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Growth and yield of 12 accessions of Pawpaw (*Carica papaya* L.) as influenced by poultry manure application rates in Derived Savanna of Nigeria

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Abstract

Pawpaw (*Carica papaya* L.) has gained important commercial status in Nigeria due to its nutritional, medicinal and health benefits. In recent times, there is a growing preference for pure organic food due to the envisaged health and environmental benefits. Thus, a study was carried out on 12 selected accessions of pawpaw evaluated under three poultry manure (PM) application rates at the Department of Crop Science, University of Nigeria, Nsukka. The field experiment was a split plot in randomized complete block design of three replications. The main plot treatment was three PM application rates (0, 5 and 10 t ha^{-1}) and the sub-plot treatment was 12 accessions of pawpaw. Accession Ijm-Cl-Ro significantly ($p<0.05$) produced the tallest plants (71.7, 87.3, 108.3, 127.4 and 150.0cm) at 3, 6, 9, 12 and 15 months after transplanting (MAT), respectively. It had the greatest number of fruits (9.3) at 11 months after the onset of fruit formation, maximum fruit weight (7.15kg) and the highest fruit yield (23.83 t ha^{-1}). Increasing PM rate increased growth traits of the pawpaw plants. Interaction of manure rate × accession on most of the growth attributes varied greatly, but showed no significant difference on yield traits. The accession Ijm-Cl-Ro with the application of 10 t ha^{-1} of PM which produced the best growth and highest fruit yield is recommended for improved productivity of pawpaw. The control plot produced no fruit throughout the study period, suggesting that manure application is crucial for sustained yield of pawpaw in the study area.

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Introduction

Pawpaw (*Carica papaya* L.) belongs to the family *Caricaceae* and it is the only species in the genus *Carica* (Organization for the Economic Cooperation and Development (OECD, 2010). It is a herbaceous perennial plant with green or purple hollow stem, which is usually single, erect and bears a crown of palmately lobed leaves.

It is a fast growing arborescent herb, with short life span. It has single straight or sometimes branched stem reaching 2-10 m height. The stem is cylindrical, spongy, fibrous, loose, hollow, gray or gray-brown coloured, 10-30cm diameter and toughened by large and protuberant scars caused by fallen leaves and flowers (Food and Agriculture Organization (FAO, 2003). The fruit is melon-like, oval to nearly round, somewhat elongate in shape weighing up to 9kg (Morton, 1987). The production areas are located in most tropical and sub-tropical countries (California Rare Fruit Growers (CRFG, 1998), and it grows best in fertile and well-drained soils (Crane *et al.,* 2007).

Pawpaw is considered one of the most important fruits because it is a rich source of antioxidants, the B vitamins, minerals, and fibre. In addition, pawpaw is a source of the digestive enzyme papain, which is used as an industrial ingredient in brewing, meat tenderizing, pharmaceuticals, beauty care products, and cosmetics (Edward and Fredy, 2012).

Despite the enormous socioeconomic and nutritional benefits, production of pawpaw is still very low and under threat due to some factors such as lack of suitable accession, drought/moisture deficit, low soil fertility, pests, unfavorable climate and many more. Out of these factors, available accession plays an important role in the productivity of most fruit tree species. The ability of crop species to respond to different abiotic and biotic stress factors (such as drought, heat waves, pest and disease pressures) contributed to their spread across the different parts of the world from their centre of origin (Hall, 2011).

There were reports of previous studies on the influence of accession and poultry manure on growth and yield of crops. Stevens *et al.* (2018) reported accessional differences in growth and yield of *Moringa oleifera* in Nigeria as well as its response to manure application. Nwankwo *et al.* (2020) who worked on two genotypes of passion fruit in Jos, Nigeria observed genetic differences in their growth and yield. Muñoz *et al.* (2004) reported that application of poultry manure resulted in higher yield of pawpaw when compared with inorganic fertilizer. Ramachandran *et al.* (1980) achieved higher yields with organic fertilizer than growing *M. oleifera* without fertilizer. Adebayo *et al.* (2011) in their study observed increased vegetative growth and dry matter yield of *M. oleifera* with organic soil amendments. Nonetheless, studies on germplasm collection and evaluation in response to poultry manure rates are uncommon and not adequately documented in the study area, especially on pawpaw.

The present study was therefore undertaken to evaluate the growth and yield of 12 accessions of pawpaw as influenced by three rates of poultry manure, with the aim of making selections that would best adapt to the derived savanna agroecology of southeastern Nigeria.

Materials and methods

Experimental site

Field experiment was conducted at the Department of Crop Science Teaching and Research Farm, Faculty of Agriculture, University of Nigeria, Nsukka (Latitude 07°29' N, Longitude 06°51' E and altitude 400m above sea level). Nsukka is characterized by sub-humid tropical conditions with bimodal annual rainfall distribution that ranges from 1155mm to 1955mm with a shift in the second peak of rainfall from September to October, a mean annual temperature of 29°C and a relative humidity that ranges from 69% to 79% (Uguru *et al.*, 2011). The experiment was carried out between May 2013 and January 2015.

Collection of papaya germplasm

Germplasm collection was between January and February 2013. Seeds were extracted from pawpaw fruits obtained from locally available papaya varieties in two Local Government Areas (LGAs) of Kogi State - Ijumu LGA (Iyamoye) and Yagba West LGA (Okoloke), and Nsukka LGA (Owerre Obukpa) of Enugu State, Nigeria. The twelve accessions of pawpaw planted were of different fruit shapes (Clavate or spheroid) and fruit pulp colours (Light yellow, bright yellow, deep yellow to orange or reddish orange) as described in Table 1.

Table 1. List of accessions evaluated showing State, Local Government Areas and collection centres in Nigeria, fruit shape, fruit pulp colour and acronyms used in the text.

