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Soil Fertility and Farming Systems Assessment in Productive Areas of Western, Central and Eastern Equatoria State, South Sudan

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Abstract

Soil is one of the most important resources for food production, and it regulates and supports ecosystem functions. For soil to sustainably perform its functions, an understanding of its potentials and limitations is crucial. The physical, chemical, and biological properties of soil need to be well understood prior to its intensive use. The soil fertility and farming systems study was carried out in the farming areas of Magwi, Juba and Yambio counties of South Sudan. Soil samples of 18, 30 and 41 were collected from Juba, Magwi and Yambio counties between November 2021 to December 2021. Each soil sampling point was geo-referenced to aid the development of nutrient spatial maps. The soil samples were packaged, labelled, and taken to the Soil, Plant and Water analytical Laboratory, at the Department of Agricultural Production, maker ere University for analysis. These samples were processed and analyzed for soil texture, soil pH, soil organic matter, nitrogen, phosphorous and bases (Calcium, Potassium and Sodium). The results of the analysis indicated that soil pH, Calcium and Potassium were within suitable ranges for most crops. However, soil organic matter, Nitrogen and available Phosphorous were all below critical limits for most crops. The soil texture across the sampled counties was predominantly sandy loam to sandy clay loam. The results from analysis indicated that both Nitrogen and Phosphorus are low (<20kg N kg-1) and (< 15kg P2O5 kg-1) in the sampled soils. For smallholder farmers to obtain optimum yields in the three sampled States of South Sudan, fertilizer application rates of at least 60kg N ha-1 and 10kg P2O5 ha-1 would be required. In addition, integrated soil fertility management and Conservation Agriculture practices should be introduced. Integration and use of improved seeds, organic and inorganic fertilizers to increase and stabilize crop yields is recommended. Training extension officers on integrated soil fertility management and conservation agriculture practices is recommended to help propagate the knowledge to smallholder farmers to apply the conservation practices to enhance crop production.

Keywords: Soil texture; Inorganic fertilizer; Macro-nutrient; Organic fertilizer; Soil fertility; Soil samples

Introduction

Agriculture is the economic mainstay of majority of the countries in Africa. However, while Agriculture based Gross Domestic Product (GDP) has been shown to be twice as effective at reducing poverty compared to GDP growth originating from other sectors, many countries in Africa are still grappling with severe food insecurity challenges, with most of them unable to produce enough for their growing populations. South Sudan is one of these countries [1].

The most important crops in the country include maize, sorghum, millet, cassava, groundnuts, and beans. Smallholder farmers are the drivers of South Sudan Agriculture sector. It is estimated that about 83% of the total farming households are resource-poor smallholder farmers who cultivate, on average, a land size of 0.4-0.5 hectares [2]. Yet, on-farm yields are low and do not exceed 0.4 t ha-1 for the major staple food crops.

South Sudan has 62 million hectares of land in the Nile River basin, approximately, 75% of the total land area is suitable for agriculture and 50% is highly suitable for crop cultivation. Despite having immense agricultural potential with abundant fertile lands, South Sudan utilizes only 4% of its vast arable lands to produce half its cereal requirements which often lead to recurring grain deficits, food insecurity, malnutrition, hunger, and rising food prices [3]. South Sudan today has one of the world's weakest and most underdeveloped economies. To revive the economy of South Sudan, the International Fertilizer Development Centre (IFDC) is implementing a seed sector development project in South Sudan which provides market-oriented interventions to support the establishment of a commercial, sustainable, and adaptive agriculture sector in South Sudan.

The project ensures the availability of improved seed down to the last-mile through Agri-entrepreneurship and support existing private sector seed companies to improve seed and input marketing, distribution, and production practices. A3-SEED seeks to reach more than 100,000 farming households, double incomes from marketable surpluses, increase farmer yields by 20-50% on target commodities, facilitate the development of 100 agro-dealers as well as 200 women-owned and 200 youth-led businesses, and bring 42,000 ha of farmland under agro ecological production.

To achieve these targets IFDC engaged the services of a consultant to conduct Soil Fertility & Farming Systems Assessment in the selected project sites of Magwi, Yambio and Juba counties. Understanding the soils and its limitation is vital to increase crop productivity.

The purpose of the assessment was to identify soil fertility gaps in the project sites and develop recommendations for promotion and dissemination of improved soil fertility management technologies.

Methodology

Description of the study areas

The study was conducted in green belt region covering Juba, Magwi and Yambio counties of Central, Eastern and Western Equatorial State of South Sudan (Figure 1). Within each county, sub-counties (Payams) and villages (Bomas) with agricultural potential were selected for soil sampling (Table 1).

Yambio County is in Western equatorial State with Longitudes: 27.606° E and 28.981° E, Latitudes: 4.269° N and 6.54°N (Figure 1). Its altitude ranges from 560-813 m above sea level and is bordered by Nzara County to the West and Ibba County to the East. It also borders Lakes State (Wulu County) to the North and the Democratic Republic of Congo to the South. This State is known for its natural resources especially teak. It is a food basket for major part of the country. According to the County falls within the equatorial maize and cassava livelihoods zone [4].

Magwi County is in Eastern Equatorial State, with Longitudes: 31.715° E and 32.887° E, Latitudes: 3.3.497° N and 4.395°N (Figure 1). Its altitude ranges from 514-2,223 m above sea level. The County borders Imatong County in the East, and Republic of Uganda in the Southwest. Crops grown in the County include cassava, maize, and sorghum with some cultivation of sweet potatoes, groundnuts, beans [5].

Juba County is in Central equatorial with Longitudes: 30.498° E and 32.206° E, Latitudes: 3.948° N and 5.49°N (Figure 1). Its altitude ranges from 539-1296 m above sea level. The County borders Imatong County in the East, Magwi County in the South, Terekeka County in the North, Kajo Keji and Mundri County in the West. Juba is the capital city of South Sudan. The main crops grown in the County include sorghum, maize, cassava. Other activities include cattle rearing and fishing [5].

Topography of study site

The areas sampled were generally on flat to gentle slopes, except for some areas in Magwi and Juba counties where slopes of >30% were found (Figure 2).

