American Journal of Plant Sciences, 2025, 16(6), 724-744
https://www.scirp.org/journal/ajps
ISSN Online: 2158-2750
ISSN Print: 2158-2742

Effect of Poultry Manure and NPK Fertilizer Soil Amendments on Some Agro-Morphological Parameters, Protein and Mineral Nutrient Contents in Cocoyam (*Xanthosoma sagitifolium* L. Schott)

Gwan Mofor Elvis[1,2*], Djeuani Astride Carole[2,3], Hermann Désiré Mbouobda[2,4], Neculina Anyinkeng[1]

[1]Department of Plant Science, Faculty of Science, University of Buea, Buea, Cameroon
[2]Laboratory of Plant Physiology and Biochemistry, Higher Teacher Training College (HTTC), University of Yaoundé 1, Yaoundé, Cameroon
[3]Department of Plant Biology, Faculty of Science, University of Yaoundé 1, Yaoundé, Cameroon
[4]Department of Biology, Higher Teacher Training College Bambili, University of Bamenda, Bamenda, Cameroon
Email: *gwanmofor@yahoo.com

How to cite this paper: Elvis, G.M., Carole, D.A., Mbouobda, H.D. and Anyinkeng, N. (2025) Effect of Poultry Manure and NPK Fertilizer Soil Amendments on Some Agro-Morphological Parameters, Protein and Mineral Nutrient Contents in Cocoyam (*Xanthosoma sagitifolium* L. Schott). *American Journal of Plant Sciences*, **16**, 724-744.
https://doi.org/10.4236/ajps.2025.166051

Received: February 1, 2025
Accepted: June 13, 2025
Published: June 16, 2025

Abstract

The main objective of our study was to evaluate the effects of poultry manure (PM) and NPK (20:10:10) fertilizers on some agro-morphological parameters, protein and mineral contents in the leaves and tubers of white and red cv cocoyam (*Xanthosoma sagittifolium* L. Schott) plants. Results revealed that the poultry manure (25 and 30 t·ha^{-1}) and NPK fertilizer (125 and 150 kg·ha^{-1}) treatments positively influenced growth, development and tuber yield in both white and red cv *X. sagittifolium* plants. The carbon-to-nitrogen (C/N ratio) in the poultry manure treatments (30 t/ha) most significantly influenced crude protein content (18.14%) in red cv *X. sagittifolium* tubers. Soil analysis revealed that the cation exchange capacities (CECs) were more significant in poultry manure treatments, thereby enhancing mineral uptake. Mineral content analysis in harvested tubers showed that calcium (Ca), magnesium (Mg), sodium (Na), phosphorus (P), iron (Fe), zinc (Zn), and manganese (Mn) were more significant in red cv *X. sagittifolium* tubers than in the white cv *X. sagittifolium* tuber for all treatments. The white cv *X. sagittifolium* tubers recorded a more significant potassium (K) content than the red cv *X. sagittifolium* tubers for all treatments. These results suggest that red cultivar *X. sagittifolium* tubers could be used as an important dietary mineral source. Principal component analysis (PCA) results confirmed high positive correlations between soil exchangeable cations (Mg^{2+} and Na^+) and average leaf number for both cultivars. PCA results also illustrated that soil exchangeable K^+ was highly correlated to yield parameters (average tuber girth, length and weight).

Keywords

Poultry Manure, NPK Fertilizer, *Xanthosoma sagittifolium* L. Schott, Protein, Mineral Content

1. Introduction

Xanthosoma. sagittifolium is an annual plant with a growth cycle lasting between 9 and 11 months [1], depending on the cultivar and growth conditions. *X. sagittifolium* is a tropical and sub-tropical rainforest plant cultivated between latitude 30˚ North and 15˚ South. In Cameroon, it grows under the forest canopy in association with other plants, such as cocoa, banana, plantains and palms. It requires optimum temperature ranges between 20˚C - 35˚C and rainfall between 1500 mm and 3000 mm. It also requires well-drained soils with pH varying between 5.5 and 6.5 and does not tolerate permanent presence of water [2].

Organic manures, like farm manures, contain humic substances, which play a vital role in soil fertility and plant nutrition. Plants grown on soils that contain adequate humin, humic acids (HAs), and fulvic acids (FAs) are less subject to stress, are healthier, produce higher yields and the nutritional quality of harvested foods is superior. These organic manures, like poultry manure, cow dung and pig dung, offer cost-effective alternatives to chemical fertilizers. They are cheaper, readily available, and improve soil structure and water holding capacities. While chemical fertilizers provide a quick release of nutrients, poultry manure offers a slower, more sustainable release, along with potential benefits for soil health and reduced environmental impact compared to synthetic fertilizer use. *X. sagittifolium* responds very well to input of fertilizer, whether organic or inorganic as reported by several workers [3]-[5]. Goat manure, cow dung and poultry manure significantly increase yields in *Colocasia esculenta* [6]. Poultry manure soil amendments increase soil carbon, organic matter and exchangeable cations. NPK fertilizer treatments also increase soil exchangeable cations [7]. Several factors can directly or indirectly affect the nutritional quality of crops. Among these are soil factors, such as pH, available nutrients, texture, organic matter content, soil water and fertilizer applications.

The importance of cocoyam (*X. sagittifolium*) is mainly nutritional. *Xanthosoma sagittifolium* provides about one-third of food intake for approximately 200 million people in the tropics and subtropics and for more than 400 million people worldwide [8]. The edible tubers and young leaves constitute a good source of carbohydrates, some proteins, vitamins, some mineral salts and fats [9]-[11]. The fresh cocoyam corms and cormels contain high calcium oxalate crystals, 780 $mg \cdot 100\ g^{-1}$ in some species [12]-[14], which is irritating to the skin and the mouth. This irritating effect of the corm and cormel is removed when cooked. Cocoyam also constitutes the staple food for populations due to its richness in nutritive elements capable of covering the quasi totality of energy needs and up to 60% of protein needs of an adult [15]. Young *X. sagittifolium* leaves contain an average of 20% protein, while the tubers have 2% - 3% protein, 15% - 39% carbohydrates and 77% water [2]. In Cameroon, different ethnic groups prepare, process, and consume cocoyam in many different forms. These forms include boiled cormels eaten with vegetable soup, ekwang, kwacoco, kwacoco eaten with banga soup, achu eaten with yellow soup or black soup, porridge cocoyam, roasted cocoyam with palm oil and cocoyam fufu with soup [16]. Cocoyam is reported to have superior nutritional value over major root and tuber crops, especially in terms of their protein digestibility and mineral composition [17]. Malnutrition is a major public health concern in many parts of the world. Among other nutrients, minerals are necessary in the human diet [18]. Minerals like Fe, Zn, Cu, Mn, Mg, P, K, Ca, and Na are essential for various bodily functions in human nutrition. Iron (Fe) is essential for oxygen transport in the blood (hemoglobin) and energy production. Zinc (Zn) is important for growth, development, and immune function. It is also involved in wound healing and carbohydrate breakdown. Copper (Cu) is essential for maintaining immune competence and acts as a cofactor of many enzymes. Manganese (Mn) is a cofactor for superoxide dismutase, an antioxidant enzyme. Magnesium (Mg) is important for processing ATP (energy currency of the cell), bone health, and muscle function. Phosphorus (P) is essential for bone health, energy metabolism, and ATP formation. Potassium (K) is important for nerve impulse transmission, muscle contraction, and maintaining fluid balance. Calcium (Ca) is a major component of bones and teeth and is also important for muscle contraction, nerve function, and blood clotting. Sodium (Na) is important for maintaining fluid balance, nerve function, and muscle contraction [19]. Therefore, the aim of this study was to determine the effect of poultry manure and NPK soil amendments on some agro-morphological parameters and nutrient contents in cocoyam leaves and tubers.

2. Materials and Methods

2.1. Site Location

Our field trial was conducted during the 2024 cropping season, on an experimental farm in Liboudi, Mbankomo sub-division, Centre region, Cameroon. The site is located at latitude 3˚49'49.54"N and longitude 11˚27'17.79"E and 705 m above sea level. The area is characterized as a humid rainforest zone and the soil is clay loam. The total annual rainfall for 2024 was 1611.8 mm while the total rainfall during the period of experimentation (April to December 2024) was 1630.6 mm.

2.2. Materials

2.2.1. Soil Amendments and Analysis

Poultry manure was obtained from Henri and Freres Poultry farm in Yaoundé, Cameroon. The poultry manure was composted for 6 weeks before applications (**Table 1**). NPK fertilizer (20:10:10) was obtained from the fertilizer unit of the Ministry of Agriculture and Rural Development, Yaoundé, Cameroon. NPK fertilizers, contain nitrogen (N), phosphorus (P), and potassium (K). They play a crucial role in plant nutrition and growth. Nitrogen (N) is essential for leaf and shoot growth, promoting vigorous plant development and contributing to chlorophyll production. Phosphorus (P) is crucial for root development, flowering, and fruit formation, supporting the plant's ability to uptake nutrients and thrive. Potassium (K) enhances plant resistance to stress, improves water regulation, and contributes to strong stems, increasing overall plant vigor. Optimizing NPK applications involves understanding the specific needs of different crops and considering factors like soil conditions, growth stages, and application methods for maximizing yield and ensuring sustainable practices [20].

