Moor Journal of Agricultural Research 26(1): 53- 72, 2025

MOOR JOURNAL OF AGRICULTURAL RESEARCH
Journal homepage: https://iart.gov.ng/moorjournal/index.php/mjar/

Land Evaluation of Balanga Irrigation Scheme, Balanga Local Government Area, Gombe State, Nigeria

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Article Info

Article history:
Received: December 2, 2024
Revised: April 11, 2025
Accepted: June 2, 2025

Keywords:
Fertility classification
Food security
Irrigation
Spatial Interpolation
Soil variability

Abstract

The productivity of Balanga Irrigation Scheme in Gombe State, Nigeria, is declining, necessitating a land evaluation to determine the causes and improve sustainable crop production. Soils samples were collected at 0 - 30 cm depths in a grid of 1km interval from the slope positions (upper, middle, and lower slope) and analysed for physiochemical properties using standard laboratory procedures. The results showed upper and middle slopes positions were clayey while lower slope was clay loam. The soil pH ranged (7.7 – 8.7) was slightly alkaline to strongly alkaline. Soil organic carbon (OC) and total nitrogen (TN) values were rated low for all slope positions (< 10 g/kg and < 1.5 g/kg). Soil available phosphorous (Avail. P.) was low to moderate for the slope positions. All the slope classes were rated high in exchangeable bases but low in soil exchangeable acidity. The highly variable properties were OC, Avail. P, and K while the least variable was pH and BS. Spatial interpolation result shows higher fertility area dominated the irrigation scheme with 48% (2689.9 ha) followed by medium fertility with 42% (2331.4 ha) and the low fertility area with 11% (593.8 ha). Based on the fertility capability classification (FCC), middle slope offers the best conditions for arable agriculture followed by lower and upper slope position. The limiting factors for crop production are gleying, excessive wetness, and the general low OC, Avail. P. and TN. The need for application of organic manure and construction of drainages based on site requirements for sustainability.

Introduction

Nigeria is the most populous country in Africa with an estimated population of 180 million in 2015, and majority of its population (65%) live in rural areas (Aidi *et al*., 2016). The major occupation of the people is agriculture characterized by low levels of productivity (Dayo *et al*., 2009), resulting in food insecurity. This makes the country rely mostly on food importation to feed the growing population despite her agricultural potential (Adelodun and Choi, 2018). The failures of most Irrigation projects in Nigeria were due to lack of conducting a detailed soil survey in place of reconnaissance or semi-detailed soil surveys and periodic soil fertility monitoring. The establishment of Irrigation Schemes without a proper detailed soil survey runs the risk of failure or inadequate economic returns. Atofarati *et al.* (2012) also reported that the major factor limiting agricultural productivity in the country is inadequate information on land. Sustainable agricultural production could be met through a systematic land evaluation of the soils.

Similarly, the Gombe State Government also has seen the need to increase food production and create employment given to the growing population in a bid to achieve zero hunger of the sustainable development goal two (SDGs 2). In addition, the State is ready to harness Balanga and Cham dam for irrigation farming

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which were grossly underutilized according to the commissioner for water resources (Azubuike, 2020). However, the State government had arranged to provide farmers with inputs (herbicides, seedlings, fertilizer, and pesticides) at a subsidized rate in preparation for future dry-season farming. However, the willingness of the government to improve food productivity and diversify the economy is far from just making policy and providing farm inputs. Over the years, farmers under Balanga irrigation scheme have been complaining of continuous decline in productivity of Balanga irrigation scheme. This had led the local farmers to apply ashes and other farm inputs to the soils in other to improve the soil productivity but with no significant improvement. There is the need for land evaluation studies which will help to reveal the limitation of the soil and the specific management practices required to achieve maximum productivity. Balanga Irrigation Scheme is the largest irrigation scheme in Gombe state with high potentials for food security if well managed. It can be a hub for crop production in the northeast and Nigeria at large.

Ironically, there are limited information on land evaluation in Balanga Irrigation Scheme for its potential to be harnessed. Previous studies on land evaluations in respect to its suitability, fertility capability and irrigation capability status was generally limited to pockets of areas over Gombe State and in particular Balanga LGA. This includes study by Salem et al., (2016) who assessed the suitability of Calcareous parent material derived soils for mango and guava production in Yamaltu Deba, Gombe State. The result shows that the soils were currently not suitable for the tree crops due to low nutrient reserve which could be corrected through appropriate management practices. Sadeeq *et al.*, (2020) assessed soil salinity conditions in Dadinkowa irrigation project, Yamaltu Deba, Gombe State. They reported that the soils were low in salinity and sodicity but use of pipes for Irrigation was recommended instead of farrow system which could gradually lead to salt accumulation in the soils. Further, Jimoh et al., (2019) also evaluated soil quality under date palm plantation in Gombe State University, Gombe LGA. The results showed that the soils are moderate in quality and have higher potential to sequester more carbon to support crop production and climate change mitigation.

Based on available literature, there are no related studies in Balanga Local Government Area. The need to fill the gap in knowledge and identify factors limiting sustainable crop production in the scheme and proffer solution to identified problems. This study evaluates the soil potentials for a wide range of land use options and formulate land use plans necessary for economically viable, socially acceptable, and environmentally sound initiatives (Sathish and Niranjana, 2010). Esu (2004) reported that studying soil in detail through the processes of soil characterization and land evaluation for various land utilization types is one of the strategies for achieving food security as well as a sustainable environment. This study aims to conduct land evaluate of Balanga irrigation scheme, Balanga Local Government Area, Gombe State, Nigeria. The specific objectives are to: (1) analyze the physical and chemical properties of the soils in the irrigation scheme (2) determine fertility capability classification of soils and generate fertility map of the irrigation scheme for sustainable management and (3) determine the variability in soil properties within each slope class.

Materials and Methods

Study area

The study area is Balanga Local Government Area of Gombe State where the dam and irrigation scheme are located. The area lies between latitude 09^0 32’ to 10^0 04’ N and longitude 11^0 20’ E to 11^0 52’ E of the Green Wich Meridian (Figure 1). It is bordered by Reme and Balanga to the south, Tula-lafiya in the west, Gelengu to the east and Swa District to the north. The Balanga dam was built in the 1980’s on River Balanga to provide water for Irrigation practice. The geology of the area is characterized by older basalt, sandstones, siltstone, shale, and fluvisols (Ikusemoran et al., 2018). The major and most important river that drains the area is River Balanga. The climate has two distinct seasons, the dry season (November–March) and the rainy season (April–October) with an average rainfall of 950mm. The mean annual temperature is about 30˚C, while the vegetation of the area is that of savanna woodland comprising scattered shrubs and trees such

