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Short-term Evaluation of Some Indigenous Legumes as Green Manures or Components of Rice-based Relay Intercropping Systems and Their Effect on Residual Soil Properties in the Rainforest Zone of Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Author BWB designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors EOE and UAE managed the analyses of the study. Author UAE managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Aim: To evaluate the potentials of some legumes as *in situ* green manures or components of relay intercropping with direct-seeded upland rice, and to assess the effect of incorporating their biomass into the soil on residual soil properties.
Study Design: The treatments were laid out in randomised complete block design, replicated three times.
Methodology: Some indigenous legumes were used as green manures or as components of upland rice-based cropping systems to assess their effect on the performance of rice and on

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residual soil properties in the rainforest region of Nigeria. *Mucuna pruriens*, *Vigna sinensis*, *Vigna subterranea, Vigna unguiculata* ; (var Ife BPC and Ife Brown), *Sphenostylis stenocarpa* were either incorporated *in situ* into the soil as green manure at 8weeks after sowing or relay-intercropped with NERICA 2 rice giving a total of 16 treatments.

Results: Significantly higher number of panicles/plant, grain and straw yield were obtained with sole, than with green manuring and relay cropping in the first cropping season, but in the second season, cowpea and mucuna bean green manures gave the same outcomes. The residual soil N accumulated during a two consecutive-year green manuring programme with either cowpea or mucuna bean was sufficient to produce a rice yield equivalent to the split application of 60 kg N/ha. Intercropping reduced rice grain yield by between 5.4 and 47.0 %, with cowpea (Ife brown)/Rice system performing best.

Conclusion: In the short-term, leguminous crop species especially those with determinate growth habit and lower carbon to nitrogen ratio can be integrated into upland rice-based cropping systems in the rainforest region of Nigeria as intercrops, but preferably as green manure crops.

Keywords: Rainforest; indigenous legumes; NERICA rice; green manure; relay cropping; residual soil fertility.

1. INTRODUCTION

Rice (*Oryza sativa* L.) is one of the most widely consumed cereals in the world, being the staple food crop for almost half of the world's population [1;2]. In Nigeria where rice consumption was limited to occasions such as Christmas and weddings, its importance has grown over the years to become a staple food [3]. Rice production ecologies in Nigeria are varied, and include lowland (Fadama), upland, mangrove, deep/floating and irrigated, with the upland ecology accounting for 20 % of total production [4]. In recent times, rice production in the country has been increasing steadily, although demand still outstrips production, necessitating the importation of huge quantities to supplement local production. In 2006 for instance, the country imported about 1.60 million tonnes of rice, making her the second largest importer of the commodity in the world after Philippines [5]. In an attempt to reverse this trend, successive administrations have initiated programmes and policies aimed at attaining self – sufficiency in rice production. Such policies include the Presidential Initiative on Rice Production, Processing and Export of 2004 [6], and the current Central Bank of Nigeria's 'Anchor Borrowers Programme' [7]. These efforts are being complemented by efforts of State Governments such as Lagos and Kebbi which resulted in the production of the 'Lake Rice' brand. Increased area sown, rather than increased yields has been the main factor behind the recent increase in rice production in Nigeria [8], and future increases are predicated on the adoption of improved varieties such as New Rice for Africa (NERICA), as well as the better management of drought, declining soil fertility, weeds, insect pests and diseases [4,9,10].

With the rising cost of mineral fertilisers, resource-poor, subsistent farmers now include legumes in rice-based cropping systems as a sustainable method of soil fertility maintenance [1,9]. Photo-insensitive, high-yielding, and short-duration legume varieties which can fit in rice-based systems as sequential, intercrop or alley crop have been developed [11], and given the complexity of designing an efficient system, it would be necessary to carefully select species, genotype and efficient management strategies [12]. Intercropping systems comprise various methods such as mixed, row, strip, relay and alley cropping systems, with relay intercropping consisting of the simultaneous growing two or more crops during part of the life cycle of each crop [13]. In general, it consists of the main crop which is sown first, and a secondary crop which is introduced later. The main objective of relay intercropping rice with cover crops is to obtain large amounts of accumulated N by the legume biomass that may improve soil quality in subsequent seasons, without a drastic reduction in the current season's yield [14]. A well-designed intercropping system combines crops that use available resources better than would single crops, and may be advantageous due to complementary use of resources by component crops. At present recommendations on the inclusion of legumes in rice-based cropping systems of the rainforest agro-ecological region of Nigeria are based on studies conducted in the guinea savannah region [15,16], but the inclusion of 'lesser-known', 'under-utilised' legumes has not been reported. It is with this realisation that, long-term field studies were designed to evaluate the potential use of some indigenous legumes as green manures or as components of upland rice-based cropping systems, and to assess their effect on residual soil properties in the rainforest region of Nigeria. The results presented in this report are preliminary findings for the 2015 and 2016 cropping seasons.