Table 1. Chemical characteristics of the poultry manure applied.

Parameters	Value
pH (H_2O)	6.9
pH (KCl)	6.8
Organic matter (%)	41.3
Organic carbon (%)	32.3
Total nitrogen (%)	4.51
Available phosphorus (%)	0.89
Potassium (%)	0.99
Calcium (%)	1.06
Magnesium (%)	0.36
C/N ratio	7:1

2.2.2. Soil Analysis

Soil samples were collected with soil auger at a depth of 0 to 20 cm from different locations of the site and bulked into a composite sample. The composite soil sample was air dried, passed through 2 mm sieve, and then analyzed for its physicochemical properties before planting and after harvest. Particle size distribution was performed to determine the soil textural class using the modified hydrometer methods of [21] [22] (**Table 2**).

Chemical analysis of the soil was according to methods of [23] for soil pH and Macro-Kjeldahl digestion method of [24] for soil nitrogen. Available soil P was determined by Bray II method [25], soil organic carbon was determined by the method of [26]. Determination of exchangeable cations (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}) and calculation of cation exchange capacities (CECs) was carried out according to the methods of [27] [28] (**Table 3**).

Table 2. Physical analyses of soil before planting and after harvest.

Physical properties (%)	Farm before planting	Treatment plots after harvest				
		Control	Poultry manure (25 t·ha^{-1})	Poultry manure (30 t·ha^{-1})	NPK (125 kg·ha^{-1})	NPK (150 kg·ha^{-1})
Moisture content	3.48^d	3.27^d	4.48^b	5.41^a	3.62^c	3.70^c
Sand	28.3^a	28.4^a	29.4^a	29.3^a	29.4^a	28.8^a
Silt	35.6^a	35.6^a	35.8^a	35.4^a	35.5^a	35.5^a
Clay	36.0^a	36.1^a	36.3^a	36.5^a	36.1^a	35.9^a
Textural class	Clay loam	Clay loam	Clay loam	Clay loam	Clay loam	Clay loam

Note: Means of the same main effect within a row followed by the same letter are not significantly different at 5% of probability level = NS, and different letters are significantly different at 5% of probability level.

Table 3. Chemical analyses of soil before planting and after harvest.

Chemical properties	Farm before planting	Treatment plots after harvest				
		Control	Poultry manure (25 t·ha^{-1})	Poultry manure (30 t·ha^{-1})	NPK (125 kg·ha^{-1})	NPK (150 kg·ha^{-1})
pH in water	5.5^b	5.5^b	6.6^a	6.7^a	5.4^b	5.4^b
pH in KCl	4.3^b	4.2^b	6.5^a	6.5^a	4.5^b	4.6^b
Organic matter (g/kg)	25.44^c	22.75^c	47.31^b	53.85^a	23.81^c	23.49^c
Total N (g/kg)	1.1^c	1.1^c	1.4^b	1.7^a	1.5^b	1.6^a
Total C (g/kg)	14.44^c	14.61^c	29.02^b	34.40^a	15.73^c	13.26^c
Available P (mg/kg)	5.57^e	4.91^e	67.84^d	97.04^c	119.5^b	131.9^a
Exchangeable Ca (cmol/kg)	1.63^c	1.64^c	1.96^b	2.38^a	1.93^b	1.97^b
Exchangeable Mg (cmol/kg)	0.76^b	0.67^c	0.81^b	1.13^a	0.77^b	0.82^b
Exchangeable K (cmol/kg)	0.07^d	0.08^d	0.13^c	0.31^a	0.17^b	0.23^b
Exchangeable Na (cmol/kg)	0.12^d	0.11^d	0.51^a	0.52^a	0.23^c	0.32^b
Cation exchange capacity (cmol/kg)	5.3^b	5.2^b	6.1^a	6.2^a	5.4^b	5.5^b

Note: KCl = Potassium chloride; N = Nitrogen; C = Carbon; P = Phosphorus; Ca = Calcium; Mg = Magnesium; K = Potassium; Na = Sodium. Means of the same main effect within a row followed by the same letter are not significantly different at 5% of probability level = NS, and different letters are significantly different at 5% of probability level.

2.3. Plant Material

The planting material consisted of white and red cultivars of *X. sagittifolium* minituber seeds of mean weight 40 g produced from acclimatized vitroplants under the shed in the plant physiology Laboratory of the Higher Teacher Training College (HTTC), University of Yaoundé I, Yaoundé, Cameroon according to the protocol of [29] [30] (**Figure 1**).

2.4. Experimental Design and Treatments

The experiment was a 4 × 2 factorial arrangement in a randomized complete block design and replicated three times. The site was ploughed, ridged and marked

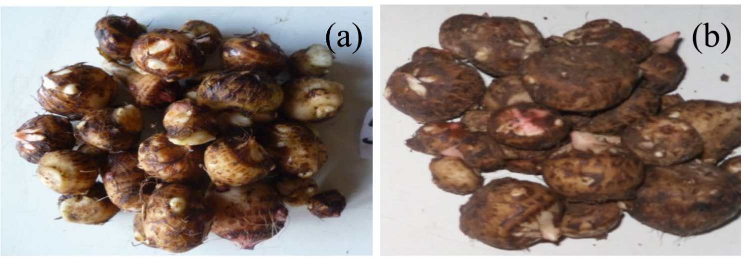


Figure 1. Aspect of *X. sagittifolium* minitubers used as seeds: (a) White cultivar; (b) Red cultivar.

out into two main blocks, one for each cultivar. Each of these main blocks was further subdivided into 3 sub blocks, which represent the three replicates. Each sub block was divided into five experimental plots, thus a total of fifteen plots were used for each cultivar. Each gross plot measured 4 m × 3 m (12 m^2) with a net plot of 2 m × 2 m. The treatments comprised three rates each of application of Poultry Manure (0, 25, and 30 $t \cdot ha^{-1}$) and NPK fertilizer (0, 125, and 150 $kg \cdot ha^{-1}$). A total of fifteen treatment combinations and three replications were used. The Poultry manure was incorporated into the soils on the experimental plots in a single application based on the treatment combinations, at 2 weeks before planting to ease decomposition, while the NPK fertilizer was applied to the cocoyam stands according to treatment allocation at 4 weeks after planting (WAP) using the ring placement method. Each minituber was planted per hole at a depth of 15 cm and at a spacing of 0.5 m × 1.0 m resulting to twenty-five plants per plot and a total of 375 plants per cultivar. All plots were kept weed free by manual weeding after every 2 weeks [7].

2.5. Evaluation of Morphological Parameters

2.5.1. Measurement of Growth Parameters

Five cocoyam plants were randomly selected from each of the net plots, tagged and then used for the determination of average plant height (cm), average number of leaves and average leaf area at 1, 2, 3, 4, 5, 6, 7, and 8 months after planting (MAP).

- A metre tape was used to measure the height of tagged plants and the mean height calculated;
- The number of leaves of tagged plants was counted manually and the average number was determined;
- The length (cm) and width (cm) of leaves of the tagged plants were measured with a metre tape. The leaf area was determined using the formula of [31] as:

$$\text{Leaf Area of Cocoyam} = 0.917\,(LW)$$

where L and W are length and width of the cocoyam leaf.

2.5.2. Measurement of Yield Parameters

Yield parameters like number of tubers per plant, length (cm) and girth (cm) of tubers, and tuber weight (g) were assessed in 5 plants per treatment after 9 months at physiological maturity as follows:

- The number of tubers per tagged plant was counted manually at harvest and average number calculated for each treatment;
- A metre tape was used to measure the length and girth of the harvested tubers and the mean lengths and girths were calculated for tagged plants of each treatment;
- The tuber weight was determined with a 0.01 electronic balance and mean weight was calculated for tagged plants of each treatment [7].

2.6. Biochemical Analysis

2.6.1. Determination of Mineral Nutrients in Harvested Cocoyam Tubers

The following procedure was used to determine Fe, Zn, Cu, Mn, Ca, Mg, K, Na and P contents.

- The cocoyam tuber samples were dried in an oven at 60˚C for 2 hours and finely ground;
- 500 mg of finely ground sample was digested in 2 mL concentrated HNO_3;
- The mixture was diluted to 50 mL;
- Instrument calibration standards were prepared from certified standards and both standards and samples read on the flame Atomic Absorption Spectrophotometer (AAS) (PerkinElmer AA400). Fe was read at 248.3 nm, Zn at 213.9 nm, Cu at 324.7 nm, Mn at 257.6 nm, Ca at 422.7 nm, Mg at 285.2 nm, K at 766.5 nm and Na 589 nm.

