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Original Research

Spatial Distribution of Soil Moisture for Arable Crop Production in Selected Locations in Southern Nigeria

JD Njoku[1], MC Iwuji[1], EU Onweremadu[2], KOE Ukaegbu[1] and AU Onyechere[3*]

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ABSTRACT

Purpose: *The study investigated spatial variability of soil moisture in soils of Southern Nigeria for arable crop production in order to cushion the effect of drought on crops Some of the crops grown during the planting season experiences drought.*

Research Method: *Auger soil samples were collected, bulked at 0-15cm and 15-30 cm depths in selected locations in Akwa Ibom, Imo and Rivers states of Southern Nigeria. Core samples were also collected for determinations of bulk density, gravimetric soil moisture and permeability characteristics of soils. The average values were presented as map.*

Findings and Values: *Soil colour indicated reduction reactions. Soil structural grade showed weak to moderate structures while fine to very fine classes dominated. Sand-sized particles dominated over other particle sizes and ranged from 800 to 910 g/kg. At the depth of 0-15cm, soil moisture ranged from 3.52 to 18.3% (dry season) and from 10.99 to 22.87% (rainy season). At 15-30cm depth, soil moisture varied from 4.69 to 19.70% (dry season) and from 12.66 to 31.49%. (rainy season). The map revealed that soils of Ngor Okpala in Imo State had the least average moisture content during the rainy season. Soil Sampling was limited to the depths of 0 to 30cm and these results may not be applicable to crops that exceed this rooting depth. This research exposes adverse soil moisture changes spatially capable of reducing crop production in soils of Southern Nigeria.*

Keywords: *Arable crop production, Drought, Permeability, Soil moisture, Spatial variability*

INTRODUCTION

Water is relevant for all life forms including plants which depend on soil water to thrive. Not all forms of soil moisture are available for plant use (Seyedeh *et al.* 2017), making investigations into moisture characteristics of soils expedient. Such investigations are necessary to avert agricultural drought that might occur during growing seasons of plants, especially arable crops.

Several scholars have emphasized the necessity to monitor soil water and moisture characteristics (Gruber & Peng 2023, Hunduma & Kebede 2020). Hunduma & Kebede (2020) stressed the use of gravimetric methods to investigate soil moisture content, while Gruber & Peng (2023) monitored the temporal

[1]Department of Environmental Management, School of Environmental Sciences, Federal University of Technology, Owerri, Imo State Nigeria.
[2]Department of Soil Science and Technology, School of Agriculture and Agricultural Technology, Federal University of Technology, Owerri, Imo State Nigeria.
[3]Department of Soil Science, School of Agriculture, University of Agriculture and Environmental Sciences, Umuagwo, Imo State Nigeria.
*onyechere.adaobi@gmail.com
https://orcid.org/0000-0003-1001-592X

variability of soil moisture and interactions of soil water at the plant-atmosphere interface. Soil moisture varies with distance on the earth's surface. Variation in soil moisture could be due to land use (Onweremadu 2014), irrigation (Datta *et al.* 2017), time of the year (Zotarelli *et al.* 2010), climate change (Barella-Ortiz 2014) vegetation of the location (Oldfield *et al.* 2019), nature of soil (Zhu *et al.* 2022), and interaction of rainfall with plant cover (Chinago 2020).

Properties of soil determine behavior of soils (Onweremadu 2022) as soil moisture characteristics differ in locations due to changes in particle size (Mobilian & Craft 2021), soil structure (Orji 2018), aggregate type (Nweke & Nnabude, 2014), organic matter content (Hatten & Liles 2019), hydraulic conductivity (Zhu *et al.* 2022), and water retention capacity (Indoria *et al.* 2020).

In recognition of the effect of climate on soil processes and behavior, soil moisture regimes are prominent in the classification of soils (Soil Survey Staff 2022). Prevailing soil moisture regimes in Nigeria include aquic, udic and ustic soil climates, which vary with the climatic zones of Nigeria. It follows that rainfall characteristics of amount, intensity and duration vary from the southern part of Nigeria towards the northern areas of the country. These rainfall characteristics dictate the type and density of plant species distribution. Consequently, plant species differ among mangrove swamp, rainforests, and savannas.