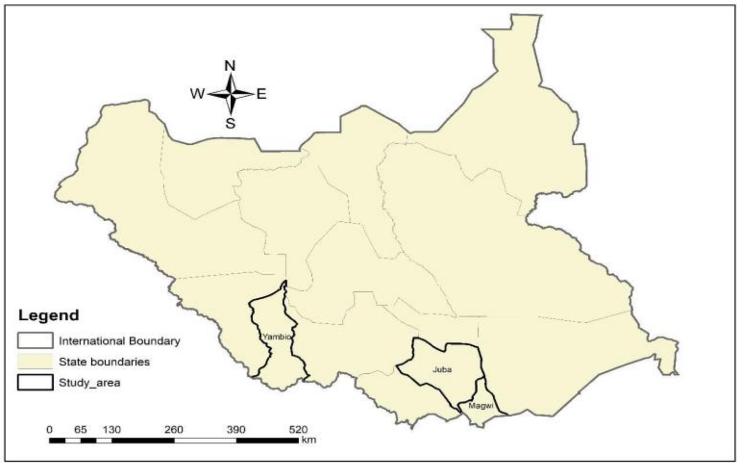

Figure 1: *Map of study areas in South Sudan.*

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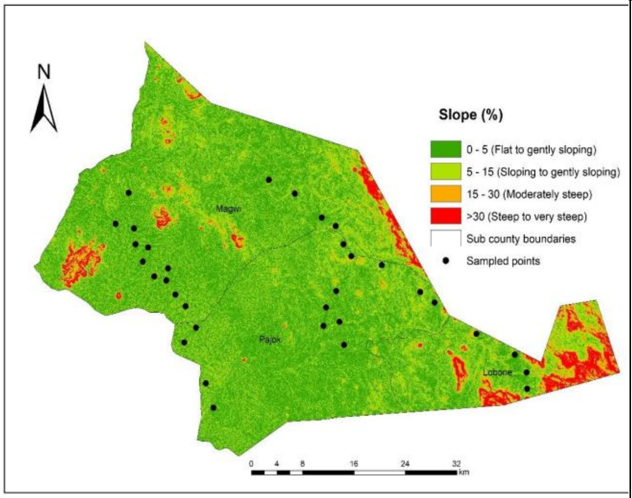
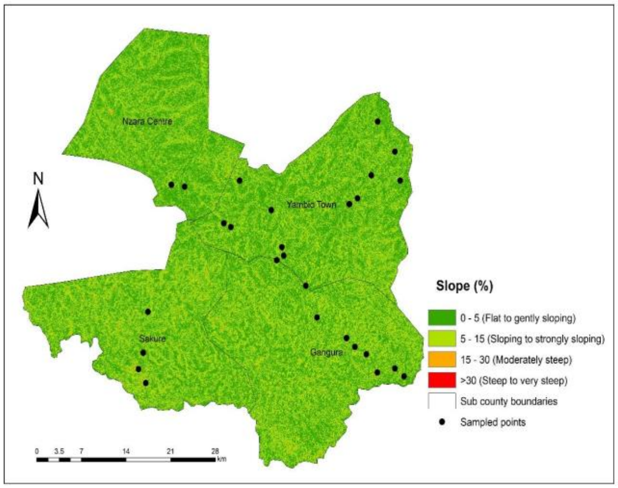


Slope map of payams in Magwi county with sampled points



Slope map of payams in Yambio County with sampled points

Slope map of payams in Juba County with sampled points.

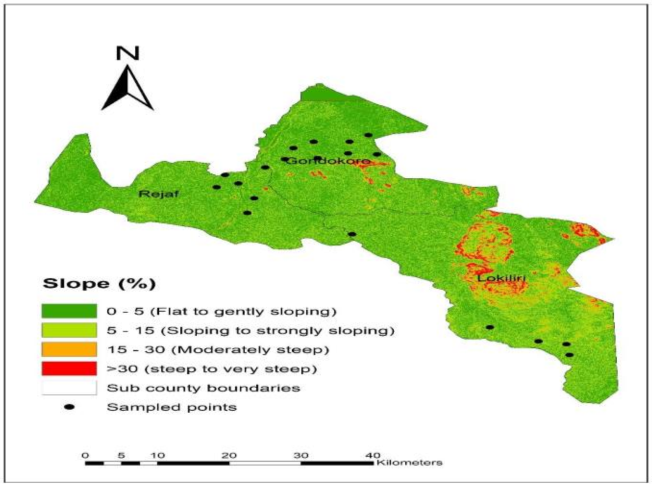
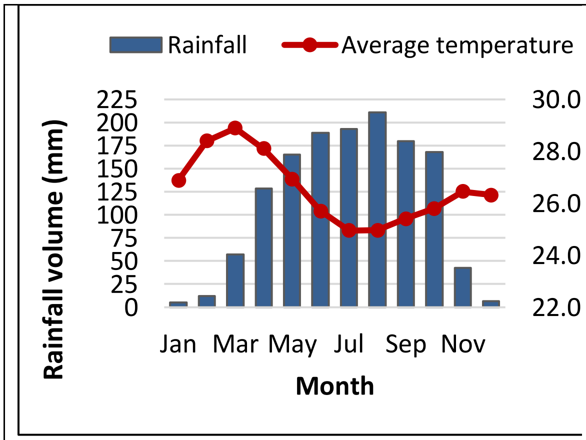
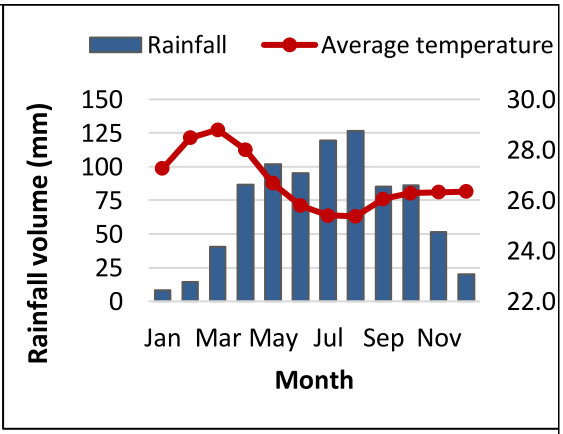


