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Biological Nitrogen Fixation and Soil Property Changes under Kidney bean (*Phaseolus vulgaris* L. Kuntze) Intercropping with Maize (*Zea mays* L.) – *Egusi* melon (*Colocynthis citrullus* L. Schrad) in Benin City, Nigeria

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ABSTRACT
A field experiment was conducted at the Faculty of Agriculture Experimental Farm, University of Benin, Benin City, Nigeria, to evaluate the influence of kidney bean (*Phaseolus vulgaris* L.) on selected soil properties in a maize (*Zea mays* L.)–egusi melon (*Colocynthis citrullus* L.) intercropping system and to estimate the amount of nitrogen fixed by kidney bean under intercropping. Seven cropping systems comprising sole maize, sole egusi melon, sole kidney bean, maize + kidney bean, egusi melon + kidney bean, maize + egusi melon, and maize + egusi melon + kidney bean were arranged in a randomized complete block design with three replicates. Soil samples (0–15 cm) were collected before planting and after harvest for analysis of selected physical and chemical properties, while crop growth, yield, and nutrient concentrations were also determined. Data were analyzed using analysis of variance, and means were separated at the 5% probability level. The soils were acidic and classified as loamy sand. Soil total nitrogen increased in plots containing kidney bean after harvest but declined in plots without the legume. Sole kidney bean recorded the highest soil total nitrogen (0.75 g kg^{-1}), significantly exceeding sole maize (0.57 g/kg), sole *egusi*-melon (0.59 g/kg), pre-plant soil (0.63 g/kg), and maize + *egusi*-melon (0.61 g/kg). Potassium, calcium, and magnesium declined after harvest across treatments. Kidney bean accumulated more nutrients and produced superior growth and yield when intercropped with maize than in the three-crop intercrop. Nitrogen fixation was consistently greater in the maize–kidney bean intercrop, with estimates of 1.15–1.33 g/kg/yr (2.30–2.66 t/ha/yr), demonstrating the potential of kidney bean to improve soil nitrogen and enhance sustainable intercropping systems.

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INTRODUCTION

Crop production in Sub-Saharan Africa is limited by low nutrient status of soil among other problems (Javed *et al*., 2022). In the past, soil fertility was sustained through fallowing. Lately, human activities due to population pressure have made land insufficient. Using chemical fertilizer in achieving high crop yield in Nigeria farming system is not sustainable as a result of scarcity and high cost of fertilizer (Jaja & Barber, 2017). Aside being expensive and scarce, it leads to soil acidity and nutrient imbalance (Masso *et al.*, 2017). Organic fertilizers exist in readily available forms; cheap and easy to assess but are usually associated with environmental pollution, when not cured and they need to be applied in relatively large amounts to meet the nutrient requirements of crops (Babayemi *et al*., 2016: Havlin, 2020; Javed *et al*., 2022).

Intercropping legumes with non-legumes is one of the traditional ways of enriching soil with nitrogen through rhizobium nodules on legume roots. Furthermore, it also controls weeds, pests and soil erosion, coupled with enhancement of soil fertility (Ehigiator *et al*., 2016). Intercropping cereals with legumes is an alternative to cereal monocropping and helps lower costs of production and better silage quality than the monocrop system**.**

Biological nitrogen fixation (BNF) is an important ecological process that supports sustainable crop production. It is the conversion of atmospheric nitrogen (N_2) into ammonia (NH_3), a plant-available form of nitrogen, by nitrogen-fixing bacteria. It improves nitrogen use efficiency, enhances soil fertility and reduces dependence on synthetic nitrogen fertilizers. Intercropping cereals with legumes creates complementary interactions in resource utilization. Cereal crops rapidly absorb mineral nitrogen from the soil because of their extensive fibrous root systems. As soil nitrogen becomes depleted, legumes compensate by fixing more atmospheric nitrogen. This shift increases the percentage of nitrogen derived from atmospheric fixation. Jensen *et al.* (2020) reported that legumes in intercrops often derive 70–95% of their nitrogen from atmospheric fixation compared with lower values in sole cropping. Rodriguez *et al.* (2020) reported that cereal-legume intercropping consistently stimulates complementary nitrogen use between legumes and cereals by increasing nitrogen fixation by grain legumes and increasing soil nitrogen acquisition in cereals.