P was extracted as above that is digested in concentrated HNO_3 and analyzed using Murphy Riley reagent also known as the phosphomolybdate blue method. It involved the formation of a blue-colored complex between phosphorus, ammonium molybdate, antimony potassium tartrate, and ascorbic acid in an acidic environment. The intensity of the blue color was directly proportional to the phosphorus concentration and measured using a spectrophotometer. P was read colorimetrically at 860nm using a UV-VIS spectrophotometer (PerkinElmer).

2.6.2. Protein Extraction and Assay in Leaves

Proteins were extracted according to the modified method of [15]. 1 g of leaves were ground in chilled mortar (4˚C) with 5 ml of Tris-Maleate buffer (10 mM pH 7.2). The crude homogenate was centrifuged for 25 min at 10,000 g using "Beckmann-Coulter microfuge 20 R centrifuge". The supernatant was removed, stored at −20˚C for future use as crude extract for protein and enzyme assays. Proteins were quantified according to method described by [32] as follows:

- 10 µl of extract was added to 490 µl of distilled water;
- 500 µl of Bradford reagent was added to the mixture;
- The mixture was incubated at 25˚C in darkness for 15 min.

The optical density (OD) of protein was read at 595 nm using a spectrophotometer (Shimadzu UV-1605 UV-visible) against a blank containing distilled water. For each extract the experiment was carried out in triplets and the protein content was expressed in mg-equivalent of BSA per Fresh Weight [32]. This in reference to the extrapolation of the standard curve obtained under the same conditions as the samples while using BSA (Bovine Serum Albumine) at 0.1 mg/ml.

2.7. Crude Protein Assay in Tubers

Determination of Crude Protein: The powdered tuber samples were analyzed for crude protein content according to the Kjeldahl's method described in the Association of Official Analytical Chemists [33].

Protein Digestion: Five grams of the sample was weighed in an ash less filter paper and put into 250 ml digestion flask. Then, 3 g of a catalytic mixture tablet (75 g of $CuSO_4$ and 0.7 g of K_2SO_4) and 15 mL of 98% H_2SO_4 were added into a digestion flask. The whole mixture was subjected to heating in a digestion chamber until transparent residue (clear light green) content was obtained, it was allowed to cool. After cooling, the digest was transferred into a 100 mL volumetric flask and made up to the mark (100 mL) with distilled water and then distilled using distillation apparatus.

Protein Distillation: Before use, the distillation apparatus was steamed for 15 min. After which, 100 ml conical flask containing 20 ml of 40% boric acid and 2 or 3 drops of Tashiro's indicator was placed under the distillation apparatus with its outlet tubes inserted into the conical flask. The digest was washed down with distilled water followed by addition of 4 drops of phenolphthalein and 20 mL of 40% (w/v) NaOH solution. The distillation was continued until about 25 mL of distillate was trapped into the boric acid plus indicator solution changed from red to light grey, showing that all the ammonia liberated had been trapped. That means the digest in the condenser was steamed through until enough ammonia gas captured by the boric acid.

Titration: The solution in the receiving flask was titrated with 0.1 mM HCl to a brown color. After titration, the % of nitrogen was calculated as follows:

$$\text{Nitrogen}(\%) = \frac{(\text{Vs} - \text{VB}) \times \text{mMHCl} \times 0.014008}{\text{Wt. of sample}} \times 100$$

where Vs = Volume (mL) of HCl required to titrate sample; VB = Volume (mL) of acid required to titrate the blank; mMacid = Molarity of acid; and Wt = Weight of sample (g). Then, percentage of crude protein in the sample was calculated from the % nitrogen as:

$$\text{Crude protein } (\%) = \%\text{N} \times \text{F}$$

where, F (conversion factor) is equivalent to 6.25 [33]. A blank was run through along with the sample and triplicate analysis was conducted for samples.

2.8. Statistical Analysis

All results obtained were descriptively analysed. The results were presented as graphs, histograms or tables using the Excel Microsoft software 2013. Results were analyzed statistically by comparison of means with one-way ANOVA using Turkeys test and determination of least significant difference (LSD) at $P < 0.05$ with the Software Package SPSS 17.0 in windows. Correlations between different parameters were analysed using sigmaplot version 11 while principal component analysis (PCA) was done by the XLSTAT 2007 Ink version 10.0 software.

3. Results

3.1. Growth Parameters

All growth parameters (plant height, number of leaves per plant and leaf area) analysed were generally more significant in the white cultivar cocoyam (white cv) plants than in the red cultivar cocoyam (red cv) plants for all treatments (Table 4 & Table 5). After six months of growth there was a significant decrease in all

Table 4. Growth parameters of white cv *X. sagittifolium* plants.

Treatment	Average plant height (cm)				Average number of leaves				Average leaf area (m^2)			
	2 map	4 map	6 map	8 map	2 map	4 map	6 map	8 map	2 map	4 map	6 map	8 map
Control	37 ± 0.07^{c}	40 ± 0.02^{c}	53 ± 0.07^{c}	35 ± 0.12^{c}	3 ± 0.47^{a}	4 ± 0.12^{a}	3 ± 0.64^{c}	2 ± 0.16^{a}	0.036 ± 0.11^{c}	0.023 ± 0.01^{d}	0.029 ± 0.01^{c}	0.022 ± 0.01^{d}
PM1	69 ± 0.55^{a}	56.7 ± 0.04^{a}	82 ± 0.12^{a}	65 ± 0.01^{a}	4 ± 0.11^{a}	4 ± 0.08^{a}	5 ± 0.17^{ab}	2 ± 0.10^{a}	0.044 ± 0.11^{b}	0.051 ± 0.02^{b}	0.076 ± 0.01^{a}	0.033 ± 0.01^{b}
PM2	70 ± 0.11^{a}	56 ± 0.16^{a}	85 ± 0.16^{a}	63 ± 0.03^{a}	4 ± 0.23^{a}	4 ± 0.13^{a}	6 ± 0.17^{a}	3 ± 0.18^{a}	0.051 ± 0.11^{a}	0.057 ± 0.04^{a}	0.079 ± 0.01^{a}	0.040 ± 0.01^{a}
NPK1	56 ± 0.05^{b}	47.7 ± 0.08^{b}	69 ± 0.12^{b}	54 ± 0.13^{b}	4 ± 0.57^{a}	4 ± 0.11^{a}	3 ± 0.16^{bc}	2 ± 0.08^{a}	0.036 ± 0.11^{c}	0.042 ± 0.01^{c}	0.056 ± 0.01^{b}	0.029 ± 0.01^{c}
NPK2	55 ± 0.15^{b}	59 ± 0.13^{a}	71 ± 0.13^{b}	55 ± 0.16^{b}	4 ± 0.31^{a}	4 ± 0.13^{a}	3 ± 0.37^{bc}	1 ± 0.09^{a}	0.035 ± 0.11^{c}	0.049 ± 0.11^{b}	0.061 ± 0.01^{b}	0.028 ± 0.01^{c}
Significance	*	*	*	*	NS	NS	*	NS	*	*	*	*

Note: map = Months after planting; PM1 = Poultry manure (25 t·ha^{-1}); PM2 = Poultry manure (30 t·ha^{-1}); NPK1 = NPK fertilizer (125 kg·ha^{-1}); NPK2 = NPK fertilizer (150 kg·ha^{-1}); NS = Not significant; * = Significant at 5% level of probability. Means of the same main effect within a column followed by the same letter are not significantly different at 5% of probability level = NS, and different letters are significantly different at 5% of probability level.

Table 5. Growth parameters of red cv *X. sagittifolium* plants.

Treatment	Average plant height (cm)				Average number of leaves				Average leaf area (m^2)			
	2 map	4 map	6 map	8 map	2 map	4 map	6 map	8 map	2 map	4 map	6 map	8 map
Control	20 ± 0.13^{d}	40 ± 0.30^{d}	51 ± 0.11^{e}	39 ± 0.12^{d}	3 ± 0.11^{a}	3 ± 0.11^{a}	4 ± 0.62^{a}	1.6 ± 0.14^{a}	0.024 ± 0.12^{c}	0.030 ± 0.11^{e}	0.039 ± 0.03^{c}	0.017 ± 01^{b}
PM1	34 ± 0.13^{a}	59 ± 0.18^{b}	65 ± 0.12^{b}	48 ± 0.16^{b}	3 ± 0.11^{a}	3 ± 0.29^{a}	5 ± 0.17^{a}	2 ± 0.28^{a}	0.029 ± 0.02^{b}	0.053 ± 0.11^{b}	0.064 ± 0.03^{a}	0.030 ± 0.01^{a}
PM2	36 ± 0.11^{a}	64 ± 0.15^{a}	67 ± 0.11^{a}	59 ± 0.26^{a}	3 ± 0.17^{a}	3.3 ± 0.04^{a}	5 ± 0.16^{a}	2 ± 0.08^{a}	0.037 ± 0.02^{a}	0.056 ± 0.12^{a}	0.066 ± 0.11^{a}	0.032 ± 0.01^{a}
NPK1	23 ± 0.18^{c}	47 ± 0.31^{c}	54 ± 0.13^{d}	48 ± 0.19^{b}	3 ± 0.01^{a}	3.1 ± 0.17^{b}	4 ± 0.18^{a}	1.9 ± 0.08^{a}	0.025 ± 0.02^{c}	0.038 ± 0.02^{d}	0.040 ± 0.01^{c}	0.019 ± 0.01^{b}
NPK2	27 ± 0.09^{b}	48 ± 0.18^{c}	58 ± 0.12^{c}	41 ± 0.17^{c}	3 ± 0.11^{a}	3.3 ± 0.16^{a}	4.7 ± 0.1^{a}	1.8 ± 0.11^{a}	0.025 ± 0.01^{c}	0.042 ± 0.11^{c}	0.057 ± 0.12^{b}	0.018 ± 0.01^{b}
Significance	*	*	*	*	NS	NS	NS	NS	*	*	*	*

