areas indicated as very low (the yellow, green, and the blue regions in Map 6) to the critical level below which it is considered 'very low', 13 kg P per ha is required, which is equivalent to about 30 kg of P_2O_5. To bring the level of available P up to 30 ppm (the critical level for "low" level or level of deficiency), an additional 39 kg P/ha is required, bringing the total to

52 kg P/ha, or about 120 kg P_2O_5 per ha. For the areas with slightly higher P_{avail} levels (the area mapped purple on Map 6), 39 kg P is required per ha to address the P deficiency, equivalent to 90 kg of P_2O_5 per ha. The application of P should be gradual and in line with the application of organic matter to ensure the capacity of the soil to retain the P applied. Otherwise, the risk is that the P applied will be lost through leaching, impacting on the use efficiency of the P application.

The potassium content is limiting for the areas mapped as red (< 3 cmol/kg is considered deficient). However, it is not very low, and for the other areas it is classified as adequate. The K deficiency can be addressed by augmenting the K application during the regular fertilizer application for the various crops. Again, attention should be given to increasing the CEC to make sure there is a proper response to the K application.

The CEC is critically low throughout the research farm (< 5 cmol/kg), considering that in practice, the CEC levels are even lower because of the high gravel content of the soil, for which we have not corrected. We already indicated how critical CEC is for soil fertility and the efficiency and effectiveness of the nutrient application. The low CEC is caused by the type of clay minerals, the relatively low clay content, and the low SOC levels. SOC/SOM contributes about 200 times more to the CEC than soil itself, and increasing the SOC levels is, therefore, the only effective way to increase CEC.

The pH levels that we have observed are not an immediate concern.

Water balance – soil physical characteristics

For most of the points, the soil texture is classified as sandy loam (SL), with clay percentages ranging between 12% and 20% and sand percentages between 66% and 80%. We have a few points for which the texture is classified as sandy clay loam (SCL) at the extremities of the farm. Applying a correction factor because of the gravel content, the effective and actual clay and silt content are a few percent lower. Consequently, some SCL points would be classified as SL, and the number of loamy sand points would increase. Based on the textural composition, almost all points are categorized as belonging to either the less or least desirable soil textural type, implying a low moisture holding capacity and indicating the water available for plant uptake at field capacity is relatively low. The soils have also been classified as extremely well-drained in all cases, and we see very little structural development in the soil that would enhance the water holding capacity.

Together with the shallowness of the soil, this means that there is a high risk for a shortage of water available for plant uptake, especially under conditions of somewhat irregular rainfall. Moisture deficit may occur only after a few dry days, and irrigation needs to be done regularly to prevent a negative impact on the crop. Moisture deficit affects the availability and uptake of nutrients by plants. The sandy and gravelly texture and the poorly developed structure also affect root development and herewith also the capacity of the crop for the uptake of water and nutrients.

Soil amendments are needed to improve the soil physical characteristics, and the only practical measure is to increase soil organic matter by adding manure, compost, or other organic resources. This stresses the importance of soil organic matter management at the Ibadan research fields. Management should strive for a 1.2% SOC level in the soils of the farm.

Ikenne research farm – soil management plan

Field layout and design

The area is flat to almost flat to very gently undulating. It allows for the establishment of plots with a rectangular shape that can be organized in a regular pattern to facilitate easy access and mechanization.

Erosion control and water conservation

Given the flat topography, the soil texture, and well-drained conditions of the soil, there is little risk of erosion and no need for specific erosion control measures. There are no concerns about water shortage and hence no need for specific water conservation measures.

Soil tillage

There are no physical constraints for implementing soil conservation tillage practices at the Ikenne research farm. Adopting conservation tillage measures could be considered for preserving soil organic carbon levels. For the control of erosion, this measure does not seem to be necessary. The use of a ripper or chisel plough should be considered.

Note that it requires several years for the soil system to adjust to the changed management regime and to be stable. Yields generally decrease during the period of transition into conservation agriculture, and special attention needs to be given to weed management. At the same time, the organic resources that will be applied need to be worked into the soil, which contradicts the methods of conservation agriculture that should then be implemented afterward.

Soil fertility and soil water management

Soil organic matter management

There seems to be a divide between the eastern and western parts of the farm that follows the change in soil organic carbon content, pH, and nutrient content. This is most likely because of land-use history and soil management.

The eastern part has SOC percentages below 0.8%, which is low. Only the northern section of this part has very low SOC levels. On average, the SOC level is around 0.7%. To increase this percentage to 1.2% for the 20cm topsoil layer 13.13 metric tons of carbon is required, which equals an estimated 22.4 metric tons (dry weight) of organic matter. See the earlier remarks made in connection with SOC management for the IITA Ibadan research farm that in practice larger amounts will be needed to achieve the desired effect.

The other western part has an average SOC level of 0.85% and requires an increase of 0.35% to reach the threshold of 1.2%. About 9.1 metric tons of carbon is needed to reach that level for the 0-20 cm of soil, equivalent to around 15 to 16 tonnes of biomass or organic resource.

Such amounts can only be achieved by using external inputs. And, it needs to be done gradually, aiming first to increase the SOC level in the top 0-10 cm of the soil. At the same time, measures need to be taken to prevent a decline in SOC levels, and this needs to be done through the use of crop residues and a crop rotation system with a crop that produces a lot of biomass and that has a favorable root-to-shoot ratio.

Soil nutrient management

The eastern part of the farm, except the strip of land to the far east, is classified as strongly acidic, with half of it can be classified as very strongly acid. The same pattern is observed for the subsoil. It is advisable to correct for the low pH because it will affect nutrient availability, especially phosphorus. The level to which the pH needs to be increased depends on the crop. For example, maize is relatively tolerant and requires a minimum pH of 5.5 but would preferably be a little higher especially when grain production is concerned. The amount of agricultural lime needed to increase the pH depends on the type of soil and the CEC. It is also determined by the depth to which the pH needs to be raised. For this section of the farm and considering the soil type, a total amount between 0.5 to 1 t/ha of lime would be needed to raise the pH by 0.5 to 1 unit. This should be applied once and checked every three years to determine the additional amount needed to maintain the pH level at the desired level.

In relation to the low pH and low CEC, exchangeable K, Ca, and Mg is rated as low to extremely low for this part of the research farm. To correct the K limitations, about 100 kg of K would be required. It would not make sense to apply this at once given the limited capacity of the soil to hold cations. Instead, this should be done gradually every year, applying more K than required for crop production. With regards to magnesium, about 300 kg would be needed to address the Mg limitation. A similar application protocol as in the case of K would have to be followed, and this should be done gradually. The Ca deficit can be alleviated by applying agricultural lime. This might also be true for Mg, depending on the source of the agricultural lime.

In the eastern part of the farm, the available P is low to very low, but less severe than the western part of the terrain, where P_{avail} is even less than 5 ppm. About 52 kg/ha might be required to address P limitations, which is equivalent to 120 kg P_2O_5/ha. For the western section, this should be 65 kg P/ha (150 P_2O_5 kg/ha). An application of that amount of soil-P should be done gradually. With each crop grown, additional P should be applied on top of the amount demanded for crop growth.

The manganese levels are deficient, and it thus follows that zinc and boron levels would also be expected to be relatively low. Application of these micronutrients is recommended. Zinc can be applied at a rate of 3 kg/ha maybe once every three years (soil concentration levels should be evaluated every three years to determine possible additional application). Boron should be applied at a maximum application rate of 1 kg/ha, because of possible toxic effects, and likewise be evaluated after three years whether additional application is required. Manganese, even though classified as deficient according to the classification system we are using, is likely not to be an actual problem on the type of soil we find in Ikenne.

For the western part of the terrain/farm, the soils are less acidic, and no correction of soil pH is required. The CEC is extremely low for this section as well, even though it is not as extreme as the eastern section. We determined the soil fertility to be very poor. This stresses the importance of rectifying the soil organic carbon levels. Other than applying manure, compost, or other organic resources, the use of biochar could be considered if such is more available or could be made available.

Notwithstanding the very low available potassium levels, the exchangeable Ca and exchangeable Mg levels are not of direct concern. K limitations need to be addressed and what has been said above concerning the eastern section of the farmland applies to this section.

The available P levels in this section are extremely low. It has already been stated that 65 kg P/ha would be needed to address this limitation. Comments about the management of the micronutrient for the eastern section apply to this section as well.

Water balance and soil physical structure

The soil's physical characteristics, considering the more favorable soil texture class and the absence of gravel make these soils favorable for crop production. Though the soils are still quite sandy, but the higher clay content makes the soil hydrological properties more favorable, compared to the soils of the Ibadan research farm for example. Drainage conditions are good, but not excessive. The soil also has sufficient capacity to hold (retain) soil moisture and making it available to the plants to reduce the risk of short-term drought effects. The increase of clay content in the subsoil is an important factor in that water will percolate slowly to the deeper soil layers and still be available for plant uptake.

Kano station research farm – Minjibir – Soil Management Plan

Field layout and design

Except for the areas close to the lake with a gentle slope, the fields are flat to almost flat. The plots are rectangular and arranged in a very regular pattern with easy access to each field. A drainage system cuts across the farm from north to south and divides the farm into a western and a larger eastern section. The drainage does not constitute any hindrance.

A strip of land along the lakeshore gets flooded and is not cultivated but could be used to produce biomass.

Erosion control and water conservation

We did not observe any clear signs of erosion. No measure to control erosion are therefore recommended. Ploughing and ridging across the direction of the slope would be adequate.

There are two wells/boreholes on the farm and an artificial lake nearby. There is enough water for irrigation purposes and no need for any specific measures to harvest and conserve water.

The land is very open or bare and possibly exposed to some wind erosion. The land/soil can be very dry and hot. The use of wind barriers or living fences and maintaining soil cover could be considered to create a better micro-environment with multiple benefits to soil quality, especially soil biological quality.

Soil tillage and land preparation

The soils are light texture soils with very little structural development. The tilling of the soil using a disk plough or mouldboard plough would loosen the soil and undo the weak structures that may have developed. It will allow the soil to become quite hot and dry in periods of no rainfall, with a detrimental effect on soil biological activity and other properties.

It would be beneficial to experiment with no or minimum tillage and maintain soil cover to see whether the micro-climatological conditions and soil quality could be improved.

Soil fertility and soil water management

Soil organic matter management

There is a trend of increasing SOC levels closer to the lake. The research farm does not use the strip of land along the lakeshore, but parts are being used by others in a less intensive manner. Nevertheless, all points show extremely low SOC levels. There is one point with SOC percentage of 1.24%, but this is associated with a strip of elephant grass at the southern border of the research fields. It shows that such SOC levels are possible from an ecological point of view.

The average SOC level is 0.31%. Elevating this to 1.1% would require 20.8 metric tons of carbon, the same as about 36 metric tons of organic material. This is a high volume of material needed. Even if the goal was to elevate the SOC percentage of the top 10 cm of the soil profile, it would still require about 18 tonnes. This requires a plan that combines the use of external resources and setting aside land to produce biomass. The strip of land near the lakeshore would be very well suited for that. The farm has access to water that can be used for biomass production. Also, measures need to be taken to reduce decomposition rates of the soil organic material, including a measure to reduce soil temperature, like maintaining a soil cover and keeping the soil moist.

Soil pH and fertility management

Part of the farm is very strongly acidic with a pH below 5.0, and the section to the west is even more acidic. It is advised to correct the pH if it is below 5.0, and this would apply to the northwestern section (the area northwest of the diagonal from the southwestern to the north-eastern corner of the farm). Considering the low CEC levels, about 0.5 to 1 t/ha of agricultural lime would be required to raise the pH with one unit. The exact needed amounts should be determined experimentally.

With respect to the nutrient status of the soil, available phosphorus is very low, apart from a few fields in the northern section of the farm, associated with sampling points MJ15, MJ22, MJ23, and MJ 26. Apart from these fields, it would be advised to raise the P_{avail} to 15 ppm. For the larger part, the P_{avail} level would still be low. This would require 39 kg of P to raise the P_{avail} level for the upper 20cm of the soil profile. And this would be equivalent to approximately 89kg P_2O_5.

Exchangeable K levels are moderate in the fringe areas along the lakeshore, which is not part of the cultivated land. For most of the farmland and mainly in the western part, the K_{exch} is considered low and even very low in parts. It should be corrected while fertilizing the crop using NPK 15-15-15 or any other compound fertilizer with relatively high K_2O content. At the same time, application of Mg would be recommended to address the limitations in available Mg.

Manganese is critically low for the entire cultivated land. This probably means that Boron and Zinc are also limiting, which we have observed in many soils in Nigeria derived from the basement rock complex. These micronutrients deficiencies can be addressed with a one-time application and needs to be evaluated every three years. Care must be taken not to apply too much boron as this can easily reach toxic levels.

The CEC is extremely low, except for the narrow strip of land near the lakeshore. This limits soil fertility and affects the productivity of the soil. As mentioned before, this can only be addressed by increasing the soil organic matter content of the soil, and it stresses the importance proper soil organic matter management on this type of soil and under these conditions. It also clarifies that taking individual measures (following up recommendations individually) will be counterproductive and that the recommended measures should be considered as a package.

Soil water management

We determined the soils to have an undesirable textural class with a sand percentage above 70% and a clay percentage below 20% for all the points. With most points having a clay percentage even below 15%, the hydrologic properties will be poor. The top and subsoil have the same textural characteristics, and the clay content does not increase with depth. The soils are very well-drained and have limited moisture retention capacity. This means that a crop is dependent on rainfall or irrigation for its direct water supply, and limited water is available for uptake by the plant from the 'reserve' moisture in the soil. There is no available sustainable solution to address the poor water retention capacity of the soil. Deep ploughing, in this case, does not help. Increasing the SOM will improve the hydrological properties, but not in a substantial way. The only option is to improve the recycling of the irrigation water, thereby increasing the frequency of application to enhance the irrigation efficiency. Applying drip irrigation or other systems through which more effective use is made of the water supplied should be considered.

The analysis of the water samples shows that the three sources of water at Minjibir station are neither contaminated nor polluted (Ayers and Westcot, 1994). Contrary to oral reports, the artificial lake is not polluted with heavy metals, and it is safe for irrigation of the research fields. The results indicate that sample 3 from the second well on Minjibir farm does not meet quality standards for irrigation because of the low pH according to FAO report[1]. Water of this nature are however common and widely used in Nigeria for irrigation.

[1] http://www.fao.org/3/T0234E/T0234E01.htm#ch1.4

References

Anon., SWC 211 - Soil Water Conservation Engineering, http://eagri.org/eagri50/AENG151/lec09.pdf; accessed 27 July 2021.

Ayers RS, Westcot DW. 1994 Water quality for agriculture. Food and Agriculture Organization of the United Nations; 1994.

E-Krishi Shiksha, Soil & Water Conservation Engineering, Lesson 6. Bunding methods and water erosion control, http://ecoursesonline.iasri.res.in/mod/page/view.php?id=2101, accessed 26 July 2021.

UNCCD, Soil bunds with contour cultivation. WOCAT database, https://knowledge.unccd.int/best-practice/soil-bund-contour-cultivation, accessed 27 July 2021.

Jason Bergtold and Marty Sailus (eds), 2020, Conservation tillage systems in the southeast production, profitability, and stewardship, SARE handbook series 15, Sustainable Agriculture Research and Education (SARE) program, USDA.