However, climate change has resulted in irregularities in the rainfall pattern as extreme rainfall events occur. The trend has led to dry spells during growing seasons, influencing to a large extent arable crop production. Onweremadu (2014) remarked that rainfall varies unpredictably in amount, intensity and duration and that these rainfall attributes co-vary in permutations to produce phenomenal agricultural drought, creating low resilience to hazards of climatic aberrations.

Droughts and floods are extremes of soil moisture which dictate the type of crops that grow on the landscape. Such climatic hazards, including temporal variability in rainfall, resulted in adverse soil moisture changes (Opara 2014) which reduced crop yield in bell pepper (Olufunmi & Adeoye 2017) and in okra (Abagyeh *et al.* 2017).

Given the role of soil moisture in sustaining crop yields, these improved food supply and guaranteed nutrition security. Amidst increasing population in a changing climate, it becomes necessary to assess soil moisture status with space in Southern Nigeria and its effect on spatial distribution of arable crops.

MATERIALS AND METHODS

Study area

The study was conducted with sampling sites situated in the Southern part of Nigeria (see Fig. 1). A total of 12 locations were sampled, four locations from each state. The states sampled were Rivers State (*Eleme, Nkpolu, Obio-Akpor, and Okrika*), Akwa Ibom State (*Essien Udim, Ikono, Obot Akara, and Ikot Ekpene*), and Imo State (*Oguta, Ngor Okpala, Umuna, and Mbato Okigwe*). The geographical coordinates of the states are as follows: Rivers State: (Latitudes $4°28′38.57″$ and $5°29′30.95″$N; Longitudes $6°26′36.01″$ and $7°38′34.77″$E), Akwa Ibom State: (Latitudes $4°27′54.84″$ and $5°30′26.03″$N; Longitudes $7°30′16.96″$ and $7°49′0.94″$E), Imo State: (Latitudes $5°14′10.42″$ and $5°56′4.88″$N; Longitudes $6°53′15.43″$ and $7°22′4.67″$E)

The states had few undulating geomorphological settings but more of plains and depressions. Soils are derived from coastal plain sands (Ngor Okpala, Essien Udim, Ikono, Obot Akara, and Ikot Ekpene), alluvium (Oguta, Eleme, and Obio-Akpor), sandstones (Umuna and Mbato Okigwe), and deltaic marine deposits (Nkpolu and Okrika). The area lies within the humid tropical climate with minimum rainfall of about 1,800 mm annually and maximum annual rainfall of about 3,000 mm. The rainfall pattern of the area is bimodal with peaks in July and September. The area has a dry spell occurring mainly during the month of August, popularly referred to as the "August Break."

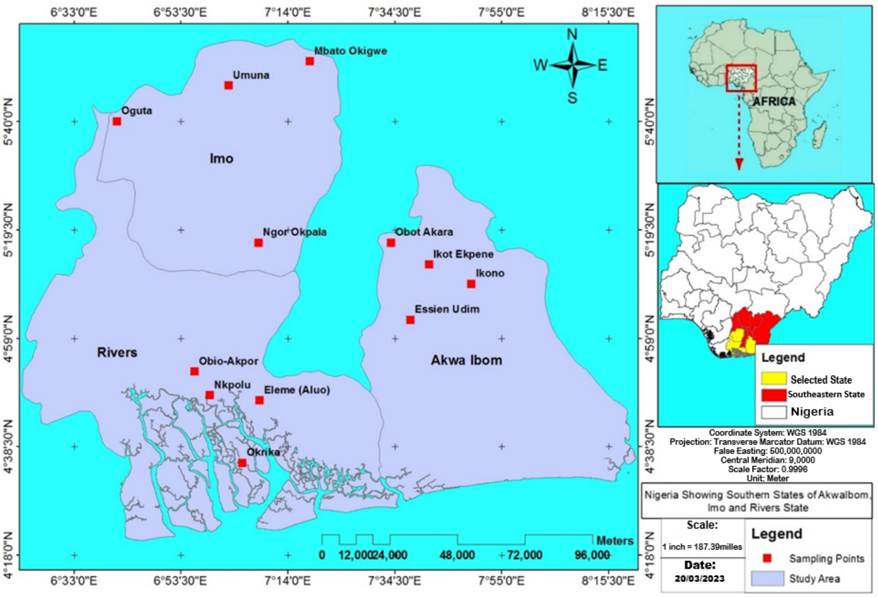

Figure 1. Study area showing sampling points.