Note: map = Months after planting; PM1 = Poultry manure (25 t·ha^{-1}); PM2 = Poultry manure (30 t·ha^{-1}); NPK1 = NPK fertilizer (125 kg·ha^{-1}); NPK2 = NPK fertilizer (150 kg·ha^{-1}); NS = Not significant; * = Significant at 5% level of probability. Means of the same main effect within a column followed by the same letter are not significantly different at 5% of probability level = NS, and different letters are significantly different at 5% of probability level.

growth parameters for all treatments in both white and red cv *X. sagittifolium* plants. The poultry manure treatments (30 t·ha^{-1}) showed the most significant increase in all growth parameters analysed from two months after planting to six months after planting among all treatments; meanwhile, within the same growth period, the control treatments (0 t of Poultry manure ha^{-1} and 0 kg of NPK ha^{-1}) recorded the least increase in average plant height and leaf area for both white and red cultivars of the cocoyam plants (Table 4 & Table 5).

3.2. Yield Parameters

After a period of 9 months, yield parameters were assessed. The four yield parameters (tuber number per plant, tuber weight, tuber length and tuber girth) analysed after harvest were generally greater in white cv cocoyam plants than in red cv cocoyam plants for all treatments. Poultry manure treatments (30 t·ha^{-1}) showed the most significant yield parameters, while the control treatments (0 t of Poultry manure·ha^{-1} and 0 kg of NPK.ha^{-1}) had the least yield parameters for both cultivars (Table 6 & Table 7).

Table 6. Yield parameters of white cv *X. sagittifolium* plants.

Yield parameters	Treatments					
	Control	PM1	PM2	NPK1	NPK2	Significance
Tuber number plant^{-1}	3 ± 0.18^c	7 ± 0.18^b	9 ± 0.18^a	6 ± 0.18^c	7 ± 0.18^b	*
Tuber weight (g)	60 ± 0.18^e	180 ± 0.18^c	280 ± 0.18^a	170 ± 0.18^d	242 ± 0.18^b	*
Tuber length (cm)	6 ± 0.26^e	11 ± 0.28^c	15 ± 0.29^a	10 ± 0.16^d	12 ± 0.26^b	*
Tuber girth (cm)	11 ± 0.11^d	14 ± 0.11^b	19 ± 0.12^a	12 ± 0.13^c	17 ± 0.12^a	*

Note: PM1 = Poultry manure (25 t·ha^{-1}); PM2 = Poultry manure (30 t·ha^{-1}); NPK1 = NPK fertilizer (125 kg·ha^{-1}); NPK2 = NPK fertilizer (150 kg·ha^{-1}); * = Significant at 5% level of probability using Turkeys test. Means of the same main effect within a row followed by the same letter are not significantly different at 5% of probability level = NS, and different letters are significantly different at 5% of probability level.

Table 7. Yield parameters of red cv *X. sagittifolium* plants.

Yield parameters	Treatments					
	Control	PM1	PM2	NPK1	NPK2	Significance
Tuber number plant^{-1}	3 ± 0.20^c	5 ± 0.38^b	6 ± 0.37^a	2.9 ± 0.40^c	4.6 ± 0.31^b	*
Tuber weight (g)	45 ± 0.34^d	120 ± 0.1^b	155 ± 0.29^a	98 ± 0.27^c	97 ± 0.33^c	*
Tuber length (cm)	4 ± 0.21^c	6 ± 0.23^b	8 ± 0.20^a	6 ± 0.20^b	8 ± 0.19^a	*
Tuber girth (cm)	11 ± 0.12^b	11 ± 0.14^b	14 ± 0.10^a	10 ± 0.56^b	15 ± 0.14^a	*

Note: PM1 = Poultry manure (25 t·ha^{-1}); PM2 = Poultry manure (30 t·ha^{-1}); NPK1 = NPK fertilizer (125 kg·ha^{-1}); NPK2 = NPK fertilizer (150 kg·ha^{-1}); * = Significant at 5% level of probability using Turkeys test. Means of the same main effect within a row followed by the same letter are not significantly different at 5% of probability level = NS, and different letters are significantly different at 5% of probability level.

3.3. Protein Content in White and Red cv *X. sagittifolium* Leaves during Growth

At 6 months of growth, leaves of poultry manure treated plants (30 t·ha^{-1}) expressed the most significant protein content (5.74 ± 0.38 mg eq BSA·g^{-1} FW) for white cv cocoyam plants followed by the same poultry manure treatments (30 t·ha^{-1}) for red cv (4.91 ± 0.52mg eq BSA·g^{-1} FW). The different treatments of red cv *X. sagittifolium* plants did not show any significant difference in protein content after 2 and 4 months of planting (Table 8).

Table 8. Protein content (mg eq BSA/g FW) in white and red cv *X. sagittifolium* leaves during growth.

Treatment	White cv			Red cv		
	2 map	4 map	6 map	2 map	4 map	6 map
Control	3.37 ± 0.39^a	3.32 ± 0.25^b	2.46 ± 0.21^d	3.47 ± 0.14^b	3.51 ± 0.51^a	3.1 ± 0.47^c
PM1	3.33 ± 0.22^a	4.33 ± 0.12^b	4.83 ± 0.21^b	3.43 ± 0.14^a	3.41 ± 0.32^a	3.89 ± 0.42^b
PM2	3.37 ± 0.25^a	4.87 ± 0.29^a	5.74 ± 0.38^a	3.49 ± 0.51^a	3.48 ± 0.48^a	4.91 ± 0.52^a
NPK1	3.34 ± 0.12^a	3.93 ± 0.03^c	3.51 ± 0.11^c	3.42 ± 0.01^a	3.53 ± 0.22^a	2.93 ± 0.32^d
NPK2	3.30 ± 0.58^a	3.87 ± 0.14^c	3.46 ± 0.39^c	3.42 ± 0.52^a	3.58 ± 0.47^a	3.10 ± 0.16^c
Significance	NS	*	*	NS	NS	*

Note: map = Months after planting; PM1 = Poultry manure (25 t·ha^{-1}); PM2 = Poultry manure (30 t·ha^{-1}); NPK1 = NPK fertilizer (125 kg·ha^{-1}); NPK2 = NPK fertilizer (150 kg·ha^{-1}); NS = Not significant; * = Significant at 5% level of probability. Means of the same main effect within a column followed by the same letter are not significantly different at 5% of probability level = NS, and different letters are significantly different at 5% of probability level.

3.4. Crude Protein Content in Harvested Tubers

The crude protein content values in the harvested red tubers were significantly higher than those of the white tubers for all the treatments evaluated. In the white cv tubers, crude protein content values were more significant in NPK (150 kg·ha^{-1}) treatments at 8.94% than in the control (0 kg·ha^{-1}) at 6.79%. Red tuber crude protein content value was very significant in poultry manure (30 t·ha^{-1}) treatments with 18.14% (Table 9).

Table 9. Crude protein content in white and red *X. sagittifolium* tubers

Treatment	White cv tuber crude protein content %	Red cv tuber crude protein content %
Control	6.79	8.08^e
PM1	7.08^c	16.33^b
PM2	8.47^b	18.14^a
NPK1	7.04^c	9.77^d
NPK2	8.94^a	10.09^c
Significance	*	*

Note:PM1 = Poultry manure (25 t·ha^{-1}); PM2 = Poultry manure (30 t·ha^{-1}); NPK1 = NPK fertilizer (125 kg·ha^{-1}); NPK2 = NPK fertilizer (150 kg·ha^{-1}); * = Significant at 5% level of probability. Means of the same main effect within a column followed by the same letter are not significantly different at 5% of probability level = NS, and different letters are significantly different at 5% of probability level.

3.5. Mineral Content in the Harvested Tubers of White and Red cv *X. sagittifolium* Plants

Mineral nutrient content assay in harvested tubers, showed that 8 out of the 9 minerals assayed were more significant in red tubers than the white tubers of *X. sagittifolium*. K was more significant in white cv *X. sagittifolium* tubers than in the red cv *X. sagittifolium* tubers. Poultry manure treatments of 30 t/ha (PM2) recorded the most significant Fe, Mg, Ca and Na contents for both cultivars. There was no significant difference in the content of the trace elements Zn and Cu, for all treatments in both cultivars of *X. sagittifolium* (Table 10 & Table 11).