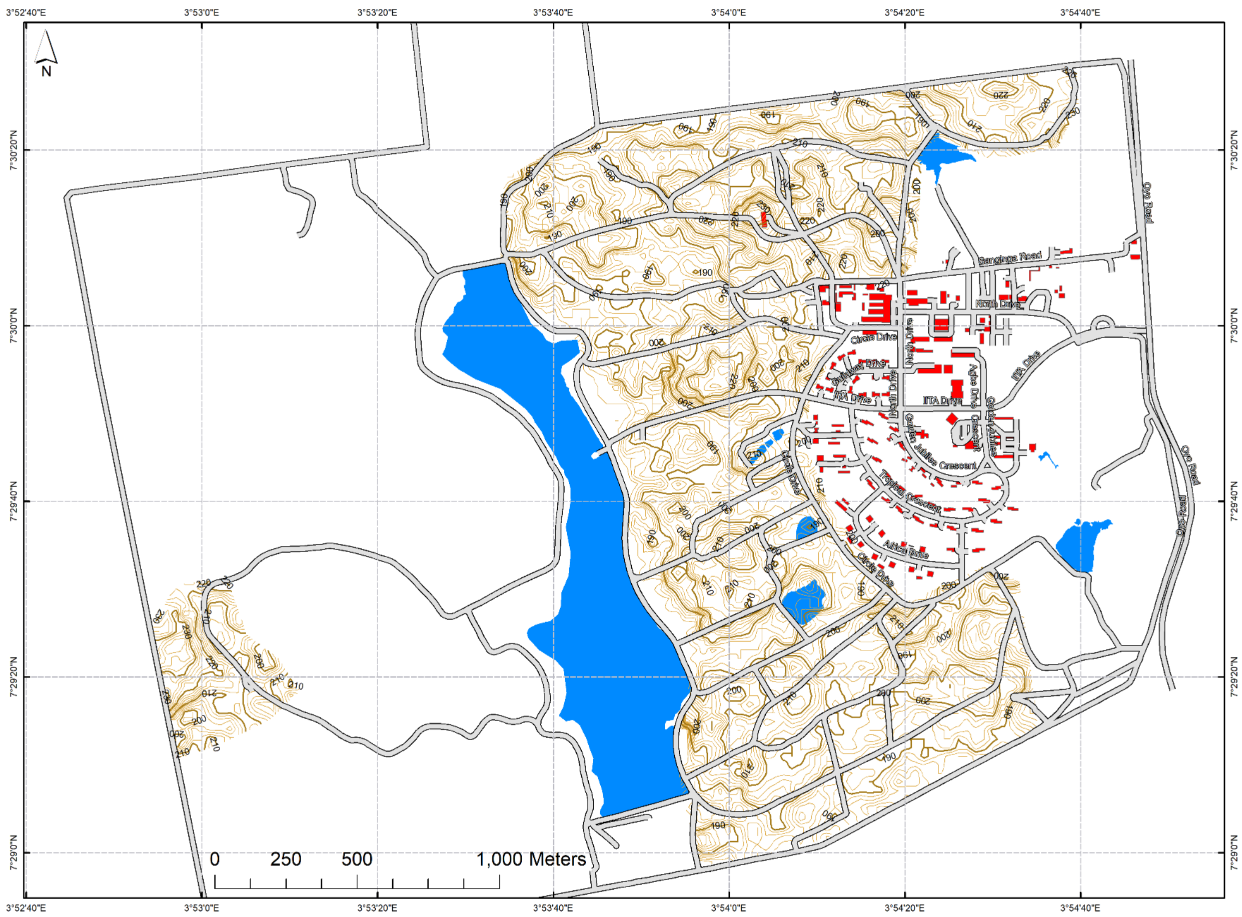
Rianne Prinsen, 2017, The Eco-plough, a better alternative to conventional ploughing, MSc thesis, Wageningen University, and Research

How cultivation affects soil. New South Wales Government, Dept. of primary industries, https://www.dpi.nsw.gov.au/agriculture/soils/structure/cultivation; accessed 26 July 2021

Jensen, T.L., 2010. “Soil pH and the Availability of Plant Nutrients,” IPNI Plant Nutrition TODAY, No. 2, https://nutrientstewardship.org/implementation/soil-ph-and-the-availability-of-plant-nutrients/; accessed 28 July 2021.

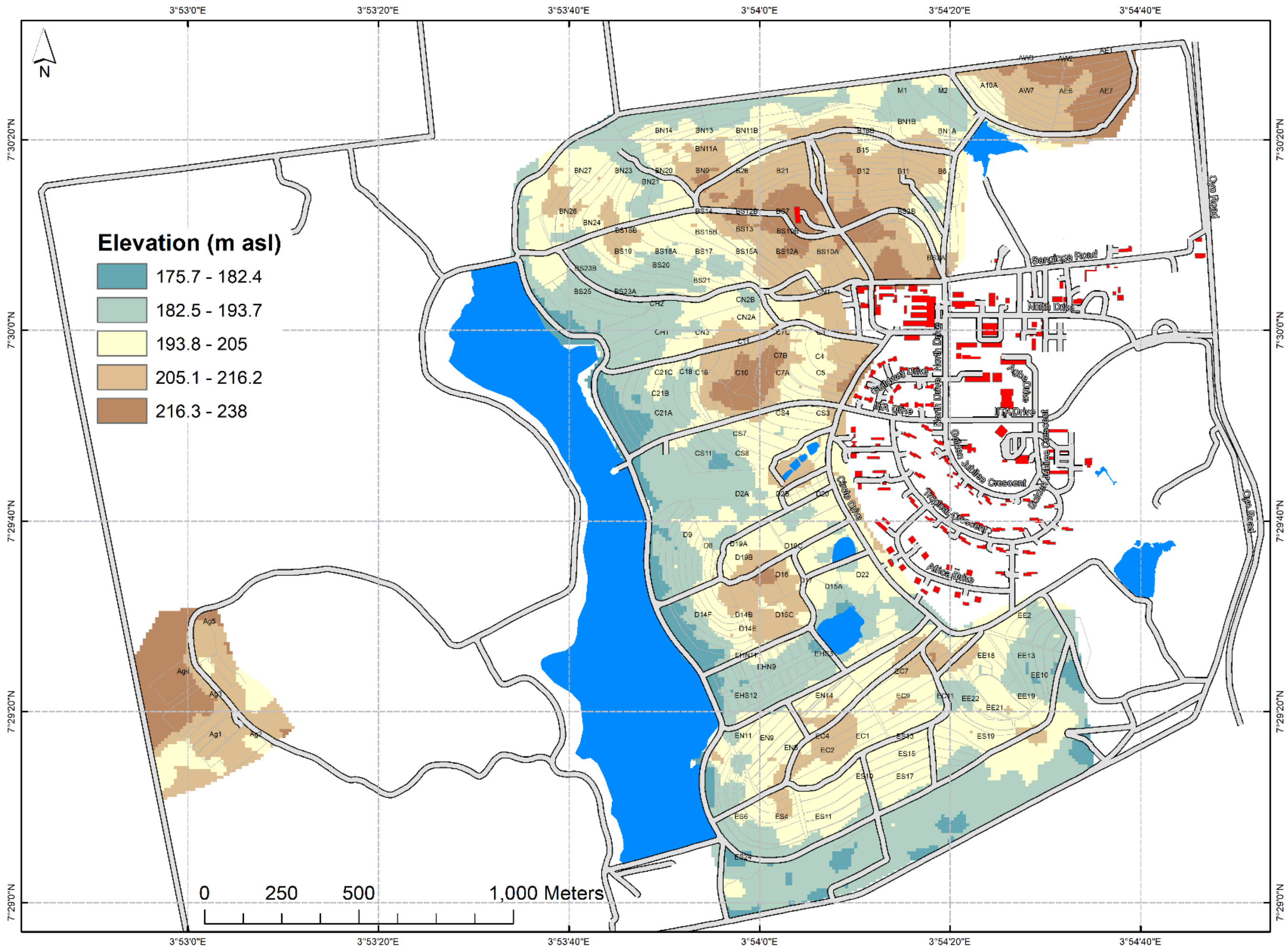
Dept. of Soil and Water Conservation Engineering, SWC211-Soil and water conservations engineering, Lecture notes, Tamil Nadu Agricultural university, http://eagri.org/eagri50/AENG151/lec09.pdf, accessed 26 July 2021.

Appendix 1. Contour Map for the Ibadan research farm



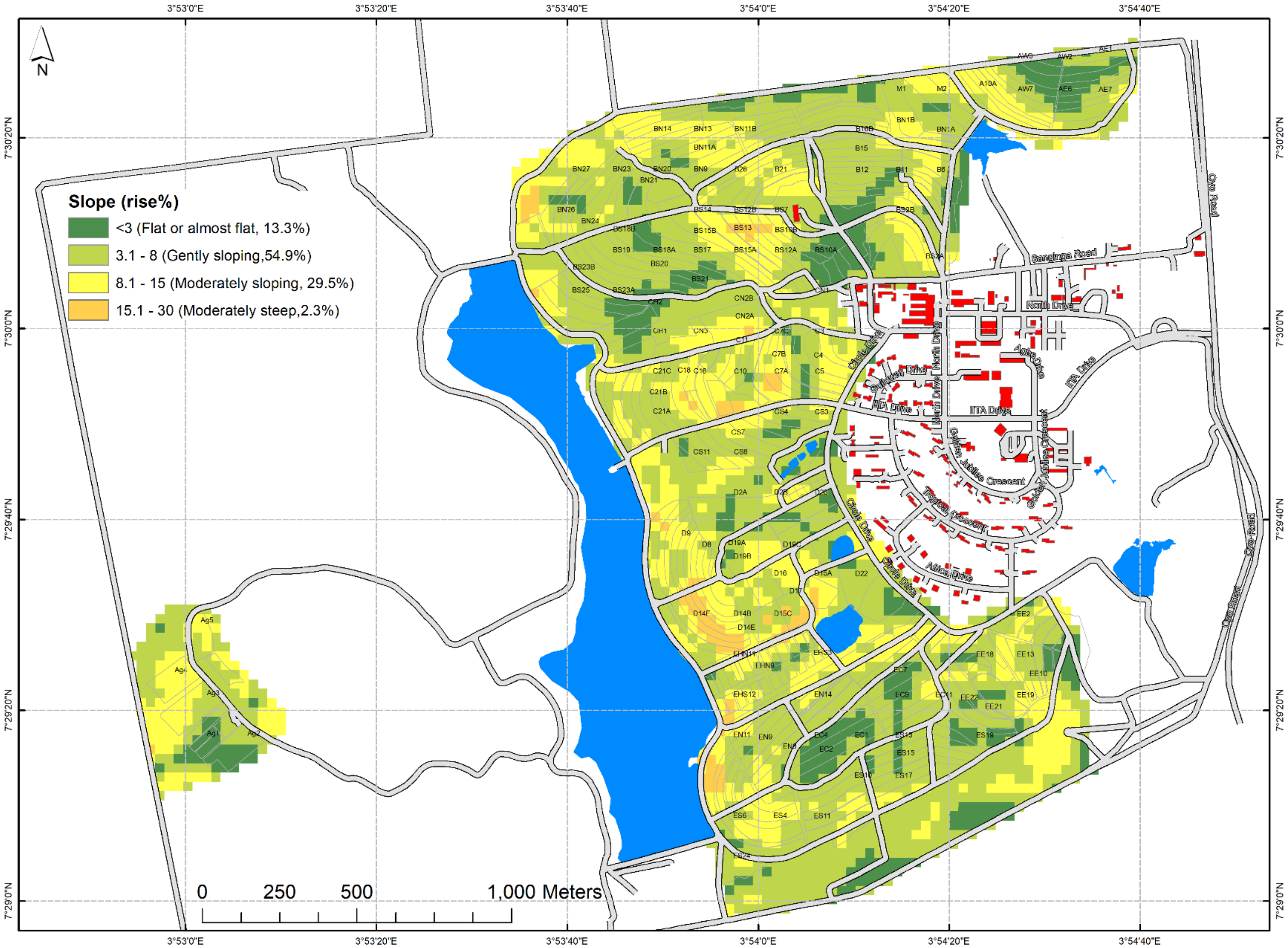
Source: Jarvis A., H.I. Reuter, A. Nelson, E. Guevara, 2008, Hole-filled seamless SRTM data V4, International Centre for Tropical Agriculture (CIAT), available from http://srtm.csi.cgiar.org. https://bigdata.cgiar.org/srtm-90m-digital-elevation-database/

Appendix 2. Elevation Map for the Ibadan research farm



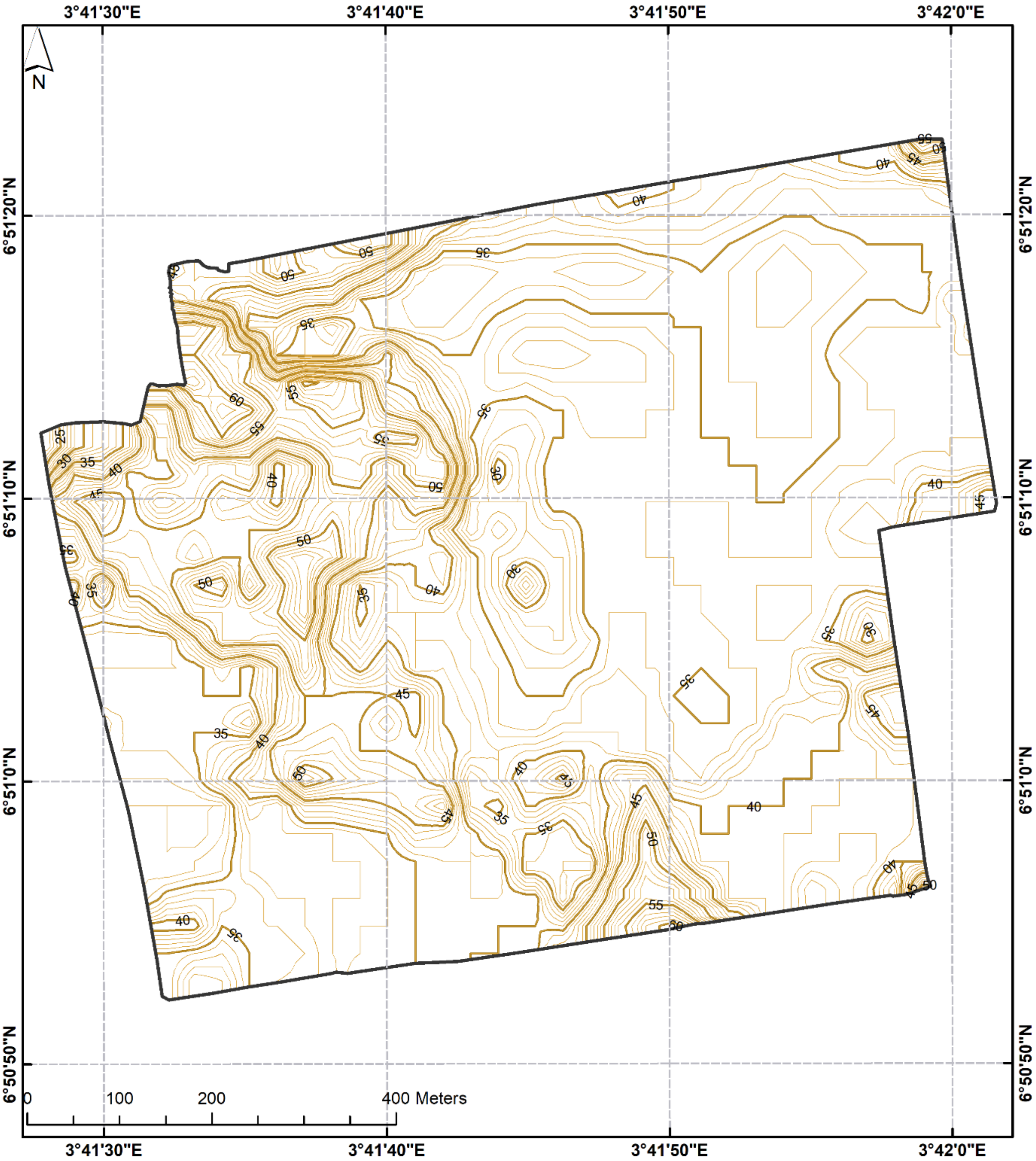
Source: Jarvis A., H.I. Reuter, A. Nelson, E. Guevara, 2008, Hole-filled seamless SRTM data V4, International Centre for Tropical Agriculture (CIAT), available from http://srtm.csi.cgiar.org. https://bigdata.cgiar.org/srtm-90m-digital-elevation-database/