2. MATERIALS AND METHODS

2.1 Location and Description of the Study Site

The field experiment was conducted at Akamkpa (latitude 5°15' N and 5°27' N and longitude 8°10' E and 8°25' E) between June and September of 2015 and 2016. This area is characterised by a bimodal annual rainfall of between 2,800 and 3,200 mm, with peaks in July and September with a short dry spell in August, while the ambient temperature and relative humidity is high, characteristic of the humid tropics [17].

The site had been under fallow for a period of three years, prior to which cassava (*Manihot esculenta* Crantz) was cultivated on a subsistent scale for about the same period of time.

2.2 Land Preparation and Field Layout

A piece of farmland measuring 42 m x 32 m (1,344 m^2) was cleared with machete, stumped and raked, before being demarcated into three blocks each with nineteen (19) plots of 3.0 m × 3.0 m. Each block was separated from the other by a 2.0 m -wide path, and plots by a 1.0 m-wide boundary. A perimeter fence made of palm fronds and Indian bamboo, and fitted with stringed traps was erected round the field to control rodents. Mounds of 5.0- 10.0 cm- high, and 10.0 – 15.0 cm-wide (at the base) were made in some plots for cultivating African yam bean, while the remainder of the field was flat – tilled to a depth of 5.0-10.0 cm. The two-year study was conducted on the same piece of land.

2.3 Method of Soil Sampling and Analysis

Soil samples were randomly collected with a soil auger at a depth of 0-30 cm before legumes were sown and after harvesting rice in both cropping seasons. The samples were bulked, air-dried, sieved with a 2mm mesh and analysed for physical and chemical properties. Soil particle size was determined by the hydrometer method using sodium hexa-metaphosphate (Calgon) as dispersal agent [18]; textural class by the use of textural triangle; soil pH was determined in distilled water (1:2.5); total Nitrogen by the modified micro-Kjedahl digestion method [19]; Organic carbon by the Walkley and Black wet oxidation technique [20]; available phosphorous was extracted with Bray II solution; exchangeable bases (Ca^{2+}, Mg^{2+}, K^+, Na^+) were extracted with 1M ammonium acetate solution buffered at pH 7.0 [21]; exchangeable Ca and Mg by EDTA complex metric titration, while Na and K was with flame photometer; exchangeable acidity was measured titrimetically using 1 M KCl against 0.05 M Sodium hydroxide; effective cation exchange capacity (ECEC) obtained by summation of all exchangeable bases and exchangeable acidity. The percentage base saturation (% BS) was obtained mathematically as follows:

$$\% BS = \{TEB\} / \{ECEC \times 100\}$$

Where: TEB = total exchangeable bases (Ca, Mg, Na, K)

2.4 Treatments, Experimental Design and Statistical Analysis

The test legume crops were Mucuna bean (*Mucuna pruriens* var. *Utilis*), Bebi bean (*Vigna sinensis*), Bambara groundnut (*Vigna subterranea* (L) Verdc.), Cowpea (*Vigna unguiculata* L. Walp.; var Ife BPC, Ife Brown), and the multi-coloured landrace of African yam bean {*Sphenostylis stenocarpa* (Hochst Ex A. Rich.) Harms}, while the upland rice variety used for the study was NERICA 2 (syn. FARO 56). With the exception of the Cowpea variety Ife Brown which had a determinate growth habit, all other legumes used in this study were of indeterminate growth, and were either incorporated *in situ* into the soil as green manure at 8 WAS (manually worked into the soil, 2 weeks before sowing rice), or relay-intercropped with rice (rice sown into 8 week-old legume field). The following treatments were laid out in randomized complete block design, replicated thrice:

a) Sole Mucuna bean
b) Sole Bebi bean
c) Sole Cowpea (Ife BPC)
d) Sole Bambara groundnut
e) Sole Cowpea (Ife Brown)

f) Sole African yam bean
g) Sow rice after ploughing-in 8 week-old Mucuna bean seedlings
h) Sow rice after ploughing-in 8 week-old Bebi bean seedlings
i) Sow rice after ploughing-in 8 week-old Bambara groundnut seedlings
j) Sow rice after ploughing-in 8 week-old Cowpea (Ife BPC) seedlings
k) Sow rice after ploughing-in 8 week-old Cowpea (Ife Brown) seedlings
l) Sow rice after ploughing-in 8week-old African yam bean seedlings
m) Sow rice into 8week- old Mucuna bean field
n) Sow rice into week-old Bebi bean field
o) Sow rice into 8 week-old Bambara groundnut field
p) Sow rice into 8 week-old Cowpea (Ife BPC)
q) Sow rice into 8week-old Cowpea (Ife Brown)
r) Sow rice into 8 week-old African yam bean field
s) Sole rice (control) - split application of 60 kg N/ha, in the form of Urea; half at sowing and the remainder at maximum tillering).

Three seeds of each crop were direct-seeded per hole and seedlings thinned to two per stand at 3 weeks after sowing (WAS). Cowpea and Bambara groundnut were sown at a spacing of 45 cm × 45 cm; Bebi bean, Mucuna bean, and African yam bean at 90 cm x 90 cm, while rice was sown in alternate, single rows at equidistant points between the legumes.

All treatments received basal application of 60 kg/ha P_2O_5 as single superphosphate, and 40kg/ha K_2O as muriate of potash, worked into the soil, one week before sowing rice. Staking of African yam bean and Bebi bean was with Indian bamboo at 6 WAS; weeds were controlled manually by hoeing and hand pulling at 4 and 8 WAS rice; birds were scared with 'scare crows' and 'bird boys' beginning from milking stage.

2.5 Data Collection and Analysis

The growth and yield parameters of rice that were collected followed the procedure of Yoshida et al. [22]. Parameters evaluated were plant height, leaf area index, number of tillers per plant, number of panicles per plant, number of spikelets per panicle, 1000-grain weight, grain yield, harvest index. The land equivalent ratio (LER) was computed using the method of Kurt [23] as follows:

$$LER = L_A + L_B + \text{---}\ L_N$$
$$= Y_A/S_A + Y_B/S_B + \text{---} + Y_N/S_N = \sum Y_N/S_N$$

Where:
L_A, L_B----L_N = LER for individual crop
Y_A, Y_B---Y_N = individual crop yield in intercrop
S_A, S_B---S_N = crop yield as sole crops.

Data collected were analyzed using the statistical software GenStat Release 10.3 DE edition [24] for randomized complete block design and comparison of treatment means was by Duncan's New Multiple Range Test (DNMRT).

3. RESULTS AND DISCUSSION

3.1 Effect of Legume Management System on Residual Soil Fertility

The pre-plant soil was sandy loam, high in organic carbon, available phosphorus, and base saturation, but low in total nitrogen, and moderate in effective cation exchange capacity (ECEC) (Table 1). The soil's pH of 5.2 was above the critical range of 4.0 - 4.5 recommended for growing upland rice in the humid forest agro-ecosystem [4].

Table 1. Physical and chemical properties of pre-plant soil

Soil property	Value
pH	5.20
Organic carbon (%)	2.10
Total nitrogen (%)	0.11
Available phosphorus (mg kg^{-1})	16.0
Exchangeable bases (cmol kg^{-1})	
Ca	4.40
Mg	2.00
Na	0.08
K	0.19
Exchangeable acidity (cmol kg^{-1})	
Al^{3+}	1.34
H^+	0.89
ECEC (cmol kg^{-1})	8.90
Base saturation (%)	74.94
Particle size (%):	
Sand	78.30
Silt	15.00
Clay	6.70
Textural class	sandy loam

Table 2. Effect of cropping system on first cropping- season, post-harvest soil physico-chemical properties (2015)