SL	State	LGA	Specific Location	Fruit Shape	Fruit flesh colour	Acronyms
1	Kogi	Ijumu	Iyamoye "Canada"	Clavate	Reddish orange	Cnd-Cl-Ro,
2	Kogi	Ijumu	Iyamoye	Clavate	Reddish orange	Ijm-Cl-Ro
3	Kogi	Ijumu	Iyamoye	Clavate	Deep yellow to orange	Ijm-Cl-Dyo
4	Kogi	Ijumu	Iyamoye	Spheriod	Light yellow	Ijm-Sp-Ly
5	Enugu	Nsukka	Owerre Obukpa	Clavate	Reddish orange	Nsk-Cl-Ro
6	Enugu	Nsukka	Owerre Obukpa	Clavate	Bright yellow	Nsk-Cl-By
7	Enugu	Nsukka	Owerre Obukpa	Spheriod	Reddish orange	Nsk-Sp-Ro
8	Enugu	Nsukka	Owerre Obukpa	Spheriod	Light yellow	Nsk-Sp-Ly
9	Kogi	Yagba West	Okoloke	Clavate	Reddish orange	Yw-Cl-Ro
10	Kogi	Yagba West	Okoloke	Clavate	Bright yellow	Yw-Cl-By
11	Kogi	Yagba West	Okoloke	Spheriod	Reddish orange	Yw-Sp-Ro
12	Kogi	Yagba West	Okoloke	Spheriod	Light yellow	Yw-Sp-Ly

Pre-nursery and nursery operations

Twelve baskets were obtained to raise the seedlings for three weeks in the pre-nursery before transplanting to the main nursery. The seeds were raised in baskets with nursery medium in volume ratios of 3:2:1 of topsoil, cured poultry manure and river sand, respectively. In the main nursery, 720 polyethylene bags with dimensions 5.0cm × 10.0cm were used to transplant 60 seedlings per accession. The seedlings were raised in the nursery bags filled with a mixture of topsoil, cured poultry manure and river sand as previously described. Shade was provided to protect the seedlings from harsh weather condition.

Land preparation

The land area was ploughed and harrowed to kill weeds and provide good internal drainage. The planting holes (30.0cm × 30.0cm × 30.0cm) were dug according to the marked plant spacing of 2.0m × 1.5m (inter-row × intra-row) giving a plant population of 3333.3 t ha^{-1}.

Treatments, experimental design and field layout

The main plot treatment was three application rates of poultry manure; PM (0, 5 and 10 t ha^{-1}) while the sub-plot treatment was the 12 accessions of pawpaw. The experiment was a split-plot laid out in a randomized complete block design (RCBD) using a single row plot of five plants replicated three times. An alleyway of 3.0 m separated each block.

The pawpaw accessions were named according to the fruit shape, fruit pulp colour and collection centers as described in Table 1.

Poultry manure was applied at 15% moisture content in three split doses. At two weeks before transplanting, 40% of the calculated manure doses were applied as bottom dressing across the manure treatments; 30% was applied as top dressing at one month after transplanting, while the complementary 30% was applied at four months after transplanting. Weeds were duly controlled with herbicide (glyphosate) when necessary.

Data collection and analysis

Data were collected on plant height measured in centimeter from the ground level to the plant apex using a flexible measuring tape. Growth vigour of the plants was recorded using a rating scale developed for the purpose of this study to determine the greenness and yellowness of the pawpaw leaves (1= Highly stressed, more yellow leaves than green leaves, shrinking and dwarf plants, 2=Stressed, few yellow leaves and green leaves with slightly vigorous plants, 3=Slightly stressed, more green leaves than yellow leaves with vigorous plants, 4=No serious indicator of water stress, vigorous growing plants with few yellow leaves, 5= No visible sign of water stress, vigorous growing plants with many green leaves).

Survival rate was determined as the percentage of plants that survived in each accession across the manure treatments at the end of the experiment. Numbers of leaves at the onset of fruit formation for each plant were counted and the average recorded on each sub-plot. Stem circumference for each plant was measured at 10cm height above ground level using flexible measuring tape. Others were number of fruits per plant at 3, 5, 7, 9 and 11 months after onset of fruit formation (MAOFF) and fruit yield per plant (kg) which was later converted to hectare basis (t ha^{-1}).

Data collected from this study were subjected to analysis of variance (ANOVA) following the procedures for split-plot experiment in randomized complete block design (RCBD) using GENSTAT software (2013). Means separation to detect the effect of manure and accession, and their interactions was by Least Significant Difference (LSD) at 5% probability level.

Results

The results of the soil physical and chemical properties of the experimental site prior to field planting (i.e. before transplanting the pawpaw seedlings) and the poultry manure sample used (Table 2) revealed that the soil pH was strongly acidic (4.9) compared to the poultry manure with pH 8.8. The soil was characterized texturally as sandy clay loam. The soil was very low in nitrogen (0.084%), organic carbon (1.03%), organic matter (1.77%) and also low in phosphorus (2.80 ppm); with the poultry manure used being high in pH, organic carbon and organic matter; and other exchangeable minerals.

Table 2. Physicochemical properties of soil of the experimental site (prior transplanting) and the poultry manure sample used in the study.

Properties	Soil sample	Poultry manure
Mechanical properties		
Clay (%)	30	-
Silt (%)	19	-
Fine sand (%)	12	-
Coarse sand (%)	39	-
Textural class	Sandy clay loam	
Chemical properties		
pH in water	4.9	8.8
pH in KCl	3.7	8.6
Organic carbon (%)	1.03	12.369
Organic matter (%)	1.77	21.324
Total nitrogen (%)	0.084	2.942
Phosphorus (ppm)	2.80	0.953 (%)
Exchangeable bases		
Calcium Ca^{2+}) cmol/kg	2.80	104.00
Magnesium (mg^{2+}) cmol/kg	0.80	384.00
Potassium (K^{+}) cmol/kg	0.37	0.145 (%)
Sodium (Na^{+}) cmol/kg	0.73	0.0195 (%)
CEC	14	-
Base saturation (%)	33.57	-
Exchangeable acidity in me/ 100 g soil		
Aluminium (Al^{3+})	1.40	-
Hydrogen (H^{+})	0.60	-

Source: Department of Soil Science laboratory, University of Nigeria, Nsukka.

Effect of accession and poultry manure rates on plant height (cm), growth vigour and survival rate of the pawpaw plants at 3, 6, 9, 12, and 15 months after transplanting (MAT)

The results in Table 3 showed significant ($p < 0.05$) differences in the height of the pawpaw accessions at 3 - 15 MAT. Accession Ijm-Cl-Ro produced the tallest plant heights (71.7, 87.3, 108.3, 127.4 and 150.0cm) at 3, 6, 9, 12 and 15 months after transplanting (MAT), respectively. The shortest plant was obtained in accession Yw-Cl-Ro (57.1cm) at 3 MAT, while Yw-Sp-Ly accession had the least plant height of 70.6cm, 85.9cm, 99.1cm, and 117.4cm at 6, 9, 12, and 15 MAT, respectively.