Appendix 3. Slope Map for the Ibadan research farm

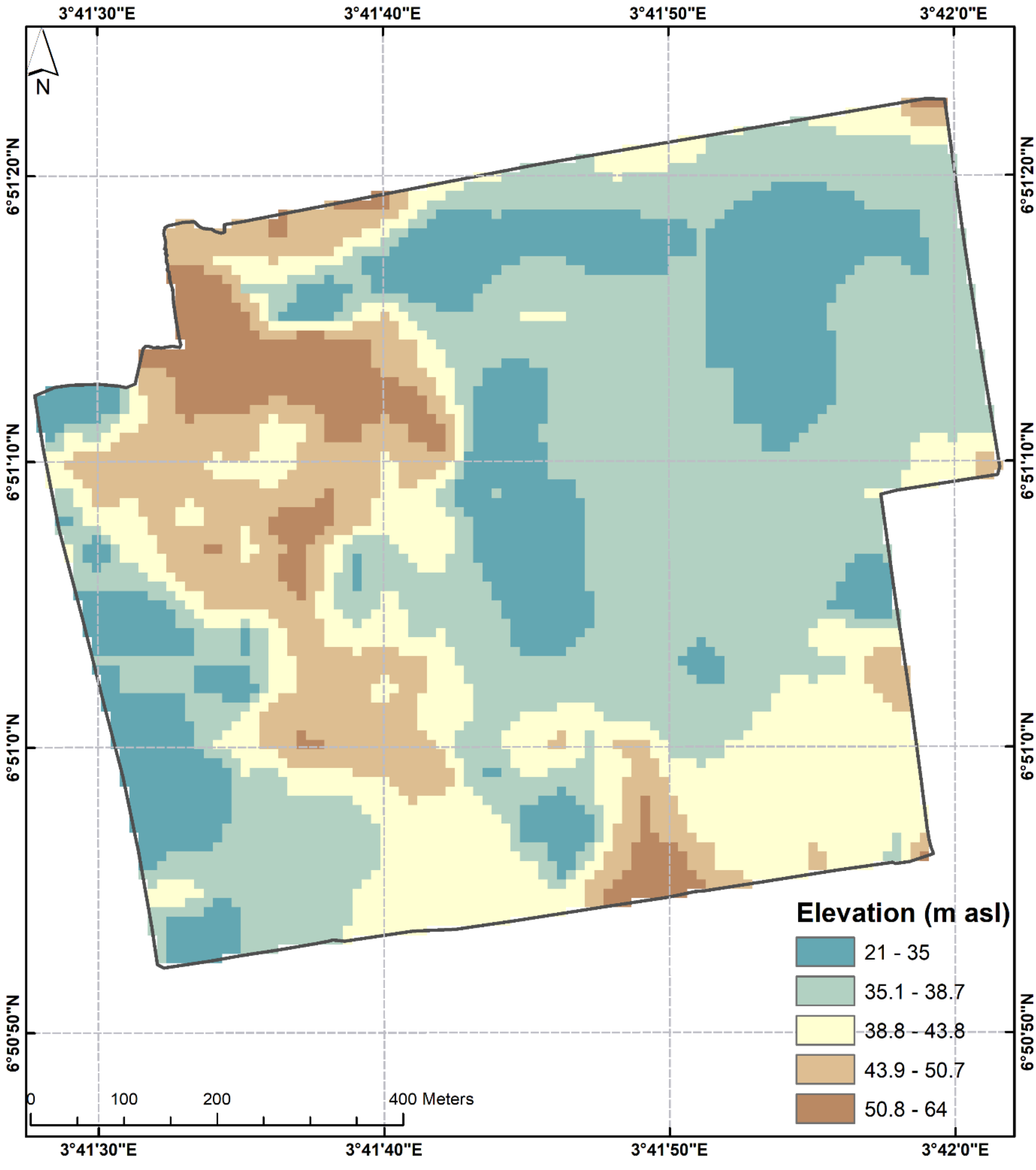


Source: Jarvis A., H.I. Reuter, A. Nelson, E. Guevara, 2008, Hole-filled seamless SRTM data V4, International Centre for Tropical Agriculture (CIAT), available from http://srtm.csi.cgiar.org. https://bigdata.cgiar.org/srtm-90m-digital-elevation-database/

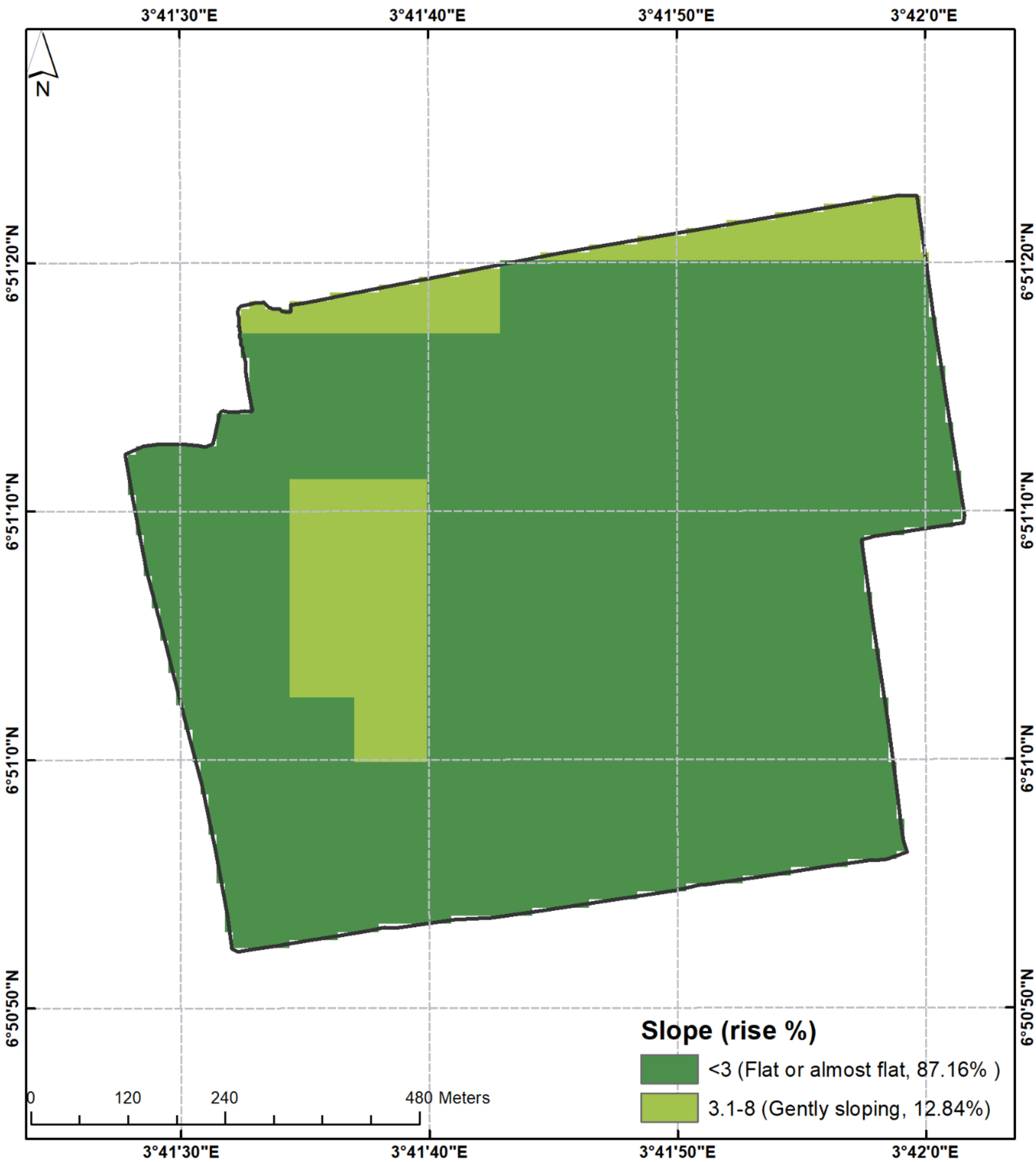
Appendix 4. Contour Map for the Ikenne research farm



Appendix 5. Elevation Map for the Ikenne research farm

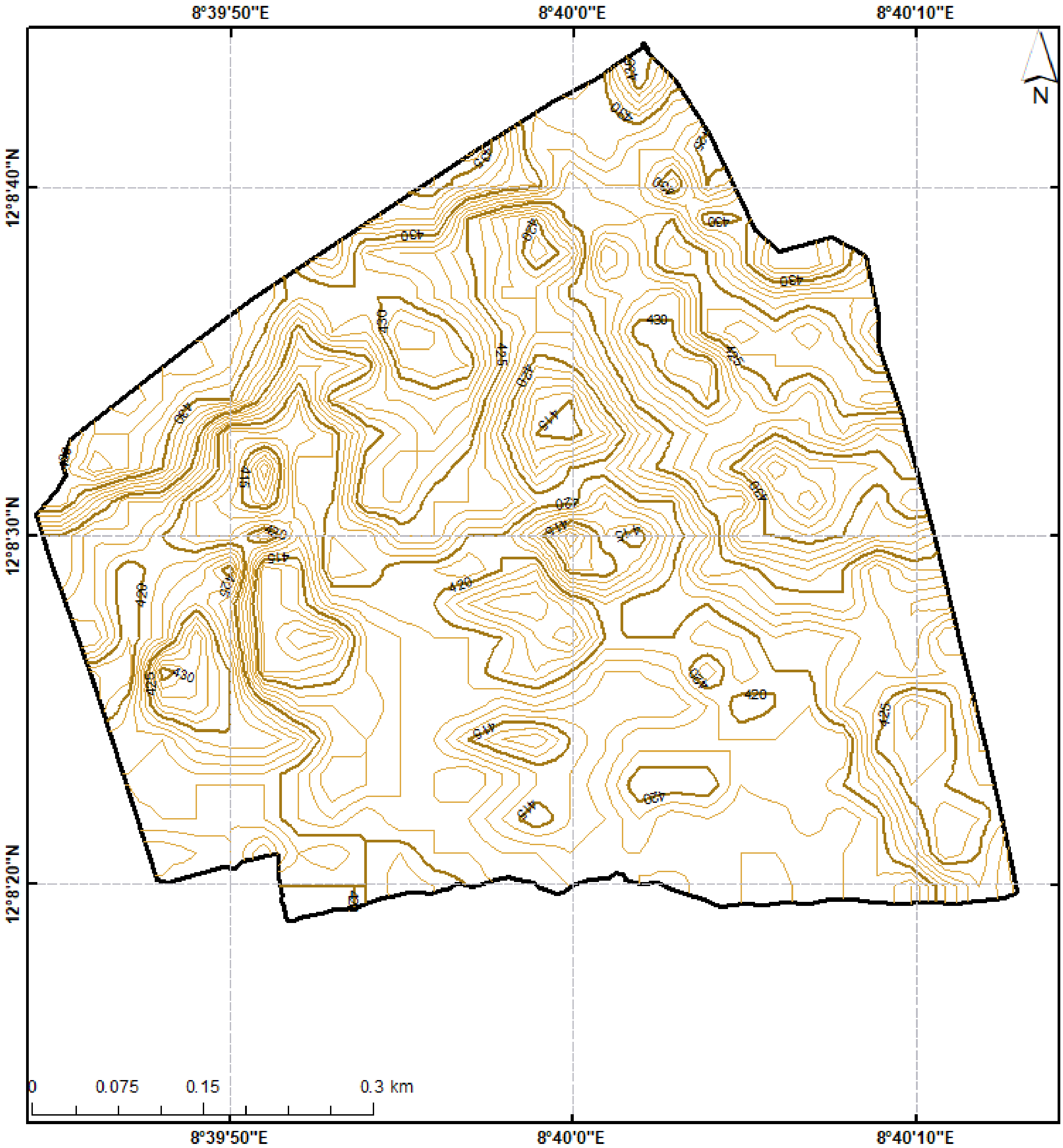


Appendix 6. Slope Map for the Ikenne research farm

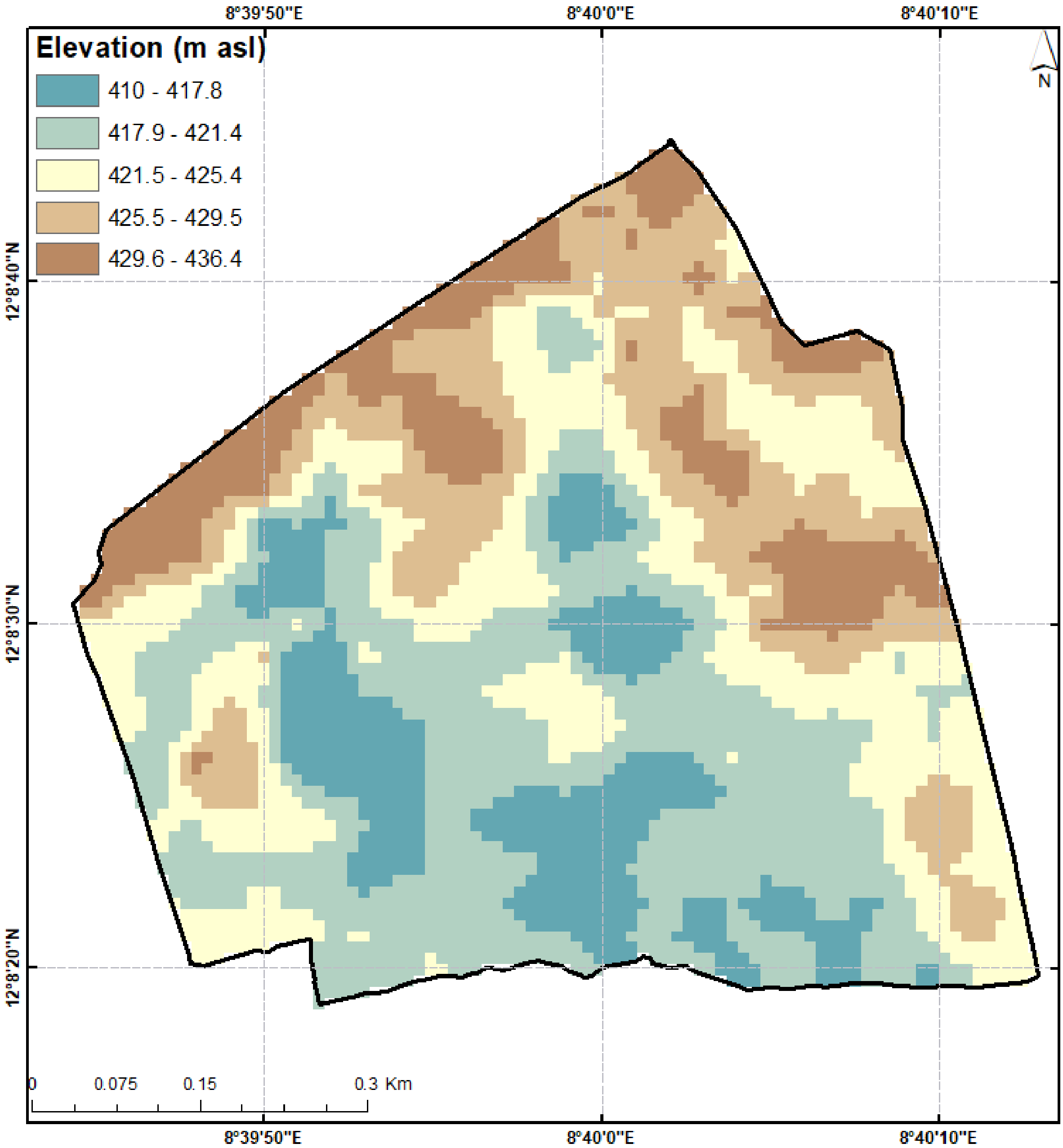


Source: Jarvis A., H.I. Reuter, A. Nelson, E. Guevara, 2008, Hole-filled seamless SRTM data V4, International Centre for Tropical Agriculture (CIAT), available from http://srtm.csi.cgiar.org. https://bigdata.cgiar.org/srtm-90m-digital-elevation-database/