Cropping system	Soil texture	pH (H_2O)	Organic carbon (%)	Total N (%)	ECEC (cmol kg^{-1})	Base saturation (%)
Sole legume						
African yam bean	SL	5.4	2.10	0.15	8.90	78.0
Bambara g/nut	SL	5.4	2.12	0.15	8.90	78.0
Bebi bean	SL	5.3	2.11	0.15	8.90	7.80
Cowpea (Ife BPC)	SL	5.3	2.11	0.18	8.90	78.0
Cowpea (Ife Brown)	SL	5.3	2.09	0.18	8.90	78.0
Mucuna bean	SL	5.3	2.12	0.16	8.90	78.0
SD	-	0.03	0.07	0.01	-	-
CV (%)	-	5.15	10.0	3.90	-	-
Green manure (*In situ*)						
African yam bean	SL	5.3	2.11	0.16	9.10	78.0
Bambara g/nut	SL	5.4	2.11	0.16	9.30	78.0
Bebi bean	SL	5.4	2.10	0.15	8.90	78.0
Cowpea (Ife BPC)	SL	5.3	2.11	0.20	9.70	78.0
Cowpea (Ife Brown)	SL	5.3	2.12	0.18	10.0	78.0
Mucuna bean	SL	5.3	2.11	0.18	8.90	78.0
SD	-	0.02	0.17	0.04	0.03	-
CV (%)	-	5.09	13.04	7.02	8.42	-
Rice/legume intercrop						
African yam bean	SL	5.4	2.15	0.15	8.90	78.0
Bambara g/nut	SL	5.4	2.10	0.16	8.90	78.0
Bebi bean	SL	5.3	2.18	0.15	8.90	78.0
Cowpea (Ife BPC)	SL	5.3	2.05	0.19	8.90	78.0
Cowpea (Ife Brown)	SL	5.3	2.15	0.19	8.90	78.0
Mucuna bean	SL	5.3	2.17	0.18	8.90	78.0
Sole Rice (Control)	SL	5.5	2.12	0.20	8.90	78.0
SD	-	0.03	0.10	0.01	-	-
CV (%)	-	5.11	12.61	8.24	-	-

SD = standard deviation; CV = coefficient of variability; SL = sandy loam

Based on Wilding [25] classification, the post-harvest soil taken after the first season cropping showed little variability in terms of its physical and chemical properties (Table 2). This classification scheme which identifies the extent of variability of soil properties based on their coefficient of variability (CV), prescribes that a CV value of < 15 % is indicative of least variability, 15-35 % moderate variability, and > 35 % high variability. However, both green manure and legume/rice systems slightly raised soil pH by between 0.1 and 0.2 units, similar to previous reports [26;27]), and increased total soil N up to, or beyond the critical 0.15 % recommended for Nigerian soils [28]. The two Cowpea varieties, followed by Mucuna bean had a more profound effect on total N accumulation compared to other legumes, with Bebi bean being the least effective. The increase in soil N was probably the result of atmospherically fixed N by legumes, rather than mineralized N from incorporated plant biomass, since there was no modification of the organic carbon content of the soil.

In addition to further increases in the pH and total soil N content of the post-harvest soil following the second cropping season harvest, there was an improvement in the organic carbon content of the soil, ECEC, and base saturation following the incorporation of green manures *in situ* .The percent carbon content increased from 2.10 in the pre-plant soil to 2.75, 2.60, 2.88, 2.26, 2.32 and 2.18 for the green manures of African yam bean, Bambara groundnut, Bebi bean, cowpea (Ife BPC), Cowpea (Ife Brown), and Mucuna bean, respectively, while the values for the corresponding rice intercrop with the respective legumes was 2.15, 2.10, 2.18, 2.16, 2.15 and 2.17 (Table 3). Bebi bean, followed by African yam bean impacted more on organic carbon accumulation due to their higher biomass production as reported in a companion study [29]. The slight increase in soil organic carbon under short-term addition of plant biomass in hot climates that promotes rapid decomposition has also been reported [30]. The modification of some soil chemical properties by green manuring implies that the residual beneficial effect of mineralisation of incorporated plant biomass is noticeable from the season following the introduction of the legume. Thus, longer-term incorporation of these materials could substantially increase soil organic matter, with the attendant beneficial effects on soil physical and chemical properties [31]. These effects are however dependent on the amount of residue added, quality of the residue environment, and the duration of addition.