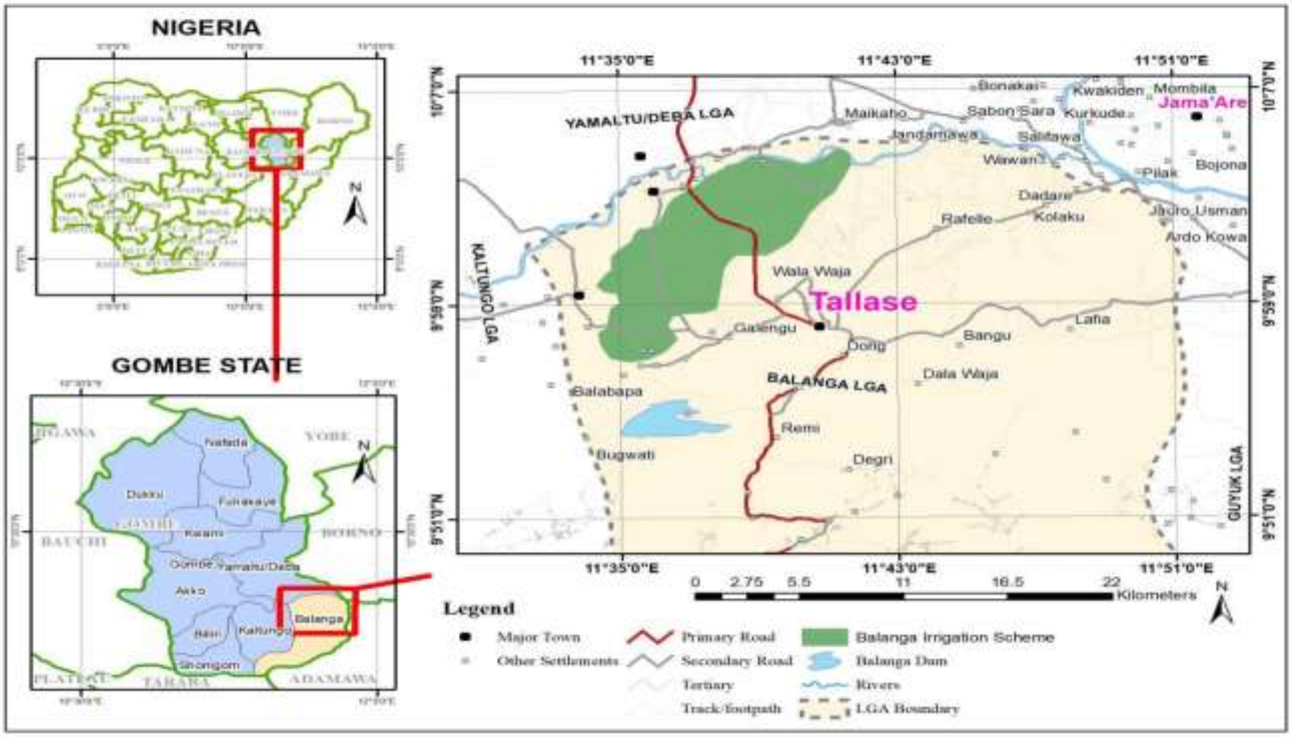

Fig. 1: Balanga LGA showing Balanga Dam and Irrigation scheme.

as *Butyrospermum, paradoxum, Tamarin indica, Parkiabiglibosa, Aflexia Africana,* and grasses (Ikusemoran *et al.,* 2018). The major crops grown include rice, guinea corn, maize, cowpea and vegetables

Field work

A Reconnaissance field survey was undertaken to identify the various land uses and ground truthing of road network identified in the Satellite images to validate the interpretation of images. Satellite imageries and digital elevation model (DEM) was used to delineate and map different soil types and slope classes (upper, middle, and lower slope positions) in the study area and other relevant geographic phenomena. A detailed soil survey was then conducted in the study area at a scale of 1:25,000. A base map with a grid at 1000m (1km) intervals was drawn covering an area of 2800 hectares. The base map was geo-referenced and uploaded into the global positioning system (GPS). Ten (10) soils samples were collected at 0 - 30 cm depths in a grid of 1km interval superimposed on the study area for each of the slope positions (upper, middle, and lower slope positions) making a total of thirty soil samples (30) (Fig. 2).

Laboratory analysis

The analysis was carried out at Department of Soil Science Laboratory, Ahmadu Bello University Zaria from June 2024 – July 2024. The soil sample were then air-dried, grounded, and sieved through a 2 mm sieve, after which less than 2 mm fractions were used for laboratory analysis using Agbenin (1995) procedure. Particle size distribution was determined by the hydrometer method. Soil pH was measured in water and 0.01M $CaCl_2$ (1:2.5 w/v) using glass electrode pH meter. Organic carbon (O.C.) was determined by the dichromate wet oxidation method of Walkley and Black. Total nitrogen (T.N.) was determined by micro Kjeldahl method. Available phosphorus (Avail. P.) was determined using Bray 1 method. Exchangeable bases (calcium (Ca), magnesium (Mg), potassium (K), and sodium (Na) in the soil were determined using the ammonium acetate extract. Sodium and potassium in the extract were determined using flame photometer, while calcium and magnesium were determined using atomic absorption spectrometer (AAS).

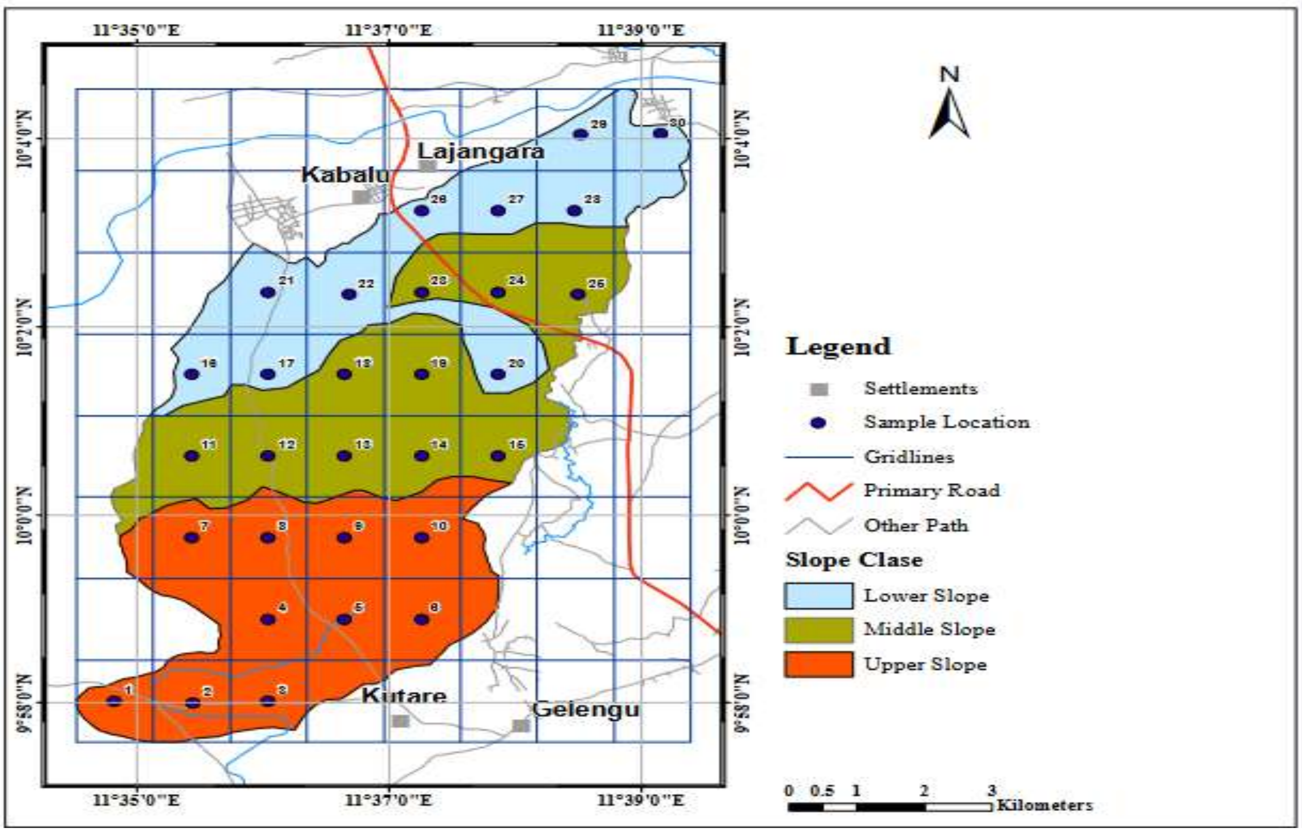

Fig. 2: Topographic map of Balanga irrigation scheme site

Evaluation of fertility capability class (FCC)

Soil fertility capability class consists of three categorical levels: type (texture of upper 20 cm of surface soil), sub–strata type (sub-soil texture between 20 and 50 cm depth), and condition modifiers (physical and chemical properties that influence the interaction between soil and fertilizer materials). Class designations from the three categorical levels are combined to form an FCC unit (Table 1).

Spatial interpolation and data analyses

This study predicted values between sampling points through Kriging interpolation analysis to generate a continuous surface, predict possible results of missing areas, and estimate missing data to produce final analyze results. Descriptive statistics and inferential statistics such as mean, standard deviation, percentage coefficient of variation (% CV) and analysis of variance (ANOVA) was used to test for variation in physical and chemical properties within and across the different slope classes. The CV classification scheme for identifying the extent of variability for soil properties are: CV values of 0-15, 16-35, and > 36% indicate low (least), moderate, and high variability, respectively.