This study was carried out to examine the influence of kidney bean (*Phaseolus vulgaris* L Kuntze) on some soil properties for maize (*Zea mays* L.) – *egusi* melon (*Colocynthis Citrullus* L. Schrad) intercrop and to estimate the amount of nitrogen fixed by kidney bean in intercrop with both maize (*Zea mays* L.) and *egusi* melon (*Colocynthis Citrullus* L. Schrad).

MATERIALS AND METHODS

Study Area

This experiment was carried out in the Experimental Field of Faculty of Agriculture, University of Benin, Benin City, Nigeria. The area lies between latitude 06° 24′ 02.2″ and 06° 24′ 03.4″ North and longitude 005° 37′ 35.9″ and 005° 37′ 36.8″ East. It is in the rainforest ecological zone of Nigeria, which is characterized by two distinct seasons: dry (November–March) and wet (April–October) (Archibong & Okuo, 2024). It has a mean annual rainfall of 2300 mm and average temperature of 27˚C (Sam *et al*., 2023). The topography of the land is a gentle slope, which falls eastwards. The soils in the area are ultisols; which are derived from recent coastal plain sands known as Benin formation (Okunsebor & Umweni, 2021). The vegetation of the area includes weeds such as: *Panicum maximum, Mimosa pudica, Eleucine indica, Sida acuta, Sporobolus pyramadalis etc.*

Planting Materials

Oba 80™ hybrid maize seeds were obtained from farmer shop in Benin City while red kidney bean seeds (local variety) and *egusi*–melon (*Bini* Cultivar) which is medium in size, brown in colour and have smooth edges, were bought from local markets in Benin City.

Crop Combinations

The crop combinations are: sole maize, sole *egusi* melon, sole kidney bean, maize + kidney bean (KC), *egusi* melon + kidney bean (KE), maize + *egusi* melon (CE), maize + *egusi* melon + kidney bean (KCE). Amounting to seven (7) crop combinations.

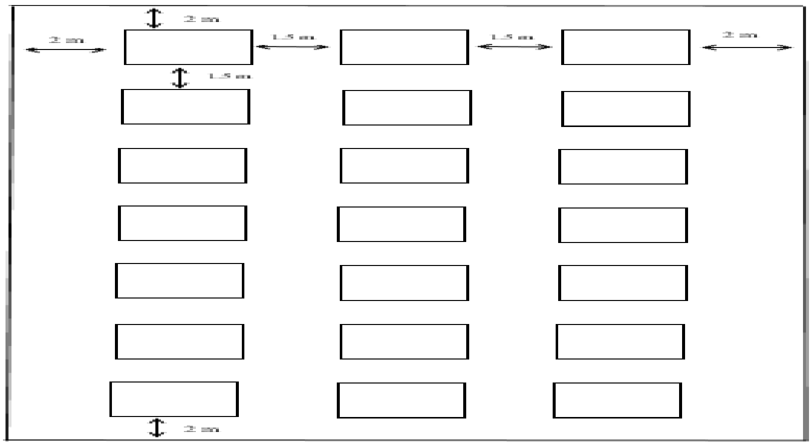

Figure 1: Experimental Layout

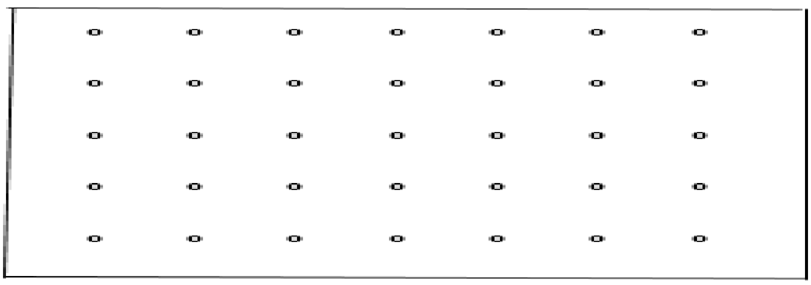

Figure 2: Plants arrangement under monocrop (90 cm x 70 cm)