Table 10. Mineral content in the harvested tubers of white cv *X. sagittifolium* plants.

Treatment	Mineral content (mg/100g)								
	Fe	Zn	Cu	Mn	Mg	P	K	Ca	Na
Control	7.16 ± 0.20^{b}	2.86 ± 0.11^{a}	1.02 ± 0.09^{a}	2.42 ± 0.12^{a}	87.0 ± 0.12^{c}	186.8 ± 0.12^{d}	1201.8 ± 0.12^{e}	73.9 ± 0.23^{c}	24.01 ± 0.12^{c}
PM1	8.83 ± 0.21^{a}	2.81 ± 0.22^{a}	1.12 ± 0.02^{a}	2.45 ± 0.02^{a}	89.0 ± 0.12^{b}	201.8 ± 0.01^{c}	1211.8 ± 0.33^{d}	87.0 ± 0.41^{b}	25.1 ± 0.12^{b}
PM2	8.91 ± 0.20^{a}	2.80 ± 0.13^{a}	1.15 ± 0.11^{a}	2.55 ± 0.32^{a}	93.0 ± 0.12^{a}	206.8 ± 0.13^{b}	1216.8 ± 0.15^{c}	94.0 ± 0.09^{a}	29.99 ± 0.12^{a}
NPK1	7.16 ± 0.11^{b}	2.89 ± 0.17^{a}	1.02 ± 0.14^{a}	2.35 ± 0.32^{a}	86.9 ± 0.12^{c}	210.8 ± 0.22^{a}	1266.8 ± 0.14^{b}	74.1 ± 0.34^{c}	24.39 ± 0.12^{c}
NPK2	6.96 ± 0.11^{b}	2.85 ± 0.12^{a}	1.11 ± 0.03^{a}	2.45 ± 0.12^{a}	86.8 ± 0.12^{c}	211.8 ± 0.32^{a}	1276.8 ± 0.13^{a}	74.0 ± 0.12^{c}	24.33 ± 0.12^{c}
Significance	*	NS	NS	NS	*	*	*	*	*

Note: PM1 = Poultry manure (25 t·ha^{-1}); PM2 = Poultry manure (30 t·ha^{-1}); NPK1 = NPK fertilizer (125 kg·ha^{-1}); NPK2 = NPK fertilizer (150 kg·ha^{-1}); NS = Not significant; * = Significant at 5% level of probability using Turkeys test. Means of the same main effect within a column followed by the same letter are not significantly different at 5% of probability level = NS, and different letters are significantly different at 5% of probability level.

Table 11. Mineral content in the harvested tubers of red cv *X. sagittifolium* plants.

Treatment	Mineral content (mg/100g)								
	Fe	Zn	Cu	Mn	Mg	P	K	Ca	Na
Control	9.46 ± 0.16^{c}	3.07 ± 0.13^{a}	1.11 ± 0.06^{a}	3.52 ± 0.22^{b}	97.0 ± 0.04^{c}	206.2 ± 0.11^{d}	901.8 ± 0.02^{d}	77.9 ± 0.10^{d}	26.91 ± 0.02^{c}
PM1	9.83 ± 0.13^{b}	3.11 ± 0.15^{a}	1.05 ± 0.11^{a}	3.55 ± 0.12^{b}	109.0 ± 0.10^{b}	211.8 ± 0.01^{c}	1018.8 ± 0.03^{c}	89.0 ± 0.13^{b}	35.1 ± 0.21^{b}
PM2	10.92 ± 0.21^{a}	3.15 ± 0.04^{a}	1.16 ± 0.11^{a}	4.56 ± 0.23^{a}	119.0 ± 0.02^{a}	216.2 ± 0.13^{a}	1024.8 ± 0.14^{b}	93.0 ± 0.17^{a}	39.09 ± 0.30^{a}
NPK1	9.85 ± 0.01^{b}	3.16 ± 0.17^{a}	1.01 ± 0.13^{a}	3.35 ± 0.17^{b}	96.9 ± 0.32^{c}	213.8 ± 0.22^{b}	1056.8 ± 0.18^{a}	81.1 ± 0.15^{c}	27.21 ± 0.16^{c}
NPK2	9.97 ± 0.21^{b}	3.13 ± 0.12^{a}	1.11 ± 0.14^{a}	3.45 ± 0.18^{b}	98.8 ± 0.11^{c}	216.1 ± 0.32^{a}	1276.8 ± 0.17^{a}	80.3 ± 0.42^{c}	27.11 ± 0.08^{c}
Significance	*	Ns	NS	*	*	*	*	*	*

Note: PM1 = Poultry manure (25 t·ha^{-1}); PM2 = Poultry manure (30 t·ha^{-1}); NPK1 = NPK fertilizer (125 kg·ha^{-1}); NPK2 = NPK fertilizer (150 kg·ha^{-1}); NS = Not significant; * = Significant at 5% level of probability using Turkeys test. Means of the same main effect within a column followed by the same letter are not significantly different at 5% of probability level = NS, and different letters are significantly different at 5% of probability level.

3.6. Principal Component Analysis between Parameters of Growth, Yield and Soil Cation Exchange Capacity

At harvest, the correlation circle in the white cv *X. sagittifolium* plants indicate an explanation for principal component 1 axis (F1) of 85.56% while principal component axis 2 (F2) explained 8.25% of variance. The combined effect of both principal component axes 1 and 2 explained 93.80% of the total variance. In red cv *X. sagittifolium* plants, principal component 1 axis (F1) recorded 79.02% while principal component 2 axis (F2) had 13.70% of variance, with a combined total effect for both axes of 92.72% (**Figure 2**).

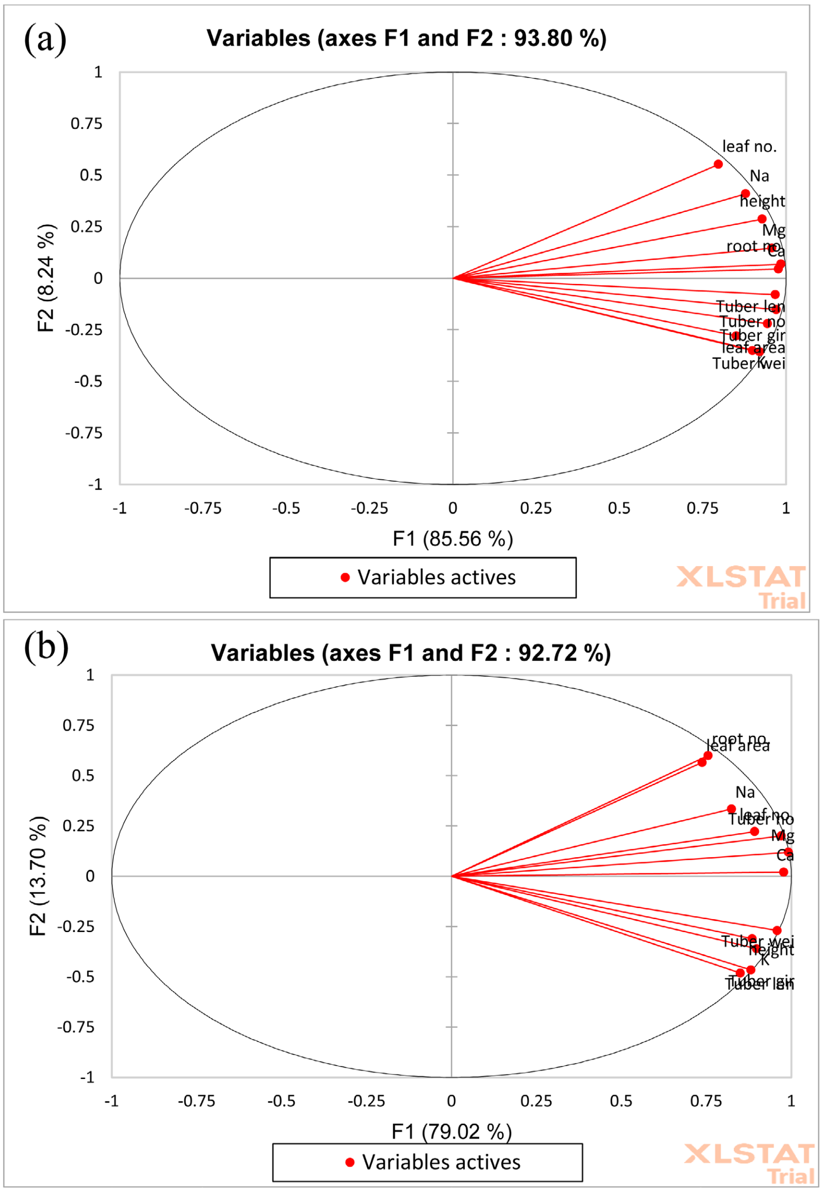
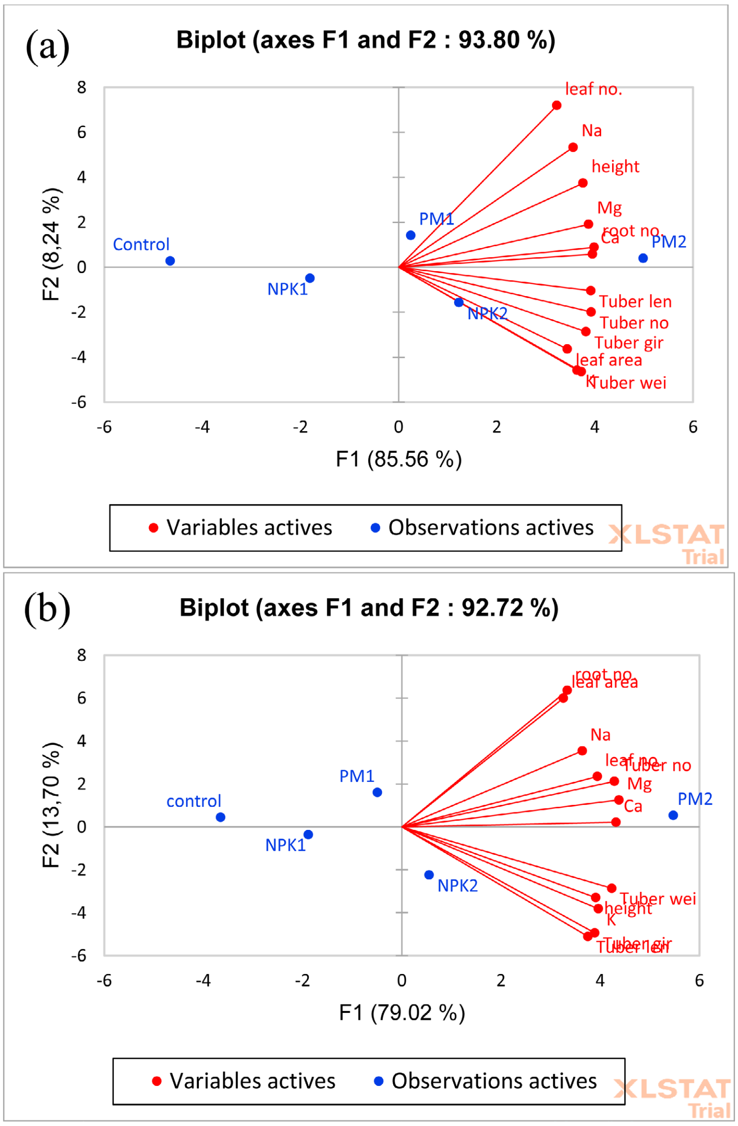