Table 3. Effect of accession and poultry manure rates on plant height (cm), growth vigour and percent survival of the pawpaw plants recorded at 3-15 months after transplanting (MAT).

Accession	Plant height (cm) at 3-15 MAT					GV	SR (%)
	3	6	9	12	15		
Cnd-Cl-Ro	63.5	79.1	97.7	117.9	123.5	3.7	68.0 (7.1)
Ijm-Cl-Dyo	63.2	77	97.6	112.6	136.7	3.3	65.8 (7.0)
Ijm-Sp-Ly	63.9	77	94.7	108	127.5	3.3	61.9 (6.3)
Ijm-Cl-Ro	71.7	87.3	108.3	127.4	150	3.3	62.4 (6.4)
Nsk-Cl-Ro	64	79.3	96.5	113	134.1	3.7	68.0 (7.1)
Nsk-Cl-By	61.8	77.8	92.2	111	128.4	3.8	72.4 (7.4)
Nsk-Sp-Ro	63.9	80	101.3	119.3	141.9	3.6	75.8 (7.9)
Nsk-Sp-Ly	63.8	84.9	104.8	120.3	145.5	3.3	71.7 (7.3)
Yw-Cl-Ro	57.1	74.7	88.6	110.1	134.7	3.6	72.5 (7.4)
Yw-Cl-By	64.4	82.7	97.8	110.2	133.6	3.4	68.0 (7.1)
Yw-Sp-Ro	62.7	77.3	93.1	112.1	135.8	3.4	61.9 (6.3)
Yw-Sp-Ly	58.3	70.6	85.9	99.1	117.4	3.4	65.8 (7.0)
LSD (0.05)	6.0	7.1	11.3	11.9	15.6	NS	NS
Manure rates (t ha^{-1})							
0	36.6	41.7	44.2	54.4	56.5	3.2	18.1 (1.7)
5	76.1	92.1	116.5	136.1	167.6	3.4	95.0 (9.7)
10	76.9	103.0	128.9	149.8	178.1	3.7	86.7 (9.3)
LSD (0.05)	3.0	3.5	5.6	5.9	7.8	0.2	1.5

Plant height at 3, 6, 9, 12, and 15 months after transplanting coincides with November 2013, February 2014, May 2014, August 2014 and November 2014. GV=Growth vigour coincided with April 2014. SR= Survival rate coincided with March 2015; values in brackets were square-root transformed and used for ANOVA.

Poultry manure (PM) had significant ($p < 0.05$) effect on plant height, growth vigour and survival rate of the pawpaw plants. Increase in PM rate resulted in increased plant height, with 10 t ha^{-1} producing the tallest plants (76.9cm, 103.0cm, 128.9cm, 149.8cm and 178.1cm) at 3, 6, 9, 12 and 15 MAT, respectively; with the best growth vigour of 3.7. Plots treated with 5 t ha^{-1} gave the highest survival rate of 95.0%, compared to 86.7% (for 10 t ha^{-1} plot) and 18.8% recorded in the control plot (0 t ha^{-1} PM application). The control plot had the least plant heights (36.6cm, 41.7cm, 44.2cm, 54.4cm and 56.5cm) at 3, 6, 9, 12 and 15 MAT, with the poorest growth vigour (3.2).

The results shown in Table 4 revealed that the interaction of manure rate × accession on plant height were not significant at 3, 6, 9 and 15 MAT, but was significantly ($p > 0.05$) different at 12 MAT. At 12 MAT, accession Nsk-Sp-Ly treated with 10 t ha^{-1} of PM had the tallest plant (167.0cm), which was statistically similar to 165.6cm recorded in Ijm-Cl-Ro, fertilized with 5 t ha^{-1} of PM. The shortest plant of 46.0cm was obtained in Yw-Sp-Ly with 0 t ha^{-1}. Seedling survival rate and the plant height values were generally poor in the control plots (0 t ha^{-1}) across the accessions where no manure was applied.

Table 4. Interaction of poultry manure rates x accession on plant height (cm), growth vigour and percentage survival of the pawpaw plants at 3 - 15 months after transplanting (MAP).