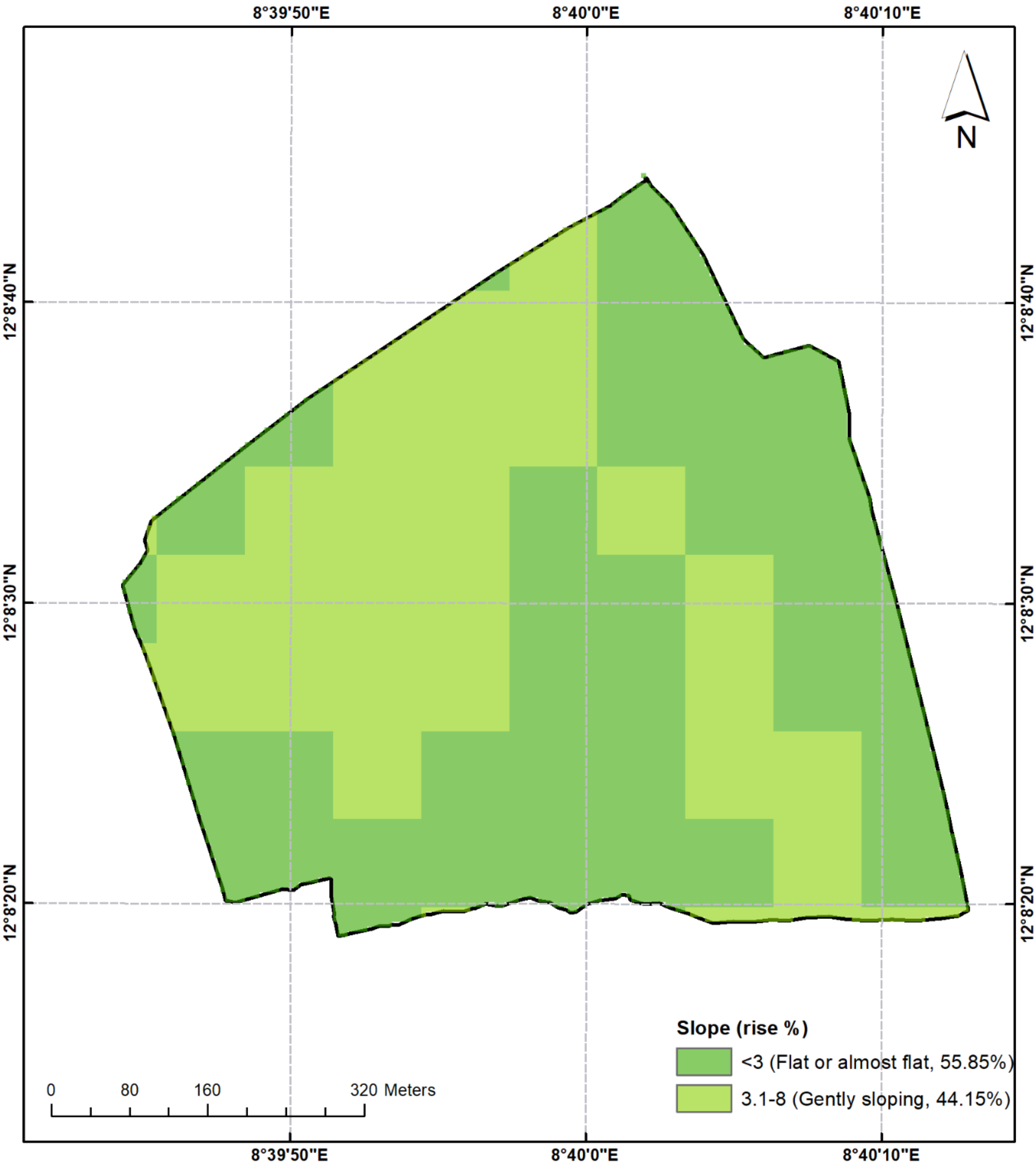
Appendix 7. Contour Map for the Minjibir Kano research farm



Appendix 8. Elevation Map for the Minjibir Kano research farm



Appendix 9. Elevation Map for the Minjibir Kano research farm



Source: Jarvis A., H.I. Reuter, A. Nelson, E. Guevara, 2008, Hole-filled seamless SRTM data V4, International Centre for Tropical Agriculture (CIAT), available from http://srtm.csi.cgiar.org. https://bigdata.cgiar.org/srtm-90m-digital-elevation-database/

Appendix 10. Some field observation data at Ibadan research fields

Sample ID	*Lat*	*Long*	*SN*	*Topographic position*	*Drainage*	*Soil depth (cm)*	*Topsoil Colour*	*Subsoil Colour*	*Remarks*
BS12	*7.5043*	*3.9029*	3	Upland	Well drained	25	10YR4/4 Dark yellowish brown	n/a	Cassava field. Very stony soils
B11	*7.5043*	3.9040	4	Upland	Well drained	25	19YR4/4 dark yellowish brown	n/a	Cassava farm
B6	*7.5045*	3.9054	7	Midslope	Well drained	30	10YR4/4 dark yellowish Brown	10YR 4/4 dark yellowish	Cassava field
B15	*7.5050*	3.9028	8	Midslope	Well drained	25	10YR4/4 dark yellowish brown	n/a	Maize field
B16B	*7.5055*	3.9026	9	Midslope	Well drained	20	10YR4/4 dark yellowish brown	n/a	Cassava field
BN20	*7.5044*	3.8969	12	Midslope	Well drained	20	10YR4/4 Dark yellowish brown	n/a	Fallow field
B21	*7.5040*	3.9003	20	Upland	Well drained	35	10YR3/4 dark yellowish brown	5YR4/3 reddish brown	Point falls on BIP building Samples taken on the lawn in front of the building
BS7	*7.5032*	3.9004	21	Upland	Well drained	30	10YR4/4 dark yellowish brown	7.5YR3/4 dark Brown	Fallow field
BS12A	*7.5019*	3.9002	23	Midslope	Well drained	40	10YR 4/4 dark yellowish Brown	10YR4/4 dark yellowish brown	Fallow field
BS10A	*7.5021*	3.9016	24	Midslope	Well drained	30	10YR3/4 dark yellowish brown	10YR4/4 dark yellowish brown	Fallow field
BS13	*7.5027*	3.8994	26	Midslope	Well drained	30	10YR4/4 dark yellowish brown	10YR 4/3 Brown	Fallow field
BS15A	*7.5020*	3.8994	27	Midslope	Well drained	45	10YR3/6 dark yellowish brown	10YR4/4 dark yellowish brown	Fallow field
BS17	*7.5019*	3.8981	28	Midslope	Well drained	35	10YR4/4 dark yellowish brown	10YR3/4 dark yellowish brown	Fallow field
BS14	*7.5031*	3.8982	31	Midslope	Well drained	30	10YR4/4 dark yellowish brown	10YR3/4 dark yellowish brown	Fallow field

BS19	*7.5021*	3.8961	33	Midslope	Well drained	20	10YR4/4 dark yellowish brown	n/a	Fallow field
C21A	*7.4972*	3.8971	43	Midslope	Well drained	40	10YR4/4 Dark yellowish brown	10YR4/4 dark yellowish brown	Fallow field
CN3	*7.4996*	3.8981	48	Midslope	Well drained	20	10YR3/6 dark yellowish brown	n/a	Fallow field
C3	*7.4994*	3.9017	54	Upland	Well drained	20	10YR3/6 dark yellowish brown	n/a	Fallow field
CS3	*7.4972*	3.9016	60	Midslope	Well drained	35	10YR4/4 dark yellowish brown	10YR3/6 dark yellowish brown	Fallow field
CS7	*7.4966*	3.8992	61	Midslope	Well drained	30	10YR4/4 dark yellowish brown	10YR4/4 dark yellowish brown	Maize field
CS11	*7.4961*	3.8981	63	Midslope	Well drained	35	10YR4/4 dark yellowish brown	10YR4/3 Brown	Cassava field
C5	*7.4985*	3.9016	66	Upland	Well drained	20	10YR4 /4 Dark yellowish brown	n/a	Fallow field
D19C	*7.4937*	3.9004	69	Upland	Well drained	30	10YR4/4 dark yellowish brown	10YR4/4 dark yellowish brown	Fallow field
D9	*7.4937*	3.8978	72	Midslope	Well drained	20	10YR4/4 dark yellowish brown	n/a	Fallow field
D14E	*7.4909*	3.8994	74	Midslope	Well drained	20	10YR4/4 Dark yellowish brown	n/a	Fallow field
D15A	*7.4926*	3.9016	79	Midslope	Well drained	40	10YR3/6 dark yellowish brown	10YR4/4 dark yellowish brown	Ploughed and harrowed field
D22	*7.4925*	3.9035	80	Midslope	Well drained	55	10YR3/4 Dark yellowish brown	10YR4/4 dark yellowish Brown	Fallow field
EE18	*7.4902*	3.9064	81	Upland	Well drained	40	10YR3/6 Dark yellowish brown	7.5YR3/4 dark brown	Fallow field with clay subsoil
ES19	*7.4878*	3.9063	86	Midslope	Well drained	50	10YR3/6 dark yellowish brown	10YR4/4 dark yellowish brown	Maize field
EE2	*7.4913*	3.9075	87	Footslope	Well drained	40	10YR4/4 Dark yellowish brown	10YR4/6 dark yellowish brown	Cassava field
EC7	*7.4896*	3.9037	89	Upland	Well drained	20	10YR3/6 dark yellowish brown	n/a	Fallow field

ES13	*7.4878*	3.9039	91	Midslope	Well drained	35	10YR4/4 dark yellowish brown	10YR3/6 dark yellowish brown	Maize field
ES15	*7.4873*	3.9040	92	Midslope	Well drained	25	10YR4/4 dark yellowish brown	n/a	Cassava field
EN9	*7.4878*	3.9002	99	Midslope	Well drained	20	10YR3/6 dark yellowish brown	n/a	Fallow field
ES11	*7.4855*	3.9016	101	Midslope	Well drained	20	10YR3/6 dark yellowish brown	n/a	Cassava field
Ag2	*7.4879*	3.8851	111	Midslope	Well drained	40	10YR3/4 dark yellowish brown	10YR3/6 dark yellowish brown	Recently prepared for planting. Yet to be planted
Ag1	*7.4878*	3.8838	112	Midslope	Well drained	40	10YR4/4 dark yellowish brown	19Y3/6 dark yellowish brown	Cassava field
Ag3	*7.4891*	3.8839	113	Midslope	Well drained	50	10YR4/4 dark yellowish brown	10YR3/6 dark yellowish brown	Cassava field
Ag5	*7.4913*	3.8838	114	Midslope	Well drained	25	10YR4/6 dark yellowish brown	n/a	Fallow field
Ag4	*7.4898*	3.8831	115	Upland	Well drained	30	10YR4/6 dark yellowish brown	10YR4/4 dark yellowish brown	Fallow field
A10A	*7.5068*	3.9064	118	Midslope	Well drained	20	10YR4/4 dark yellowish brown	n/a	Freshly prepared for planting
AW3	*7.5076*	3.9075	120	Upland	Well drained	35	10YR4/4 dark yellowish brown	10YR3/6 dark yellowish brown	Partly fallow partly cassava field
AW2	*7.5075*	3.9086	121	Upland	Well drained	20	10YR4/4 dark yellowish brown	n/a	Fallow field
AE7	*7.5067*	3.9099	123	Midslope	Well drained	35	10YR4/4 dark yellowish brown	10YR3/6 dark yellowish brown	Maize field being prepared foe planting
AE1	*7.5077*	3.9099	124	Midslope	Well drained	30	10YR4/4 dark yellowish brown	10YR3/6 dark yellowish brown	Fallow field

Appendix 11. Some field observation data at Ikenne research fields

Sample ID	*Lat*	*Long*	*Drainage level*	*Soil depth(cm)*	*SOIL2/topsoilColour*	*SOIL2/SubsoilColour*	*remarks*
IK1	*6.8485*	*3.6934*	Well drained	100	10YR2/2 very dark brown	5YR3/4 dark reddish brown	Cassava field
IK2	*6.8497*	3.6949	Well drained	120	19YR2/2 very dark brown	2.5YR3/6 dark red	Fallow field
IK3	*6.8497*	3.6965	Well drained	120	7.5YR3/4 dark brown	2.5YR3/6 dark red	Fallow field previously cultivated with cassava
IK4	*6.8496*	3.6981	Well drained	120	7.5YR3/4 dark brown	7.5YR4/6 strong brown	Fallow field previously cultivated with maize
IK5	*6.8512*	3.6925	Well drained	100	7.5YR3/4 dark	5YR4/6 yellowish red	Fallow field
IK6	*6.8509*	3.6933	Well drained	100	10YR2/2 very dark brown	5YR3/4 dark reddish brown	Fallow field
IK7	*6.8508*	3.6960	Well drained	100	10YR2/2 very dark brown	5YR4/6 yellowish red	Cassava field
IK8	*6.8521*	3.6918	Well drained	100	10YR2/2 very dark brown	7.5YR4/6 strong brown	Fallow field
IK9	*6.8523*	3.6930	Well drained	100	7.5YR3/4 dark brown	5YR3/4 dark reddish brown	Fallow field
IK10	*6.8520*	3.6950	Well drained	120	7.5YR3/4 dark brown	2.5YR4/3 reddish brown	Fallow field previously cultivated with maize
IK11	*6.8523*	3.6970	Well drained	100	7.5YR3/4 dark brown	2.5YR3/4 dark reddish brown	Maize field
IK12	*6.8520*	3.6981	Well drained	120	5YR3/3 dark reddish brown	5YR4/6 yellowish red	Fallow field
IK13	*6.8533*	3.6934	Well drained	100	7.5YR3/4 dark brown	5YR3/4 Dark reddish brown	Fallow field
IK14	*6.8533*	3.6949	Well drained	100	10YR2/2 very dark brown	5YR3/4 dark reddish brown	Fallow field
IK15	*6.8533*	3.6965	Well drained	100	7.5YR3/4 dark brown	2.5YR3/6 dark red	Maize field