Figure 2. Correlation circles between parameters of growth (average height, leaf number, root number, leaf area), yield (average tuber number, tuber weight, tuber length and tuber girth) and soil exchangeable cations (K^+, Mg^{2+}, Na^+ an Ca^{2+}) in (a) white cv and (b) red cv *X. sagittifolium* plants.

In both white and red cv *X. sagittifolium* plants, positive correlations exist between parameters of growth, yield and soil exchangeable bases as indicated in factorial diagrams of principal component analysis (PCA). High positive correlations between sodium and magnesium exchangeable bases with average leaf number were observed while exchangeable potassium bases were highly correlated with yield parameters in both cultivars. In white cv plants, PM1 (25 t·ha^{-1}) and NPK2 (150 kg·ha^{-1}) samples were closely associated to each other while in red cv plants, control and NPK1 (125 kg·ha^{-1}) samples showed a close association (**Figure 3**).



Note: Cont = Control; PM1 = Poultry manure (25 t·ha^{-1}); PM2 = Poultry manure (30 t·ha^{-1}); NPK1 = NPK1 fertilizer (125 kg·ha^{-1}); NPK2 = NPK fertilizer (150 kg·ha^{-1}); Na = Sodium; Mg = Magnesium; Ca = Calcium; K = Potassium.

Figure 3. Principal component analysis factorial diagrams of data relative to the effect of different soil amendments (poultry manure and NPK fertilizer) on some agro-morphological parameters and some soil exchangeable cations in (a) white cv and (b) red cv *X. sagittifolium* plants.

4. Discussion

Results obtained show that poultry manure and NPK fertlizer treatments significantly influenced growth, development and tuber yield in white and red cv *X. sagittifolium* plants. The growth and yield performance for the white cultivar cocoyam plants were significantly higher than those for the red cultivar cocoyam plants. These results are concordant with those obtained by [7] who showed that the white cultivar *X. sagittifolium* minitubers was more productive than the red cultivar *X. sagittifolium* minitubers. Poultry manure treatments (30 t·ha^{-1}) for both cultivars produced better growth and yield traits compared to the control treatments.

Poultry manure and NPK fertilizer treatments induced biochemical responses in the leaves of *X. sagittifolium* plants during growth. Our results show that the total soluble protein content in the leaves of white cv *X. sagittifolium* plants decreased with time in the control and NPK treatments. [30] worked on the effect of arbuscuar mycorrhizal fungi on mintuberization in *X. sagittifolium* plants obtained a decrease in total soluble leaf protein content over time, especially during maturation of *X. sagittifolium* minitubers. [34] also demonstrated that the total protein content decreased during the maturation of microtubers in irish potatoes. But contrary results were obtained in the poultry manure (30 t·ha^{-1}) treated white cv *X. sagittifolium* plants, which had a significant increase in total soluble protein content during the first 6 months of growth. Since proteins play an important role in the growth and repair of plant cells, this could suggest a positive correlation between protein content and the different growth parameters assessed during growth of plants treated with Poultry manure (30 t·ha^{-1}). In red cv *X. sagittifolium* plants, there was no significant difference in total soluble leaf protein content for all treatments during the first 4 months of growth. The NPK fertilizer (150 kg·ha^{-1}) treatments recorded a significant decrease in total soluble protein content between 4 and 6 months of growth. These variations in total soluble protein content could be due to differences in the available nutritional factors like carbon-to-nitrogen (C/N ratio) in each treatment plot, which affects protein formation in leaves. The carbon-to-nitrogen (C/N) ratio is a crucial factor in biological systems, particularly impacting protein synthesis. The low C/N ratio value of our poultry manure probably favoured the synthesis of amino acids. These amino acids are the monomers of proteins. Concordantly, [35] showed that low C/N values also promote the synthesis of glutamate and other amino acids, ultimately enhancing protein synthesis in microalgae like *Chlorella vulgaris*. Nitrogen is an essential nutrient that plants require for the synthesis of amino acids, proteins, and many other important metabolites. Consequently, the amount of N that is assimilated and distributed from roots to source leaves and finally to developing sinks, like fruits and seeds, has significant consequences for plant metabolism and growth. Importantly, nitrogen and carbon metabolism are highly interrelated [36]-[38]. The crude protein analysis of harvested tubers showed that red cv *X. sagittifolium* tubers (cormels) had a more significant crude protein content than the white cv *X. sagittifolium* tubers for all treatments. Poultry manure (30 t/ha) treated red cv tubers had the most significant values (18.12%), suggesting that the high C/N ratio of the poultry manure applied favoured the synthesis of proteins in cormels. [39] also evaluated poultry manure application rates on the nutrient composition of *Dioscorea bulbifera* (Aerial yam) and demonstrated a significant increase in the crude protein content (6.28%) in harvested tubers with poultry manure applications of 3 t·ha^{-1}.

Soil fertility is very critical for optimum production of crops. Results from physical analyses of different treatment plots before planting and after harvest showed that the soil textural class was clay loam before planting and remained clay loam after harvest for all treatment plots. This implies that poultry manure and NPK fertilizer treatments did not significantly influence soil texture. Poultry manure treatments significantly improved soil moisture content as compared to the NPK fertilizer and control treatments. The soil organic content of poultry manure treatments was higher than that of NPK fertilizer treatments and could account for the increase in the moisture-holding capacity of soil particles. Increased levels of organic matter led to greater pore space with the immediate result that water infiltrated more readily and could be held in the soil [40]. Decomposed poultry manure stimulates microbial activities, which contribute to soil fertility restoration. Effective microorganisms accelerate the breakdown of organic matter from the manure to humus. This speeds up mineralization of the organic matter and provides surplus nutritive elements like exchangeable cations (K^+, Mg^{2+}, Na^+ and Ca^{2+}) compared to the initial soil [41] [42]. Together with the beneficial effect of chicken manure as the source of nutrients and high cation exchange capacity (CEC), effective microorganisms will be able to increase crop yields and improve crop quality. It will also increase the population of beneficial microorganisms in the soil [43]. Our poultry manure and NPK fertilizer treatments significantly improved the total nitrogen and available phosphorus contents compared to the control treatments. Exchangeable Calcium, Magnesium, Potassium and Sodium had more significant values in poultry manure treatments compared to the control treatments. [44] also showed that poultry manure relatively increases soil Nitrogen, Phosphorous, Potassium, Calcium, Magnesium, and organic Carbon. Nitrogen, Phosphorous and Potassium are primary nutrients that are needed by plants in fairly large quantities for their growth and development. Cation exchange capacity (CEC) is a useful indicator of soil fertility because it shows the soil's ability to supply important plant nutrients: calcium, magnesium, potassium and sodium [45]. The cation exchange capacities (CECs) were most significant in poultry manure treatments compared to other treatments after harvest. Results obtained from the analysis of the mineral content of harvested tubers showed that calcium (Ca), magnesium (Mg), sodium (Na), phosphorus (P), iron (Fe), zinc (Zn), and manganese (Mn) were more significant in red cv *X. sagittifolium* tubers than in the white cv *X. sagittifolium* tuber for all treatments. The white cv *X. sagittifolium* tubers recorded a more significant potassium (K) content than the red cv *X. sagittifolium* tubers for all treatments. This suggests that red cultivar *X. sagittifolium* tubers could be used as a dietary mineral source. Similarly, [39] evaluated poultry manure application rates on the nutrient composition of *Dioscorea bulbifera* (Aerial yam), showed that phosphorus, calcium and magnesium contents were significantly increased by poultry manure application. [46] also studied mineral composition of Ethopian green and purple cocoyams (*Xanthosoma sagittifolium* L. Schott) and demonstrated that Ethopian cocoyams are also very good sources of the essential mineral nutrients.