Results

Soil physical properties

The mean sand content was 28, 30, and 36 g/kg for upper, middle, and lower slope positions, respectively (Table 2). Sand values increased down the slope class and there was no significant difference ($p > 0.05$) across the slope classes. Further, the Upper (CV=24.80%) and lower (CV=30.26%) slope positions were observed to be moderately variable in mean sand content, while middle slope (CV=15.68%) was least variable (Table 2). Mean silt content was 27, 28, and 26 g/kg for upper, middle, and lower slope positions, respectively (Table 2). Silt content was observed to be irregularly distributed down the slope class and there was no significant difference ($p > 0.05$) between the slope classes. The lower (CV=25.97%) slope was moderately variable while upper (CV=15.52%) and middle (CV=10.99%) slopes were least variable (Table

Table 1: Fertility Capability Classification (FCC) showing texture, chemical and modifiers

Level	Description	Interpretation
Types	Top soil	Texture of top 20 cm of the soils
S	Sandy	Loamy sand and sand
L	Loamy	< 35% clay
C	Clayey.	> 35% clay
O	Organic	> 20% at 50 cm depth or more
Substrate	Sub soil	Texture of top soils within 50 cm of the surface
Types		
S	Sandy	Loamy sand and sand
L	Loamy	< 35% clay
C	Clayey	> 35% clay
R	Rocky	Hard layer restricting root growth
Modifiers		
K	Low K contents	K value < 0.2 $Cmolkg^{-1}$
E	Low CEC	CEC < 4 and 7 $Cmolkg^{-1}$
A	Al toxicity	Al > 60% $Cmolkg^{-1}$
H	Acidic	Acidity level 4 – 6.0 in water and KCl
S	Salinity.	> 4 dsm^{-1}
G	Gleying.	Mottles < 2 chroma within 60 cm of soil.
N	Nitric.	> 15% Na saturation of CEC.
I	Low P. reserves.	< 8 $mgkg^{-1}$
C	Cat clay	pH < 3.5 in water.
%	Slope	1 – 6% of slope gradient.
W	Ponding	Excessive water accumulation at 20 cm depth

Source: Sanchez *et al*. (1982) in Egbuchua (2011)

2). The mean clay content was 44, 41 and 37 g/kg for upper, middle, and lower slope position, respectively (Table 2). Clay values decreased down the slope class and there was no significant difference ($p > 0.05$) across the slope classes. Upper (CV=16.99 %) and lower (CV=21.53%) slope positions were moderately variable while middle slope (CV=11.09%) was least variable in clay content, similar to sand content (Table 2). Similarly result of soil interpolation shows higher distribution of sand in lower slope, silt in the middle slope while clay in the upper slope position (Figs. 3a-c).

Table 2: Soil physical and chemical properties of study area.

Soil Properties	Topography	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum	C V	Sig.
(%) Clay	Upper	9	44.22	7.51	2.50	28.00	54.00	16.99	0.162
	Middle	9	41.33	4.58	1.53	34.00	50.00	11.09	
	Lower	7	37.43	8.06	3.05	28.00	54.00	21.53	
(%) Silt	Upper	9	27.33	4.24	1.41	20.00	34.00	15.52	0.737
	Middle	9	28.44	3.13	1.04	24.00	34.00	10.99	
	Lower	7	26.57	6.90	2.61	18.00	36.00	25.97	
(%) Sand	Upper	9	28.44	7.06	2.35	22.00	46.00	24.80	0.155
	Middle	9	30.22	4.74	1.58	24.00	38.00	15.68	
	Lower	7	36.00	10.89	4.12	16.00	48.00	30.26	
pH (H_20)	Upper	9	7.77	0.28	0.09	7.28	8.04	3.62	0.007
	Middle	9	7.97	0.13	0.04	7.73	8.13	1.66	
	Lower	7	8.74	1.01	0.38	7.70	9.91	11.53	
pH ($CaCl_2$)	Upper	9	7.07	0.16	0.05	6.85	7.26	2.25	0.206
	Middle	9	7.23	0.15	0.05	6.90	7.38	2.06	
	Lower	7	7.24	0.31	0.12	6.66	7.62	4.32	
EC	Upper	9	0.07	0.04	0.01	0.05	0.16	51.95	0.407
	Middle	9	0.08	0.06	0.02	0.05	0.25	76.43	
	Lower	7	0.05	0.01	0.00	0.04	0.06	17.64	
OC	Upper	9	0.65	0.13	0.04	0.42	0.84	20.16	0.605
	Middle	9	0.78	0.38	0.13	0.19	1.44	49.14	
	Lower	7	0.71	0.27	0.10	0.38	1.14	38.81	
TN	Upper	9	0.07	0.01	0.00	0.06	0.09	12.08	0.041
	Middle	9	0.08	0.02	0.01	0.06	0.12	23.25	
	Lower	7	0.07	0.01	0.01	0.05	0.09	21.46	
Avail. P.	Upper	9	7.02	1.64	0.55	4.90	8.82	23.40	0.023
	Middle	9	17.69	12.78	4.26	8.33	48.02	72.25	
	Lower	7	16.52	4.80	1.81	10.78	23.03	29.05	

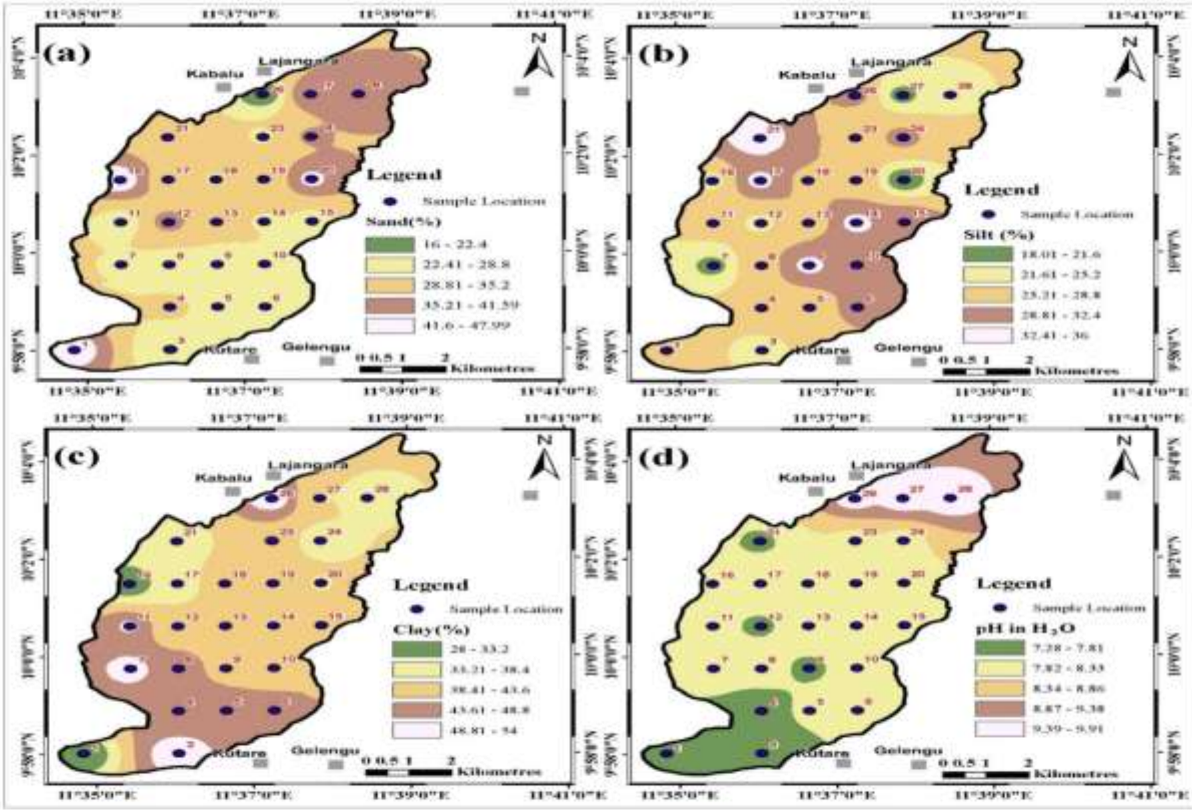

Fig. 3: Soil interpolation of (a) sand, (b) silt, (c) clay and (d) soil pH (H_2O)