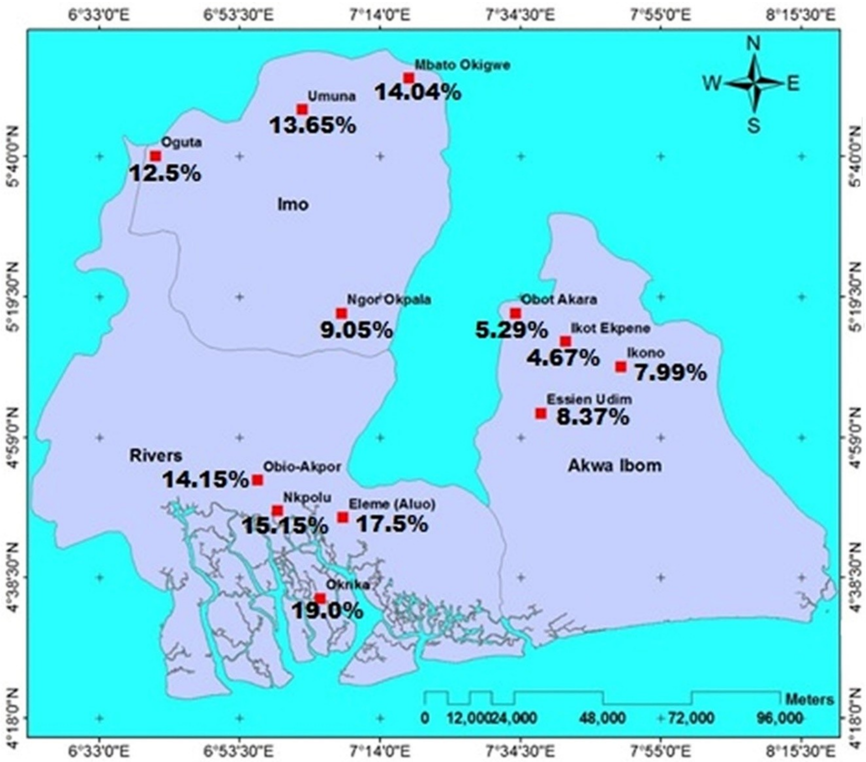

Figure 2. Spatial distribution of moisture content (dry season)

The vegetation of the area is mainly evergreen rainforest with mangrove swamp forest found at the southernmost part bordering the Atlantic Ocean. The vegetation is arranged in tiers with sun-loving plant species towering above shade-loving types mainly located at the forest floor. Climbers and twining plant species are found clinging to shrubs and trees. The hydrology of the area is governed mainly by the River Niger and the Atlantic Ocean, with each state having many rivers and their tributaries.

Socioeconomic activities vary in the area, dominated by arable crop production. Other socioeconomic activities include hunting, fishing, processing of farm products, cottage industries, and exploitation of crude oil. Slash-and-burn techniques are used for land clearing. Agriculture is rainfed with crops varying in response to vegetational zone.

Brief description of sampling sites

Rivers State: The site is located on a flat sandy terrain with depressions interspersing the landscape. Tall plant species dominate the area with taller trees found at the creeks. Climbing plant species were observed, and various forms of organic materials at different stages of decomposition were found. Termitaria were observed as the major faunal activity of the area. Prop and hanging roots, especially pneumatophores, were found.

Akwa Ibom State: The site represents a secondary forest with many plant species growing on an undulating slope. Grasses were sparsely observed. It is a typical rainforest soil with faintly dark to brown, sandy loam textures. Outstandingly strong soil aggregates were observed on soil surfaces. Evidence of old farming activity was found. There were few erosion channels on the landscape. The forest floor was characterized by different stages of organic matter decomposition.

Imo State: The site is a gentle sloping terrain of about 5% slope with a secondary forest. A variety of plant species dominated by oil palm trees (*Elaeis guineensis*) were found. Plant species, as in other agro-ecologies, were arranged in storeys with emergent trees like Iroko towering above others. Litter from plants was observed at the forest floor, and various forms of faunal activities were present. Soils were well-drained and rill erosion channels were found.

Field studies

A reconnaissance visit was conducted at the sites before actual field work for familiarization. A free survey technique was used in each site. Physiography, vegetation, and climatic zonation guided field collection of soil samples. Cores were used to collect soil samples from undisturbed sites. These core samples were collected during rainy and dry seasons in each site and state. Sampled sites were georeferenced using a handheld global positioning system (GPS) receiver (Garmin, Kansas, USA). Morphological properties of soils were examined and recorded. Core samples were covered with white cloth, bagged, labelled, and transported to the laboratory for determinations of physical properties including soil moisture content. Soil color was determined using the Munsell colour chart.