IK16	*6.8532*	3.6976	Well drained	120	7.5YR3/4 dark brown	7.5YR4/6 strong brown	Fallow field previously cultivated with maize
IK17	*6.8533*	3.6995	Well drained	100	7.5YR3/4 dark brown	2.5YR3/6 dark red	Cassava field
IK18	*6.8545*	3.6934	Well drained	100	7.5YR3/4 dark brown	2.5YR3/4 dark reddish brown	Fallow field
IK19	*6.8545*	3.6951	Well drained	100	7.5YR3/4 dark brown	5YR3/4 dark reddish brown	Fallow field previously planted with cowpea
IK20	*6.8545*	3.6984	Well drained	100	7.5YR3/4 dark brown	2.5YR3/6 dark red	Fallow field previously cultivated with maize
IK21	*6.8545*	3.6997	Well drained	120	7.5YR3/4 dark brown	2.5YR3/6 dark red	Fallow field previously cultivated with cassava
IK22	*6.8557*	3.6996	Well drained	100	5YR3/3 dark reddish brown	5YR4/6 yellowish red	Fallow field previously cultivated with cassava
IK23	*6.8512*	3.6991	Well drained	100	7.5YR3/4 dark brown	2.5YR4/6 red	Cassava field
IK24	*6.8488*	3.6964	Well drained	100	10YR3/4 dark yellowish brown	5YR3/4 dark reddish brown	Being harrowed for plant
IK25	*6.8497*	3.6972	Well drained	120	7.5YR3/4 dark brown	5YR4/6 yellowish red	Cassava field
IK26	*6.8554*	3.6966	Well drained	100	7.5YR3/4 dark brown	5YR3/4 dark reddish brown	Fallow field
IK27	*6.8490*	3.6942	Well drained	120	7.5YR3/4 dark brown	2.5YR3/6 dark red	Cassava field
IK28	*6.8549*	3.6934	Well drained	100	7.5YR3/4 dark brown	2.5YR4/6 red	Fallow field
IK29	*6.8508*	3.6930	Well drained	100	10YR2/2 very dark brown	5YR3/4 dark reddish brown	Cassava field
IK30	*6.8489*	3.6939	Well drained	100	7.5YR3/6 dark brown	2.5YR 3/4 dark reddish brown	Cassava field
IK31	*6.8488*	3.6961	Well drained	100	7.5YR3/4 dark brown	5YR3/4 dark reddish brown	Being prepared for planting
IK32	*6.8497*	3.6985	Well drained	120	7.5YR3/4 dark brown	2.5YR3/6 dark red	Fallow field previously cultivated with maize
IK33	*6.8533*	3.6990	Well drained	100	7.5YR3/4 dark brown	2.5YR3/6 dark red	Fallow field
IK34	*6.8545*	3.6980	Well drained	100	7.5YR3/4 dark brown	5YR4/6 yellowish red	Fallow field previously cultivated with maize
IK35	*6.8533*	3.6970	Well drained	100	7.5YR3/4 dark brown	2.5YR3/6 dark reddish	Maize field

IK36	*6.8520*	3.6945	Well drained	100	7.5YR3/4 dark brown	2.5YR3/6 dark red	Fallow field

Appendix 12. Some field observation data at Minjibir research fields, Kano

Sample ID	*Lat*	*Long*	*SOIL1/Drainage_class*	*Soil depth (cm)*	*Topsoil colour*	*Subsoil colour*	*Remarks*
MJ7	*12.1392*	*8.6686*	Moderately drained	120	10YR5/3 brown	10YR6/3 pale brown	close to the dam. mottles present within the 0-20cm
MJ6	*12.1395*	8.6685	Moderately drained	120	10YR5/4 yellowish brown	7.5YR5/4 brown	nice strong brown subsoil about 15% clay. Plow field previously planted with cowpea
MJ8	*12.1391*	8.6697	Moderately drained	n/a	10YR5/2 grayish brown	10YR5/3 brown	Mottles present at topsoil becomes sandy around 60 to 70 cm and hard to auger and yellowish brown at deeper depth. land not in use
MJ13	*12.1405*	8.6664	Well drained	120	7.5YR5/4 brown	7.5YR4/6 strong brown	Cowpea field. No mottles even at lowet depth. deeper soils: sandy loam and firmer
MJ12	*12.1407*	8.6652	Well drained	120	10YR4/3 Brown	10YR5/3 brown	Soil becomes very loose. Land previously planted with cowpea. Deeper subsoil is brown and becomes sandier. colour variation @80cm.
MJ2	*12.1396*	8.6652	Moderately drained	120	10YR4/3 brown	10YR5/3 brown	Sandy subsoil. Previously cultivated with cowpea
MJ3	*12.1393*	8.6652	Poorly drained	120	10YR3/2 very dark grayish brown	10YR4/2 dark grayish brown	A horizon about 10 to 12 cm, Nice very dark grayish brown and sandy loam. Deeper soils are brown. Land not in use
MJ22	*12.1435*	8.6652	Well drained	120	5YR4/4 reddish brown	5YR4/6 yellowish red	Harvested cowpea field. No mottles at subsoil
MJ23	*12.1434*	8.6653	Well drained	120	5YR4/4 reddish brown	5YR4/6 yellowish red	Harvested cowpea field Deeper subsoil:2.5YR2/6 red and loam clay %23

MJ17	*12.1421*	8.6652	Well drained	120	7.5YR4/4 brown	5YR4/6 red	Previously cultivated with cowpea. Deeper soils: 2.5YR4/6 red
MJ21	*12.1420*	8.6687	Well drained	120	7.5YR4/4 brown	5YR5/4 reddish brown	harvested cowpea field. Red sub subsoil loamy sand
MJ25	*12.1435*	8.6686	Well drained	120	7.5YR5/4 brown	7.5YR4/4 brown	harvested cowpea field. Deeper soils: 5YR4/6 yellowish red more clay about 16%
MJ26	*12.1431*	8.6688	Well drained	120	10YR4/4 dark yellowish brown	7.5YR4/4 brown	harvested cowpea field. Presence of gravels on soil surface. Deeper soils become sandier. No colour variation until 100cm where it becomes yellowish red. no mottles
MJ24	*12.1435*	8.6675	Well drained	120	7.5YR4/4 brown	7.5YR4/4 brown	Very fine sand. harvested cowpea field. Deeper soils :2.5YR4/6 yellowish red and fine sand
MJ19	*12.1420*	8.6675	Well drained	120	7.5YR5/3 brown	7.5YR4/4 brown	Harvested cowpea field. At 80cm the soils become 2.5YR4/8 red with very fine sand
MJ20	*12.1419*	8.6675	Well drained	120	7.5YR5/3 brown	5YR5/4 reddish brown	harvested cowpea field. Deeper subsoil : 2.5YR4/8 red
MJ14	*12.1406*	8.6686	Well drained	120	7.5YR4/4 brown	7.5YR4/6 Strong brown	Harvested cowpea field. more clay about 18% in deep subsoil 2.5YR4/8 red
MJ10	*12.1410*	8.6630	Well drained	120	7.5YR5/3 brown	10YR4/3 brown	harvested cowpea field. No colour variation. very fine ÅŸans at deeper soils
MJ9	*12.1408*	8.6629	Well drained	120	7.5YR5/3 Brown	7.5YR5/3 Brown	harvested cowpea field. No colour and texture variations
MJ15	*12.1418*	8.6641	Well drained	120	7.5YR5/4 brown	5YR4/6 yellowish red	maize cowpea field
MJ16	*12.1421*	8.6640	Well drained	120	7.5YR5/4 brown	5YR4/4 reddish brown	Notill plot. maize cowpea field. Presently on fallow. Deeper subsoil 5YR4/6 yellowish red
MJ11	*12.1406*	8.6640	Well drained	120	10YR4/4 dark yellowish brown	10YR4/4 dark yellowish brown	Harvested cowpea field. Deeper subsoil 7.5YR4/6 strong brown. No textural variation

MJ1	*12.1393*	8.6640	Well drained	120	10YR4/4 Dark yellowish brown	10YR4/4 dark yellowish brown	Fallow land. Deeper subsoil: 10R5/6 Yellowish brown. the soil is firm and very sandy
MJ4	*12.1391*	8.6663	Well drained	120	10YR5/3 Brown	10YR5/3 Brown	Mottles present at topsoil. Ground water at 100cm deeper soils 10YR6/2 light brownish gray.
MJ5	*12.1393*	8.6674	Poorly drained	120	10YR4/3 brown	10YR5/3 brown	Land not in use. Deeper subsoil: 10YR5/6 Yellowish brown. Sandy loam and firm. Mottles present at topsoil layer
MJ18	*12.1422*	8.6663	Well drained	120	7.5YR4/4 brown	5YR4/4 reddish brown	Harvested cowpea field. Deeper subsoil -loamy sand 2.5YR4/6 red

Appendix 13. Results of the soil analysis of Ibadan Research fields (topsoil) colour-coded according to the sufficiency level of each of the soil property

Red	Very low
Yellow	Low
Green	Adequate/optimum
Blue	High

Sample ID		Sand %	Silt %	Clay %	Textural class	pH (H20)	OC (%)	N	Meh_P ppm	Ca cmol/kg	Mg cmol/kg	K cmol/kg	Na cmol/kg	ECEC cmol/kg	Mn ppm	Fe ppm
Ag5	TOP	48	15	36	Sandy clay	6.1	0.78	0.06	1.15	2.18	0.7	0.22	0.19	3.28	59.98	368.88
Ag4	TOP	50	15	34	Sandy clay loam	5.9	0.86	0.064	0.17	2.04	0.7	0.32	0.2	3.26	53.42	374.78
AW7	TOP	56	15	28	Sandy clay loam	5.9	1.03	0.105	0.59	3.69	1.22	0.25	0.21	5.37	115.93	226.6
AW2	TOP	58	13	28	Sandy clay loam	5.9	0.95	0.101	0.73	3.83	1.22	0.21	0.23	5.49	124.24	207.59
CS4	Top	62	13	24	Sandy loam	6	0.9	0.092	0.68	3.47	1.24	0.49	0.07	5.26	110.58	91.24
D16	Top	62	11	26	Sandy loam	6.4	0.66	0.056	9.79	3.67	1.12	0.2	0.17	5.17	109.37	84.98
AE7	TOP	62	15	22	Sandy loam	6.4	1.2	0.11	12.16	3.45	1.21	0.58	0.17	5.41	93.2	81.7
AW3	TOP	62	13	24	Sandy clay loam	5.5	1.35	0.135	0.73	2.67	0.68	0.36	0.2	3.91	50.8	365.6
EHS12	Top	62	10	28	Sandy clay loam	6.2	0.97	0.058	2.43	2.17	0.7	0.38	0.07	3.32	98.97	96.47
B21	Top	63	13	24	Sandy loam	6.5	1.17	0.106	36.44	5.14	1.28	0.62	0.05	7.09	214.76	111.5

ES4	TOP	63	14	23	Sandy clay loam	6.1	1.14	0.097	0.17	2.31	1.07	0.43	0.08	3.9	101.07	100.72
EE2	Top	64	11	24	Sandy clay loam	6.8	1.48	0.168	18.85	6.26	1.11	0.26	0.07	7.7	133.85	94.82
ES19	Top	64	13	22	Sandy clay loam	6.5	2.13	0.297	25.68	8.38	1.37	0.38	0.09	10.22	110.25	77.12
BN1B	Top	65	13	22	Sandy loam	7.2	1.33	0.09	114.78	6.9	1.28	0.82	0.07	9.08	123.79	95.81
EHN9	TOP	65	14	21	Sandy loam	6.5	0.98	0.105	0.59	3.63	0.98	0.55	0.17	5.34	101.94	136.78
C16	Top	66	15	18	Sandy loam	5.9	0.87	0.067	5.26	2.42	0.72	0.44	0.07	3.66	154.61	99.73
EE21	Top	66	13	20	Sandy loam	7	1.1	0.112	163.37	5.44	0.99	0.65	0.08	7.16	111.56	157.76
EE22	Top	66	11	22	Sandy loam	7	1.07	0.121	159.19	5.52	1.01	0.68	0.1	7.31	115.49	167.59
B26	Top	67	15	18	Sandy loam	6.3	0.83	0.075	4.32	2.52	1.01	0.41	0.06	3.99	281.21	117.38
C21A	Top	68	13	18	Sandy loam	5.8	0.6	0.044	2.03	1.44	0.53	0.32	0.06	2.34	139	80.78
CH2	Top	68	13	18	Sandy loam	5.7	0.68	0.072	1.89	1.57	0.69	0.59	0.05	2.91	111.38	83.4
CS3	Top	68	13	18	Sandy loam	5.6	0.56	0.054	2.7	1.22	0.47	0.26	0.07	2.01	138.6	76.86
CS7	Top	68	13	18	Sandy loam	6.1	1.02	0.096	0.68	3.17	1.17	0.5	0.08	4.92	109.38	99.73
D19B	Top	68	9	22	Sandy loam	6.4	1.06	0.09	8.81	3.51	0.87	0.34	0.21	4.93	105.44	94.82
Ag1	TOP	68	11	20	Sandy loam	7.2	0.96	0.09	12.02	3.94	1.32	0.42	0.15	5.83	101.51	102.03
Ag2	TOP	68	13	18	Sandy loam	7.2	0.92	0.07	14.25	3.77	1.28	0.41	0.14	5.6	115.93	126.94
EC11	TOP	68	13	18	Sandy loam	6.2	0.94	0.062	0.87	2.49	1.05	0.14	0.28	3.97	50.36	410.84
BN20	Top	69	13	18	Sandy loam	6.6	0.59	0.096	19.42	3.35	1.12	0.77	0.06	5.3	188.64	89.93
EC9	TOP	69	20	11	Sandy loam	6.9	1.05	0.075	72.78	3.59	1.19	0.4	0.16	5.34	128.61	193.82
BS18B	Top	70	12	18	Sandy loam	5.5	0.79	0.059	8.9	1.52	0.54	0.44	0.06	2.55	173.43	121.95