Soil chemical properties

Soil pH (H_2O) mean values were 7.77, 7.97, and 8.74 for upper, middle and lower slope positions, respectively (Table 2). Soil pH values increased down the slope class and were significantly different ($p < 0.05$) across the slope classes. All the slope classes show low variability (CV< 12%) in soil pH (Table 2). Soil interpolation shows higher distribution of soil pH in lower slope position (Figure 3a-d). Soil pH ($CaCl_2$) values were 7.07, 7.23, and 7.24 for upper, middle and lower slope positions, respectively (Table 2). Soil pH ($CaCl_2$) values increased down the slope class and there was no significant difference ($p > 0.05$) across the slope classes. All the slope classes were least variable (CV< 15%) in terms of soil pH ($CaCl_2$), which is similar to pH (H_2O). Soil organic carbon (OC) mean values were 6.50, 7.84, and 7.10 g/kg for upper, middle, and lower slope positions, respectively (Table 2). Soil OC values were irregularly distributed down the slope class and there was no significant difference ($p > 0.05$) across the slope classes. All the slope classes were highly variable (CV> 49%) in terms of soil OC (Table 2). Mean values of total nitrogen (TN) were 0.68, 0.83, and 0.66 g/kg for upper, middle, and lower slope positions, respectively (Table 2). Similar to OC, TN values were irregularly distributed down the slope class and there was no significant difference ($p > 0.05$) across the slope classes. The upper slope was least variable (CV= 12.08%) while middle (CV= 23.25%) and lower (CV= 21.46%) slopes were moderately variable in soil TN. Mean values of available phosphorous (Avail. p.) values were 7.02, 17.7, and 16.5 mg/kg for upper, middle, and lower slope positions, respectively (Table 2). Available P. values were also irregularly distributed down the slope classes and there was no significant difference ($p > 0.05$) across the slope classes. The upper (CV= 23.40%) and lower (CV= 29.05%) slopes were moderately variable, while the middle slope (CV= 72.25%) was found to be highly variable in Avail. P. content. Result of soil interpolation show that organic carbon and total nitrogen were higher in middle slope while available phosphorus was higher in lower slope position, implying the middle and lower slope are higher in fertility (Figs. 4a-d).

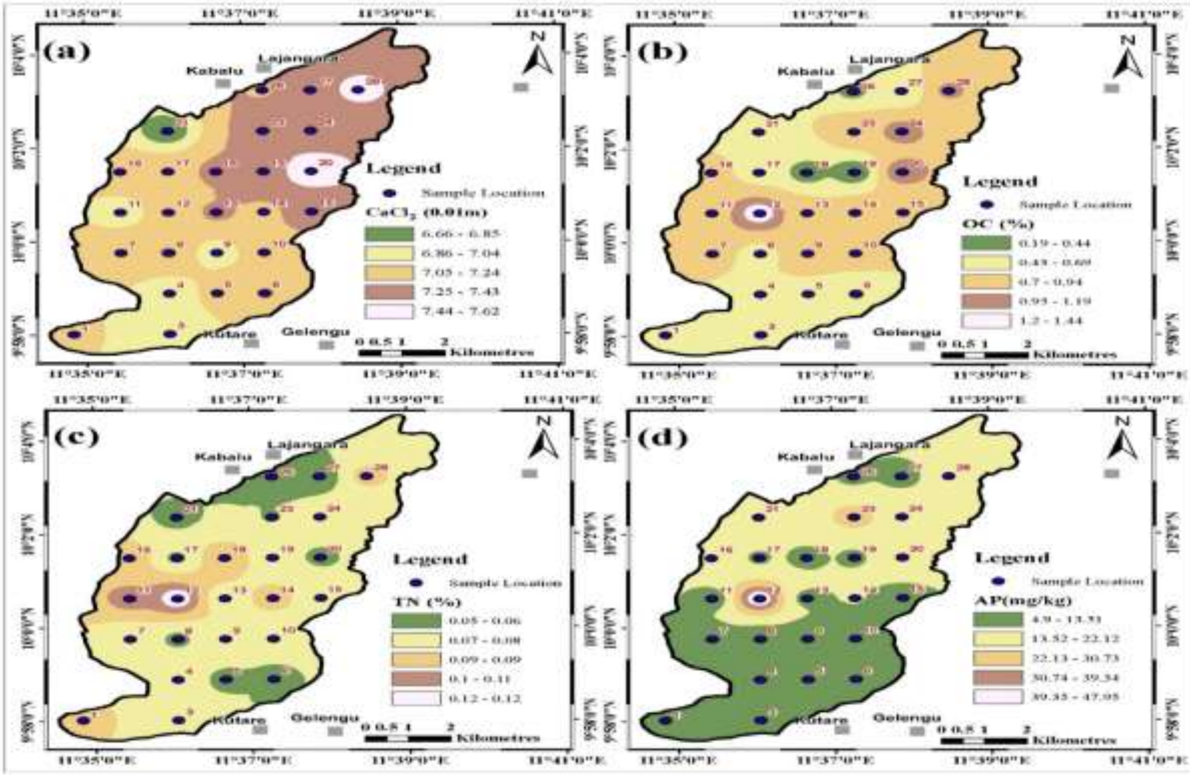

Fig. 4: Distribution of (a) pH ($CaCl_2$), (b) organic carbon, (c) total nitrogen and (d) available phosphorus

The mean values of exchangeable calcium (Ca) were 15.8, 19.5, and 16.5 cmol(+)/kg for upper, middle, and lower slope positions, respectively (Table 3). Also, exchangeable Ca. values were observed to be irregularly distributed down the slope class and there was no significant difference ($p > 0.05$) across the slope classes. The upper (CV= 20.28%) and middle (CV= 27.50%) slopes were moderately variable while the lower slope (CV= 43.41%) was highly variable in Ca soil content (Table 3). The mean values of exchangeable magnesium (Mg) were 4.75, 5.86, and 4.97 cmol(+)/kg for upper, middle, and lower slope positions, respectively (Table 3). Similar to Ca, Mg values were observed to be irregularly distributed down the slope class and there was no significant difference ($p > 0.05$) between the slope classes. Same as exchangeable Ca, the upper (CV= 20.28%) and middle (CV= 27.50%) slopes were moderately variable while lower slope (CV= 43.41%) was highly variable in Mg soil content (Table 3). The mean values of exchangeable potassium (K) were 4.75, 5.86, and 4.97 cmol(+)/kg for upper, middle, and lower slope positions, respectively (Table 3). Exchangeable K values increased down the slope class and there was no significant difference ($p > 0.05$) across the slope classes. Further, all the slope classes were observed to be highly variable (CV> 43.21%) in soil K content (Table 3). The mean values of exchangeable sodium (Na) were 0.64, 0.57, and 0.62 cmol(+)/kg for upper, middle, and lower slope positions, respectively (Table 3). Also, exchangeable Na. values were found to be irregularly distributed down the slope position and there was no significant difference ($p > 0.05$) across the slope positions. The upper slope position was observed to be moderately variable (CV= 25.54%), middle slope least variable (CV= 13.64%), while lower slope was highly variable (CV= 72.16%) in exchangeable Na content (Table 3).

Table 3: Soil chemical properties of Balanga soils.