Figure 2: *Slop map of Payams at the study areas with sample points.*



Average monthly rainfall and temperature patterns for Yambio for the period 1991-2020



Average monthly rainfall and temperature patterns for Magwi for the period 1991-2020

Average monthly rainfall and temperature patterns for Juba for the period 1991-2020

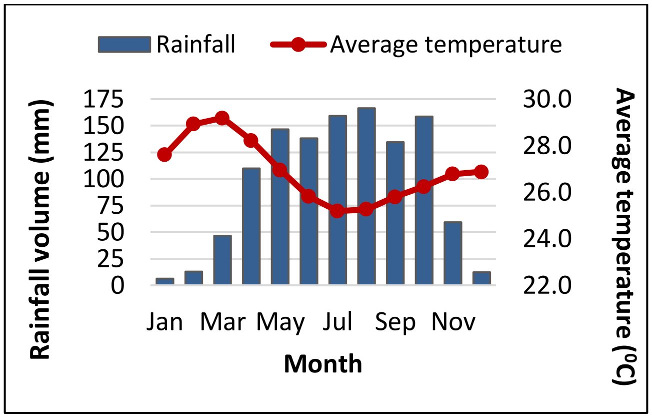
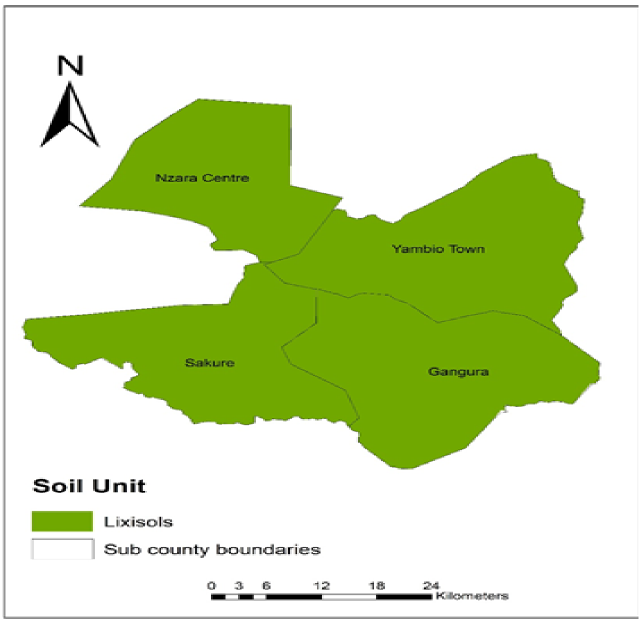
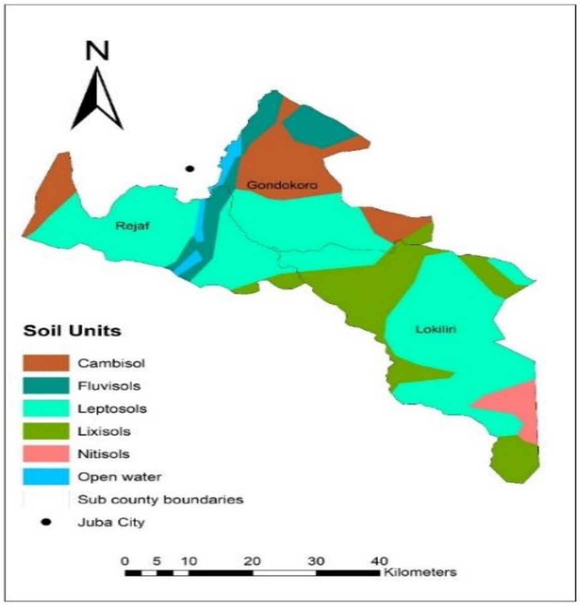


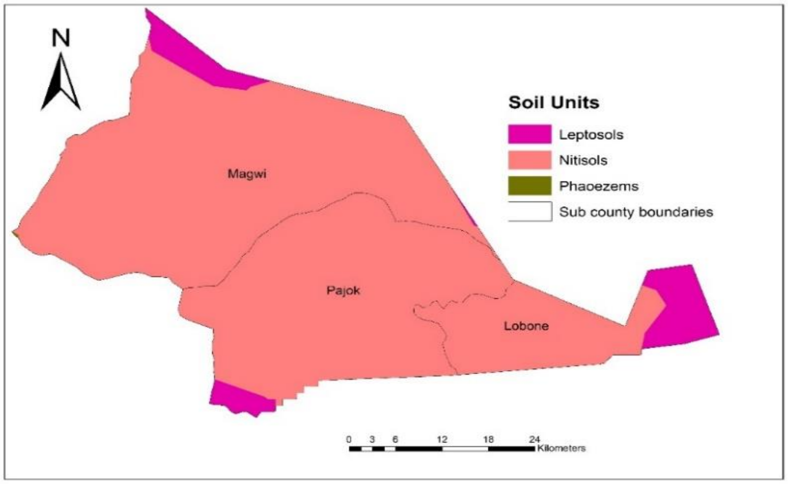
Figure 3: *Average monthly rainfall and temperature patterns for sampled areas for the period 1991-2020.*