BS19	Top	70	12	18	Sandy loam	6.2	0.98	0.082	6.34	2.58	0.84	0.47	0.04	3.93	170.22	133.71
BS20	Top	70	12	18	Sandy loam	5.8	0.74	0.057	2.83	2.24	0.73	0.29	0.14	3.41	137	93.85
C10	Top	70	13	16	Sandy loam	5.9	0.65	0.059	2.97	1.85	0.53	0.33	0.04	2.75	156.21	103
C21B	Top	70	11	18	Sandy loam	5.8	0.61	0.043	3.1	1.44	0.51	0.31	0.06	2.31	146.61	81.44
CN1	Top	70	11	18	Sandy loam	5.8	1.16	0.11	4.45	2.95	1	0.67	0.06	4.68	123.39	14.79
CS8	Top	70	11	18	Sandy loam	5.6	1.03	0.119	5.4	2.84	0.95	0.34	0.05	4.17	69.35	97.77
D20	Top	70	11	18	Sandy loam	5.7	0.5	0.04	1.22	1.3	0.42	0.24	0.06	2.02	97.77	78.82
EE19	Top	70	11	18	Sandy loam	6.3	0.97	0.072	93.69	3.51	0.67	0.29	0.09	4.55	115.06	143.99
AE6	TOP	70	17	12	Sandy loam	7.1	1.03	0.101	28.74	4.34	1.08	0.48	0.07	5.97	124.24	86.29
Ag3	TOP	70	11	18	Sandy loam	7	0.85	0.082	39.33	3.16	1.09	0.36	0.17	4.77	100.63	140.06
B12	Top	71	11	18	Sandy loam	7	0.58	0.05	32.51	2.58	0.86	0.27	0.15	3.86	146.21	114.11
B15	Top	71	11	18	Sandy loam	6.7	0.63	0.05	39.13	1.99	0.77	0.26	0.21	3.23	112.98	119.34
B16B	Top	71	11	18	Sandy loam	5.7	0.89	0.074	10.25	1.52	0.68	0.38	0.06	2.63	181.94	104.96
BN13	Top	71	11	18	Sandy loam	5.8	1.85	0.173	16.59	5.06	1.65	0.25	0.07	7.04	114.58	215.39
BN1A	Top	71	13	16	Sandy loam	6.1	0.9	0.053	2.97	2.4	0.85	0.23	0.09	3.57	79.36	131.75
EHS3	TOP	71	12	17	Sandy loam	6.4	0.99	0.079	65.81	3.57	0.94	0.65	0.11	5.27	129.92	170.87
EN11	TOP	71	12	17	Sandy loam	6.9	0.39	0.03	9.79	2.12	0.7	0.33	0.15	3.29	126.86	142.02
ES11	TOP	71	12	17	Sandy loam	7	0.54	0.042	3.1	2.59	0.82	0.35	0.14	3.89	118.99	111.21
ES17	TOP	71	12	17	Sandy loam	6.9	1.05	0.073	47.7	3.24	0.93	0.52	0.08	4.78	115.49	125.63
ES24	TOP	71	14	15	Sandy loam	6.6	0.6	0.05	19.54	4.38	1.4	0.16	0.17	6.11	48.62	158.42
BS7	Top	72	11	16	Sandy loam	6.1	0.78	0.055	1.62	2.09	0.59	0.59	0.05	3.31	171.83	104.31

D14F	Top	72	9	18	Sandy loam	5.6	0.47	0.033	0.95	0.79	0.3	0.18	0.05	1.32	143.81	84.7
EC7	Top	72	9	18	Sandy loam	6	0.63	0.056	1.01	1.47	0.28	0.19	0.1	2.04	111.12	105.96
EE18	Top	72	11	16	Sandy loam	6.3	0.97	0.096	2.12	2.57	0.61	0.31	0.05	3.54	84.02	69.9
EC1	TOP	72	11	16	Sandy loam	6.4	1.04	0.094	1.15	2.83	1.11	0.14	0.3	4.38	63.04	395.76
EC2	TOP	72	9	18	Sandy loam	6.4	0.62	0.049	27.21	2.12	0.63	0.28	0.17	3.2	111.12	133.5
EC4	TOP	72	11	16	Sandy loam	6.9	0.71	0.057	50.48	3.16	1.04	0.33	0.17	4.7	102.82	125.63
B11	Top	73	11	16	Sandy loam	7.1	0.36	0.034	17.4	2.11	0.76	0.31	0.14	3.31	141.4	89.28
B6	Top	73	9	18	Sandy loam	6.3	0.79	0.061	8.36	1.59	0.71	0.5	0.04	2.85	214.76	86.01
BN11 A	Top	73	9	18	Sandy loam	6.3	0.93	0.09	10.25	2.11	0.76	0.47	0.04	3.37	203.55	86.67
BN11B	Top	73	11	16	Sandy loam	6.4	1.35	0.126	9.44	3.43	1.11	0.22	0.07	4.84	129.4	186.64
BN14	Top	73	9	18	Sandy loam	6.3	0.61	0.058	0.54	2.34	0.85	0.2	0.07	3.46	113.38	159.85
CN3	Top	73	10	16	Sandy loam	6.9	0.59	0.052	21.04	3.03	0.9	0.35	0.12	4.4	138.2	85.36
EN14	TOP	73	10	17	Sandy loam	7	0.57	0.043	1.42	2.79	0.83	0.32	0.17	4.1	123.8	149.89
ES10	TOP	73	10	17	Sandy loam	7.3	0.48	0.041	120.17	3.91	0.81	0.39	0.18	5.28	110.25	155.79
ES15	TOP	73	10	17	Sandy loam	7.2	0.87	0.078	24.56	3.55	1.07	0.43	0.17	5.22	119.43	106.62
BN26	Top	74	10	16	Sandy loam	6.4	1.15	0.101	8.23	3.92	1.23	0.94	0.05	6.15	163.82	99.73
BS15B	Top	74	10	16	Sandy loam	6.1	0.74	0.068	3.24	1.2	0.39	0.33	0.05	1.97	163.02	72.29
BS21	Top	74	10	16	Sandy loam	6.6	0.4	0.028	0.95	1.44	0.42	0.35	0.04	2.25	137.8	75.56
BS23B	Top	74	10	16	Sandy loam	6.4	0.67	0.053	2.56	2.34	0.5	0.26	0.05	3.16	161.82	76.86
C18	Top	74	9	16	Sandy loam	5.5	0.84	0.073	3.51	2.13	0.67	0.31	0.07	3.18	142.6	94.51
CH1	Top	74	11	14	Sandy loam	5.9	0.52	0.05	17.4	1.04	0.42	0.45	0.06	1.97	138.6	100.39

CS11	Top	74	9	16	Sandy loam	5.6	0.44	0.042	2.03	0.35	0.21	0.15	0.04	0.75	135.8	72.29
D14B	Top	74	7	18	Sandy loam	5.5	0.53	0.04	3.24	1.16	0.35	0.29	0.19	1.99	108.58	80.13
D15A	Top	74	9	16	Sandy loam	5.5	0.48	0.036	1.22	0.77	0.3	0.19	0.06	1.31	123.39	70.98
D2B	Top	74	9	16	Sandy loam	5.5	0.82	0.063	3.38	1.12	0.26	0.14	0.04	1.56	119.43	112.52
EE13	Top	74	7	18	Sandy loam	6.1	1.09	0.085	1.56	3.49	0.81	0.36	0.07	4.73	99.76	86.95
BN23	Top	75	9	16	Sandy loam	6.3	0.76	0.068	11.06	1.91	0.6	0.44	0.04	2.99	229.17	99.08
ES13	TOP	75	8	17	Sandy loam	7	0.57	0.051	9.23	2.98	0.89	0.39	0.15	4.42	120.74	93.51
ES6	TOP	75	10	15	Sandy loam	6.8	0.55	0.047	39.33	4.44	1.41	0.14	0.08	6.07	58.67	256.11
BS25	Top	76	8	16	Sandy loam	6.5	0.71	0.064	1.35	2.52	0.52	0.39	0.04	3.47	161.02	73.6
BS2B	Top	76	8	16	Sandy loam	6.1	0.61	0.052	0.68	1.36	0.4	0.38	0.04	2.17	168.62	112.8
C7C	Top	76	11	12	Sandy loam	5.6	0.44	0.038	15.92	0.84	0.35	0.44	0.11	1.75	137	99.08
CN2A	Top	76	7	16	Sandy loam	6.1	0.75	0.068	18.34	1.5	0.54	0.62	0.06	2.71	141	87.97
CN2B	Top	76	11	12	Sandy loam	6	0.52	0.035	22.53	1.4	0.32	0.25	0.04	2.01	122.59	102.35
D14E	Top	76	7	16	Sandy loam	5.8	0.53	0.04	2.29	1.1	0.31	0.2	0.04	1.66	122.59	73.6
AE10	TOP	76	9	14	Sandy loam	7.2	0.23	0.02	5.19	1.67	0.55	0.26	0.14	2.61	82.27	77.12
D17	Top	77	8	14	Sandy loam	6.3	0.54	0.055	9.93	1.35	0.3	0.2	0.07	1.92	89.7	111.86
D19A	Top	77	8	14	Sandy loam	6.3	0.63	0.062	11.6	1.49	0.37	0.22	0.07	2.14	76.15	108.59
M1	TOP	77	8	15	Sandy loam	5.5	0.88	0.064	4.63	2.61	1.25	0.24	0.17	4.27	22.83	328.23
BN27	Top	78	10	12	Sandy loam	6.5	0.74	0.068	14.84	2.76	0.79	0.31	0.04	3.89	185.94	104.96
BN9	Top	78	8	14	Sandy loam	6	0.3	0.031	6.61	1.32	0.46	0.22	0.1	2.1	219.56	108.88
BS10A	Top	78	8	14	Sandy loam	6.8	0.43	0.04	9.17	1.52	0.63	0.29	0.07	2.51	193.94	148.74

BS10B	Top	78	10	12	Sandy loam	6.6	0.37	0.045	9.04	1.73	0.67	0.32	0.07	2.8	121.39	94.51
BS12A	Top	78	10	12	Sandy loam	6.6	0.53	0.056	21.45	1.83	0.72	0.35	0.1	2.99	167.42	99.73
BS14	Top	78	8	14	Sandy loam	7.2	0.47	0.037	28.34	2.3	0.69	0.33	0.12	3.44	155.01	104.31
BS17	Top	78	12	10	Sandy loam	7.1	0.56	0.041	39.13	1.95	0.68	0.3	0.12	3.04	126.59	117.38
BS23A	Top	78	8	14	Sandy loam	6.4	0.67	0.043	2.16	1.85	0.47	0.34	0.04	2.69	136.6	77.52
BS2A	Top	78	8	14	Sandy loam	6.6	1.09	0.24	4.05	3.01	1.24	0.5	0.05	4.8	162.22	93.2
C21C	Top	78	9	12	Sandy loam	5.7	0.45	0.032	31.04	1.2	0.32	0.19	0.04	1.75	103.38	105.62
C3	Top	78	9	12	Sandy loam	6.3	0.37	0.035	16.86	1.81	0.44	0.17	0.04	2.46	85.36	78.82
C4	Top	78	9	12	Sandy loam	6.2	0.46	0.042	16.73	1.89	0.42	0.2	0.05	2.56	81.36	74.9
C5	Top	78	9	12	Sandy loam	5.5	0.43	0.034	7.82	0.47	0.23	0.19	0.07	0.97	145.01	96.47
C7A	Top	78	9	12	Sandy loam	5.5	0.53	0.035	10.79	0.51	0.24	0.18	0.07	1	131.4	93.85
D15C	Top	78	7	14	Sandy loam	5.8	0.28	0.027	11.6	1.1	0.38	0.25	0.07	1.81	133.8	73.6
D19C	Top	78	9	12	Sandy loam	6.2	0.61	0.049	7.28	1.63	0.44	0.27	0.1	2.43	81.4	70.56
D2A	Top	78	7	14	Sandy loam	5.7	0.76	0.058	3.24	1.06	0.24	0.15	0.05	1.5	119.86	116.45
D8	Top	78	9	12	Sandy loam	6.5	0.33	0.025	0.87	0.98	0.17	0.13	0.05	1.33	73.09	78.43
D9	Top	78	9	12	Sandy loam	6.3	0.48	0.035	3.38	1.23	0.2	0.14	0.05	1.62	75.28	79.08
EE10	Top	78	7	14	Sandy loam	5.5	0.67	0.051	8.67	0.78	0.2	0.16	0.05	1.2	83.58	90.23
AE1	TOP	78	9	12	Sandy loam	7.4	0.41	0.028	16.48	1.8	0.56	0.22	0.13	2.72	74.4	88.92
BN21	Top	79	7	14	Sandy loam	5.6	0.53	0.052	6.07	0.33	0.22	0.19	0.04	0.78	21.72	172.92
M2	TOP	79	6	15	Sandy loam	5.6	1.24	0.125	4.07	2.75	1.33	0.42	0.21	4.71	24.14	342
BS12B	Top	80	10	10	Sandy loam	6.7	0.62	0.083	64.76	2.21	0.84	0.36	0.12	3.52	168.22	96.47

BS13	Top	80	8	12	Sandy loam	7	0.37	0.032	23.33	2.13	0.6	0.32	0.11	3.16	161.82	106.27
D22	Top	80	7	12	Sandy loam	6.5	0.74	0.07	12.57	1.69	0.41	0.31	0.1	2.51	106.75	108.59
BS15A	Top	82	8	10	Loamy sand	6.9	0.42	0.031	36.44	1.38	0.46	0.29	0.11	2.23	123.39	110.84
BS18A	Top	82	8	10	Loamy sand	6.4	0.47	0.042	32.39	1.46	0.29	0.23	0.05	2.02	114.18	102.35
BN24	Top	84	6	10	Sandy loam	5.6	0.71	0.049	7.15	0.51	0.25	0.15	0.06	0.97	21.32	189.91

Appendix 14. Results of the soil analysis of Ibadan Research fields (Subsoil) colour-coded according to the sufficiency level of each of the soil property

Sample ID	Soil	Sand%	Silt%	Clay%	Textural class	pH (H20)	OC%	N %	Meh_P ppm	Ca cmol/kg	Mg cmol/kg	K cmol/kg	Na cmol/kg	ECEC cmol/kg	Mn ppm	Fe ppm
B21	Sub	70	12	18	Sandy loam	6.4	0.78	0.072	17	2.64	0.81	0.31	0.14	3.89	189.14	76.21
BN23	Sub	66	12	22	Sandy clay loam	6.6	0.9	0.089	11.6	3.05	0.96	0.45	0.13	4.6	241.98	81.44
B6	Sub	72	12	16	Sandy loam	6.6	0.56	0.051	23.6	2.36	0.75	0.37	0.11	3.6	197.15	91.89
BN1A	Sub	64	14	22	Sandy clay loam	6.1	1.34	0.125	48.57	3.94	1.12	0.61	0.08	5.75	225.97	104.31
BN1B	Sub	80	4	16	Sandy loam	6.5	0.46	0.038	2.29	1.57	0.44	0.38	0.04	2.43	266	78.17
BN26	Sub	80	4	16	Sandy loam	6.7	0.82	0.06	3.91	1.61	0.47	0.36	0.04	2.48	188.34	85.36
BN27	Sub	78	10	12	Sandy loam	6.5	0.69	0.064	7.96	2.21	0.75	0.32	0.06	3.34	153.81	91.89
BS10A	Sub	70	12	18	Sandy loam	6.2	0.73	0.08	5.26	1.63	0.52	0.47	0.05	2.68	284.41	114.11
BS12A	Sub	74	8	18	Sandy loam	6.1	0.77	0.091	3.37	1.69	0.47	0.4	0.03	2.6	266	112.8
BS13	Sub	60	16	24	Sandy clay loam	6.3	1.27	0.114	13.76	4.32	1.11	0.59	0.06	6.07	299.62	101.04
BS14	Sub	84	4	12	Loamy sand	6	0.48	0.033	59.36	0.77	0.19	0.22	0.11	1.28	150.21	142.21
BS15B	Sub	80	8	12	Sandy loam	6.3	0.47	0.03	45.88	1.2	0.28	0.24	0.12	1.83	111.38	104.31
BS15A	Sub	70	12	18	Sandy loam	6.2	0.94	0.076	4.32	2.07	0.62	0.5	0.1	3.28	138.6	78.17
BS17	Sub	72	10	18	Sandy loam	5.5	1.03	0.066	4.05	1.3	0.42	0.2	0.05	1.97	135.4	72.29
BS12B	Sub	66	12	22	Sandy clay loam	5.8	1.19	0.118	4.86	3.23	0.94	0.41	0.06	4.64	177.03	69.68