Manure rates (t ha^{-1})	Accession	Plant height (cm) at 3 -15 MAT					GV	SR (%)
		3	6	9	12	15		
0	Cnd-Cl-Ro	39.4	44.6	52.2	80.5	87.9	3.3	16.3 (2.3)
	Ijm-Cl-Dyo	38.6	43.4	49.0	54.4	57.9	3.0	15.1 (3.3)
	Ijm-Sp-Ly	36.0	42.3	47.2	51.8	55.0	3.0	14.0 (2.0)
	Ijm-Cl-Ro	40.0	45.1	49.3	57.4	61.8	2.9	0.0 (0.7)
	Nsk-Cl-Ro	36.3	41.0	44.5	48.5	55.3	3.7	24.0 (2.6)
	Nsk-Cl-By	39.9	41.1	42.5	49.8	56.0	3.8	0.0 (0.7)
	Nsk-Sp-Ro	39.4	44.7	47.8	55.2	64.4	3.4	0.0 (0.7)
	Nsk-Sp-Ly	35.4	44.0	48.5	53.1	58.1	3.1	15.1 (2.0)
	Yw-Cl-Ro	31.2	34.9	40.2	55.8	61.9	3.1	17.5 (2.1)
	Yw-Cl-By	37.3	45.2	49.1	53.2	57.9	3.0	17.5 (2.1)
	Yw-Sp-Ro	30.4	35.1	40.3	46.8	52.4	3.0	0.0 (0.7)
	Yw-Sp-Ly	30.1	34.3	40.1	46.0	48.7	3.2	15.1 (2.0)
5	Cnd-Cl-Ro	76.1	93.8	117.1	135.2	161.3	3.8	98.0 (9.7)
	Ijm-Cl-Dyo	74.2	90.0	118.1	140.7	180.9	3.4	86.7 (8.8)
	Ijm-Sp-Ly	76.8	88.6	110.1	126.7	153.4	3.1	93.3 (9.3)
	Ijm-Cl-Ro	87.2	106.9	140.1	165.6	198.7	3.3	100.0 (10.0)
	Nsk-Cl-Ro	74.6	90.2	112.0	131.8	162.6	3.5	100.0 (10.0)
	Nsk-Cl-By	70.0	85.2	105.3	125.6	149.5	3.1	100.0 (10.0)
	Nsk-Sp-Ro	76.2	91.0	119.3	140.1	171.3	3.8	100.0 (10.0)
	Nsk-Sp-Ly	76.2	96.2	121.7	140.8	177.5	3.4	100.0 (10.0)
	Yw-Cl-Ro	70.6	90.8	114.9	133.9	171.7	3.7	100.0 (10.0)
	Yw-Cl-By	81.1	95.2	114.7	131.8	168.9	3.6	93.3 (9.3)
	Yw-Sp-Ro	80.2	96.7	123.5	140.3	172.1	3.9	100.0 (10.0)
	Yw-Sp-Ly	70.0	81.4	100.6	120.5	143.7	3.3	100.0 (10.0)
10	Cnd-Cl-Ro	75.0	99.0	123.6	137.9	160.3	3.9	98.0 (9.7)
	Ijm-Cl-Dyo	76.9	97.3	125.7	142.7	171.4	3.7	80.0 (8.4)
	Ijm-Sp-Ly	78.9	100.2	126.8	145.5	174.0	3.8	80.0 (8.4)
	Ijm-Cl-Ro	87.8	110.0	135.3	159.1	189.3	3.8	86.7 (8.8)
	Nsk-Cl-Ro	81.1	107.0	132.9	158.7	184.3	3.7	93.3 (9.3)
	Nsk-Cl-By	75.6	106.9	128.8	157.7	179.6	3.3	100.0 (10.0)
	Nsk-Sp-Ro	75.8	104.4	136.7	162.5	189.9	3.6	100.0 (10.0)
	Nsk-Sp-Ly	79.8	114.3	144.0	167.0	200.9	3.6	100.0 (10.0)
	Yw-Cl-Ro	69.7	98.3	120.7	140.5	170.5	3.9	100.0 (10.0)
	Yw-Cl-By	74.8	107.4	129.7	145.7	174.1	3.6	100.0 (10.0)
	Yw-Sp-Ro	77.4	100.1	126.6	149.2	183	3.4	74.7 (8.2)
	Yw-Sp-Ly	70.6	91.9	116.3	130.7	159.8	3.9	80.0 (8.4)
LSD (0.05)		NS	NS	NS	20.51	NS	0.96	NS

Plant height at 3, 6, 9, 12, and 15 months after transplanting coincides with November 2013, February 2014, May 2014, August 2014 and November 2014. GV = Growth vigour coincided with April 2014. SR = Survival rate coincided with March 2015. Values in brackets were square root transformed and used for ANOVA. NS = non-significant.

Effect of accession and poultry manure rates on number of leaves of the pawpaw plants produced at 3, 6, 9, 12, 15 months after transplanting (MAT) and at onset of fruit formation (OFF)

Table 5 showed that accession did not influence the number of leaves produced by the pawpaw plants at 3 and 6 MAT, but differed significantly ($p < 0.05$) at 9, 12 and 15 MAT, and at the onset of fruit formation (OFF). Accessions Cnd-Cl-Ro and Nsk-Cl-Ro produced the highest number of leaves of 10.1 each at 9 MAT, followed by accessions Ijm-Cl-Dyo, Nsk-Cl-By and Nsk-Sp-Ro that gave 9.0 each which were statistically similar with accessions Cnd-Cl-Ro and Nsk-Cl-Ro. Accession Yw-Cl-Ro produced the least number of leaves (7.1) at 9 MAT. At 12 and 15 MAT, Cnd-Cl-Ro produced the highest number of leaves of 11.3 and 13.7 which were not statistically different from 10.3 and 13.5 leaves produced by accession Nsk-Sp-Ly at 12 and 15 MAT, respectively. Accessions Nsk-Sp-Ro and Nsk-Sp-Ly produced the highest number of leaves (9.8) at the OFF, which is statistically similar with Nsk-Cl-Ro (9.7) and Nsk-Cl-By (9.6).

The accession Yw-Sp-Ly gave the least number of leaves of 8.2 at the OFF. Manure rate significantly ($p < 0.05$) influenced the number of leaves produced at 3, 6, 9, 12 and 15 MAT and at the OFF. Application of 10 t ha^{-1} of PM produced the highest number of leaves at 3, 6, 9, 12, 15 MAT and at the OFF with 15.4, 10.0, 11.2, 13.1, 16.4 and 11.4, while 0 t ha^{-1} had the least number of leaves of 7.0, 3.3, 4.0, 5.0, 5.7 and 4.9, respectively. The number of leaves produced by the 10 t ha^{-1} treated plants were, in most cases, significantly ($p \leq 0.05$) higher than those of the 5 t ha^{-1} treated plants.

The results in Table 6 showed significant ($p \leq 0.05$) interaction of poultry manure × accession on number of leaves produced by the pawpaw plants at 3, 6, 9, 12 and 15 MAT and at onset of fruit formation (OFF). Interaction between accession Nsk-Cl-Ro and 10 t ha^{-1} of PM produced the highest number of leaves (19.9) at 3 MAT, followed by accession Ijm-Cl-Dyo and 10 t ha^{-1} of PM (15.8).

Table 5. Effect of accession and poultry manure rates on number of leaves of the pawpaw plants at 3–15 months after transplanting (MAT) and onset of fruit formation (OFF).