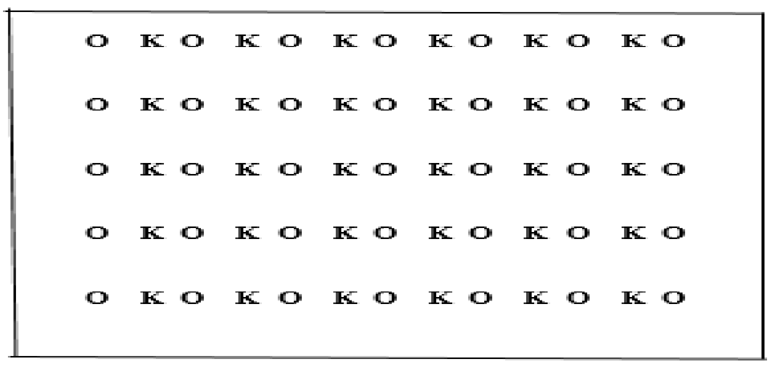

Figure 3: Plots with kidney bean in intercrop. (Where K = kidney bean)

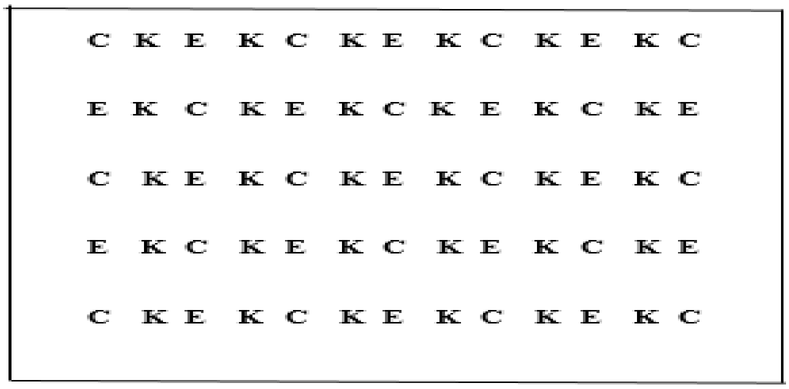

Figure 4: Plots with all three crops in intercrop. (Where K = kidney bean, C = Maize, E = Egusi-melon)

Cultural Practices

Maize, melon and kidney bean were planted as monocrops using a spacing of 90 cm between rows and 70 cm within rows on plots measuring 5.4 m x 2.8 m (Fig. 2a).

In maize + kidney bean intercrop/*egusi*–melon intercrop plots, maize and *egusi*–melon were planted using spacing of 90 cm by 70 cm while kidney bean was planted at the middle of the rows (45 cm) from maize/*egusi*–melon rows (Fig. 2b).

In kidney bean + maize + *egusi*–melon intercrop, maize and *egusi*–melon were planted in alternate arrangement in the rows while kidney bean was planted 45 cm away from rows of maize and *egusi*–melon (Fig. 2c).

Each plot contained 35 stands of crops in monoculture and contained 65 stands in intercrop (35 stands of maize + *egusi*–melon plus 30 stands of kidney bean.

Weeding was done when necessary, using a hoe, while insecticides were used to control pests

Experimental Design

This experiment was carried out as a Randomized Complete Block Design (RCBD) with three replicates.

Variables Measured

Plant Height/Vine Length (cm)

The plant height of maize and vine length of *egusi* melon and kidney bean, from base to tip were measured at 50% flowering, using a tape and the means were determined and recorded.

Number of Leaves

The number of leaves at 50% flowering stage was counted and mean determined and recorded.

Stem Girth (cm)

The circumference of stems at collar level at 50% flowering was measured using a tape and recorded.

Fresh Grain Weight (g)

The weight of fresh grains (ear of maize and pods of kidney bean and *egusi* melon) per plot was taken and made equivalent of a hectare.

Seed Weight (g)

the weight of 100 seeds was measured and average weight of seeds was calculated.

Nutrient Concentration (%)

The shoots of crops were analyzed for nutrient content and values obtained were recorded.

Biological Nitrogen Fixation (BNF)

The BNF was determined according to the nitrogen difference procedures of Bergersen, (1980) and Evans and Taylor (1987), as outlined in Peoples *et al*. (1989)

Q = [Nitrogen yield (legume) – Nitrogen yield (control)] Bergersen (1980)

Q = [N yield (legume) – N yield (control) + (N soil (legume) – N soil (control)] Evans & Taylor (1987).