BS21	Sub	80	8	12	Sandy loam	6	0.27	0.021	51.27	1.02	0.23	0.21	0.05	1.51	140.6	146.13
BS23B	Sub	80	8	12	Sandy loam	6	0.35	0.031	49.92	1.5	0.34	0.24	0.07	2.14	134.6	143.52
BS23A	Sub	76	8	16	Sandy loam	6.5	0.89	0.064	6.21	2.76	0.96	0.42	0.04	4.18	127.39	108.88
BS2A	Sub	72	12	16	Sandy loam	6.2	1.04	0.095	2.43	2.03	0.6	0.37	0.04	3.04	143.81	101.04
BS7	Sub	70	12	18	Sandy loam	6.1	0.87	0.089	2.56	2.13	0.62	0.4	0.06	3.2	198.64	73.6
C10	Sub	68	14	18	Sandy loam	7	1.58	0.133	53.97	7.27	1.67	0.55	0.15	9.64	157.41	125.22
C11	Sub	68	13	18	Sandy loam	6.1	0.73	0.054	7.96	2.86	0.91	0.39	0.11	4.27	83.76	84.7
C16	Sub	70	13	16	Sandy loam	6.4	0.73	0.066	23.33	2.76	0.9	0.41	0.12	4.19	168.22	106.27
C18	Sub	74	9	16	Sandy loam	6.4	0.47	0.043	9.85	1.85	0.61	0.31	0.1	2.87	131.4	86.01
C21A	Sub	74	9	16	Sandy loam	6.8	0.87	0.05	12.28	2.32	0.79	0.37	0.11	3.59	144.61	67.06
C7B	Sub	76	9	14	Sandy loam	6.3	0.84	0.061	58.02	2.38	0.57	0.42	0.05	3.43	151.41	91.89
CH1	Sub	68	13	18	Sandy loam	6.5	0.97	0.085	25.76	3.43	0.95	0.46	0.05	4.89	111.78	104.31
CH2	Sub	68	13	18	Sandy loam	6.4	1.12	0.106	35.09	4.02	1.08	0.51	0.05	5.67	141.4	138.29
CN2B	Sub	74	9	16	Sandy loam	5.7	0.79	0.073	4.05	1.26	0.48	0.46	0.06	2.26	151.41	103
CS11	Sub	72	11	16	Sandy loam	5.6	0.48	0.036	1.76	0.33	0.2	0.16	0.05	0.74	152.21	89.28
ES19	Sub	74	9	16	Sandy loam	5.7	0.39	0.038	6.75	1.2	0.31	0.27	0.07	1.85	121.79	91.89
CS3	Sub	76	7	16	Sandy loam	5.7	0.43	0.044	7.55	1.24	0.34	0.32	0.07	1.97	131.4	95.81
CS4	Sub	74	9	16	Sandy loam	5.6	1.01	0.065	3.91	1.65	0.44	0.26	0.04	2.4	120.59	92.55
CS7	Sub	74	9	16	Sandy loam	5.6	0.96	0.075	6.88	2.11	0.5	0.37	0.05	3.03	135	99.08
CS8	Sub	78	8	13	Sandy loam	5.5	1.14	0.091	5.13	1.75	0.42	0.36	0.05	2.58	101.38	72.94
D15A	Sub	72	9	18	Sandy loam	5.2	0.69	0.065	3.37	1.16	0.37	0.38	0.05	1.95	125.79	78.17

D15C	Sub	74	9	16	Sandy loam	5.9	0.92	0.081	5.94	1.48	0.47	0.43	0.07	2.45	127.39	80.78
D16	Sub	78	9	12	Sandy loam	5.5	0.87	0.05	4.59	0.53	0.24	0.24	0.04	1.05	93.77	92.55
D19C	Sub	70	11	18	Sandy loam	5.5	1.06	0.072	3.1	1.55	0.53	0.36	0.04	2.48	99.37	107.58
D20	Sub	74	9	16	Sandy loam	5.8	1.13	0.089	7.15	1.75	0.62	0.48	0.05	2.9	102.98	103.65
D22	Sub	78	9	12	Sandy loam	5.2	0.35	0.036	3.78	0.53	0.16	0.15	0.04	0.88	96.97	82.74
D2A	Sub	70	13	16	Sandy loam	5.6	0.88	0.059	3.91	1.42	0.4	0.25	0.04	2.11	74.16	87.97
D2B	Sub	74	9	16	Sandy loam	5.6	0.92	0.074	2.03	1.46	0.45	0.32	0.04	2.27	102.98	85.36
D9	Sub	68	11	20	Sandy loam	5.7	1.18	0.112	4.18	2.64	0.78	0.34	0.06	3.82	106.18	95.81
EC9	SUB	74	7	18	Sandy loam	6.1	0.78	0.072	2.96	1.73	0.32	0.19	0.05	2.28	102.82	83.67
EE10	Sub	66	14	20	Sandy loam	6.8	1.51	0.118	83.64	7.21	1.26	0.67	0.05	9.18	96.97	84.05
EE18	Sub	70	12	18	Sandy loam	5.8	1.04	0.094	4.59	2.09	0.67	0.42	0.04	3.21	100.57	80.13
EE21	Sub	66	12	22	Sandy clay loam	6.1	1.18	0.099	1.76	2.56	0.81	0.4	0.05	3.82	114.58	70.98
EE2	Sub	70	12	18	Sandy loam	5.6	0.94	0.073	6.48	1.73	0.49	0.32	0.05	2.59	123.39	112.15
AE1	SUB	76	12	12	Sandy loam	5.6	0.7	0.06	3.64	1.3	0.4	0.23	0.04	1.96	109.38	120.64
AE7	SUB	74	12	14	Sandy loam	6	0.53	0.04	1.76	1.02	0.36	0.25	0.04	1.68	115.79	124.57
Ag1	SUB	76	10	14	Sandy loam	5.7	0.86	0.054	22.93	1.85	0.58	0.26	0.05	2.74	95.77	112.8
Ag2	SUB	74	12	14	Sandy loam	6.7	0.42	0.038	21.04	1.83	0.63	0.27	0.07	2.8	91.37	103.65
Ag3	SUB	74	12	14	Sandy loam	6.4	0.57	0.057	18.21	2.32	0.77	0.4	0.08	3.57	103.38	105.62
Ag4	SUB	74	12	14	Sandy loam	6	0.94	0.065	22.8	2.44	0.78	0.31	0.06	3.59	106.18	113.46
AW3	SUB	72	12	16	Sandy loam	6	0.51	0.041	12.28	1.65	0.6	0.38	0.09	2.72	126.59	132.41
AW7	SUB	68	12	20	Sandy loam	7.2	1.26	0.098	64.76	7.43	1.78	0.62	0.15	9.98	95.77	117.38

EC11	SUB	64	12	24	Sandy clay loam	7.1	0.69	0.06	63.41	5.91	1.42	0.56	0.11	8	157.01	140.25
EC4	SUB	68	12	20	Sandy loam	7	0.94	0.091	11.74	4.24	1	0.37	0.14	5.75	92.57	100.39
EHN9	SUB	68	12	20	Sandy loam	6.6	1.25	0.102	4.05	3.63	1.04	0.59	0.05	5.31	139	94.51
EHS12	SUB	74	10	16	Sandy loam	6.6	1.17	0.133	3.64	3.47	0.96	0.46	0.04	4.93	109.38	58.57
EHS3	SUB	68	12	20	Sandy loam	6.2	1.09	0.081	2.83	2.24	0.68	0.38	0.04	3.34	157.01	87.97
EN11	SUB	76	10	14	Sandy loam	6.5	0.95	0.074	3.78	1.89	0.62	0.33	0.08	2.91	162.62	92.55
ES11	SUB	72	12	16	Sandy loam	6.2	0.47	0.037	26.44	1.38	0.62	0.34	0.11	2.45	145.81	122.6
ES13	SUB	74	12	14	Sandy loam	6.4	0.82	0.05	31.16	1.52	0.58	0.32	0.05	2.46	142.6	146.13
ES17	SUB	74	12	14	Sandy loam	6.4	0.45	0.043	19.42	1.65	0.63	0.28	0.07	2.64	115.79	106.92
M1	SUB	75	13	12	Sandy loam	7	0.73	0.046	20.5	1.91	0.77	0.36	0.07	3.1	107.38	97.77
M2	SUB	69	13	18	Sandy loam	6	0.37	0.033	13.89	2.21	0.79	0.38	0.14	3.52	148.61	92.55

Appendix 15. Results of the soil analysis of IKenne Research fields colour-coded according to the sufficiency level of each of the soil property

Sample ID	Soil	PARTICLE SIZE			Textural class	pH(H20)	OC	N	Meh P	Ca	Mg	K	Na	ECEC	Mn	Fe
ID	layer	%SAND	%SILT	%CLAY	Textural class	1:2.5	%	%	ppm	----------cmol+/kg----------					ppm	ppm
IK 1	TOP	74	6	19	Sandy loam	6.4	0.70	0.068	0.20	2.28	0.76	0.21	0.08	3.32	65.61	56.92
IK 17	SUB	50	5	45	Sandy clay	5.6	0.56	0.054	0.64	2.22	1.03	0.13	0.10	3.49	42.88	62.82
IK 2	TOP	74	6	19	Sandy loam	6.2	0.71	0.082	1.22	1.23	0.47	0.19	0.09	1.98	52.28	69.37
IK 23	SUB	50	6	43	Sandy clay	4.9	0.52	0.049	0.64	1.88	0.65	0.21	0.07	2.82	77.20	74.62
IK 3	TOP	76	4	19	Sandy loam	5.2	0.87	0.070	3.71	0.69	0.30	0.18	0.08	1.26	47.47	77.90
IK 31	SUB	50	6	43	Sandy clay	5.2	0.52	0.057	1.51	1.82	0.68	0.31	0.09	2.90	36.11	47.08
IK 4	TOP	68	8	23	Sandy loam	4.9	0.87	0.094	12.33	0.89	0.35	0.23	0.10	1.58	68.02	97.57
IK 5	SUB	52	4	43	Sandy clay	5.9	0.48	0.050	0.93	2.34	0.75	0.15	0.11	3.35	54.03	52.98
IK 5	TOP	74	10	15	Sandy loam	5.7	0.76	0.073	0.64	1.92	0.82	0.25	0.16	3.14	76.76	73.96
IK 4	SUB	52	6	41	Sandy clay	5.3	0.49	0.058	0.35	1.78	0.71	0.17	0.09	2.75	57.31	68.06
IK 6	TOP	78	4	17	Sandy loam	6.2	1.22	0.115	5.31	5.21	1.22	0.24	0.15	6.82	61.24	73.31
IK 33	SUB	54	5	41	Sandy clay	4.7	0.51	0.046	1.66	1.43	0.45	0.37	0.08	2.32	73.05	88.39
IK 7	TOP	78	4	17	Sandy loam	5.5	0.66	0.057	18.61	0.18	0.12	0.25	0.09	0.64	30.65	79.86
IK 25	SUB	54	4	41	Sandy clay	4.2	0.52	0.051	1.51	0.71	0.31	0.24	0.07	1.33	71.08	54.29
IK 8	TOP	78	4	17	Sandy loam	5.5	0.79	0.067	0.93	1.52	0.66	0.19	0.07	2.45	62.56	48.39
IK 14	SUB	54	7	39	Sandy clay	6.0	0.48	0.046	1.08	3.21	0.86	0.12	0.10	4.28	59.50	53.64
IK 9	TOP	76	6	17	Sandy loam	5.8	0.66	0.061	0.35	2.02	0.76	0.18	0.08	3.04	68.02	68.06
IK 28	SUB	54	6	39	Sandy clay	5.6	0.70	0.063	0.78	3.58	0.58	0.15	0.07	4.40	90.75	56.26
IK 10	TOP	74	8	17	Sandy loam	6.0	0.91	0.078	2.25	2.97	0.74	0.19	0.08	3.99	71.08	75.27
IK 20	SUB	56	5	39	Sandy clay	4.4	0.50	0.044	1.22	0.95	0.34	0.18	0.11	1.59	70.64	73.31
IK 11	TOP	74	6	19	Sandy loam	4.8	0.58	0.045	6.92	0.44	0.23	0.16	0.09	0.92	35.89	74.62
IK 22	SUB	56	5	39	Sandy clay	5.6	0.52	0.046	1.37	2.14	0.78	0.15	0.08	3.14	45.51	68.72
IK 12	TOP	76	9	15	Sandy loam	5.6	0.88	0.061	18.18	0.87	0.41	0.26	0.09	1.63	40.92	74.62
IK 3	SUB	56	4	39	Sandy clay	5.1	0.53	0.050	1.22	1.33	0.51	0.12	0.07	2.03	24.96	52.98

IK 13	TOP	74	7	19	Sandy loam	5.4	0.80	0.059	3.12	2.28	0.72	0.19	0.08	3.27	60.81	56.26
IK 24	SUB	56	4	39	Sandy clay	5.1	0.56	0.050	1.08	1.84	0.65	0.15	0.09	2.73	46.82	62.82
IK 14	TOP	68	13	19	Sandy loam	5.7	1.16	0.101	3.12	4.02	1.23	0.29	0.12	5.66	64.09	51.01
IK 27	SUB	56	4	39	Sandy clay	5.5	0.58	0.048	0.93	2.14	0.86	0.18	0.17	3.36	56.44	60.19
IK 15	TOP	74	9	17	Sandy loam	4.9	0.72	0.056	95.53	0.55	0.35	0.32	0.12	1.35	59.06	108.06
IK 30	SUB	56	4	39	Sandy clay	5.5	0.49	0.047	1.37	2.02	0.92	0.17	0.09	3.19	60.37	70.68
IK 16	TOP	74	9	17	Sandy loam	4.9	0.61	0.057	31.22	0.42	0.28	0.34	0.08	1.12	53.59	108.06
IK 32	SUB	56	4	39	Sandy clay	4.5	0.48	0.046	0.35	1.60	0.75	0.18	0.09	2.63	75.23	64.13
IK 17	TOP	74	9	17	Sandy loam	5.4	0.86	0.062	1.51	2.42	0.81	0.27	0.08	3.59	79.17	83.80
IK 8	SUB	58	2	39	Sandy clay	5.6	0.51	0.058	0.78	2.04	0.88	0.11	0.11	3.15	66.71	68.06
IK 18	TOP	76	5	19	Sandy loam	5.6	0.82	0.069	4.15	2.36	0.76	0.26	0.07	3.46	95.56	80.52
IK 16	SUB	58	5	37	Sandy clay	4.7	0.60	0.044	1.22	0.67	0.41	0.23	0.11	1.42	83.32	69.37
IK 19	TOP	78	7	15	Sandy loam	5.2	0.59	0.043	15.54	0.59	0.17	0.19	0.10	1.05	57.53	67.41
IK 21	SUB	58	5	37	Sandy clay	5.4	0.50	0.040	1.22	2.12	0.72	0.11	0.11	3.06	46.82	72.00
IK 20	TOP	74	7	19	Sandy loam	4.8	0.70	0.048	13.06	0.59	0.18	0.21	0.09	1.08	56.87	83.14
IK 1	SUB	58	6	35	Sandy clay	6.5	0.45	0.050	0.49	2.22	0.82	0.13	0.07	3.24	60.37	59.54
IK 21	TOP	76	7	17	Sandy loam	5.2	0.58	0.053	0.49	1.68	0.52	0.28	0.08	2.57	55.12	74.62
IK 2	SUB	58	6	35	Sandy clay	6.4	0.52	0.056	1.81	2.14	0.61	0.09	0.07	2.92	57.31	79.21
IK 22	TOP	74	9	17	Sandy loam	5.6	0.62	0.051	1.51	2.32	0.76	0.21	0.09	3.38	57.31	64.78
IK 35	SUB	60	5	35	Sandy clay loam	4.6	0.62	0.044	0.78	1.45	0.53	0.17	0.09	2.24	68.24	71.34
IK 23	TOP	70	10	19	Sandy loam	5.0	0.70	0.055	5.02	0.52	0.28	0.28	0.12	1.19	94.25	97.57
IK 11	SUB	58	8	33	Sandy clay	4.2	0.57	0.056	0.49	0.53	0.26	0.13	0.07	1.00	58.62	64.78
IK 24	TOP	68	12	19	Sandy loam	4.7	0.90	0.072	5.17	1.05	0.43	0.23	0.07	1.79	62.12	83.14
IK 12	SUB	62	5	33	Sandy clay loam	4.7	0.54	0.045	0.20	0.73	0.45	0.17	0.08	1.44	71.73	59.54
IK 25	TOP	78	4	17	Sandy loam	4.9	0.71	0.060	10.87	0.53	0.18	0.29	0.08	1.09	38.73	80.52
IK 13	SUB	62	5	33	Sandy clay loam	5.8	0.52	0.041	0.93	2.08	0.81	0.10	0.07	3.06	52.06	56.26
IK 26	TOP	78	4	17	Sandy loam	4.7	0.68	0.044	12.33	0.30	0.19	0.29	0.07	0.85	44.85	71.34
IK 7	SUB	64	2	33	Sandy clay	5.1	0.47	0.045	3.56	1.05	0.30	0.25	0.09	1.69	55.12	54.95