	Number of leaves at 3-15 MAT					
Accession	3	6	9	12	15	OFF
Cnd-Cl-Ro	11.3	7.7	10.1	11.3	13.7	9.2
Ijm-Cl-Dyo	12.2	6.7	9.0	9.9	13.1	8.8
Ijm-Sp-Ly	11.9	7.4	8.0	9.4	11.8	8.4
Ijm-Cl-Ro	12.1	7.6	8.7	10.8	13.2	9.1
Nsk-Cl-Ro	13.8	7.1	8.3	9.7	11.8	9.7
Nsk-Cl-By	11.0	6.7	9.0	10.7	13.0	9.6
Nsk-Sp-Ro	11.9	6.8	9.0	9.7	12.8	9.8
Nsk-Sp-Ly	12.2	7.6	10.1	10.3	13.5	9.8
Yw-Cl-Ro	12.2	6.9	7.1	8.8	12.3	8.7
Yw-Cl-By	11.7	6.9	7.8	8.7	11.3	7.9
Yw-Sp-Ro	11.6	6.7	7.4	9.9	12.1	8.4
Yw-Sp-Ly	11.1	7.0	8.0	8.68	11.8	8.2
LSD (0.05)	NS	NS	1.49	1.43	1.66	0.89
Manure rates (t ha^{-1})						
0	7.0	3.3	4.0	5.0	5.7	4.9
5	13.2	8.0	10.2	12.3	15.6	10.1
10	15.4	10	11.2	13.1	16.4	11.4
LSD (0.05)	0.72	0.57	0.74	0.71	0.84	0.44

Number of leaves at 3, 6, 9, 12, and 15 months after transplanting coincided with November 2013, February 2014, May 2014, August 2014 and November 2014; OFF = Onset of fruit formation which coincided with March 2014. NS=non-significant.

At 6 MAT, accession Ijm-Sp-Ly treated with 10 t ha^{-1} of PM recorded the highest number of leaves (10.9) while accessions Nsk-Cl-By and Yw-Sp-Ro with 0 t ha^{-1} produced the least number of leaves of 3.0 each. Accession Nsk-Sp-Ly treated with 10 t ha^{-1} of PM produced the highest number of leaves (13.9) at 9 MAT, followed by accession Nsk-Cl-By that received 10 t ha^{-1} of PM (12.8). At 12 MAT, accession Cnd-Cl-Ro grown with 5 t ha^{-1} of PM produced the highest number of leaves of 14.4 which is statistically similar with 14.0 leaves produced by Ijm-Cl-Ro treated with 5 t ha^{-1} of PM. Accession Yw-Cl-By treated with 0 t ha^{-1} had the least number of leaves (4.0) at 12 MAT. At 15 MAT, accession Nsk-Sp-Ly grown with 10 t ha^{-1} of PM had the highest number of leaves of 19.0, while the least (3.4) was obtained in accession Nsk-Cl-By with 0 t ha^{-1} of PM. Accession Nsk-Cl-By treated with 10 t ha^{-1} of PM produced the highest number of leaves (13.1) at the onset of fruit formation, while the least was obtained in Ijm-Cl-Ro with 0 t ha^{-1} (3.6).

Table 6. Interaction of manure rates x accession on number of leaves of pawpaw plant at 3 -15 months after transplanting (MAT) and at the onset of fruit formation (OFF).

Manure rates (t ha-1)	Accession	Number of leaves at 3-15 MAT					
		3	6	9	12	15	OFF
0	Cnd-Cl-Ro	6.6	3.6	5.4	6.6	9.1	5.1
	Ijm-Cl-Dyo	1.9	3.1	4.4	4.9	5.7	5.3
	Ijm-Sp-Ly	7.4	3.7	3.8	4.7	5.1	4.4
	Ijm-Cl-Ro	7.7	3.4	2.8	5.3	5.5	3.6
	Nsk-Cl-Ro	7.1	3.9	4.1	4.7	5.3	5.5
	Nsk-Cl-By	5.9	3.0	3.0	5.7	3.4	4.4
	Nsk-Sp-Ro	6.4	2.6	3.7	4.3	6.0	5.8
	Nsk-Sp-Ly	8.0	3.9	4.8	4.7	5.4	6.0
	Yw-Cl-Ro	7.0	3.4	4.6	4.8	6.4	4.8
	Yw-Cl-By	7.5	3.1	3.8	4.0	5.0	4.8
	Yw-Sp-Ro	6.1	3.0	3.7	4.8	5.0	3.8
	Yw-Sp-Ly	7.2	3.6	4.7	4.9	5.6	5.3
5	Cnd-Cl-Ro	12.2	9.0	12.3	14.4	16.6	10.8
	Ijm-Cl-Dyo	13.1	7.7	10.9	13.0	17.3	10.1
	Ijm-Sp-Ly	12.8	8.0	9.0	11.0	14.8	9.7
	Ijm-Cl-Ro	14.1	9.0	11.3	14.0	17.8	10.7
	Nsk-Cl-Ro	14.2	7.0	9.6	11.6	13.9	10.1
	Nsk-Cl-By	12.6	7.4	11.0	12.8	16.6	11.5
	Nsk-Sp-Ro	13.4	7.9	11.6	11.9	15.1	10.6
	Nsk-Sp-Ly	13.8	8.9	12.0	12.9	16.1	10.5
	Yw-Cl-Ro	14.3	8.2	9.1	11.6	15.2	9.9
	Yw-Cl-By	13.8	7.3	9.2	12.2	14.8	8.6
	Yw-Sp-Ro	13.2	7.4	9.6	12.4	14.9	10.3
	Yw-Sp-Ly	11.4	7.4	8.0	10.2	13.1	8.4
10	Cnd-Cl-Ro	15.2	10.2	12.7	13.0	15.2	11.8
	Ijm-Cl-Dyo	15.8	9.2	11.4	11.8	16.4	10.8
	Ijm-Sp-Ly	15.2	10.9	11.2	12.8	15.4	11.2
	Ijm-Cl-Ro	14.6	10.2	11.8	13.0	16.3	10.0
	Nsk-Cl-Ro	19.9	10.6	11.3	12.8	16.0	11.9
	Nsk-Cl-By	14.9	9.7	12.8	13.8	18.8	13.1
	Nsk-Sp-Ro	15.6	9.8	12.0	12.8	17.1	12.4
	Nsk-Sp-Ly	15.0	10.0	13.9	13.3	19.0	12.7
	Yw-Cl-Ro	15.2	8.9	7.9	10.0	15.4	11.4
	Yw-Cl-By	13.7	10.0	10.2	9.6	14.2	10.1
	Yw-Sp-Ro	15.4	9.6	9.0	12.3	16.6	11.1
	Yw-Sp-Ly	15.0	10.2	11.2	10.9	16.6	10.9
LSD (0.05)		2.52	1.97	2.58	2.48	2.94	1.54

Number of leaves at 3, 6, 9, 12, and 15 months after transplanting coincides with November 2013, February 2014, May 2014, August 2014 and November 2014; OFF= Onset of fruit formation which coincided with March 2014.