Laboratory analyses

Particle size analysis was determined using the Bouyoucos hydrometer method according to the procedure of Gee & Or (2002). Values of the size fractions were used to obtain textural classes with the aid of a textural triangle. Bulk density was estimated by the core method according to Grossman & Reinsch (2002). Total porosity was calculated using the relationship between bulk density and particle density with an assumed particle density value of 2.65 mg/m^3:

$$TP = \left(1 - \frac{BD}{PD}\right) \times 100$$

where:

- TP = Total porosity
- BD = Bulk density
- PD = Particle density (2.65 mg/m^3)

Soil moisture was determined gravimetrically

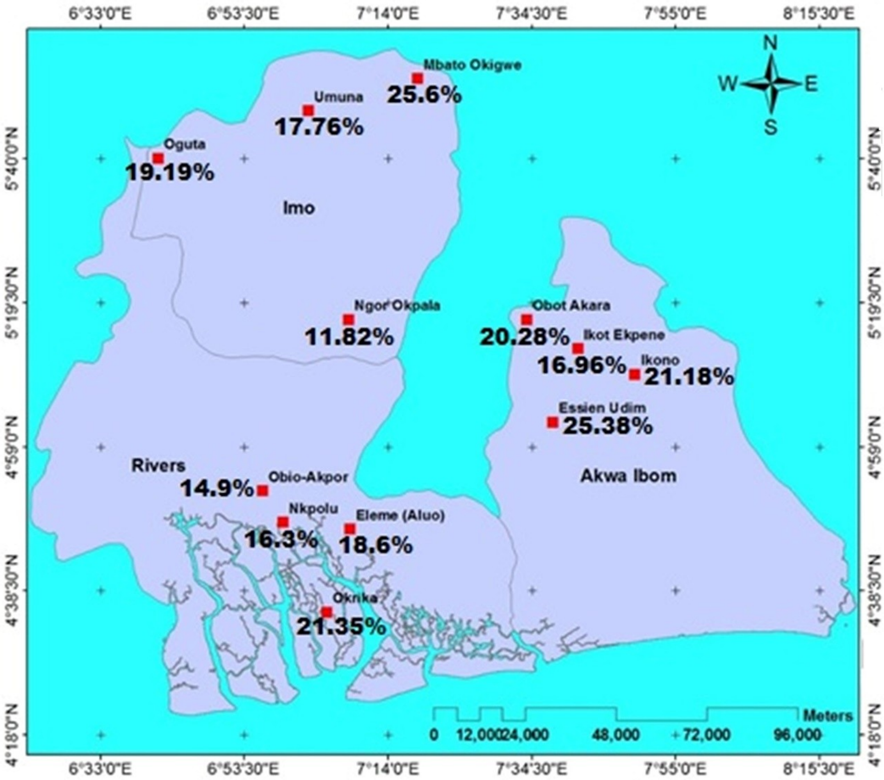

Figure 3. Spatial distribution of moisture content (rainy season)

(on mass basis) (Obi 1987) as:

$$\text{Soil Moisture (\%)} = \frac{\text{Mass of water at saturation}}{\text{Oven-dry mass of soil}} \times 100 \quad (1)$$

Permeability was determined as the amount of soil water moving downwards via a saturated soil (Carter *et al.* 1999).

RESULTS AND DISCUSSION

Table 1 shows some morphological properties of studied soils. With the exception of soils of Ngor Okpala in Imo state that was brown (0–15 cm depth) and reddish brown (15–30 cm depth), most other soils had colour shades ranging from pale brown, brownish yellow, yellow, gray, light gray, olive, and olive yellow indicating poor to imperfect drainage due to pedogenic process of reduction.

These colorations due to reduction reaction were more predominant in Akwa Ibom and Rivers states of Southern Nigeria. By implication, arable crops that are water-tolerant are suggested and recommended to farmers but with land improvement, a variety of crop species are adaptable.