Plant biomass with a lower C: N ratio appeared to have had a more profound effect on soil organic matter accumulation, probably because of a faster rate of degradation by soil microorganisms, indicating that the quality of a legume is an important factor in the choice of a green manure crop. This however, contradicts reports by Sauerbeck [32], Voroney et al. [33], and Barber and Navarro [34] that different types of crop residues have similar effects on soil organic matter and that its accumulation is a function of microbial product recalcitrance rather than initial residue composition.

3.2 Effect of Cropping System on Vegetative Growth of Rice

Plant height was not significantly influenced ($p > 0.05$) by the various treatments at early vegetative growth (4 WAS) in the first cropping season, perhaps because neither the fixed nor mineralized N could have been available to rice plants at this stage. However, at maximum tillering stage (8 WAS) rice plants from green manured plots (excepting Bebi bean green manure), as well as those from Rice/Ife Brown and Rice/Bambara groundnut systems were as tall as sole Rice which received 60kg N /ha. Rice plants under Bebi bean green manure and Rice/Bebi bean intercrop combination consistently gave the shortest plants (Table 4).

Table 3. Effect of cropping system on second cropping season, post-harvest soil physical and chemical properties (2016)

Cropping system	Soil texture	pH (H_2O)	Organic carbon (%)	Total N (%)	ECEC (cmol kg^{-1})	Base saturation (%)
Sole legume						
African yam bean	SL	5.4	2.12	0.18	8.9	78.0
Bambara g/nut	SL	5.4	2.06	0.16	8.9	78.0
Bebi bean	SL	5.3	2.18	0.16	8.9	78.0
Cowpea (Ife BPC)	SL	5.2	2.11	0.20	8.9	78.0
Cowpea (Ife Brown)	SL	5.2	2.09	0.20	8.9	78.0
Mucuna bean	SL	5.3	2.05	0.19	8.9	78.0
SD	-	0.03	0.07	0.01	-	-
CV (%)	-	5.15	11.40	4.66	-	-
Green manure (*In situ*)						
African yam bean	SL	5.4	2.75	0.17	11.10	79.0
Bambara g/nut	SL	5.4	2.60	0.16	13.70	81.1
Bebi bean	SL	5.5	2.88	0.15	13.50	80.5
Cowpea (Ife BPC)	SL	5.5	2.26	0.21	10.60	79.4
Cowpea (Ife Brown)	SL	5.5	2.32	0.20	10.50	79.0
Mucuna bean	SL	5.4	2.18	0.18	9.80	79.0
SD	-	0.01	0.22	0.04	0.07	0.14
CV (%)	-	5.09	16.04	7.02	15.90	10.6
Rice/legume intercrop						
African yam bean	SL	5.4	2.15	0.15	8.90	78.0
Bambara g/nut	SL	5.4	2.10	0.18	8.90	78.0
Bebi bean	SL	5.3	2.18	0.15	8.90	78.0
Cowpea (Ife BPC)	SL	5.3	2.16	0.20	8.90	78.0
Cowpea (Ife Brown)	SL	5.3	2.15	0.20	8.90	78.0
Mucuna bean	SL	5.3	2.17	0.19	8.90	78.0
Sole Rice (Control)	SL	5.5	2.12	0.20	8.90	78.0
SD	-	0.03	0.10	0.01	-	-
CV (%)	-	5.11	12.61	8.24	-	-

Table 4. Rice plant height (cm) as influenced by cropping system in 2015 and 2016 in Akamkpa