Where Q = quantity of Nitrogen fixed by plant (g/kg)

Sole maize plots and sole *egusi*–melon plots were used as control plots in estimating BNF

Soil and Plant Analysis

Five soil samples were taken from the experimental site at 0-15 cm depth before the experiment and bulked to make a composite sample. After harvest of crops, soil samples were taken at a depth of 0–15 cm from every plot. The soil samples were air-dried, crushed, and passed through a 2 mm sieve for analysis. Soil pH was determined potentiometrically in a 1:1 soil-water suspension. Particle size distribution was determined by the hydrometer method of Bouyoucos (1962) as modified by Gee & Or (2002). Organic carbon was determined by the method of Walkley & Black (1934), and total nitrogen by the micro-Kjeldahl digestion method of Bremner (1996). Available phosphorus was extracted using $CaCl_2$ extraction method of Houba *et al*., (2000) and determined by molybdemun-blue colorimetrically method of Murphy and Riley (1962). Exchangeable bases (K, Ca, Mg, Na) were extracted with 1N ammonium acetate (pH 7) and determined; K and Na were read using flame photometry while Ca and Mg were determined by EDTA titration (Black, 1965). Exchangeable acidity was determined by titration method of Sun and Yang (2022). Effective cation exchange capacity and base saturation were calculated

At harvest of the crops, 5 plants each were randomly selected from the central rows of each plot for agronomic measurements to avoid border effects. Plant samples were oven dried for forty–eight hours at 75℃. The plants were ground to powder and placed in Muffle furnace for about forty-eight hours at 450℃ to completely turn samples into ashes. Ashes were treated with both 0.1 M HCl and 1 M HCl and filtered (A.O.A.C., 1990). The filtrates were used for determination of N, P, K, Ca and Mg. P was determined by the molybdenum–blue colorimetric procedure of Murphy & Riley, (1962). K was determined using flame photometer while Ca and Mg contents were determined volumetrically by EDTA titration procedure (Black, 1965). The N content was determined by Micro–Kjedahl digestion method (Bremner, 1996).

Statistical Analysis

Data collected were subjected to statistical analysis using ‘Genstat’ version 8 (2012) and Tukey’s honest test was used to separate the means at 5% level of probability.

RESULTS AND DISCUSSION

Particle size distribution and Chemical Properties of Experimental Soil

The result on Table 1 shows that the soil used in the experiment were dominated by the sand fraction and belong to the loamy sand textural class. This implies that cropping pattern did not affect the textural class of the soil. Airueghian *et al.*, (2018): Okunsebor & Umweni, (2021) reported that top soil in the experimental field was dominated by sand fraction and belong to the loamy sand textural class.

The total nitrogen (TN) content (Table 1) was 0.63 g/kg in the soil before sowing; it reduced to 0.57 g/kg in the sole maize plot but increased to 0.75 g/kg in the sole kidney bean plot. The 0.75 g/kg recorded in the sole kidney bean plot was significantly higher than the values recorded from the sole maize (0.57 g/kg) and sole *egusi*–melon (0.59 g/kg) plots at 5% level of significance. The higher total nitrogen content in plots where legumes were planted may be due to biological nitrogen fixation by kidney bean. Baghdadi *et al*. (2018) reported that plots where cereals were planted had less total nitrogen after harvest of crops while plots where legumes were sown had higher total nitrogen after harvest of crops. Yong *et al*. (2018); Hu *et al*. (2021) also reported higher nitrogen in soil after harvest of legumes.

The highest TOC value of 14.36 g/kg (recorded in the kidney bean + *egus*i–melon intercrop plot) was significantly ($P \leq 0.05$) higher than the values (11.50 g/kg and 12.30 g/kg) recorded in the sole maize and kidney bean + maize intercrop plots respectively, at 5% level of probability. The least total organic carbon recorded in sole maize plot may be due to less litter fall from maize plant (Ngwira *et al.*, 2022).

The phosphorus, potassium and calcium and magnesium contents in the soil were highest (12.41 mg/kg, 0.20 cmol/kg, 0.54 cmol/kg and 0.39 cmol/kg respectively) in the soil before sowing and recorded their least values (9.12 mg/kg, 0.17 cmol/kg, 0.39 cmol/kg and 0.28 cmol/kg respectively) in the kidney bean + maize + *egusi*-melon intercrop plots. The reduction in the potassium, calcium and magnesium contents after harvest of crops may be due to absorption of nutrients by crops. Schoebitz *et al*. (2020) reported less phosphorus, potassium, calcium and magnesium from plots after harvest of crops.