Soil structural grade differed among soils distributed on the landscape. Generally, there was poor to moderate aggregation as soil grades were 1 (weak structure) and 2 (moderate structure), respectively. Again, granular structures dominated over crumb structure types as the latter retains more soil moisture. Earlier, Adesodun & Adekonojo (2011) noted that high clay content results to higher micro aggregation while high organic matter content results in larger micro - aggregates. Clay content of soils were low especially in soils of Ikot Ekpene (Akwa Ibom state) and Ngor Okpala (Imo state) and this could have influenced the weak grades of soil structure. The study recommends that organic materials including left-overs from previous harvests should be left to decay on soils for adequate soil structure. Table 2 presents soil physical properties. Sand-sized particles dominated the textural class indicating rapidity of soil moisture mobility and low retentivity in soils (Table 2). Sand varied from 820 g/kg(Ikono) to 880 g/kg (Ikot Ekpene) in Akwa Ibom state, 828 g/kg (Mbato Okigwe) to 910 g/kg(Ngor Okpala) in Imo State while 800 g/kg (Okrika) to 870g/kg (Nkpolu) in Rivers State. Next in abundance is clay-sized particles which ranged from 60 g/kg

Table 1. Morphological properties of soils

Sample Location	Soil Depth (cm)	Colour Matrix Moist	Structure		
			Grade	Class	Type
Essien Udim	0–15	Pale Brown (10YR0/3)	2	F	gr
	15–30	Brownish yellow (10YR6/6)	2	F	sbk
Ikono	0–15	Pale brown (2.5Y7/6)	1	VF	gr
	15–30	Yellow (2.5Y7/6)	2	F	gr
Obot Akara	0–15	Light gray (10YR7/1)	2	F	gr
	15–30	Light gray (10YR7/2)	2	F	gr
Ikot Ekpene	0–15	Grayish brown (10YR5/2)	1	F	gr
	15–30	Gray (10YR6/1)	2	F	gr
Oguta	0–15	Yellow (2.5Y7/6)	1	VF	cr
	15–30	Yellow (2.5Y7/8)	2	F	cr
Ngor Okpala	0–15	Brown (10YR4/3)	1	VF	gr
	15–30	Reddish brown (5YR4/3)	2	F	sbk
Umuna	0–15	Dark brown (7.5YR3/3)	1	F	gr
	15–30	Brown (7.5YR4/3)	2	F	gr
Mbato Okigwe	0–15	Brown (7.5YR4/4)	1	F	gr
	15–30	Light brown (7.5YR6/4)	2	F	gr
Eleme	0–15	Dark grey (5Y4/1)	1	F	gr
	15–30	Gray (5Y5/1)	1	M	gr
Nkpolu	0–15	Olive (5Y4/3)	3	F	gr
	15–30	Olive (5Y4/4)	1	M	gr
Obio-Akpor	0–15	Gray (2.5Y5/1)	3	M	cr
	15–30	Gray (2.5Y6/1)	1	M	cr
Okrika	0–15	Olive yellow (5Y6/6)	1	F	cr
	15–30	Olive yellow (5Y6/8)	3	M	cr

Grade: 1 = Weak, 2 = Moderate, 3 = Strong; Class: F = Fine, VF = Very Fine, M = Medium; Type: cr = Crumb, gr = Granular, sbk = Subangular blocky

Table 2. Particle size distribution, bulk density and porosity of soils

Sample Location	Depth (cm)	Particle Size distribution (g/kg)			Bulk density (Mg/m^3)	Total Porosity (%)
		Sand	Silt	Clay		
Essien Udim	0–15	850	50	100	1.21	54.33
	15–30	830	60	110	1.35	49.05
Ikono	0–15	860	40	100	1.20	54.71
	15–30	820	60	120	1.40	47.16
Obot Akara	0–15	870	40	90	1.26	52.45
	15–30	860	30	110	1.41	46.79
Ikot Ekpene	0–15	880	60	60	1.18	55.47
	15–30	870	50	80	1.28	51.69
Oguta	0–15	840	40	120	1.33	49.81
	15–30	830	50	120	1.38	47.92
Ngor Okpala	0–15	910	10	80	1.22	53.96
	15–30	900	20	80	1.27	52.07
Umuna	0–15	810	30	160	1.29	51.32
	15–30	800	60	140	1.35	49.05
Mbato Okigwe	0–15	830	40	130	1.31	50.56
	15–30	820	70	110	1.37	48.30
Eleme	0–15	840	40	120	1.33	49.51
	15–30	820	50	130	1.39	47.54
Nkpolu	0–15	870	30	100	1.35	49.05
	15–30	860	30	110	1.41	46.79
Obio-Akpor	0–15	850	40	110	1.31	50.56
	15–30	830	60	110	1.38	47.92
Okrika	0–15	820	30	150	1.29	51.32
	15–30	800	50	150	1.37	48.30

TS = Total solid; TSS = Total soluble solid; TTA = Titratable acidity; SG = Specific gravity; FC = Foam capacity; VC = Viscosity.