Principal component analysis (PCA) results, confirmed high positive correlations between soil exchangeable cations (Mg^{2+} and Na^+) and average leaf number for both cultivars, thereby indicating their role in the biosynthesis of leaf tissues. Magnesium is a central component in the structure of chlorophyll, which actively takes part in the process of photosynthesis. PCA results also illustrated that soil exchangeable K^+ was highly correlated to yield parameters (average tuber girth, length and weight). Similarly, according to [47] [48], Potassium plays a crucial role in tuber formation and quality, in sweet potatoes (*Ipomoea batatas*) and Irish poatato (*Solanum tuberosum*). It enhances photosynthesis, the movement of carbohydrates from leaves to tubers, and overall tuber yield and quality. Potassium also contributes to the dry matter content of tubers. Plant roots absorb potassium ions from the soil and transport them in the xylem via the transpiration stream to the shoots. There, in source tissues where sufficient chemical energy (ATP) is available, K^+ is loaded into the phloem and then transported with the phloem stream to other parts of the plant, like the roots. This further highlights the role of K^+ in the transport of sugars from leaves to storage organs. In addition, [49] showed that cycling of K^+ has been uncovered to be part of a sophisticated mechanism that enables the shoot to communicate its nutrient demand to the root, contributes to the K^+ nutrition of transport phloem tissues and transports energy stored in the K^+ gradient between phloem, cytosol and the apoplast. This potassium battery can be tapped by opening AKT2-like potassium channels and then enables the ATP-independent energization of other transport processes, such as the reloading of sucrose.

5. Conclusion

Our results show that for all treatments, the white cultivar *X. sagittifolium* plants depicted better growth and yield parameters than the red cultivar plants. Poultry manure (30 $t \cdot ha^{-1}$) stimulated the most significant responses in terms of better growth and yield among all treatments in both cultivars, suggesting that poultry manure increases cation exchange capacities, which offer higher nutrient contents and a more favourable pH to the soil than other treatments. Both poultry manure (30 $t \cdot ha^{-1}$) and NPK (150 $kg \cdot ha^{-1}$) treatments in both cultivars significantly influenced protein and mineral contents in harvested *X. sagittifolium* tubers. This analysis suggests that red cv *Xanthosoma sagittifolium* tubers can serve as an essential dietary source for calcium (Ca), magnesium (Mg), sodium (Na), phosphorus (P), iron (Fe), zinc (Zn), and manganese (Mn) in addition to other traditional sources like cereals.

Acknowledgements

The authors would like to thank the Laboratory of Plant Physiology and Biochemistry, Higher Teacher Training College (HTTC), University of Yaoundé 1, and the Laboratory of Soil, Plants, Water and Fertilizer Analysis IRAD in Cameroon for providing equipment for this study.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Ngouo, L.V. (1988) Contribution to the Study of Cocoyam (*Xanthosoma* spp.) in Cameroon: Identification Analysis of Some Obstacles in the Production of Hybrids. Doctorate Thesis, University of Yaoundé I (Cameroon).

[2] Fonteur, D.A., Mboua, J.C., Mouen, M., Ndzana, X., Tchuango, M. and Zok, S. (2000) Root and Tuber Plants in Africa: Contribution to Development after Harvest. 385 p.

[3] Ogbonna, P.E. and Nwaeze, N.J. (2012) Evaluation of Growth and Responses of Cocoyam (*Colocasia esculenta*) Cultivars to Rates of NPK 15:15:15 Fertilizer. *African Journal of Agricultural Research*, **7**, 6553-6561.

[4] Ojeniyi, S.O., Amusan, O.A. and Adekiya, A.O. (2013) Effect of Poultry Manure on Soil Physical Properties, Nutrient Uptake and Yield of Cocoyam (*Xanthosoma sagittifolium*) in South West Nigeria. *American-Eurasian Journal of Agricultural and Environmental Sciences*, **13**, 121-125.

[5] Hota, R., Jena, A.K. and Narayana, K.L. (2014) Effects of Inorganic and Organic Amendments on Yield of Cocoyam (*Colocasia esculenta*) and on Soil Properties. *World Journal of Agricultural Research*, **2**, 70-81.

[6] Hamma, I.L., Mahmoud, B.A., Wakili, A. and Hayatuddeen, M.A. (2014). Performance of Cocoyam (*Colocosia esculentus* L.) as Influenced by Organic and Inorganic Manure in Samaru, Zaria, Nigeria. *International Journal of Agronomy and Agricultural Research*, **5**, 97-103.

[7] Gwan, M.E., Djeuani, A.C., Tene Tayo, P.M., Boudjeko, T. and Omokolo, N.D. (2019) Field Performance of *Xanthosoma sagittifolium* L. Schott Mini-Tubers Grown under the Influence of Poultry Manure and NPK Fertilizers: Changes in Content of Some Secondary Metabolites. *Journal of Biology, Agriculture and Healthcare*, **9**, 30-42.

[8] Alfred Okwuchukwu, U. (2020) Cocoyam Has a Huge Market but Few Farmers Cultivate It. Report on Research Program on Roots, Tubers and Bananas.

[9] Sefa-Dedeh, S. and Agyir-Sackey, K.E. (2004) Chemical Composition and Effects of Processing on Oxalate Content of Cocoyam *Xanthosoma sagiittifolium* and *Colocasia esculenta* Cormels. *Food Chemistry*, **85**, 479-487.

[10] Ndabikunze, B.K., Talwana, H.A.L., Mongi, R.J., Issa-Zacharia, A., Serem, A.K., Palapala, V. and Nandi, J.O.M. (2011) Proximate and Mineral Composition of Cocoyam (*Colocasia esculenta* L. and *Xanthosoma sagittifolium* L.) Grown along the Lake Victoria Basin in Tanzania and Uganda. *African Journal of Food Science*, **5**, 248-254.

[11] Matikiti, A., Allemann, J., *et al.* (2017) Nutritional Composition of Cocoyam (*Colocasia esculenta*), Grown in Manicaland Province in Zimbabwe. *Asian Journal of Agriculture and Rural Development*, **7**, 48-55. https://doi.org/10.18488/journal.1005/2017.7.3/1005.3.48.55

[12] Sanful, R.E. and Darko, S. (2010) Production of Cocoyam, Cassava and Wheat Flour Composite Rock Cake. *Pakistan Journal of Nutrition*, **9**, 810-814. https://doi.org/10.3923/pjn.2010.810.814

[13] Priscila de Souza Araújo, S.D.S.A., Giunco, A.J. and J. S. Argandoña, S.M.S.E. (2019) Bromatology, Food Chemistry and Antioxidant Activity of *Xanthosoma sagittifolium* (L.) Schott. *Emirates Journal of Food and Agriculture*, **31**, 188-195. https://doi.org/10.9755/ejfa.2019.v31.i3.1924

[14] Rozali, Z.F., Zulmalisa, Z., Sulaiman, I., Lubis, Y.M., Noviasari, S., Eriani, K., *et al.* (2021) Decreased of Calcium Oxalate Levels in the Purple Taro Flour (*Colocasia esculenta*) from Aceh Province, Indonesia Using Three Immersion Methods. *IOP Conference Series*: *Earth and Environmental Science*, **711**, Article ID: 012022. https://doi.org/10.1088/1755-1315/711/1/012022

[15] Boudjeko, T., Omokolo, N.A., Driouich, A. and Balangé, A.P. (2005) Peroxidase and Pectin Methylesterase Activities in Cocoyam (*Xanthosoma sagittifolium* L. Schott) Roots Upon *Pythium myriotylum* Inoculation. *Journal of Phytopathology*, **153**, 409-416. https://doi.org/10.1111/j.1439-0434.2005.00993.x

[16] Njualem, D.K., Achiri, T.D., Florente, T.N., Nkuh, A.A., Tatah, E.L. and Yaya, F.V. (2020) Response of Some Cameroonian Cocoyam *Xanthosoma sagittifolium* (L.) Schott. Cultivars/Landraces to Tissue Culture Techniques. *Journal of Applied Life Sciences International*, **23**, 1-9. https://doi.org/10.9734/jalsi/2020/v23i930182