Nutrient Concentration in Shoots of Crops

As shown on Table 2, nitrogen, phosphorus, potassium, calcium and magnesium contents in the vine of kidney bean were highest in the kidney bean + maize intercrop plot (having values 3.10%, 0.28%, 0.80%, 0.62% and 0.50% respectively) and least (2.92%, 0.22%, 0.74%, 0.57% and 0.47% respectively) in the kidney bean + maize + *egus*i–melon plot. The concentrations of the kidney bean vine from the kidney bean + maize intercrop plot were significantly higher than that from the kidney bean + maize + *egus*i–melon intercrop plot at 5% level of significance. The peak nitrogen in the kidney bean + maize plot may be as a result this may be because kidney bean fixes nitrogen.

Table 1: Particle Size Distribution and Chemical Properties of Soil from Experiment

Crop mixture	pH				Exchangeable Bases				Exch. Acidity							
	(1:1)	TOC	TN	Av. P	K	Ca	Mg	Na	H	Al	ECEC	BS	Sand	Silt	Clay	TC
	in water	(g/kg)		(mg/kg)	(cmol/kg)							(%)	(g/kg)			
Before sowing	5.45^{b}	14.20^{a}	0.63^{b}	12.41^{a}	0.20^{a}	0.54^{a}	0.39^{a}	0.18^{d}	0.89^{b}	0.33^{a}	2.53	51.78	856.66	79.34	64.00	LS
Sole kidney bean	5.23^{c}	13.70^{a}	0.75^{a}	12.04^{a}	0.19^{ab}	0.46^{bc}	0.29^{b}	0.24^{a}	0.97^{b}	0.25^{b}	2.40	49.17	868.67	68.33	63.00	LS
Sole maize	5.46^{b}	11.50^{b}	0.57^{b}	11.78^{a}	0.19^{ab}	0.42^{c}	0.32^{b}	0.21^{b}	1.02^{b}	0.30^{ab}	2.46	46.34	862.00	72.67	65.33	LS
Sole *egusi* melon	5.25^{c}	12.48^{a}	0.59^{b}	11.96^{a}	0.19^{ab}	0.52^{ab}	0.36^{a}	0.18^{d}	0.98^{b}	0.36^{a}	2.59	48.26	858.00	71.67	70.33	LS
Kidney bean + maize	5.56^{a}	12.30^{b}	0.70^{ab}	11.56^{a}	0.18^{b}	0.39^{c}	0.25^{cd}	0.19^{cd}	1.14^{ab}	0.23^{b}	2.38	42.44	867.33	70.33	62.34	LS
Kidney bean + *egusi*-melon	5.17^{c}	14.36^{a}	0.72^{ab}	12.23^{a}	0.18^{b}	0.42^{c}	0.28^{c}	0.23^{a}	1.26^{a}	0.38^{a}	2.75	40.36	861.67	73.67	64.66	LS
Maize + *egusi*-melon	5.61^{ab}	13.56^{a}	0.61^{b}	10.31^{b}	0.19^{ab}	0.49^{b}	0.32^{b}	0.21^{b}	1.20^{ab}	0.29^{ab}	2.70	44.81	869.00	69.00	62.00	LS
Kidney + Maize + *egusi*-melon	5.09^{c}	14.26^{a}	0.67^{ab}	9.12^{c}	0.17^{b}	0.39^{c}	0.28^{d}	0.19^{cd}	1.30^{a}	0.29^{ab}	2.53	39.31	856.00	77.00	67.00	LS
HSD	0.175	1.013	0.112	1.054	0.0265	0.044	0.035	0.013	0.216	0.075						
CV (%)	5.7	4.8	9.8	7.6	8.4	7.9	12.0	10.3	17.9	19.3						

Means with same alphabet(s) in the same column are not significantly different ($P \leq 0.05$)
Where TC = Textural Class, HSD = Honest significant difference, CV = coefficient of variation, LS = Loamy Sand.