The inconsistent performance of the accessions at 6, 9 and 12 MAT was as a result of some leaf abscission which coincided with the fruiting period. In general, the number of leaves produced per plant increased sequentially with increasing manure rates across the accessions, and was poorest in the control plants with no manure amendment.

Effect of accession and poultry manure rates on stem circumference (cm) of the pawpaw plants measured at 15, 16, 17, 18, and 19 months after transplanting (MAT)

Table 7 showed that accession and poultry manure application significantly ($p \leq 0.05$) influenced the stem circumference of the pawpaw plants at 15, 16, 17, 18, and 19 MAT. At 15 MAT, accessions Cnd-Cl-Ro and Nsk-Sp-Ro produced the widest stem circumference of 13.4cm, which is statistically similar with 13.3cm obtained in Nsk-Sp-Ly. The least (11.2cm) was obtained in accession Yw-Cl-By. However, at 16, 17, 18, and 19 MAT, accession Cnd-Cl-Ro consistently had the widest stem circumference of 14.9, 15.0, 15.2 and 15.7cm, respectively, while the least values were obtained in accession Ijm-Sp-Ly at 15, 16, 17, 18 and 19 MAT.

Table 7. Effect of accession and poultry manure rates on stem circumference (cm) of the pawpaw plants measured at 15 – 19 months after transplanting (MAT).

	Months After Transplanting				
Accession	15	16	17	18	19
Cnd-Cl-Ro	13.4	14.9	15.0	15.2	15.7
Ijm-Cl-Dyo	12.6	12.8	12.8	13.0	13.0
Ijm-Sp-Ly	11.1	11.3	11.4	11.9	11.9
Ijm-Cl-Ro	13.0	13.4	13.6	13.8	14.0
Nsk-Cl-Ro	11.6	11.7	11.8	11.7	11.8
Nsk-Cl-By	11.7	11.9	12.0	12.0	12.0
Nsk-Sp-Ro	13.4	14.1	14.3	14.6	15.5
Nsk-Sp-Ly	13.3	13.4	13.4	13.9	13.4
Yw-Cl-Ro	11.3	11.8	11.9	12.0	12.0
Yw-Cl-By	11.2	11.7	11.8	12.0	12.0
Yw-Sp-Ro	12.7	13.0	13.0	13.2	13.3
Yw-Sp-Ly	11.4	11.5	11.6	11.8	11.9
LSD (0.05)	1.37	1.39	1.39	1.42	1.57
	Manure rates (t ha^{-1})				
0	5.0	5.6	5.6	5.6	5.7
5	15.0	15.3	15.6	15.7	15.9
10	16.7	16.9	17.0	17.3	17.7
LSD(0.05)	0.68	0.69	0.69	0.71	0.79

Stem circumference at 15, 16, 17, 18 and 19 months after transplanting coincided with November 2014, December 2014, January 2015, February 2015 and March 2015, respectively

Stem circumference increased significantly with poultry manure application across the growth period. Application of 10 t ha^{-1} of PM produced the widest stem circumference of 16.7, 16.9, 17.0, 17.3 and 17.7cm at 15, 16, 17, 18 and 19 MAT, while 0 t ha^{-1} had the least stem circumference of 5.0, 5.6, 5.6, 5.6 and 5.7cm at 15, 16, 17, 18 and 19 MAT, respectively. Interaction of manure rate × accession on stem circumference is presented in Table 8.

The result showed no significant ($p > 0.05$) difference at 15 MAT, but significantly differed at 16, 17, 18 and 19 MAT. Accession Nsk-Sp-Ro treated with 10 t ha^{-1} of PM had the widest stem circumference of 19.1, 19.4, 19.8, and 22.2cm at 16, 17, 18, and 19 MAT, respectively; which did not significantly differ from the corresponding values obtained in accession Nsk-Sp-Ly at 10 t ha^{-1} of PM. Plants that received no manure amendment (0 t ha^{-1} of PM) produced the least stem circumference across the accessions. The accession Cnd-Cl-Ro, however produced moderately wide stem circumference, even without manure application.

Effect of accession and poultry manure on fruit weight (kg), fruit yield (t ha^{-1}) and the number of fruits of pawpaw produced at 7, 9 and 11 months after the onset of fruit formation

The results in Table 9 showed that accession had significant ($p \leq 0.05$) effect on number of fruits produced at 7, 9 and 11 months after the onset of fruit formation (MAOFF), as well as, fruit weight per plant (kg) and fruit yield per hectare (t ha^{-1}). Accession Ijm-Sp-Ly produced the highest number of fruits per plant at 7 and 9 MAOFF, (4.9 and 8.3, respectively) which were statistically similar with 4.6 and 7.8 produced by accession Ijm-Cl-Ro. However, at 11 MAOFF, accession Ijm-Cl-Ro had the greatest number of fruits (9.3), with the maximum fruit weight (7.1kg) and highest fruit yield (t ha^{-1}) of 23.8 t ha^{-1}. Accession Nsk-Cl-Ro produced no fruit at 7 MAOFF, while accession Yw-Cl-Ro had the least values with respect to number of fruit produced at 9 and 11 MAOFF, fruit weight and fruit yield (1.9, 3.1, 1.4kg and 4.67 t ha^{-1}, respectively).

Table 8. Interaction of manure rate x accession on stem circumference (cm) of pawpaw recorded at 15 – 19 months after transplanting (MAT).