Soil map for Yambio County

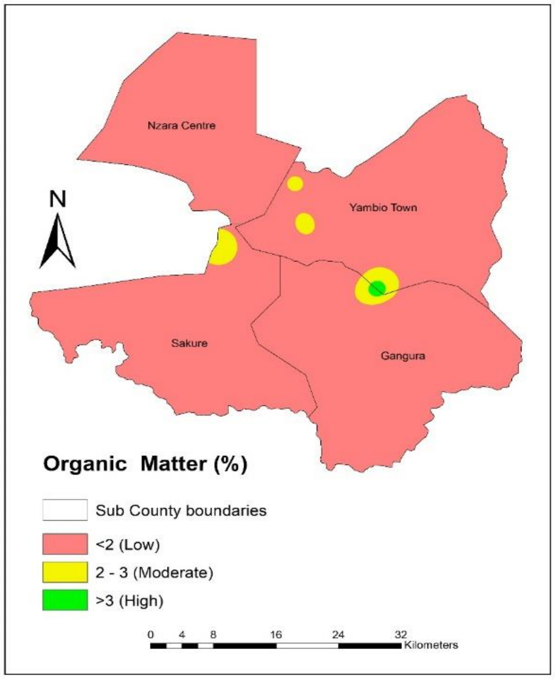


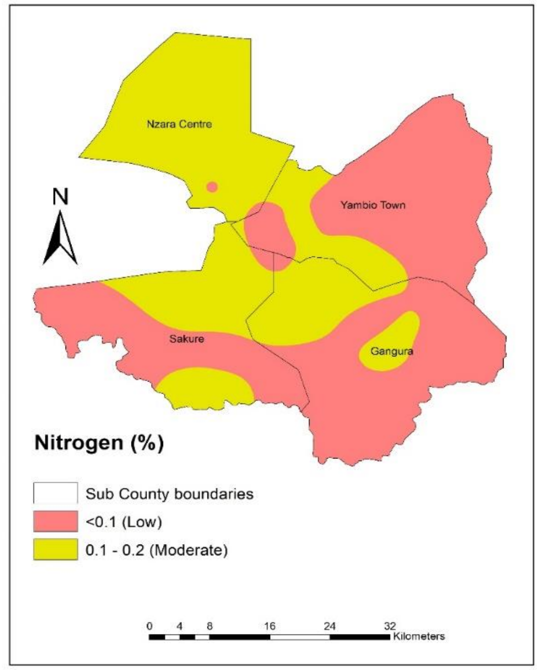
Soil Map for Juba County

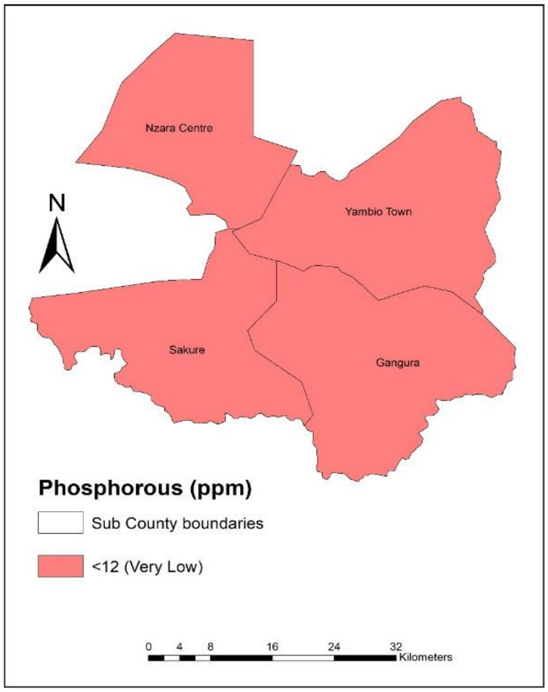


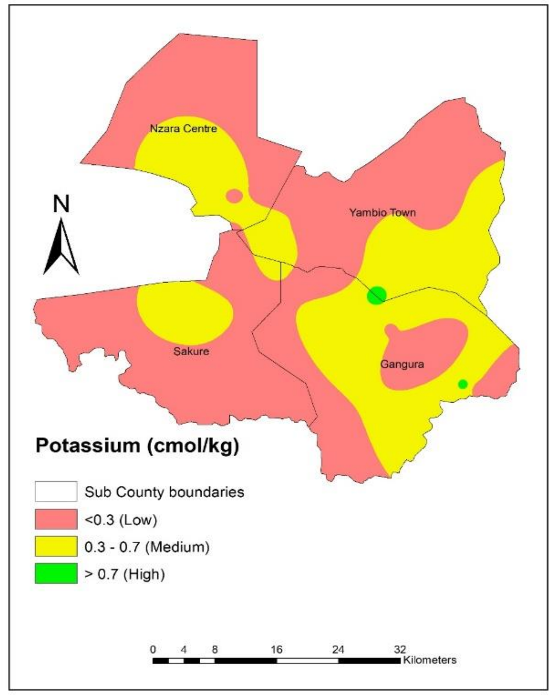
Soil map of Magwi county

Figure 4: *Soil map of the study areas.*


Nzara Centre
Yambio Town
Sakure
Gangura
N
Organic Matter (%)
Sub County boundaries
<2 (Low)
2 - 3 (Moderate)
>3 (High)
0 4 8 16 24 32 Kilometers


Nzara Centre
Yambio Town
Sakure
Gangura
N
Nitrogen (%)
Sub County boundaries
<0.1 (Low)
0.1 - 0.2 (Moderate)
0 4 8 16 24 32 Kilometers


Nzara Centre
Yambio Town
Sakure
Gangura
N
Phosphorous (ppm)
Sub County boundaries
<12 (Very Low)
0 4 8 16 24 32 Kilometers


Nzara Centre
Yambio Town
Sakure
Gangura
N
Potassium (cmol/kg)
Sub County boundaries
<0.3 (Low)
0.3 - 0.7 (Medium)
> 0.7 (High)
0 4 8 16 24 32 Kilometers