IK 27	TOP	76	8	15	Sandy loam	5.5	0.72	0.052	0.49	1.98	0.77	0.26	0.14	3.14	70.20	68.72
IK 36	SUB	66	3	31	Sandy clay loam	5.7	0.42	0.039	0.35	1.88	0.66	0.17	0.08	2.79	48.13	61.51
IK 28	TOP	74	6	19	Sandy loam	5.6	0.92	0.065	6.34	2.59	0.69	0.21	0.08	3.58	76.11	67.41
IK 9	SUB	64	6	29	Sandy clay loam	5.9	0.52	0.049	0.93	2.08	0.70	0.11	0.10	2.98	66.49	74.62
IK 29	TOP	74	8	17	Sandy loam	5.8	1.06	0.087	0.93	2.87	1.11	0.24	0.11	4.34	78.29	70.03
IK 10	SUB	68	2	29	Sandy clay loam	6.1	0.79	0.065	0.35	2.42	0.58	0.16	0.07	3.23	55.12	66.75
IK 30	TOP	76	6	17	Sandy loam	5.9	0.59	0.051	2.68	1.94	0.66	0.20	0.12	2.92	81.13	77.24
IK 26	SUB	68	2	29	Sandy clay loam	4.5	0.47	0.035	0.20	0.53	0.27	0.24	0.08	1.13	59.06	62.16
IK 31	TOP	72	8	19	Sandy loam	5.0	1.19	0.088	5.31	10.30	0.69	0.38	0.08	11.45	54.69	68.72
IK 15	SUB	66	7	27	Sandy clay loam	4.6	0.55	0.041	5.90	0.71	0.29	0.22	0.12	1.34	74.58	69.37
IK 32	TOP	73	7	19	Sandy loam	4.6	0.72	0.064	9.55	0.61	0.22	0.25	0.17	1.25	66.05	81.83
IK 29	SUB	66	6	27	Sandy clay loam	5.8	0.56	0.038	0.35	2.00	0.73	0.16	0.08	2.97	67.80	74.62
IK 33	TOP	68	11	21	Sandy loam	4.8	1.00	0.086	28.84	1.47	0.52	0.39	0.09	2.46	63.65	113.96
IK 34	SUB	70	5	25	Sandy clay loam	4.6	0.55	0.039	6.19	0.44	0.19	0.31	0.08	1.02	67.36	75.93
IK 34	TOP	76	7	17	Sandy loam	4.7	0.68	0.048	22.27	0.42	0.19	0.17	0.09	0.86	48.13	91.01
IK 6	SUB	70	4	25	Sandy clay loam	6.5	0.71	0.054	0.49	2.55	1.02	0.18	0.08	3.83	55.78	61.51
IK 35	TOP	76	7	17	Sandy loam	4.7	0.80	0.059	7.80	1.05	0.45	0.24	0.14	1.88	59.50	87.08
IK 18	SUB	72	3	25	Sandy clay loam	5.7	0.55	0.039	2.10	1.92	0.67	0.20	0.08	2.87	78.73	61.51
IK 36	TOP	78	7	15	Sandy loam	5.4	0.78	0.053	2.10	2.30	0.75	0.23	0.08	3.36	58.40	55.60
IK 19	SUB	72	3	25	Sandy clay	5.0	0.45	0.040	3.85	0.87	0.37	0.23	0.08	1.55	63.65	64.78

Appendix 16. Results of the soil analysis of Minjibir Kano Research fields colour-coded according to the sufficiency level of each of the soil property

Sample	Soil	PARTICLE SIZE			Textural class	pH(H20)	OC	N	Meh P	Ca	Mg	K	Na	Exch. Acidity	ECEC	Mn	Fe
ID	layer	%SAND	%SILT	%CLAY	Textural class	1:2.5	%	%	ppm	---------------------------------cmol+/kg-------------------						ppm	ppm
MJ 1	TOP	70	3	27	Sandy loam	4.6	0.23	0.022	4.16	0.74	0.18	0.11	0.04	1.65	2.71	30.56	65.73
MJ 1	SUB	84	6	10	Loamy Sand	4.4	0.19	0.014	1.01	0.70	0.20	0.15	0.04	1.65	2.74	38.33	62.82
MJ 2	TOP	80	8	12	Sandy loam	5.3	0.50	0.033	6.48	1.90	0.48	0.56	0.09	1.25	4.28	66.41	253.38
MJ 2	SUB	80	8	12	Sandy loam	5.6	0.21	0.014	2.52	1.49	0.35	0.30	0.08	0.00	2.23	62.82	122.13
MJ 3	TOP	80	8	12	Sandy loam	6.7	1.24	0.105	13.31	7.79	2.01	1.12	0.92	0.00	11.83	156.63	440.19
MJ 3	SUB	64	14	22	Sandy loam	7.1	0.14	0.011	4.43	1.03	0.32	0.31	0.34	0.00	2.00	46.09	197.96
MJ 4	TOP	80	8	12	Sandy loam	7.1	0.40	0.046	8.39	9.64	2.82	4.62	0.51	0.00	17.59	28.17	315.61
MJ 4	SUB	80	8	12	Sandy loam	7.4	0.14	0.010	1.97	3.72	0.83	2.71	0.25	0.00	7.51	4.27	217.41
MJ 5	TOP	82	8	10	Loamy Sand	7.0	0.53	0.043	4.16	9.88	3.05	1.12	0.41	0.00	14.46	80.15	433.71
MJ 5	SUB	80	8	12	Sandy loam	7.3	0.20	0.014	0.33	1.39	0.30	0.12	0.25	0.00	2.06	38.92	163.93

MJ 6	TOP	80	8	12	Sandy loam	6.1	0.38	0.028	13.72	1.39	0.30	0.38	0.30	0.00	2.37	28.77	75.46
MJ 6	SUB	80	10	10	Sandy loam	5.5	0.16	0.014	11.53	0.86	0.17	0.20	0.31	0.00	1.53	34.74	70.59
MJ 7	TOP	80	8	12	Sandy loam	5.9	0.45	0.032	3.47	1.07	0.23	0.32	0.37	0.00	2.00	68.80	293.25
MJ 7	SUB	80	10	10	Sandy loam	5.8	0.25	0.023	0.88	0.46	0.13	0.15	0.17	0.00	0.92	26.98	133.79
MJ 8	TOP	84	6	10	Loamy Sand	6.6	0.50	0.033	4.02	1.51	0.40	0.55	0.61	0.00	3.07	78.96	306.86
MJ 8	SUB	80	8	12	Sandy loam	6.6	0.28	0.027	1.42	0.50	0.15	0.26	0.26	0.00	1.17	37.73	195.05
MJ 9	TOP	80	10	10	Sandy loam	4.1	0.32	0.023	10.44	0.54	0.13	0.11	0.09	1.65	2.52	25.18	85.18
MJ 9	SUB	80	8	12	Sandy loam	4.2	0.26	0.024	7.30	0.64	0.18	0.15	0.06	1.65	2.68	43.70	76.43
MJ 10	TOP	80	8	12	Sandy loam	4.1	0.22	0.017	8.25	0.66	0.15	0.13	0.09	1.65	2.68	28.17	82.26
MJ 10	SUB	84	6	10	Loamy Sand	4.4	0.24	0.019	6.20	0.84	0.25	0.20	0.05	1.55	2.89	42.51	69.62
MJ 11	TOP	80	8	12	Sandy loam	5.2	0.31	0.021	8.39	1.00	0.22	0.19	0.08	0.65	2.14	31.75	72.54
MJ 11	SUB	80	8	12	Sandy loam	4.5	0.22	0.017	5.11	0.70	0.20	0.30	0.04	1.45	2.69	37.13	71.57
MJ 12	TOP	84	6	10	Loamy Sand	5.4	0.69	0.053	14.13	3.29	0.69	0.23	0.06	0.25	4.51	70.59	76.43

MJ 12	SUB	76	10	14	Sandy loam	5.7	0.27	0.024	10.17	1.19	0.23	0.20	0.09	0.00	1.71	33.55	61.84
MJ 13	TOP	78	10	12	Sandy loam	5.6	0.32	0.022	9.48	1.13	0.19	0.23	0.25	0.00	1.81	34.74	63.79
MJ 13	SUB	80	10	10	Sandy loam	5.5	0.26	0.024	3.75	1.25	0.27	0.32	0.29	0.00	2.14	37.13	59.90
MJ 14	TOP	78	8	14	Sandy loam	5.6	0.34	0.025	8.66	1.19	0.25	0.24	0.31	0.00	1.99	22.20	73.51
MJ 14	SUB	80	12	8	Sandy loam	5.4	0.23	0.014	4.70	1.41	0.33	0.32	0.29	0.45	2.80	27.57	50.18
MJ 15	TOP	74	10	16	Sandy loam	4.5	0.21	0.015	27.51	0.68	0.08	0.16	0.05	1.45	2.42	21.60	61.84
MJ 15	SUB	80	10	10	Sandy loam	4.5	0.25	0.026	15.76	0.96	0.20	0.25	0.06	1.45	2.92	46.09	56.01
MJ 16	TOP	78	8	14	Sandy loam	4.7	0.26	0.019	13.31	0.72	0.18	0.21	0.09	1.40	2.59	26.38	68.65
MJ 16	SUB	80	10	10	Sandy loam	4.6	0.20	0.013	5.11	1.03	0.21	0.19	0.09	1.40	2.94	48.48	54.07
MJ 17	TOP	76	10	14	Sandy loam	5.3	0.33	0.025	9.76	1.17	0.22	0.16	0.11	0.65	2.31	41.91	46.29
MJ 17	SUB	84	8	8	Loamy Sand	5.0	0.28	0.022	13.17	0.66	0.12	0.23	0.09	0.75	1.85	34.74	51.15
MJ 18	TOP	78	10	12	Sandy loam	5.5	0.41	0.036	5.79	1.37	0.30	0.28	0.11	0.00	2.06	44.30	55.04
MJ 18	SUB	80	12	8	Loamy Sand	5.3	0.36	0.038	5.11	0.92	0.20	0.30	0.11	0.65	2.18	61.03	56.01

MJ 19	TOP	76	10	14	Sandy loam	5.8	0.36	0.029	12.62	1.65	0.25	0.34	0.12	0.00	2.36	58.04	57.95
MJ 19	SUB	84	8	8	Loamy Sand	6.3	0.21	0.017	13.31	1.23	0.27	0.63	0.07	0.00	2.20	61.63	59.90
MJ 20	TOP	76	10	14	Sandy loam	6.1	0.42	0.030	15.49	1.73	0.25	0.23	0.09	0.00	2.30	44.90	66.71
MJ 20	SUB	80	10	10	Sandy loam	6.4	0.24	0.019	6.75	1.39	0.32	0.43	0.18	0.00	2.32	41.91	59.90
MJ 21	TOP	76	8	16	Sandy loam	5.8	0.37	0.027	9.21	1.23	0.22	0.18	0.09	0.00	1.72	40.72	71.57
MJ 21	SUB	84	8	8	Loamy Sand	5.5	0.29	0.028	7.16	1.11	0.29	0.21	0.19	0.00	1.80	58.04	65.73
MJ 22	TOP	76	8	16	Sandy loam	5.3	0.36	0.033	23.14	0.84	0.21	0.19	0.09	0.60	1.93	46.09	88.10
MJ 22	SUB	80	10	10	Sandy loam	5.3	0.24	0.021	11.53	1.02	0.30	0.30	0.09	0.60	2.30	71.19	69.62
MJ 23	TOP	76	8	16	Sandy loam	5.1	0.31	0.024	16.72	0.66	0.16	0.17	0.10	0.65	1.74	43.11	90.04
MJ 23	SUB	80	7	13	Sandy loam	5.1	0.27	0.026	10.85	0.52	0.17	0.23	0.09	0.65	1.67	64.62	73.51
MJ 24	TOP	74	9	17	Sandy loam	5.2	0.22	0.020	9.76	9.76	0.27	0.36	0.06	0.55	11.00	56.85	62.82
MJ 24	SUB	80	5	15	Sandy loam	5.5	0.40	0.035	24.37	1.55	0.48	0.25	0.09	0.00	2.37	43.70	80.32
MJ 25	TOP	84	5	11	Loamy Sand	5.8	0.44	0.030	8.25	1.43	0.25	0.20	0.09	0.00	1.97	64.62	73.51

MJ 25	SUB	84	7	9	Loamy Sand	5.9	0.29	0.025	5.39	1.23	0.31	0.32	0.05	0.00	1.92	91.50	69.62
MJ 26	TOP	78	7	15	Sandy loam	5.9	0.39	0.029	14.67	1.59	0.27	0.29	0.06	0.00	2.21	67.01	76.43
MJ 26	SUB	80	5	15	Sandy loam	6.3	0.32	0.028	16.45	1.33	0.25	0.44	0.09	0.00	2.12	81.34	73.51

Appendix 17. Lab results of the water samples at Minjibir research fields

Your ID	*pH*	*TDS (ppm)*	*Elect. Cond. (uS/cm)*	*NO3-N (ppm)*	*PO4-P (ppm)*	*Mn (ppm)*	*Cd (ppm)*	*Ca (ppm)*	*Mg (ppm)*	*K (ppm)*	*Ca-Hardness(mg\L)*	*Mg-Hardness(mg\L)*	*Total-Hardness(mg\L)*	*Fe (ppm)*	*Na (ppm)*	*Cu (ppm)*	*Zn (ppm)*	*NH4-N (ppm)*	*Se (ppm)*
1- Lake	7.1	372	745	*1.24*	0.09	0.09	0.01	15.60	8.63	28.73	38.96	*35.52*	*74.48*	0.34	19.61	0.07	0.04	0.93	0.04
2- Open well Plot 18 MJ	6.0	71	342	*12.64*	0.04	0.03	0.01	20.64	3.99	5.73	51.54	*16.42*	*67.96*	0.09	1.19	0.04	0.02	0.42	0.08
3- Open well Plot 19 MJ	5.1	204	407	*1.44*	0.29	0.01	0.01	25.52	5.22	6.02	63.73	*21.51*	*85.23*	0.11	1.27	0.02	0.03	0.78	0.04