Manure rates (t ha^{-1})	Accession	Months After Transplanting				
		15	16	17	18	19
0	Cnd-Cl-Ro	8.1	12.0	12.0	12.0	12.9
	Ijm-Cl-Dyo	4.1	4.1	4.1	4.1	4.1
	Ijm-Sp-Ly	4.0	4.0	4.0	4.0	4.0
	Ijm-Cl-Ro	5.2	5.9	5.9	5.9	6.6
	Nsk-Cl-Ro	4.0	4.0	4.0	4.0	4.0
	Nsk-Cl-By	4.4	4.9	4.9	4.7	4.7
	Nsk-Sp-Ro	6.0	7.1	7.2	7.2	8.2
	Nsk-Sp-Ly	5.6	5.6	5.6	5.7	4.9
	Yw-Cl-Ro	5.2	5.2	5.2	5.2	5.2
	Yw-Cl-By	4.0	4.7	4.7	4.7	4.7
	Yw-Sp-Ro	5.4	5.9	6.0	6.0	6.0
	Yw-Sp-Ly	3.8	3.8	3.9	4.0	4.0
5	Cnd-Cl-Ro	16.0	16.1	16.3	16.8	16.9
	Ijm-Cl-Dyo	16.7	16.9	17.0	17.0	17.1
	Ijm-Sp-Ly	13.4	13.7	13.8	13.9	14.0
	Ijm-Cl-Ro	16.9	17.2	17.3	17.4	17.6
	Nsk-Cl-Ro	13.6	13.8	14.0	14.1	14.2
	Nsk-Cl-By	14.1	14.3	14.4	14.6	14.7
	Nsk-Sp-Ro	15.9	16.2	16.4	16.6	17.2
	Nsk-Sp-Ly	15.8	16.0	16.1	16.2	16.3
	Yw-Cl-Ro	13.9	15.0	15.2	15.3	15.3
	Yw-Cl-By	15.0	15.1	15.3	15.8	15.9
	Yw-Sp-Ro	15.9	16.1	16.3	16.4	16.6
	Yw-Sp-Ly	13.8	13.9	14.0	14.1	14.2
10	Cnd-Cl-Ro	16.1	16.6	16.7	16.9	17.3
	Ijm-Cl-Dyo	16.9	17.1	17.2	17.8	17.9
	Ijm-Sp-Ly	16.0	16.4	16.6	17.7	17.9
	Ijm-Cl-Ro	16.8	17.1	17.3	17.9	17.9
	Nsk-Cl-Ro	17.1	17.2	17.3	17.4	17.6
	Nsk-Cl-By	16.4	16.4	16.6	16.7	16.8
	Nsk-Sp-Ro	18.7	19.1	19.4	19.8	22.2
	Nsk-Sp-Ly	18.7	18.7	18.8	18.9	19.0
	Yw-Cl-Ro	15.0	15.0	15.1	15.3	15.5
	Yw-Cl-By	14.9	15.1	15.2	15.3	15.4
	Yw-Sp-Ro	16.7	16.7	16.9	17.4	17.6
	Yw-Sp-Ly	16.63	16.8	17.0	17.2	17.3
LSD (0.05)		NS	2.41	2.40	2.46	2.72

Stem circumference at 15, 16, 17, 18 and 19 months after transplanting coincided with November 2014, December 2014, January 2015, February 2015 and March 2015 respectively. NS=non-significant.

Table 9. Effect of accession and poultry manure rates on number of fruit of pawpaw produced at 7– 11 months after the onset of fruit formation (MAOFF), fruit weight (kg) and the fruit yield (t ha^{-1}).

Accession	7 MAOFF	9 MAOFF	11 MAOFF	Fruit weight (kg)	Fruit yield (t h^{-1})
Cnd-Cl-Ro	2.9	5.7	7.4	5.3	17.8
Ijm-Cl-Ro	4.6	7.8	9.3	7.1	23.8
Ijm-Cl-Dyo	3.2	6.2	7.1	4.9	16.3
Ijm-Sp-Ly	4.9	8.3	8.7	6.9	23.2
Nsk-Cl-Ro	0.0	2.7	3.2	2.3	7.8
Nsk-Cl-By	0.4	3.2	4.0	1.9	6.6
Nsk-Sp-Ro	1.7	4.4	5.3	3.5	11.9
Nsk-Sp-Ly	2.7	4.7	5.3	3.0	10.0
Yw-Cl-Ro	0.4	1.9	3.1	1.4	4.7
Yw-Cl-By	3.6	5.1	6.7	2.9	9.9
Yw-Sp-Ro	2.4	5.7	5.7	3.4	11.4
Yw-Sp-Ly	0.3	3.1	3.5	2.0	6.7
LSD (0.05)	1.1	3.4	3.5	2.5	8.6
Manure rate (t h^{-1})					
5	1.9	4.2	5.0	3.1	10.4
10	2.6	5.7	6.5	4.3	14.5
LSD (0.05)	NS	1.4	1.4	1.1	3.5

Harvesting of fruits was done within October 2014 to January 2015. NS = Non-significant. 0 t h^{-1} produced no fruit during the experimental period.

Table 10. Interaction of manure rate x accession on number of pawpaw fruits produced per plant at 7 – 11 months after the onset of fruit formation (MAOFF), fruit weight and fruit yield (t ha^{-1}).

Manure rates (t h^{-1})	Accessions	7 MAOFF	9 MAOFF	11 MAOFF	Fruit weight (kg)	Fruit yield (t ha^{-1})
5	Cnd-Cl-Ro	2.8	5.3	7.0	5.3	17.6
	Ijm-Cl-Ro	4.0	6.7	8.7	4.9	16.5
	Ijm-Cl-Dyo	1.7	4.3	5.2	3.4	11.4
	Ijm-Sp-Ly	3.9	7.1	7.6	6.3	21.3
	Nsk-Cl-Ro	0.0	1.7	2.0	0.3	1.1
	Nsk-Cl-By	0.8	4.2	5.0	2.9	9.8
	Nsk-Sp-Ro	1.0	3.0	3.4	2.4	8.2
	Nsk-Sp-Ly	2.3	4.3	3.3	2.0	6.6
	Yw-Cl-Ro	0.0	1.0	2.6	1.2	4.0
	Yw-Cl-By	3.3	3.9	6.2	3.3	11.1
	Yw-Sp-Ro	3.3	5.2	5.2	2.8	9.2
	Yw-Sp-Ly	0.0	3.2	3.8	2.5	8.5
10	Cnd-Cl-Ro	3.0	6.1	7.8	5.4	18.0
	Ijm-Cl-Ro	5.2	8.9	9.9	9.3	31.1
	Ijm-Cl-Dyo	4.7	8.0	9.1	6.3	21.2
	Ijm-Sp-Ly	5.9	9.4	9.8	7.5	25.2
	Nsk-Cl-Ro	0.0	3.8	4.4	4.3	14.5
	Nsk-Cl-By	0.0	2.3	3.0	1.0	3.3
	Nsk-Sp-Ro	2.3	5.7	7.2	4.7	15.5
	Nsk-Sp-Ly	3.0	5.1	7.2	4.0	13.4
	Yw-Cl-Ro	0.8	2.9	3.6	1.6	5.3
	Yw-Cl-By	3.8	6.3	7.2	2.6	8.7
	Yw-Sp-Ro	1.5	6.2	6.2	4.1	13.6
	Yw-Sp-Ly	0.5	3.1	3.1	1.4	4.8
LSD (0.05)		NS	NS	NS	NS	NS

Harvesting of fruits was done within October 2014 to January 2015. NS=Non-significant. 0 t h^{-1} produced no fruit during the experimental period.