Table 2: Nutrient Concentration in Shoots of Crops

	Kidney Bean Shoot in					Maize Shoot in					*Egusi*-melon Shoot in				
	KB	KC	KE	KCE	HSD	C	KC	CE	KCE	HSD	E	KE	CE	KCE	HSD
Nitrogen (%)	3.00^{b}	3.10^{a}	2.96^{bc}	2.92^{c}	0.0421	1.85^{a}	1.74^{c}	1.79^{b}	1.70^{c}	0.0418	2.70^{a}	2.66^{a}	2.63^{b}	2.60^{b}	0.0402
Phosphorus (%)	0.25^{b}	0.28^{a}	0.24^{bc}	0.22^{c}	0.0224	0.16^{a}	0.13^{b}	0.15^{ab}	0.12^{b}	0.0201	0.21^{a}	0.19^{ab}	0.21^{a}	0.17^{b}	0.0202
Potassium (%)	0.77^{b}	0.80^{a}	0.76^{bc}	0.74^{c}	0.0235	0.58^{a}	0.53^{bc}	0.54^{b}	0.51^{c}	0.0240	0.68^{a}	0.65^{b}	0.66^{ab}	0.62^{c}	0.0241
Calcium (%)	0.60^{ab}	0.62^{a}	0.58^{b}	0.57^{b}	0.0221	0.36^{a}	0.32^{b}	0.32^{b}	0.30^{b}	0.0237	0.43^{a}	0.40^{b}	0.41^{ab}	0.39^{b}	0.0202
Magnesium (%)	0.48^{b}	0.50^{a}	0.48^{b}	0.47^{b}	0.0192	0.30^{a}	0.25^{bc}	0.27^{b}	0.24^{c}	0.0208	0.39^{a}	0.35^{bc}	0.36^{b}	0.33^{c}	0.0218

Means with same alphabets in the same row under same crop are not significantly different at 5% level of significance

KB = Kidney bean, C = Maize, E = *Egusi*-melon, KC = Kidney bean + Maize intercrop, KE = kidney bean + *Egusi*-melon intercrop, CE = maize + *Egusi*-melon intercrop, KCE = Kidney bean + Maize + *Egusi*-melon intercrop, HSD = Honest Significant Difference into the soil and accumulates parts of it in its vine (Lepiz-Ildefonso *et al.*, 2024) and because maize allocates much of its nutrients to grain formation rather than stem tissue (Chen *et al*., 2016).

Meanwhile the peak nitrogen, phosphorus, potassium, calcium and magnesium contents in the shoot of maize (1.85%, 0.16%, 0.58%, 0.36% and 0.30% respectively) were recorded in the sole maize plot while the least concentrations 1.70%, 0.12%, 0.51%, 0.30% and 0.24% respectively) were recorded in the kidney bean + maize + *egus*i–melon intercrop plot. The concentrations in the maize shoot from the sole maize plot were significantly higher than those from the kidney bean + maize + *egus*i–melon intercrop plot at 5% level of probability. Bhat *et al.* (2015) reported higher nutrient concentration in the shoot of apple in monoculture plots.

Similarly, the peak nitrogen, phosphorus, potassium, calcium and magnesium contents (2.70%, 0.21%, 0.68%, 0.43% and 0.39% respectively) in the vine of *egus*i–melon were recorded in the sole *egus*i–melon plot while the least contents (2.60%, 0.17%, 0.62%, 0.39% and 0.33% respectively) were recorded in the kidney bean + maize + *egus*i–melon intercrop plot. The concentrations in the sole *egus*i–melon plot were significantly ($P \leq 0.05$) higher than those recorded in the kidney bean + maize + *egus*i–melon intercrop plot. Singh *et al.* (2018) reported higher nutrient concentration in the shoots of sugarcane in monoculture plots. The less nitrogen contents in the kidney bean, maize and *egusi*-melon shoots from the kidney bean + maize + *egusi*-melon plots may be due to competition for nutrients by the three crops (Batista *et al*., 2020).