Soil Properties	Topography	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum	C V	Sig.
Ca	Upper	9	15.82	3.21	1.07	11.00	22.20	20.28	0.316
	Middle	9	19.56	5.38	1.79	9.20	26.80	27.50	
	Lower	7	16.57	7.19	2.72	7.80	29.40	43.41	
Mg	Upper	9	4.75	0.96	0.32	3.30	6.66	20.28	0.316
	Middle	9	5.87	1.61	0.54	2.76	8.04	27.50	
	Lower	7	4.97	2.16	0.82	2.34	8.82	43.41	
K	Upper	9	0.57	0.25	0.08	0.30	1.07	43.21	0.697
	Middle	9	0.58	0.26	0.09	0.29	1.02	44.39	
	Lower	7	0.75	0.77	0.29	0.32	2.46	102.32	
Na	Upper	9	0.64	0.16	0.05	0.48	0.96	25.54	0.838
	Middle	9	0.57	0.08	0.03	0.44	0.71	13.64	
	Lower	7	0.63	0.45	0.17	0.38	1.65	72.16	
H+Al	Upper	9	0.53	0.14	0.05	0.40	0.80	26.52	0.365
	Middle	9	0.44	0.09	0.03	0.40	0.60	19.84	
	Lower	7	0.49	0.16	0.06	0.40	0.80	32.40	
ECEC	Upper	9	22.63	4.16	1.39	16.80	31.40	18.39	0.440
	Middle	9	26.72	6.52	2.17	13.30	36.80	24.41	
	Lower	7	23.87	9.47	3.58	11.90	40.50	39.66	
HCO_3	Upper	9	1.16	0.28	0.09	0.80	1.60	24.13	0.211
	Middle	9	1.44	0.38	0.13	1.00	2.00	26.61	
	Lower	7	1.37	0.37	0.14	0.60	1.80	27.19	
ESP	Upper	9	2.87	0.70	0.23	1.90	4.23	24.22	0.400
	Middle	9	2.23	0.48	0.16	1.58	3.31	21.30	
	Lower	7	2.89	1.91	0.72	1.24	6.65	66.29	
BS	Upper	9	97.66	0.66	0.22	96.55	98.25	0.68	0.267
	Middle	9	98.27	0.56	0.19	97.08	98.92	0.57	
	Lower	7	97.68	1.30	0.49	95.20	99.02	1.33	
SAR	Upper	9	0.20	0.05	0.02	0.14	0.27	23.23	0.548
	Middle	9	0.16	0.02	0.01	0.14	0.19	11.27	
	Lower	7	0.20	0.15	0.06	0.10	0.53	73.68	

Results of soil interpolation show exchangeable Ca and Mg were higher in lower slope while exchangeable Na and K were higher in middle slope position, implying the middle and lower slopes are higher in fertility similar to OC, TN and Avail. P. (Figs. 5 a-d). The mean exchangeable Acidity (H^{+}+Al^{3+}) values were 0.53, 0.44, and 0.48 cmol/kg for upper, middle, and lower slope positions, respectively (Table 3). The soil exchangeable acidity mean values were also observed to be irregularly distributed down the slope classes and there was no significant difference ($p > 0.05$) across the slope classes. Further, all the slope classes were moderately variable (CV< 27%) in soil exchangeable acidity (Table 3). The mean Effective Cation Exchange Capacity (ECEC) values were 22.63, 26.72, and 23.87 cmol/kg for upper, middle, and lower slope positions, respectively. Also, the mean soil ECEC values were irregularly distributed down the slope class and there was no significant difference ($p > 0.05$) across the slope classes.

Upper (CV=18.39%) and middle (CV=24.41%) slope classes were moderately variable while lower slope was highly variable (CV=39.66%) in soil ECEC status. Soil electrical conductivity (ECe) mean values were 0.064, 0.084, and 0.054 dS/m for upper, middle, and lower slope positions, respectively (Table 2). Soil ECe values were also observed to be irregularly distributed down the slope classes and there was no significant difference ($p > 0.05$) across the slope classes. The upper and middle slope classes were highly variable in terms of soil ECe status (CV> 51%) (Table 2). Soil bicarbonate (HCO_3) mean values were 1.15, 1.44, and 1.37 mg/kg for upper, middle, and lower slope positions, respectively (Table 3). Soil HCO_3 values were irregularly distributed down the slope class and there was no significant difference ($p > 0.05$) across the slope classes. All the slope classes were moderately variable in Soil HCO_3 status (CV> 24%) (Table 3). Results of soil interpolation shows exchangeable acidity was higher in upper slope, ECEC was higher in lower slope, soil HCO_3 was higher in middle slope position, while ECe was generally low across all the slope classes (Figs. 6 a-d).

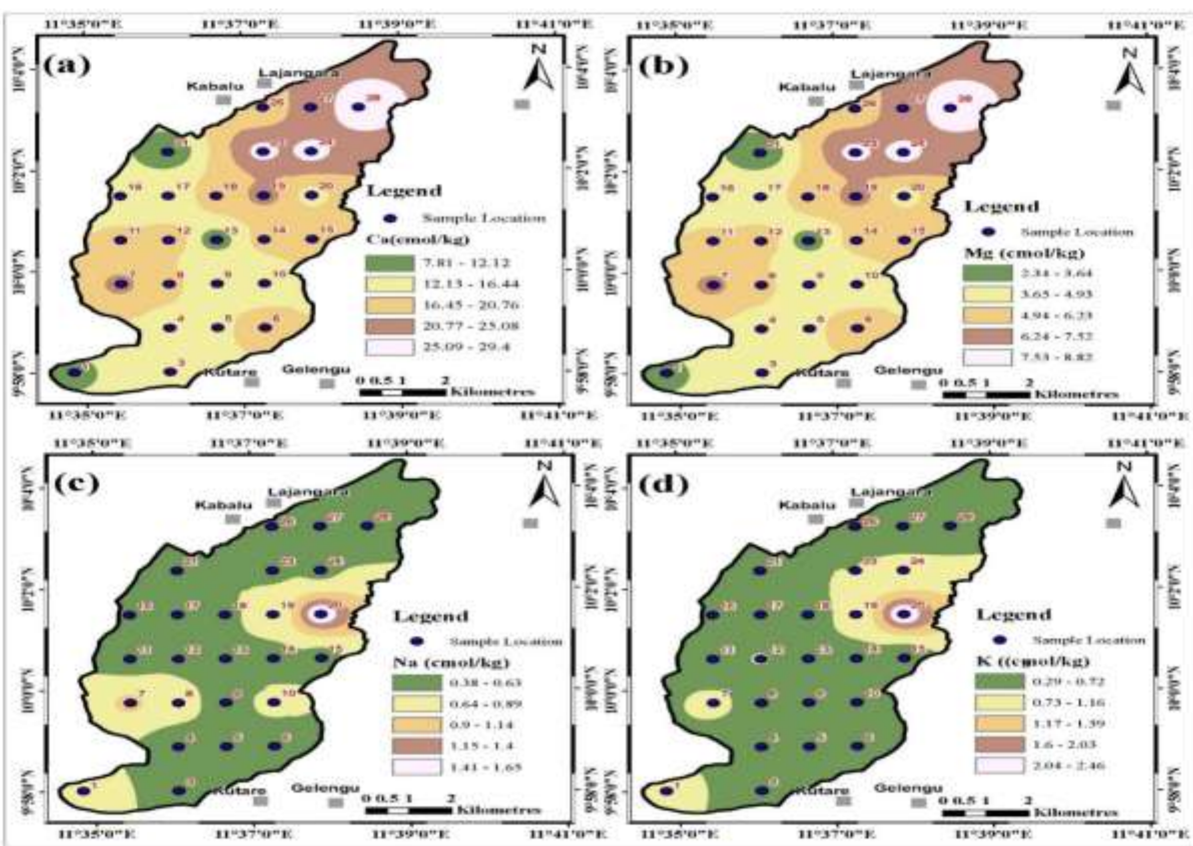

Fig. 5: Distribution of soil exchangeable (a) calcium, (b) magnesium, (c) potassium and (d) sodium