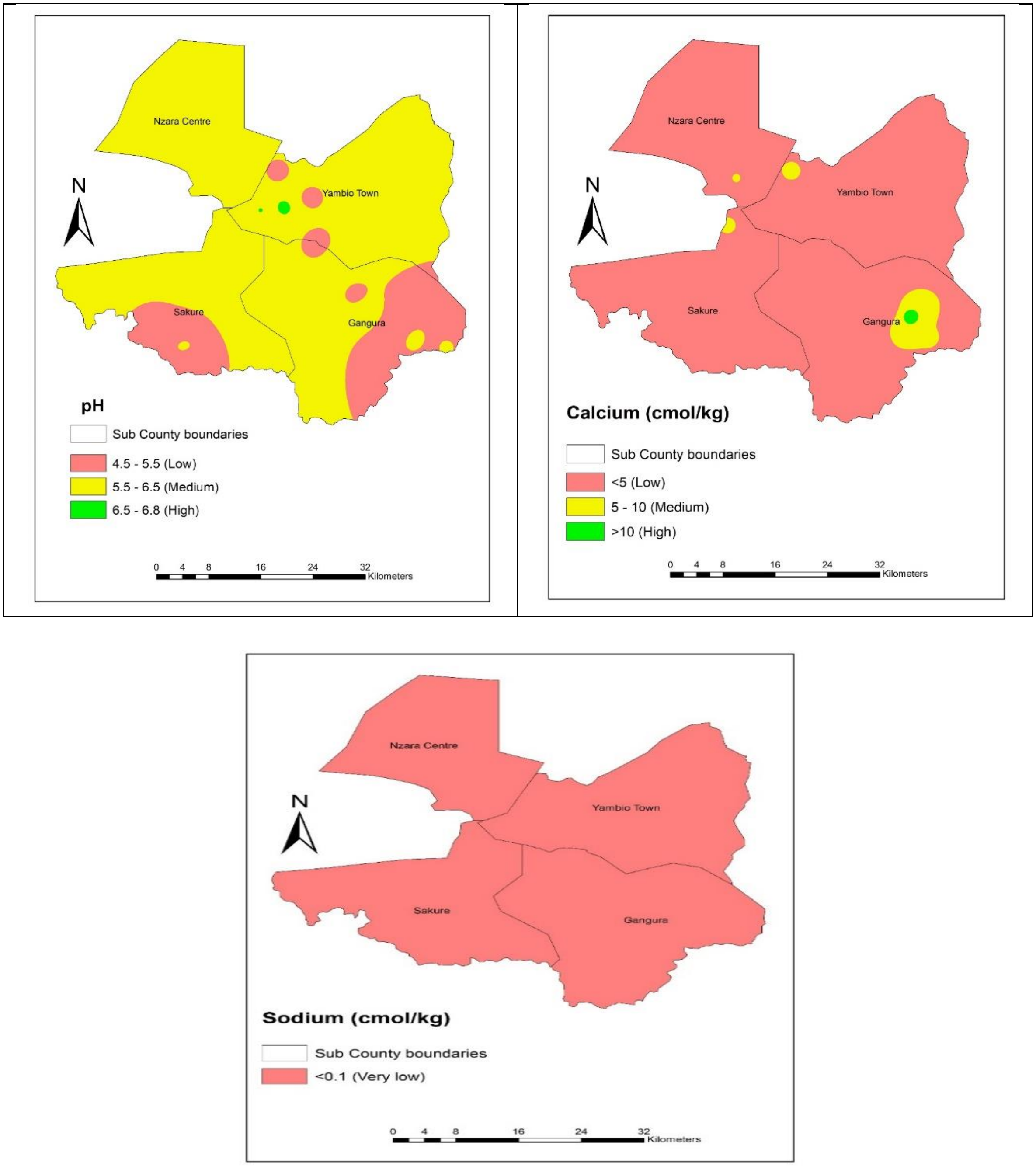


Figure 5: *Spatial maps showing distribution of Organic Matter, Nitrogen, Phosphorous, Potassium, pH, Calcium and Sodium in Yambio County*.