Manure rates showed no significant ($p > 0.05$) effect on the number of fruits produced at 7 MAOFF but significant differences were observed on number of fruits produced at 9 and 11 MAOFF, as well as, fruit weight (kg) and fruit yield (t ha^{-1}). Among the manure application rates, highest number of fruits per plant (5.7 and 6.5) was obtained with the application of 10 t ha^{-1} of PM at 9 and 11 MAOFF, respectively. Plants treated with 10 t ha^{-1} of PM also produced heavier fruits (4.3kg) and maximum fruit yield (14.5 t ha^{-1}) relative to 4.2 and 5.0 (for number of fruits per plant), fruit weight (3.1kg) and fruit yield of 10. 4 t ha^{-1} obtained in plots that received 5 t ha^{-1} of PM.

The control plot (0 t ha^{-1} of PM) had no fruit throughout the study period. In Table 10, interaction of manure rate × accession on the number of fruits produced at 7, 9 and 11 MAOFF, fruit weight (kg) and fruit yield (t ha^{-1}) showed no significant ($p > 0.05$) differences. However, the accessions produced correspondingly higher values of the yield traits with 10 t ha^{-1} of PM than the 5 t ha^{-1} application rate.

The accession Ijm-Cl-Ro treated with 10 t ha^{-1} of PM produced the highest fruit yield of 31.1 t ha^{-1} compared to 1.1 t ha^{-1} fruits produced by Nsk-Cl-Ro with 5 t ha^{-1} of PM which had the least value.

Discussion

Effect of accession on growth and yield parameters of pawpaw

The results obtained in this work revealed accessional differences in the growth and yield parameters measured. The divergence in morphological and yield traits observed among the accessions evaluated may be attributed to their genetic makeup and adaptation pattern. Accession Ijm-Cl-Ro had the tallest height, produced the highest number of fruit at 11 MAOFF, and gave the maximum fruit weight (kg) and fruit yield (t ha^{-1}). The results of this study agreed with the report of Somsri (1999) who found differences in the height, number of leaves, stem girth and floral traits of varieties of pawpaw evaluated in South-East Queensland. Davamani *et al.* (2013) reported genetic variability in fruit length, fruit yield and number of fruits per plant in pawpaw from Kenya. Lakshmi (2000) observed genetic variation in fruit shape, fruit pulp colour and fruit yield of pawpaw varieties evaluated in Vellayani. Similarly, Nasim *et al.* (2012), Berhe and Andargachew (2020) reported the effect of genetic potential on grain yield of maize.

The effect of poultry manure on the growth and yield of pawpaw

Poultry manure rates had significant effect on growth and fruit yield of the pawpaw plants. This observation could be due to more available soil nutrients released by the poultry manure which improved growth and yield of pawpaw in plots that received PM than the control plot with no PM application. This result is in agreement with the findings of Olubode and Fawusi (1998) who reported positive effects of organic manure on pawpaw growth and yield in Abeokuta (Nigeria). Baiyeri (2002) observed that the number of fruits per bunch of plantain is influenced by plant nutrition. The results of the present investigation are in conformity with the findings of Naik and Sri (2007) in India, who reported that application of animal manures produced more fruits in guava. Increase in poultry manure rate increased growth and yield traits of pawpaw in the present study.

The result is in agreement with a previous work on plantain by Baiyeri *et al.* (2009) who reported that bunch yield and individual fruit size increased when manure was applied at 10 t ha^{-1}. Ndubuaku *et al.* (2015) also found that 10 t ha^{-1} poultry manure application had the greatest pod yield of *Moringa oleifera* in Nsukka. These results are also in accordance with the findings of Mitchell and Tu (2005), Warren *et al.* (2006), and Ogundare (2011) who reported that poultry manure applied at 10 t ha^{-1} was significantly higher in growth and yield parameters of cotton in Southern USA, and corn (in Virginia and Akure, respectively) when compared with the control (no manure application). Ogundiran (2013) also reported that application of poultry manure at 10 t ha^{-1} produced significant increase in plant height, stem girth, number of leaves and fruit yield of okra in Ijebu-Ode (Nigeria).

Interaction of accessions × poultry manure rates

Interaction of poultry manure rates × accession significantly influenced most of the growth attributes measured. The results could be attributed to the genetic makeup of the accessions and sufficient plant nutrients released by the 10 t ha^{-1} poultry manure application rate with the resultant positive growth and yield response. Cultivar and environmental differences had produced a wide array of modified forms in plant performance, such that the number and types of modifications have varied in reports by various researchers (Nakasone and Paull, 1998). Observations from the present study support the earlier reports of Agbogidi and Ofuoku (2005) that plants respond differently to environmental factors based on their genetic makeup and their adaptation capability indicating variability among species.

Conclusion

This study indicates that genetic differences that could warrant selection existed among the accessions evaluated with respect to their morphological growth attributes and fruit yield. Expectedly, large morphological structures translated to better adaptation of the accessions as evident in correspondingly higher fruit yields in plants with large stature. It was observed that accession Ijm-Cl-Ro recorded the tallest plant height, with maximum fruit weight (kg) and fruit yield (t ha^{-1}). Thus, Ijm-Cl-Ro accession is recommended for pawpaw growers in Nsukka. Application rate of 10 t ha^{-1} of poultry manure enhanced growth and yield of pawpaw in the study area, and therefore, recommended for intending pawpaw farmers in the derived savanna agroecology of Nsukka, southeastern Nigeria.

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