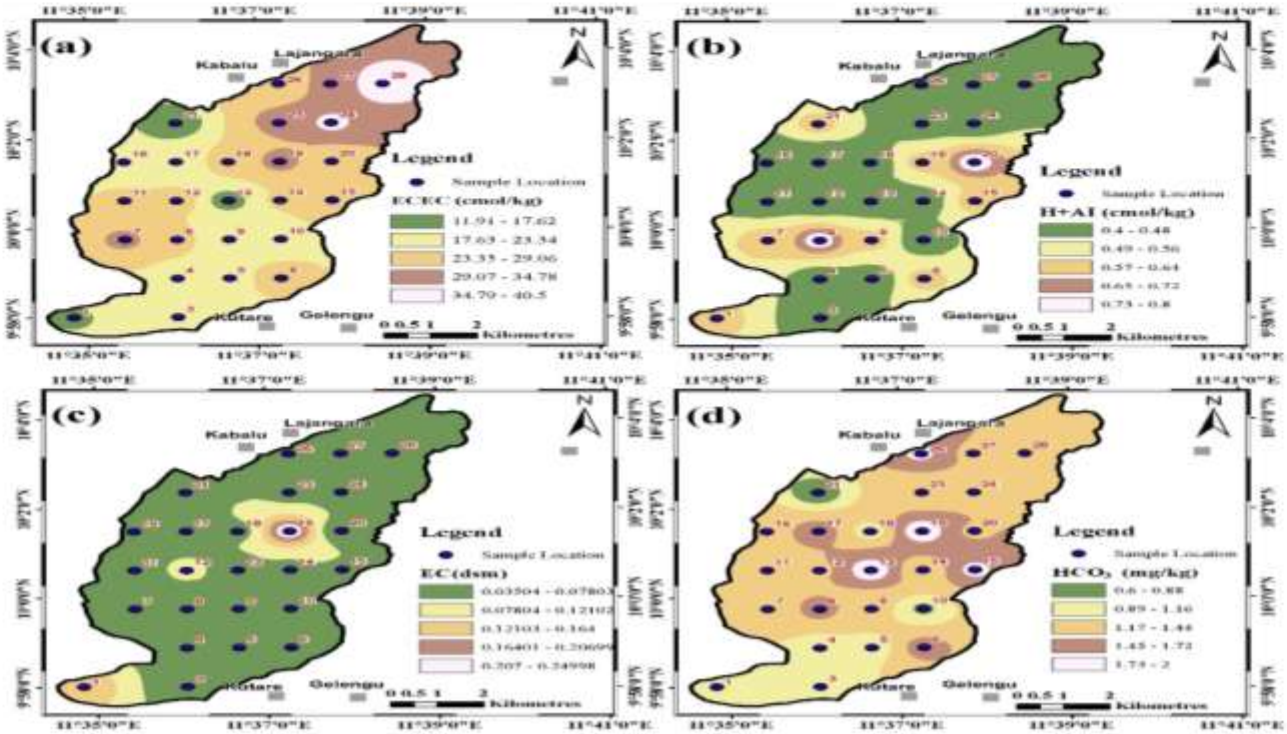

Fig. 6: Distribution of (a) exchangeable acidity, (b) effective cation exchange capacity, (c) electrical conductivity and (d) soil bicarbonate

The mean exchangeable sodium percentage (ESP) values were 2.87, 2.32, and 2.88% for upper, middle, and lower slope positions, respectively (Table 3). Soil ESP values decreased and increased down the slope class and there was no significant difference ($p > 0.05$) across the slope classes. Upper and middle slope classes were moderately variable, while lower slope was highly variable in ESP similar to ECEC (Table 3). Base Saturation (BS) values were 97.6, 98.2 and 97.7% for upper, middle and lower slope positions, respectively (Table 3). Soil BS values were irregularly distributed down the slope class and there was no significant difference ($p > 0.05$) across the slope classes. BS was also observed to be generally low in variability in all the slope classes (CV<1.33%) (Table 3). Sodium Absorption Ratio (SAR) values were 0.20, 0.16, and 0.20% for upper, middle and lower slope positions, respectively (Table 3). Soil SAR values were irregularly distributed down the slope class and there was no significant difference ($p > 0.05$) across the slope classes. Upper slope class was moderately variable, middle slope class was least variable while lower slope was highly variable in SAR (Table 3).

Variability of soil properties in Balanga irrigation scheme

The least variable soil properties (<15%) were observed to be pH, total nitrogen (TN), and base saturation (BS) on the upper slope; clay, silt, pH, sodium (Na), exchangeable sodium percentage (ESP), and BS on the middle slope; and pH and BS on the lower slope (Table 4). Moderately variable properties (15–35%) included clay, silt, sand, organic carbon (OC), available phosphorus (Avail. P), calcium (Ca), magnesium (Mg), Na, exchangeable acidity (H^{+}+Al^{3+}), effective cation exchange capacity (ECEC), bicarbonate (HCO_3^-), sodium adsorption ratio (SAR), and ESP on the upper slope; sand, TN, Ca, Mg, HCO_3^-, and ESP on the middle slope; and electrical conductivity of the extract (EC), TN, Avail. P, H^{+}+Al^{3+}, ECEC, and HCO_3^- on the lower slope. Highly variable soil properties (>35%) included EC and potassium (K) on the upper slope; EC, OC, Avail. P, and K on the middle slope; and clay, silt, sand, OC, Ca, Mg, K, Na, ECEC, ESP, and SAR on the lower slope.

Table 4. Variability grouping of soil properties along the Slope positions.

Group	CV (%)	Soil Properties
		Upper Slope
Least variable	<15	pH, TN, BS,
		clay, silt, sand, OC, Avail. P., Ca, Mg, Na, H+Al,
Moderately variable	15 - 35	ECEC, HCO_3, SAR ESP
Highly variable	>35	EC, K
		Middle Slope
Least variable	<15	clay, silt, pH, Na, ESP, BS
Moderately variable	15 - 35	sand, TN, Ca, Mg, HCO_3, ESP
Highly variable	>35	EC, OC, Avail. P., K
		Lower Slope
Least variable	<15	pH, BS
Moderately variable	15 - 35	EC, TN, Avail. P., H+ Al, ECEC, HCO_3
Highly variable	>35	clay, silt, sand, OC, Ca, Mg, K, Na, ECEC, ESP, SAR

The soil samples from different slope classes exhibit considerable variations in key parameters that influence soil fertility/quality for agriculture production. Generally, the higher fertility area dominated the irrigation scheme with 48% (2689.9 ha) followed by medium fertility with 42% (2331.4 ha) and the low fertility area occupied the least 11% (593.8 ha) (Table 5). Fig. 7 shows the spatial variation of soil fertility/quality of Balanga irrigation scheme.

Table 5: Soil fertility ratings across slope classes

Fertility Ratings	Area (ha)	Percentage (%)
Low	593.79	10.57
Moderate	2331.42	41.52
High	2689.91	47.90
Total	5615.12	100.00

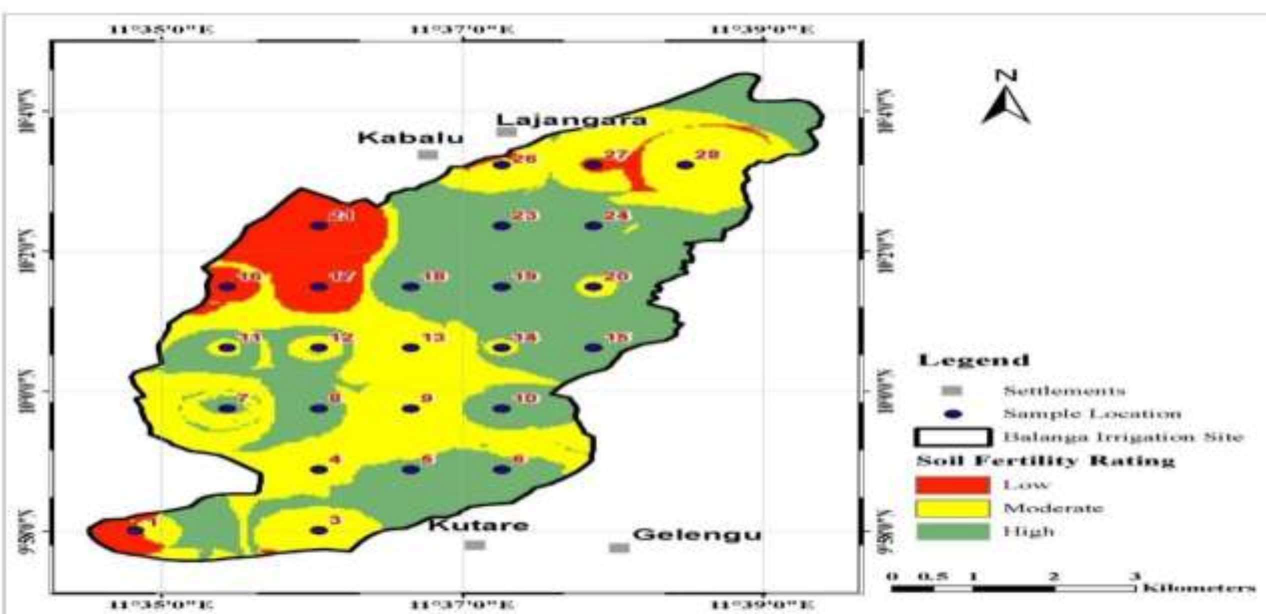

Fig. 7: Soil fertility distribution of Balanga irrigation scheme

Fertility Capability Classification units and Interpretations

The Fertility Capability Classification and interpretations were quantitatively based on the results of the physical and chemical analysis of soils, and collaborated with those established by Sanchez *et al*. (1982) for wetland soils (Table 6).