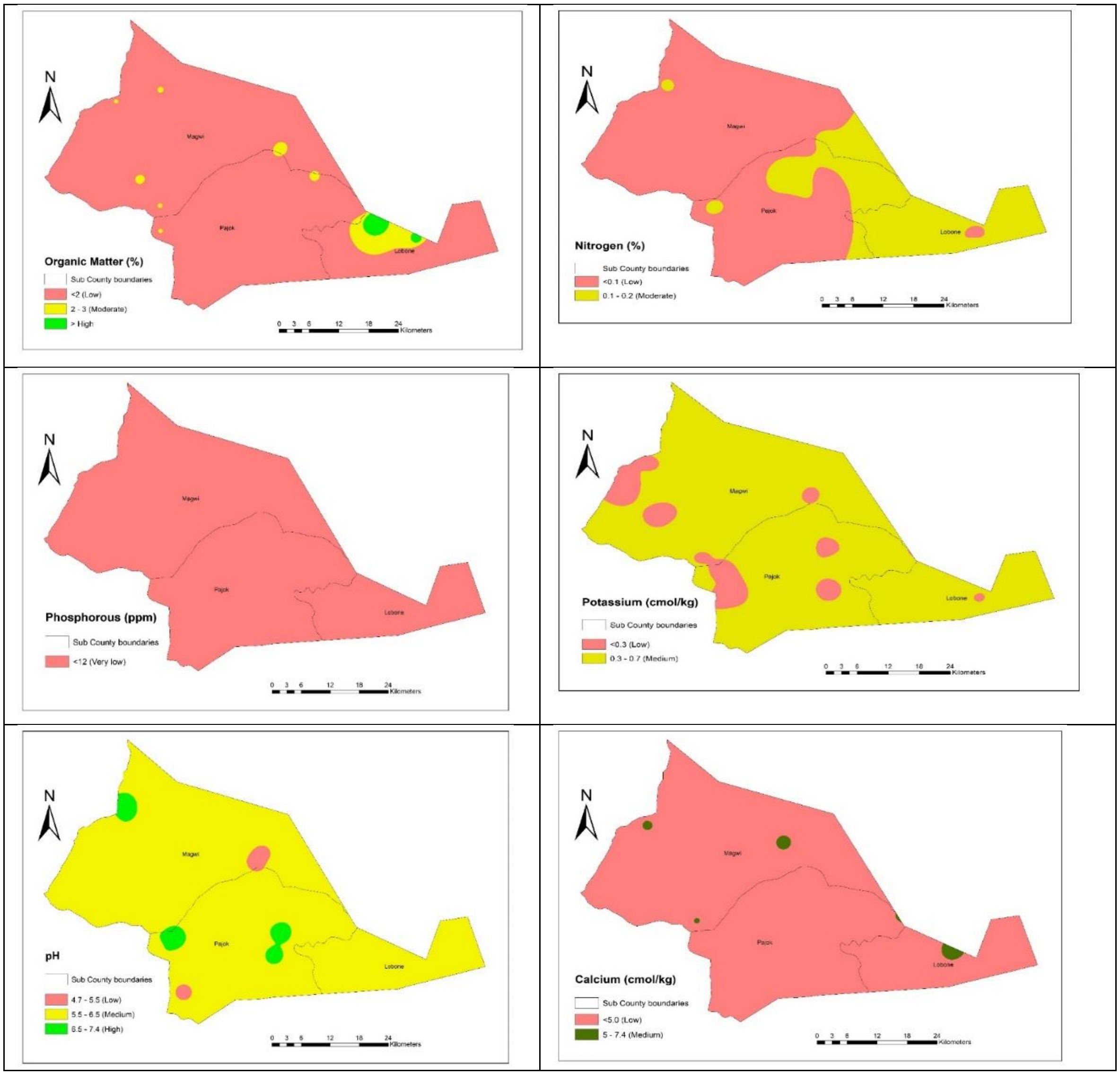
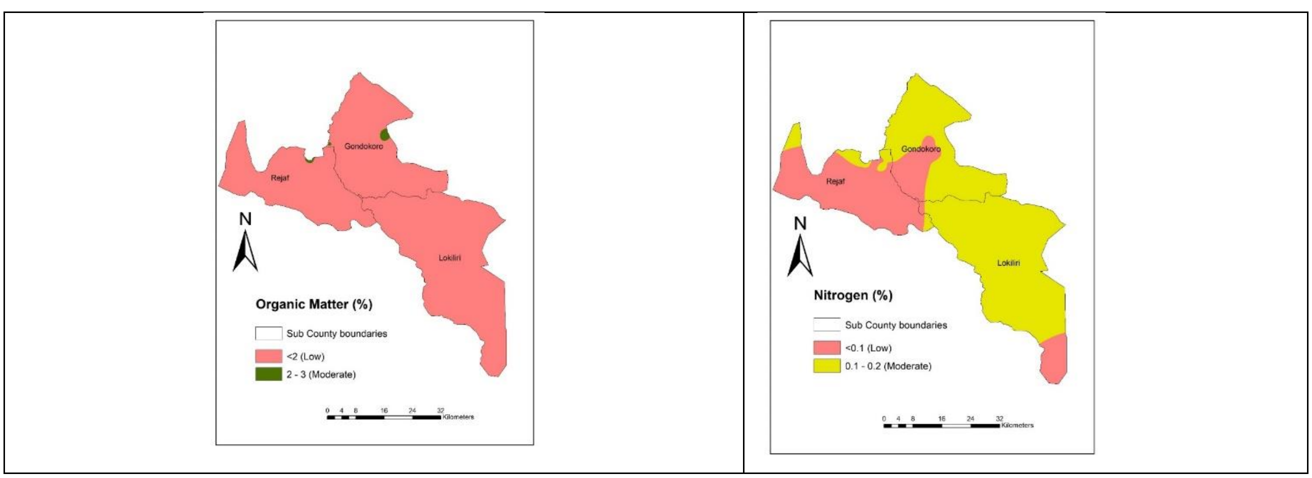
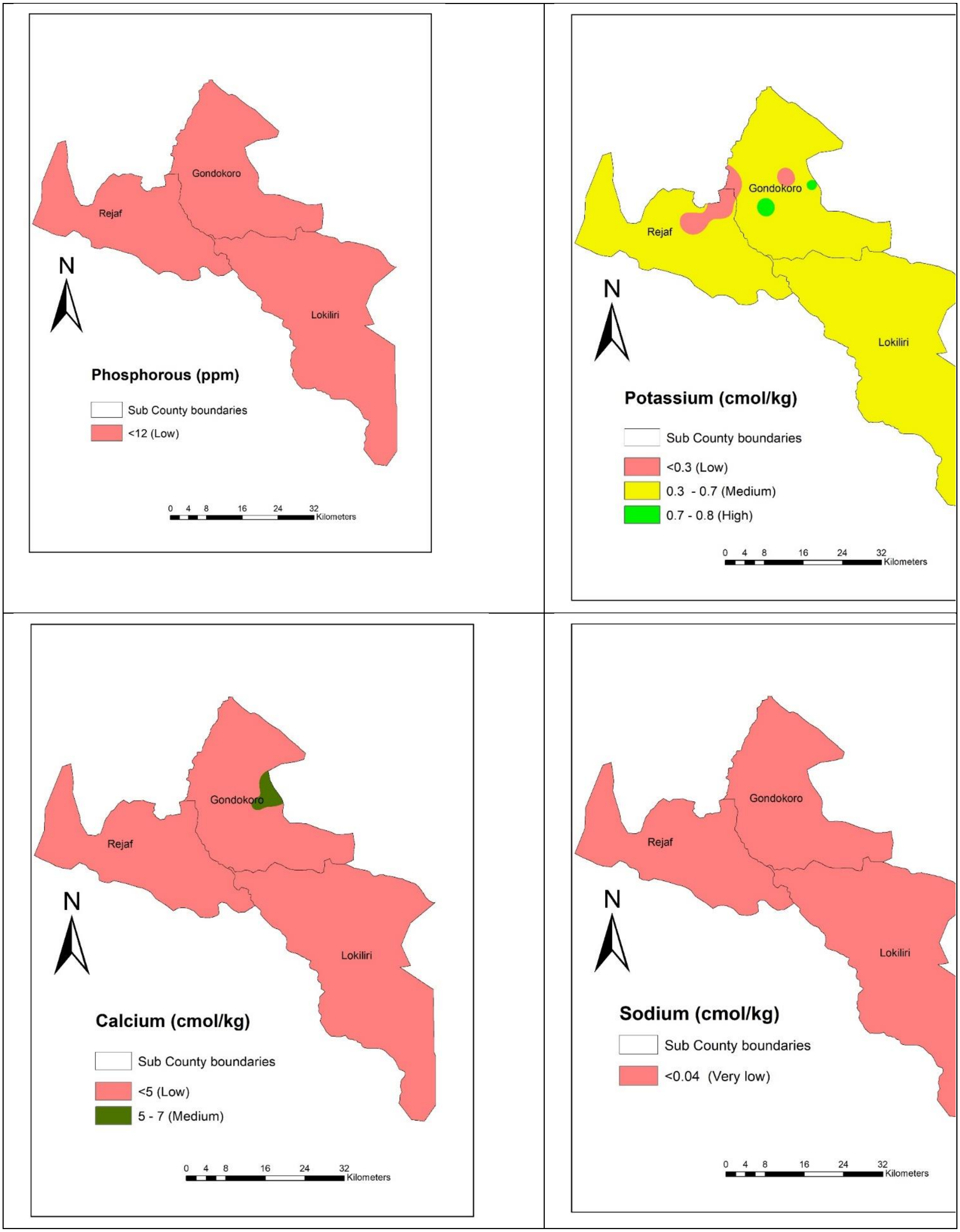


__Figure 6:__ Spatial maps showing distribution of Organic Matter, Nitrogen, Phosphorous, Potassium, pH, and Calcium in Magwi County.