[17] Boakye, A.A., Wireko-Manu, F.D., Oduro, I., Ellis, W.O., Gudjónsdóttir, M. and Chronakis, I.S. (2018) Utilizing Cocoyam (*Xanthosoma sagittifolium*) for Food and Nutrition Security: A Review. *Food Science & Nutrition*, **6**, 703-713. https://doi.org/10.1002/fsn3.602

[18] Kiani, A.K., Dhuli, K., Donato, K., Aquilanti, B., Velluti, V., Matera, G., *et al.* (2022) Main Nutritional Deficiencies. *Journal of Preventive Medicine and Hygiene*, **63**, E93-E101. https://doi.org/10.15167/2421-4248/jpmh2022.63.2S3.2752

[19] Gharibzahedi, S.M.T. and Jafari, S.M. (2017) The Importance of Minerals in Human Nutrition: Bioavailability, Food Fortification, Processing Effects and Nanoencapsulation. *Trends in Food Science & Technology*, **62**, 119-132. https://doi.org/10.1016/j.tifs.2017.02.017

[20] Bai, S.H., Omidvar, N., Gallart, M., Kämper, W., Tahmasbian, I., Farrar, M.B., *et al.* (2022) Combined Effects of Biochar and Fertilizer Applications on Yield: A Review and Meta-Analysis. *Science of the Total Environment*, **808**, Article ID: 152073.

[21] Gee, G.W. and Bauder, J.W. (1986) Particle Size Analysis. In: Klute, A., Ed., *Methods of Soil Analysis*, *Part* 1, American Society of Agronomy, 91-100.

[22] Kettler, T.A., Doran, J.W. and Gilbert, T.L. (2001) Simplified Method for Soil Particle-Size Determination to Accompany Soil-Quality Analyses. *Soil Science Society of America Journal*, **65**, 849-852. https://doi.org/10.2136/sssaj2001.653849x

[23] Mclean, E.O. (1982) Soil pH and Lime Requirement. In: Page, A.L., Ed., *Methods of Soil Analysis*, *Part* 2, *Chemical and Microbiological Properties*, American Society of Agronomy, 199-224.

[24] Kjeldahl, J. (1883) New Method for the Determination of Nitrogen in Organic Substances. *Journal of Analytical Chemistry*, **22**, 366-383.

[25] Bray, R.H. and Kurtz, L.T. (1945) Determination of Total, Organic, and Available Forms of Phosphorus in Soils. *Soil Science*, **59**, 39-46. https://doi.org/10.1097/00010694-194501000-00006

[26] Schumacher, B.A. (2002) Methods for the Determination of Total Organic Carbon (TOC) in Soils and Sediments. Ecological Risk Assessment Support Center Office of

Research and Development.

[27] Warncke, D. and Brown, J.R. (1982) Potassium and Other Basic Cations. In: *Recommended Chemical Soil Test Procedures for the North Central Region*, Missouri Agricultural Experiment Station, 102 p.

[28] Thomas, G.W. (1982) Exchangeable Cations. In: *Methods of Soil Analysis*, Wiley, 154-157.

[29] Djeuani, A.C., Mbouobda, H.D., Niemenak, N., *et al.* (2014) Effect of Carbon Source on Mini Tuberization of Cocoyam (*Xanthosoma sagittifolium*): Analysis of Soluble Sugars and Amino Acids Contents. *Current Research in Microbiology and Biotechnology*, **2**, 519-526.

[30] Djeuani, A.C., Mbouobda, H.D., Fotso Niemenak, N. and Omokolo, N.D. (2017) Improvement of Cocoyam (*Xanthosoma sagittifolium L. Schott*). Mini-Tubers Production under Treatment of *Glomus intraradices* and *Gigaspora margarita* and Their Impact on Some Secondary Metabolite Contents. *Journal of Plant Science and Research*, **4**, 169-173.

[31] Biradar, R.S., Venkateswarali, T. and Hrishi, N. (1978) Leaf Area Estimation in Colocasia. *Journal of Root Crops*, **4**, 51-53.

[32] Bradford, M. (1976) A Rapid and Sensitive Method for the Quantitation of Microgram Quantities of Protein Utilizing the Principle of Protein-Dye Binding. *Analytical Biochemistry*, **72**, 248-254. https://doi.org/10.1006/abio.1976.9999

[33] AOAC (2005) Official Method of Analysis. Association of Official Analytical Chemists.

[34] Borgmann, K., Sinha, P. and Frommer, W.B. (1994) Changes in the Two-Dimensional Protein Pattern and in Gene Expression during the Sink-to-Source Transition of Potato Tubers. *Plant Science*, **99**, 97-108. https://doi.org/10.1016/0168-9452(94)90124-4

[35] Cai, Y., Zhai, L., Fang, X., Wu, K., Liu, Y., Cui, X., *et al.* (2022) Effects of C/N Ratio on the Growth and Protein Accumulation of Heterotrophic Chlorella in Broken Rice Hydrolysate. *Biotechnology for Biofuels and Bioproducts*, **15**, Article No. 102. https://doi.org/10.1186/s13068-022-02204-z

[36] Palenchar, P.M., Kouranov, A., Lejay, L.V. and Coruzzi, G.M. (2004) Genome-Wide Patterns of Carbon and Nitrogen Regulation of Gene Expression Validate the Combined Carbon and Nitrogen (CN) Signaling Hypothesis in Plants. *Genome Biology*, **5**, 91-101.

[37] Krapp, A. and Truong, H.N. (2005) Regulation of C/N Interaction in Model Plant Species. In: *Enhancing the Efficiency of Nitrogen Utilization in Plants*, Haworth Press, 127-173.

[38] Nunes-Nesi, A., Fernie, A.R. and Stitt, M. (2010) Metabolic and Signaling Aspects Underpinning the Regulation of Plant Carbon-Nitrogen Interactions. *Molecular Plant*, **3**, 973-996.

[39] Ezeocha, V.C., Nwogha, J.S., Ohuoba, A.N. and Chunku, L.I. (2014) Evaluation of Poultry Manure Application Rates on the Nutrient Composition of *Dioscorea bulbifera* (*Aerial yam*). *Nigerian Food Journal*, **32**, 92-96.

[40] Jehangir, H., Jay Capasso, M., *et al.* (2017) Raising Soil Organic Matter Content to Improve Water Holding Capacity. SL447 Soil and Water Science Department, UF/IFAS Extension, University of Florida.

[41] Hu, J., Lin, X., Wang, J., Dai, J., Chen, R., *et al.* (2011) Microbial Functional Diversity, Metabolic Quotient, and Invertase Activity of a Sandy Loam Soil as Affected by Long-

Term Application of Organic Amendment and Mineral Fertilizer. *Journal of Soil Sediment*, **11**, 271-280.

[42] Sathya, V. and Maheswari, M. (2017) Nutrient Mineralization during the Application of Poultry Manure. *Nature Environment and Pollution Technology*, **16**, 905-909.

[43] Zhen, Z., Liu, H., Wang, N., Guo, L., Meng, J., *et al.* (2014) Effects of Manure Compost Application on Soil Microbial Community Diversity and Soil Microenvironments in a Temperate Cropland in China. *PLOS ONE*, **9**, 22-41.

[44] Agbede, T.M. and Adekiya, A.O. (2016) Effect of Cocoa Pod Ash and Poultry Manure on Soil Properties and Cocoyam Productivity of Nutrient Depleted Tropical Alfisol. World Academy of Science and Engineering Technology. *International Journal of Biological*, *Biomolecular*, *Agricultural*, *Food and Biotechnological Engineering*, **10**, 140-147.

[45] Hazelton, P.A. and Murphy, B. (2007) Interpreting Soil Test Results, What Do All the Numbers Mean? Common-Wealth Scientific and Industrial Research Organization Publishing (CSIRO).

[46] Wada, E., Feyissa, T. and Tesfaye, K. (2019) Proximate, Mineral and Antinutrient Contents of Cocoyam (*Xanthosoma sagittifolium* (L.) Schott) from Ethiopia. *International Journal of Food* Science, **2**, 1-7.

[47] Christopher, M., Aboyeji, A.O., *et al.* (2019) Response of Soil Chemical Properties, Performance and Quality of Sweet Potato (*Ipomoea batatas* L.) to Different Levels of K Fertilizer on a Tropical Alfisol. *The Open Agriculture Journal*, **13**, 58-66.

[48] Panthi, U., Bartaula, S., Adhikari, A., *et al.* (2019) Effects of Potassium Levels on Growth and Productivity of Potato Varieties in Inner Terai of Nepal. *Journal of Agriculture and Natural Resources*, **2**, 274-281.

[49] Dreyer, I., Gomez-Porras, J.L. and Riedelsberger, J. (2017) The Potassium Battery: A Mobile Energy Source for Transport Processes in Plant Vascular Tissues. *New Phytologist*, **216**, 1049-1053.