Upper slope soils

The fertility indicators designated as C, C, g, i, v, and c. depict that the soil has clayey (C) topsoil (Types) that is characterized by low infiltration rate and very slow permeability. The C typifies clayey soil in the subsoils. The modifiers represented in lower case letters showed the following: (g), depicts gleying as a major pedogenetic process; (i) which implies low phosphorus levels due to fixation processes in the soil from sesquioxides; (v) which implies vertic properties of expansion and contraction in reaction to water availability; (c) which implies low phosphorus due to medium to high P-fixation capacity and very high levels of P-fertilizer or special P-management practices are to be adopted.

Middle slope soils

The fertility indicators designated as C, C, g, and v, depict that the soil has clayey (C) topsoil (Types) that are characterized by low infiltration rate and very slow permeability. The C typifies clayey soil in the subsoils. The modifiers represented in lower case letters showed the following: (g), depicts gleying as a major pedogenetic process; (i) which implies low phosphorus levels due to fixation processes in the soil from sesquioxides; (v) which implies vertic properties of expansion and contraction in reaction to water availability.

Lower slope soils

The fertility indicators designated as C, C, g, v and w, depict that the soil has clayey (C) topsoil (Types) that are characterized by low infiltration rate and very slow permeability. The C typifies clayey soil in the subsoils. The modifiers represented in lower case letters showed the following: (g), depicts gleying as a major pedogenetic process; (v) which implies vertic properties of expansion and contraction in reaction to water availability, (w) depicts ponding due to excessive waterlogging in most parts of the years.

Table 6: Fertility capability classification (FCC)* of toposequence in the study area

Slope Class	Type1	Subtrata Type2	Condition Modifiers3														FCC Unit
			G	D	K	E	a	H	b	I	V	S	N	P	C	%	
Upper	C	C	+	-	-	-	-	-	-	+	+	-	-	-	+	+	C C givc
Middle	C	C	+	-	-	-	-	-	-	-	+	-	-	-	-	-	C C gv
Lower	C	C	+	-	-	-	-	-	-	-	+	-	-	+	-	-	C C gvp

*: After Sanchez *et al.*, (1982). 1, 2: S = sandy; L = loamy; C = clay

3: g = gleying; d = dry; k = low K reserves; e = low CEC; a = aluminium toxicity; h = acidic; b = basic; c = high fixation of P by iron; v = Vertisol; s = salinity; n=nitric; c=cat clay, p = ponding

Discussion

Soil physical properties

The higher mean sand content obtained at the lower slope (36 g/kg), though insignificant could be related to variation in the degree of pedogenic processes such as clay lessivage, erosion and deposition of material from upland. This is corroborated by Esu (2010) and Brady and Weil (2017) whom reported that topography influences the pattern of soil texture distribution over the landscape. A notable feature in all the soils studied is their high silt content which corroborates Chandan *et al.* (2020); Jimoh *et al.* (2020); Mohammed *et al.* (2022) who all reported higher silt content in their various studies. The high silt content obtained in this study could be a reflection of the nature of parent material and stage of soil genesis. Such high silt content requires the addition of organic matter to stabilize the soil, in order to enhance soil structure for effective cultivation. The moderate variability in clay content recorded at the upper and lower slope positions, could be attributed to processes such as clay lessivage, eluviation and illuviation. Texturally, upper and middle slope were clayey in texture, while lower slope was clay loam. Higher clay distribution in the upper slope could attributed to transportation of sand particles from upper slope down to lower slope position due to the effect of topography, leaving back accumulation of clay particles in the upper slope. The deposition of transported particles in the lower slope position, or processes such as clay lesivage, eluviation and illuviation or both could be responsible for lower slope position texture. The implication of high clay content includes: shrink-swell behavior, poor drainage, compaction, and difficult to cultivate but will be rich in plant nutrients and retains it firmly against leaching. This soil could be improved through aeration and introductions leguminous crops and microbes to break down nutrients and enhance root penetration.

Soil chemical properties

The mean soil pH (H_2O) values, were rated as slightly alkaline for upper slope, moderately alkaline for middle slope and strongly alkaline for lower slope, while soil pH ($CaCl_2$) values were rated neutral for all slope classes (Malgwi, 2007). The significantly higher pH (8.74) value recorded in soils at the lower slope could be attributed to low leaching process due to high clay content. Soil interpolation shows higher distribution of soil pH in lower slope position and could be attributed to transportation and deposition of materials from upper slope leading to enrichment of the lower slope soils and low leaching process.

The soil OC values recorded in this study were rated low for all slope classes (Malgwi, 2007). Low OC could be attributed to continuous cultivation, leaching, erosion, and high rate of mineralization of organic matter due to high temperature and bush burning in the area. The low OC content in the soils across the slope classes corroborated Morgan (1991) as cited by Oriako *et al.* (2022) whom reported low OC in soils of their study area and was consistent with the level of organic carbon content in tropical soils as they are mostly low. Salem et al. (2016); Jimoh et al. (2019); Jimoh et al. (2022) have previously reported low OC in soil of Gombe state and were attributed it to continuous cultivation and bush burning. Similarly, TN was low similar to OC, earlier works have reported low total N in their various studies (Salem et al., 2016; Jimoh et al., 2019; Befekadu *et al.*, 2022; Okechukwu *et al.*, 2023) and this may be associated with the mobility of nitrogen which can be easily lost through various mechanisms like NH_3 volatilization, succeeding denitrification, chemical and microbial fixation, leaching, and runoff (Mahmud *et al.*, 2021) or anthropogenic processes such as continuous cultivation, crop residue removal, bush burning and low levels of N fertilizer application (Elias and Agegnehu, 2020).

Soil Avail. P. was low to medium and could be attributed to low OC in the soils and also the fixation of phosphorus by iron and aluminum under drained acidic condition of the soils. Usually, phosphorus reacts with Al^{3+} and Fe^{2+} in acid soils to form aluminium phosphate ($AlPO_4^{-2}$) which are not readily available for plants uptake (Egbuchua, 2011, Angela and Daniel, 2022). This corroborates Awwal *et al.* (2022) whom reported low to high available P values and Jimoh et al. (2022) who reported high available P. while assessing the characteristics of soils along toposequences. The implication of low OC and TN in the soils will be reduced crop productivity and increase in soil degradation, this will require application of organic and in-organic fertilizer to improve the soil organic matter which is the corner stone of soil fertility and quality for sustainability. Inter cropping with leguminous crop will also help buildup soil nutrients in the soils.

Exchangeable Ca and Mg were rated high across the soils. This could be attributed to their dominance as against other cations in soils of the study area and to the nature of the parent material. On the contrary, Mahmud *et al.* (2019) reported low to medium exchangeable Mg content in their assessment of the variability of some soil properties along a toposequence in a basaltic parent material of Vom, Plateau State Nigeria. The level of Mg content obtained in this study might be a reflection to the parent material, from which the soils were derived (Brady and Weil, 2017). The mean soil K and Na values were found to be high (Malgwi, 2007), for all slope classes. This high variability in soil K values within each slope class could be attributed to the effect of pedogenic processes such as erosion, deposition, and leaching (Isola *et al.,* 2020). Babalola *et al.* (2011) attributed the content and distribution of Na to the nature of the parent material (colluvial). The exchangeable bases were higher in middle and lower slope position, implying the middle and lower slopes are higher in fertility similar to OC, TN and Avail. P. This implies the soil were sufficiently supplied with base element with no deficiency. The low acidity across the study area implies the soils have little or no acidity problems, indicating the absence of the possibility of aluminum toxicity. The range of soil ECEC values, obtained in this study was generally rated high for all slope classes (Malgwi, 2007).