Gondokoro
Rejaf
Lokiliri
N
Phosphorous (ppm)
Sub County boundaries
<12 (Low)
0 4 8 16 24 32 Kilometers
Gondokoro
Rejaf
Lokiliri
N
Potassium (cmol/kg)
Sub County boundaries
<0.3 (Low)
0.3 - 0.7 (Medium)
0.7 - 0.8 (High)
0 4 8 16 24 32 Kilometers
Gondokoro
Rejaf
Lokiliri
N
Calcium (cmol/kg)
Sub County boundaries
<5 (Low)
5 - 7 (Medium)
0 4 8 16 24 32 Kilometers
Gondokoro
Rejaf
Lokiliri
N
Sodium (cmol/kg)
Sub County boundaries
<0.04 (Very low)
0 4 8 16 24 32 Kilometers

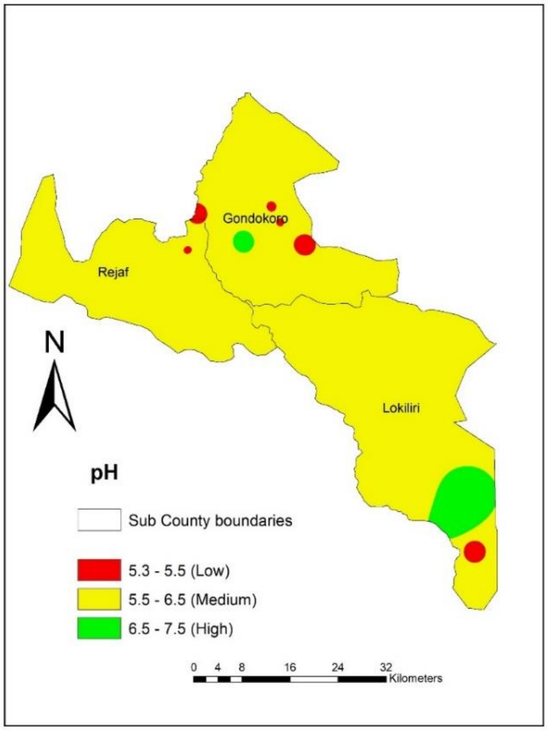


Figure 7: *Spatial maps showing distribution of Organic Matter, Nitrogen, Phosphorous, Potassium, pH, Calcium and Sodium in Juba County*.

Rainfall and temperature of study area

The study areas experience a unimodal pattern regarding seasonal rainfall, with onset observed in March, the peak in August and cessation in November (Figure 3). The dry season on the other hand begins in December and ends in February. This kind of pattern yields an average growing period of at least 8 to 9 months in length.

The relatively long growing season favours the production of annual and perennial crops. Such pattern is also regarded as being conducive for cattle rearing as the rainfall received is sufficient to support production of pasture. For the case of average temperature, a sinusoidal pattern is observed during the year where warmer temperature are recorded during the dry season and cooler temperatures during the wet season. The highest temperature is observed at onset of rainfall (March) whereas the lowest temperature occurs in August during the peak of the wet season.

Soils of the study areas

Six main soil mapping units were identified within the project areas (Figure 4). These were described following the World Reference Base international soil classification system as follows: [6]

1. **Leptosols:** Very thin soils dominated by coarse fragments and overlying a continuous rock, they are mostly found in medium to high altitude areas.
2. **Nitisols:** Deep red soils characterized by nutty like soil structure, relatively weathered soils dominated by low activity clays and iron oxides. Phosphorus fixation is a common characteristic of these soils.
3. **Vertisols:** Soils with high clay content (mostly swelling clays). Deep and wide cracks extending from the soil surface are the common field characteristics.
4. **Fluvisols:** These are generally young soils characterized by accumulation of lacustrine or marine deposits due to the influence of river deposition.
5. **Cambisols:** These are soils characterized by slight to moderate weathering from the parent material, with less profile differentiation and low amounts of illuviated clays and organic matter.
6. **Ferralsols:** Highly weathered soils characterized by low cation exchange capacity and dominated by iron and aluminium oxides.

Soil Sampling and mapping

The consultant and the extension workers carried out transect walks to identify the different soil mapping units including their boundaries and field characterization of the identified soil units.

Auger point observations were made across the selected fields, taking note of field observable soil properties such as colour, soil texture, structure, and soil organic matter. Augerings were also used for preliminary assessment of depth of plough (top) layer. These sampling points were geo-referenced and plotted on the county respective maps (Figure 2). Selection of sampling points was done following standard procedures but also based on safety and access to the fields. Sampling was done to depth of 30 cm using an auger. For each sampling site, 10 sub samples were picked and mixed in a basin for quarter sampling and generation of a composite samples. A total of 18, 30 and 41 soil samples were collected from Juba, Magwi and Yambio County respectively (Table 1).

Table 1: *States, Counties and payams of the selected project areas.*

State	County	Payam	No of soil samples
Western Equatoria	Yambio	Gangura	41
		Sakure	
		Nzara Centre	
		Yambio	
Central Equatoria	Juba	Rejaf	18
		Gondokoro	
		Lokiliri	
Eastern Equatoria	Magwi	Magwi	32
		Pajok	
		Lobone	
Total			**88**

Table 2: *Descriptive statistics of soil properties in Juba, Magwi and Yambio counties.*