Growth and Yield Parameters of Crops

The growth and yield parameters of kidney bean, maize and *egusi*-melon (at 50% flowering) in both monocropping and in intercropping are shown on Table 3. The stem girth of kidney bean in kidney bean + maize (4.10 cm) was significantly ($P \leq 0.05$) higher than the girth from kidney bean in other plots. This may be due to the fact that kidney bean took advantage of the erect nature of maize and used them as support, providing more space for growth of kidney bean vines. Stem girth of maize (Table 3) (at 50% tasseling) was significantly ($P \leq 0.05$) reduced when intercropped with kidney bean. This may be because kidney bean vines climbed maize stems. Similarly, the girth of *egusi*-melon (at 50% flowering) was significantly ($P \leq 0.05$) reduced from the 2.87 cm in the sole *egusi*-melon plot to 2.68 cm in the kidney bean + maize + *egusi*-melon plot. The less girths in the kidney bean + maize + *egusi*-melon plot may be due to competition for space and resources by the three crops (Kumar *et al*. 2014; Isaac *et al*., 2020).

As shown on Table 3, the number of leaves and vine length (at 50% flowering); weight of 100 grains, average weight of pods and yield of fresh pods of kidney bean were significantly ($P \geq 0.05$) enhanced by intercropping kidney bean with maize, having their peak values 38, 264.0 cm 32.8 g 1.04 g and 0.72 t/ha respectively in the kidney bean + maize intercrop plot. This may not be unconnected with the fact that kidney bean vines used maize stems as support (Bitew *et al.*, 2021).

Meanwhile, maize growth was significantly ($P \geq 0.05$) reduced by intercropping. Highest growth and yield parameters: Stem girth (7.40 cm), number of leaves (11), plant height (194.5 cm) weight of 100 grains (29.5 g), average weight of ear (137.0 g) and ear yield (7.23 t/ha) were recorded in the sole maize plot. Similarly, *egusi*-melon growth was significantly ($P \geq 0.05$) reduced by intercropping. Highest growth and yield parameters: Stem girth (2.87 cm), number of leaves (18)

Table 3: Growth and Yield Parameters of Crops

	Kidney bean in					Maize in					*Egusi*-melon in				
	KB	KC	KE	KCE	HSD	C	KC	CE	KCE	HSD	E	KE	CE	KCE	HSD
Stem girth (cm)	3.70^{b}	4.10^{a}	3.65^{b}	3.40^{b}	0.3521	7.40^{a}	6.60^{b}	7.25^{a}	6.25^{b}	0.5718	2.87^{a}	2.83^{ab}	2.80^{b}	2.68^{c}	0.0453
Number of leaves	26^{b}	38^{a}	22^{b}	19^{b}	8.416	11^{a}	8^{a}	10^{a}	8^{a}	ns	18^{a}	16^{a}	15^{a}	14^{a}	ns
Plant height/ vine length (cm)	242.0^{b}	264.0^{a}	230.0^{bc}	221.0^{c}	20.190	194.5^{a}	165.3^{b}	187.6^{a}	163.5^{b}	15.64	182.0^{a}	176.5^{ab}	173.5^{b}	170.5^{b}	7.65
Weight of 100 grains (g)	31.9^{a}	32.8^{a}	31.2^{ab}	30.7^{b}	1.715	29.5^{a}	20.6^{b}	26.8^{ab}	19.5^{b}	6.854	10.10^{a}	9.87^{ab}	9.63^{b}	9.40^{b}	0.365
Average weight of pod/ear (g)	1.02^{a}	1.04^{a}	1.02^{a}	0.98^{a}	ns	137^{a}	114.5^{b}	122^{b}	104^{c}	9.351	1066.0^{a}	953.0^{c}	987.5^{b}	925.5^{c}	30.32
Yield /plot (kg)	1.06^{a}	1.09^{a}	0.95^{b}	0.86^{c}	0.0561	10.99^{a}	9.75^{b}	5.17^{c}	4.89^{c}	0.981	39.44^{a}	34.31^{b}	17.78^{c}	16.66^{c}	4.572
Yield of fresh pod/ear (t/ha)	0.70^{a}	0.72^{a}	0.63^{b}	0.57^{b}	0.061	7.23^{a}	6.45^{b}	3.42^{c}	3.24^{c}	0.532	$26;08^{a}$	22.69^{b}	11.76^{c}	11.02^{c}	2.430

*means with same alphabets in the same row under same crop are not significantly different at 5% level of significance

Where: KB = Kidney bean, C = Maize, E = *Egusi*-melon, KC = Kidney bean + Maize intercrop, KE = kidney bean + *Egusi*-melon intercrop, CE = maize + *Egusi*-melon intercrop, KCE = Kidney bean + Maize + *Egusi*-melon intercrop, HSD = Honest Significant Difference, ns = not significant. vine length (182.0 cm) weight of 100 grains (10.10 g), average weight of pod (1066.0 g) and pod yield (26.08 t/ha) were recorded in the sole *egusi*-melon plot. This may be due to less competition for space and nutrients by crops. Dagne and Gedefa (2023); Anitha and Venkatesan (2023) all reported less leaves and yield in the intercrop plots.