The high ECEC across the soils confirm Imadojemu, *et al.* (2017) whom attributed the high ECEC levels in the studied soils to high surface colloidal particulates (humus) as well as weatherable parent material which had encouraged intense addition of exchangeable cations in these soils. These levels of ECEC values are also an indication that the studied soils have a good nutrient release and buffering capacity. The slightly higher acidity in the upper slope could be attributed to loss of nutrient through leaching and erosion of materials down slope. Higher ECEC in the lower slope position could be attributed to accumulations of materials from upland through erosion and deposition. These range of soil ECe values were rated as low across the slope classes (Malgwi, 2007), and fall below the critical limits of 4 dSm^{-1} to be defined as saline soil (Soil Survey Division Staff, 2017). The general low level of ESP (<3%) and SAR (< 13) recorded across the study area implies that sodicity is not a significant pedogenic process, indicating that soils of the study area do not contain a concentration of soluble salt that may possibly hinder the growth of plants (Soil Survey Division Staff, 2017). This confirm reports of Ibrahim *et al*. (2018) and Jimoh *et al*. (2020) in soils of Guinea Savanna. Generally, the mean values were low indicating non-saline status of the soils according to the limits set by Leticia *et al.* (2015). BS values are used as a diagnostic character for classifying soils (Meena *et al.,* 2014). BS is also used in classifying the fertility level of soil with values greater or lower than 50% indicating fertile or low fertility soil respectively (FAO, 2014). Based on the soil BS, the soils are classified as fertile having BS of >50%. The middle and lower slope BS which was higher than upper slope corroborated Jimoh et al. (2022) whom reported significant higher BS on the middle and lower slope than upper slope in soils of Tula.

Variability of soil properties of Balanga irrigation scheme

Silt, BS and pH of the soils was among the least variable properties in soils along the toposequence. Similar trends were reported by Oku et al. (2010) and Awoonor and Dogbey (2021). Additionally, they identified sand, clay, OC, Avail. P, ECEC, $H^{+}+Al^{3+}$, TN, Ca, and Mg as moderately variable, while silt, clay, OC, Avail. P, TN, K, and ECEC were reported as highly variable. These findings are supported by Agbede (2009), who noted that soil properties such as pH and BS tend to remain relatively stable across topographic gradients. Similarly, Brady and Weil (2016) emphasized the strong variability of OC, K, and ECEC in response to slope position. Soil Survey Staff (2014) also recognized the influence of slope on the spatial variability of chemical properties, especially those related to nutrient retention and mobility.

The soil samples from different slope classes exhibit considerable variations in key parameters that influence soil fertility/quality for agriculture production. Based on slope class, Middle slope stands out with the highest fertility considering higher organic carbon, total nitrogen, available phosphorus, calcium, magnesium, ECEC, and favorable pH suggesting the best overall soil fertility/quality. Lower slope was also characterized by high potassium, base saturation, and moderate organic carbon, total nitrogen, available phosphorus, calcium, magnesium, ECEC, and favorable pH suggesting medium soil fertility/quality. The upper slope was characterized by high clay content indicating more compact, high exchangeable acidity, Sodium, sodium absorption ratio, low carbonate, moderate total nitrogen indicating less fertile soil. This corroborates Amaresh (2015); Miheretu and Yimer (2018), Bufebo *et al*., (2021), Mesfin *et al.*, (2022); Jimoh *et al*. (2022), who also reported soils developed on varying altitudes differed widely in their properties/quality and turn led to different management options for combating various crop production-related constraints. These variations highlight the need for location-specific soil management practices to optimize agricultural productivity. The low fertility areas are characterized by hilly terrain with many stones and rock outcrops. This implies that the irrigation scheme has a high potential for crop productivity when site-specific recommendations are applied.

Fertility capability classification units and interpretations

Based on slope class, Middle slope stands out with the highest fertility considering higher organic carbon, total nitrogen, available phosphorus, calcium, magnesium, ECEC, and favorable pH suggesting the best overall soil fertility/quality (Fig. 6). Lower slope was also characterized by high potassium, base saturation, and moderate organic carbon, total nitrogen, available phosphorus, calcium, magnesium, ECEC, and favorable pH suggesting medium soil fertility/quality. The upper slope was characterized by high clay content indicating more compact, high exchangeable acidity, Sodium, sodium absorption ratio, low carbonate moderate total nitrogen indicating less fertile soil. This corroborates Amaresh (2015); Miheretu and Yimer (2018), Bufebo et al., (2021), Mesfin et al., (2022); Jimoh et al. (2022) who also reported soils developed on varying altitudes differed widely in their properties/quality and turn led to different management options for combating various crop production-related constraints. These variations highlight the need for location-specific soil management practices to optimize agricultural productivity. Generally, the higher fertility area dominated the irrigation scheme with 48% (2689.9 ha) followed by medium fertility with 42% (2331.4 ha) and the low fertility area occupied the least 11% (593.8 ha) (Table 5). The low fertility areas are characterized by hilly terrain with many stones and rock outcrops. This implies that the irrigation scheme has a high potential for crop productivity when site-specific recommendations are applied. Generally, FCC over the irrigation scheme varied over the toposequence. This corroborates Amaresh (2015) who also reported soils developed at varying altitudes differed widely in their properties and as a result influenced FCC which varied widely and in turn led to different management options for combating various crop production-related constraints. The limitations of the soils were mainly wetness, slightly high pH, low organic carbon, and phosphorous which was similar to the report of Egbuchua (2011) who reported common limiting factors in soils of Delta state were excessive wetness, high acidity, low P. content, salinity especially with mangrove swamps, and low potassium reserves. The agricultural potentials of Balanga irrigation scheme can be improved by liming, application of both organic and inorganic manures since their response to fertilizer application is likely to be guaranteed due to the characteristics of the soils.

Overall soil fertility and management implications of Balanga irrigation scheme

Based on fertility variation, High fertility/quality areas are characterized by favorable conditions such as balanced texture, good organic carbon content, optimal pH, and high nutrient-holding capacity. These areas are most suitable for intensive agriculture and require minimal soil amendments. Moderate fertility/quality areas have moderate soil quality with noticeable limitations in parameters such as organic carbon content and low exchangeable bases. These areas require moderate soil management practices, including organic amendments, liming, or periodic fertilization to maintain productivity. Low fertility/quality areas represent low soil fertility/quality, characterized by poor conditions such as high compaction, low organic carbon, low nutrient-holding capacity, and unfavorable pH levels. Intensive soil rehabilitation efforts are necessary to make these areas suitable for agriculture. Practices may include deep tillage, extensive organic amendments, and frequent liming or fertilization. The considerable variations in soil quality across different slope classes necessitate tailored soil management practices to optimize agricultural productivity. Areas with higher soil fertility/quality require minimal interventions, whereas areas with lower soil quality demand more intensive soil rehabilitation efforts. Understanding these variations allows for better planning and implementation of soil management strategies to enhance crop yields and sensure sustainable agricultural practices.

Conclusion

This study assessed the land evaluation of soils across different slope positions within the Balanga Irrigation Scheme, Gombe State, Nigeria. The findings revealed significant variation in soil physical and chemical properties based on topography. Middle slope positions exhibited the highest soil fertility characteristics such as higher levels of organic carbon, total nitrogen, available phosphorus, and cation exchange capacity followed by the lower slopes, while the upper slopes had the least fertility potential. Key limiting factors identified across the site included gleying, excessive wetness, low levels of organic carbon and nitrogen, phosphorus fixation, and, in some areas, slightly high pH levels. Despite these challenges, the overall soil fertility status of the Balanga Irrigation Scheme indicates a high potential for increased agricultural productivity if appropriate land management and soil improvement strategies are applied. The study underscores the importance of slope-based site-specific soil fertility management in ensuring sustainable crop production in irrigated landscapes.

Recommendations

1. Apply organic manure and balanced fertilizers (especially nitrogen and phosphorus) to enhance soil nutrient content, particularly in the upper slopes.
2. Construct drainage channels in waterlogged areas and develop irrigation schedules to prevent excessive wetness and nutrient leaching.
3. Implement soil conservation practices such as contour farming, mulching, and the use of cover crops to reduce erosion and maintain soil structure.
4. Conduct regular soil testing and mapping to guide precise and site-specific soil management interventions.
5. Strengthen agricultural extension services to educate farmers on sustainable soil and water management practices.

Acknowledgments

The support of the Department of Geography, Faculty of Science, Gombe State University and the Department of Soil Science, Ahmadu Bello University, Nigeria is hereby acknowledged for granting the platform to conduct this research.

Funding:

The support of the Nigeria Tertiary Education Trust Fund (Tetfund) under Gombe State University Gombe, Nigeria, was appreciated.

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