Table 3. Soil moisture and permeability of soils

Sample Location	Depth (cm)	Moisture content (%)		Permeability (cm)		Permeability Index	
		Dry	Rainy	Dry	Rainy	Dry	Rainy
Essien Udim	0–15	7.93	19.27	0.70	0.60	3	3
	15–30	8.81	31.49	0.65	0.50	3	3
Ikono	0–15	8.11	22.87	0.75	0.55	3	3
	15–30	7.88	19.49	0.60	0.50	3	3
Obot Akara	0–15	5.89	21.10	0.65	0.60	3	3
	15–30	4.69	19.47	0.60	0.55	3	3
Ikot Ekpene	0–15	3.52	17.76	0.70	0.65	3	3
	15–30	5.83	16.16	0.55	0.45	3	2
Oguta	0–15	12.20	19.27	0.50	0.40	3	2
	15–30	12.80	19.12	0.45	0.35	2	2
Ngor Okpala	0–15	8.90	10.99	6.90	4.60	5	4
	15–30	9.20	12.66	5.70	4.55	5	4
Umuna	0–15	13.20	17.22	1.60	1.40	4	3
	15–30	14.10	18.31	0.50	0.45	3	2
Mbato Okigwe	0–15	12.45	21.30	0.60	0.50	3	3
	15–30	15.63	29.90	0.50	0.40	3	2
Eleme	0–15	17.30	18.40	0.65	0.50	3	3
	15–30	17.70	18.80	0.45	0.40	2	2
Nkpolu	0–15	14.70	15.90	0.50	0.40	3	2
	15–30	15.60	16.70	0.40	0.35	2	2
Obio-Akpor	0–15	13.40	14.10	0.45	0.40	2	2
	15–30	14.90	15.70	0.40	0.35	2	2
Okrika	0–15	18.30	21.00	0.50	0.45	3	2
	15–30	19.70	21.70	0.40	0.35	2	2

Permeability Index: 2 = Slow, 3 = Moderately slow, 4 = Moderate, 5 = Moderately rapid to 120 g/kg in Akwa Ibom State, 80g/kg to 160 g/kg in Imo State and 110 g/kg to 150 g/kg in Rivers State.

There were variations in bulk density and total porosity values of soils (Table 2). Bulk density had a universe relationship with total porosity of soils of Southern Nigeria.

Higher values of bulk density in subsurface horizons could be as a result of decreased soil organic matter content with depth as earlier stated by Kamalu & Nwonuala (2015).

Results of soil moisture and permeability of soils are given on Table 3. Generally, permeability index (P.I.) of soils varied from slow, moderately slow, moderate to moderately rapid (Table 3). With the exception of soils of Ngor Okpala that is moderately rapid, other soils exhibited different grades of low permeability suggesting the ability of the soils to temporarily retain soil moisture for arable crop uptake and production. Rapidity of Ngor Okpala soils is traceable to the porous nature of its parent material (coastal plain sands) which is known to have several macropores.

Soil moisture values varied in space and with seasons (Fig 2 and Fig 3). Rainy season soil moisture values were higher than dry season soil moisture. This temporal variability differed on the landscape of Southern Nigeria implying that crops can be allocated along the space according to moisture requirements. However, it suggests that water-loving crops (examples: rice, sugarcane, cocoyam, banana and plantain) can be cultivated within the rainy season while water-hating crops or drought resistant plant species (examples: cowpea, peanuts, Bambara groundnut, and cassava) can be grown in the dry season.

This will promote all -season availability of crops for human consumption. It is posited that crops that have the capacity of completing their life cycle within each season are preferred.

CONCLUSION

Soil moisture varied spatially and temporally in Akwa Ibom, Imo and Rivers states. Variation was in relation with other soil properties like colour, bulk density and total porosity which differed in space. The variation suggests that soil moisture in the southern part of Nigeria is suitable for a variety of crops. It becomes necessary to match crops to soils with reference to the soil moisture characteristics.

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