Parameter (unit)	**Juba** Mean (SD) N = 18	**Magwi** Mean (SD) N =30	**Yambio** Mean (SD) N = 41	**Critical levels**[1]
pH	5.9 (0.59)	6 (0.5)	5.6 (0.6)	5.5 – 7.5
SOM (%)	1.4 (0.9)	1.2 (1.1)	0.79 (0.9)	3
N (%)	0.11 (0.05)	0.09 (0.04)	0.09 (0.04)	0.2
Av. P (ppm)	1.7 (2.3)	1.7 (2.4)	1.8 (3.3)	15
K (cmol+ Kg^{-1})	0.44 (0.25)	0.4 (0.2)	0.34 (0.25)	0.4
Na (cmol+ Kg^{-1})	0.01 (0.007)	0.01 (0.003)	.014 (0.18)	
Ca (cmol+ Kg^{-1})	2.9 (2.2)	2.2 (2.1)	3.0 (2.6)	1
Sand (%)	66.8 (11.6)	70.6 (6.6)	67 (9.7)	
Clay (%)	20.6 (9.5)	18.3 (6.0)	17.2 (8.0)	
Silt (%)	12.6 (4.7)	11.0 (2.3)	13 (4.0)	
SOM=Soil Organic Matter, N=Nitrogen, Av.P=Average Phosphorus, K=Potassium, Na=Sodium, Ca=Calcium				

Farming system assessment

A Checklist was developed to collect data on individual farm systems, enterprise patterns, household livelihoods and constraints. Each enumerator moved with a checklist and used it to guide the discussion with the selected agricultural extension workers and farmers living in the sampled areas.

A total of 64 respondents were interviewed across the study areas, i.e., 14 from Juba, 22 from Magwi and 28 from Yambio County.

Data Analysis

The soil samples were packaged, clearly labelled, and taken to the Soil, Plant and Water analytical Laboratory, at the department of Agricultural Production, Maker ere University. The samples were air dried for three days and ground using a porcelain pestle and mortar and sieved through a 2 mm sieve to remove debris and other non-soil materials including stones and roots.

Soil properties analyzed include soil pH, total Nitrogen, available Phosphorus, and Organic matter, Potassium, Calcium and Sodium. Soil pH was measured on a soil-water solution at a ratio of 1:2.5 by the help of a pH meter, total Nitrogen (N) was determined

calorimetrically following a digestion using concentrated Sulphuric acid and Selenium powder plus Salicylic acid. Available phosphorus content was determined spectrophotometrically at 882 nm wavelength after its reaction with ammonium moly date in the presence of ascorbic acid on mehlich 1 extract [7].
Organic matter was analyzed using the Walkley Black method. Exchangeable Potassium (K) and Calcium (Ca) were read on Mehlich 1 extracts using a flame photometer.

Developing spatial nutrient maps

Spatial soil fertility maps for the macro-nutrients were generated using spatial analysis, geo-statistical and interpolation tools embedded in ArcGIS 10.8 and crop specific nutrient deficient areas were shown and their coverage computed.

Soil fertility and crop specific fertilizer management recommendations were developed by comparing soil Kit results against known critical levels for each soil parameter. The soil properties which have been retrieved were incorporated into the new soils data to be analyzed.

Key Findings and Results

The soil analysis results showed that soil pH, Calcium and Potassium were within the suitable ranges for most crops. However, soil organic matter, Nitrogen and available Phosphorous were all below critical limits for most crops.

The soil texture across the three counties were dominantly sandy loam to sandy clay loam. The results of spatial soil fertility maps showed that soil organic matter, Nitrogen, available Phosphorous and Calcium were between low and moderate across all the counties.
Soil pH is within suitable range for all the counties while Potassium was sufficient for most areas. The results of the farming systems assessment indicated that subsistence rain fed agriculture is commonly practiced for most of the population with only a handful of the population engaged in formal employment and trade.

The major crops grown in the study areas include maize pigeon peas, soybean, beans, cassava, sorghum, sesame, and cassava. Majority of the farmers depend on family labour and do not apply agriculture inputs like fertilizers and pesticides.
Among the challenges faced by the farmers include land tenure where the land is owned by government, soil erosion particularly in steep slopes, poor roads, pests and diseases and limited access to markets. The major livestock enterprises include cattle, goats, sheep, chicken, and piggery. Other sources of livelihood in the area are hunting. Water resource is very vital and important for agriculture, and the areas are blessed with a few rivers including the River Nile in Juba where fishing is practiced.

Interpretation of the Results

The soils in the area are predominantly sandy loam, well drained with suitable soil pH range pH range (5.5-7.5).
Nitrogen and available phosphorous are the main limiting nutrients in these soils [8]. Nitrogen is usually the most limiting nutrient, yet it is very important for chlorophyll production, cell division, protein synthesis and general plant vigour [9]. Nitrogen is easily lost in the soil through leaching, volatilization, and immobilization. These pathways should therefore be managed to keep nitrogen in the soil. Browning /yellowing of the lower leaves, starting at the apex through the midrib is field deficiency symptom for inadequate levels of Nitrogen in the soil.

Like Nitrogen, Phosphorous is one of the macro nutrients, needed by the plants in large quantities. It is important in root development, provision of energy to the biochemical processes cell division and elongation, flower initiation, fruit, and seed development [10].
Soil pH influences availability of phosphorous to plants. In these soils however, the soil pH is in suitable range and cannot be a reason for its low levels. Purpling of leaves starting with the old ones (lower leaves) is and indicator of low levels of Phosphorous. Very low levels of soil organic matter in these soils also limits the potential of these soils hold water and nutrients, and thus these soils are susceptible to leaching and degradation. It must be noted that soil organic matter is mainly affected by land use change and accumulation of soil organic matter is affected by the environmental factors particularly soil moisture and temperatures.

Recommendations and Conclusions

As a starting point, legumes and cover crops like soybean and beans should be included as intercrops to enhance build-up of organic matter and nitrogen biological fixation.
Soil nutrient management is best achieved by integrating organic fertilizers. Animal manure is a common source of organic fertilizers but will require bigger quantities to meet the crop nutrient requirements, supplementing it with inorganic sources is recommended especially for the poor nutrient soils in the sampled areas.
To realize optimum yields in the study areas, fertilizer application rates of at least 60kg N ha-1 and 10kg P2O5 ha-1 would be required. It must be noted that soils are highly variable and thus there is “no fit to all recommendation”.
In addition, integrated soil fertility management (ISFM) and soil Conservation Agriculture (CA) practices should be introduced. Integration and use of improved seeds, organic and inorganic fertilizers to increase and stabilize crop yields is recommended. Training extension officers on ISFM and CA practices is

recommended to help propagate the knowledge to smallholder farmers to enhance crop production.

Acknowledgements

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