Estimated Biological Nitrogen Fixation by Kidney bean

The results on Table 4 show that kidney bean fixed more nitrogen when intercropped with maize than when intercropped with *egusi*-melon in the two estimation methods used. According to the Bergersen (1980) method, BNF was estimated at 1.15 g/kg/yr (2.30 t/ha/yr) in the kidney bean + maize intercrop (KC), compared with 0.30 g/kg/yr (0.60 t/ha/yr) in the kidney bean + *egusi*- melon intercrop (KE). Similarly, the Evans and Taylor (1987) method produced higher estimates of 1.33 g/kg/yr (2.66 t/ha/yr) in kidney bean + maize intercrop plot and 0.46 g/kg/yr (0.92 t/ha/yr) in the kidney bean + *egusi*-melon intercrop (KE).

The higher BNF values observed in the kidney bean + maize intercrop suggests a more efficient symbiotic relationship between kidney bean and nitrogen-fixing rhizobia in the intercropping system (Nguyen, 2018). Some factors may be responsible for this observation. Maize is a cereal crop with a high demand for soil nitrogen and lacks the ability to fix atmospheric nitrogen. Furthermore, it is erect, competes less directly with the kidney bean for space and nutrients because of its root depth and canopy structure. Yet, it has a strong demand for soil nitrogen (Rodriguez *et al*., 2020). This nitrogen depletion encourages the kidney bean to fix atmospheric nitrogen through its symbiotic association with *Rhizobium* bacteria (Jensen *et al*., 2020). In contrast, *egusi*-melon possesses a spreading growth habit that may increase competition for light, moisture, and soil nutrients, thereby reducing the photosynthetic efficiency and carbon allocation necessary for active nodule formation and nitrogen fixation (Abubakari *et al*., 2016).

The high BNF values recorded in the kidney bean + maize intercrop plots suggest enrichment of soil nitrogen pool, reduced dependence on synthetic nitrogen fertilizers, improved soil fertility, and enhanced sustainability of cropping systems, as part of the fixed nitrogen becomes available to the associated cereal crop during the growing season through rhizosphere interactions, while larger amounts are returned to the soil through decomposition of crop residues after harvest.

Consequently, cereal–legume intercropping systems contribute to improved nutrient cycling, increased nitrogen-use efficiency, and long-term soil productivity.

Table 4: Estimated Biological Fixation (BNF) by Kidney bean in intercrop with Maize and *Egusi*-melon

BNF Estimation Method	KC (g/kg/yr)	KE (g/kg/yr)	KC (t/ha/yr)	KE (t/ha/yr)
Bergersen 1980	1.15	0.30	2.30	0.60
Evans & Taylor, 1987	1.33	0.46	2.66	0.92

Where KC = kidney bean + maize, KE = Kidney bean + egusi-melon

CONCLUSION

The soils before and after the experiment were acidic and belong to the loamy sand textural class. The total nitrogen content increased in plot where kidney bean was planted. The potassium, calcium and magnesium contents of the soils reduced after harvest of crops. Nitrogen, phosphorus, potassium, calcium and magnesium contents of the shoots of kidney bean were highest in the kidney bean + maize plots, while those of the maize and *egusi*-melon were highest in their respective monoculture (sole maize and sole *egusi*-melon) plots and least in the kidney bean + maize + *egusi*-melon plots. Furthermore, the stem girth, number of leaves, vine length, weight of 100 grains, average weight of pods and yield of kidney bean all recorded their least values in the kidney bean + maize + *egusi*-melon plots. Kidney bean fixed more nitrogen in intercrop with maize (1.15-1.33 g/kg/yr) than with *egusi*-melon (0.30-0.46 g/kg/yr) in the two methods used. This means less expenses on mineral fertilizer and higher profit for farmers. Further studies should be carried out using other methods line ^{15}N isotopic method or the molecular method

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