Cropping system	2015				2016			
	Weeks After Sowing				Weeks After Sowing			
	4	8	12	Mean	4	8	12	Mean
Rice/Green manure								
Bebi bean	9.93^{a}	49.67^{b}	68.03^{c}	42.54	16.15^{d}	61.61^{b}	82.60^{ab}	53.45
African yam bean	9.99^{a}	57.77^{a}	87.73^{a}	42.54	24.27^{b}	70.04^{a}	86.87^{ab}	60.39
Bambara groundnut	10.33^{a}	62.80^{a}	85.43^{a}	52.85	19.18^{c}	73.42^{a}	91.23^{a}	61.28
Cowpea (Ife BPC)	10.03^{a}	58.68^{a}	89.40^{a}	52.70	25.29^{ab}	66.53^{b}	84.13^{ab}	58.65
Mucuna	10.31^{a}	60.96^{a}	85.18^{a}	52.15	28.46^{a}	70.40^{a}	88.19^{a}	62.35
Cowpea (Ife brown)	10.50^{a}	58.91^{a}	83.46^{a}	**50.96**	19.16^{c}	69.81^{a}	89.64^{a}	**59.54**
Rice/legume intercrop								
Bebi bean	10.13^{a}	51.13^{b}	79.77^{b}	47.01	15.23^{d}	59.37^{b}	73.60^{c}	49.40
African yam bean	9.93^{a}	54.60^{b}	74.58^{b}	46.34	19.19^{c}	68.46^{a}	75.68^{c}	54.44
Bambara groundnut	10.20^{a}	57.48^{b}	75.87^{be}	**47.85**	19.22^{c}	63.48^{b}	78.43^{b}	**53.71**
Cowpea (Ife BPC)	10.17^{a}	63.82^{a}	75.16^{b}	**49.72**	16.36^{d}	65.30^{b}	81.42^{b}	**54.36**
Mucuna bean	10.13^{a}	50.82^{b}	74.03^{b}	**44.99**	18.28^{c}	59.66^{b}	79.41^{b}	**52.45**
Cowpea (Ife brown)	10.13^{a}	50.63^{b}	76.27^{b}	**45.68**	16.30^{d}	68.41^{a}	81.40^{b}	**55.37**
Sole Rice (Control)	10.32^{a}	62.78^{a}	88.09^{a}	**53.73**	30.10^{a}	73.20^{a}	93.33^{a}	**65.54**

Values having the same superscript within the column are not significantly different at P≤ 0.05 probability (DMRT test)

Table 5. Effect of cropping systems on rice leaf area index in 2015 and 2016 cropping seasons

Cropping system	2015				2016			
	Weeks After Sowing				Weeks After Sowing			
	4	8	12	Mean	4	8	12	Mean
Green manure/Rice								
Bebi bean	0.04^{a}	1.29^{b}	2.64^{bc}	1.32	0.05^{a}	1.14^{d}	2.06^{b}	1.08
African yam bean	0.04^{a}	1.29^{b}	2.69^{b}	1.41	0.05^{a}	1.34^{cd}	2.52^{b}	1.30
Bambara groundnut	0.06^{a}	1.28^{b}	2.92^{b}	1.42	0.07^{a}	1.77^{c}	2.83^{b}	1.56
Cowpea (Ife BPC)	0.05^{a}	1.60^{b}	3.02^{a}	1.56	0.07^{a}	2.34^{b}	3.24^{a}	1.88
Mucuna	0.05^{a}	1.20^{b}	2.97^{b}	1.41	0.05^{a}	2.06^{bc}	3.32^{a}	1.81
Cowpea (Ife brown)	0.06^{a}	1.60^{b}	3.19^{a}	**1.62**	0.07^{a}	2.41^{b}	3.47^{a}	**1.98**
Legume/Rice intercrop								
Bebi bean	0.05^{a}	1.23^{b}	1.48^{d}	0.59	0.05^{a}	1.08^{d}	1.71^{c}	0.95
African yam bean	0.05^{a}	1.38^{b}	1.59^{d}	1.01	0.06^{a}	1.22^{d}	1.95^{bc}	1.08
Bambara groundnut	0.05^{a}	1.35^{b}	1.71^{d}	**1.04**	0.05^{a}	1.24^{d}	2.02^{bc}	**1.10**
Cowpea (Ife BPC)\	0.06^{a}	1.58^{b}	2.22^{c}	**1.29**	0.08^{a}	1.27^{cd}	2.25^{b}	**1.20**
Mucuna bean	0.05^{a}	1.29^{b}	2.18^{c}	**1.17**	0.06^{a}	1.32^{cd}	2.14^{b}	**1.17**
Cowpea (Ife brown)	0.05^{a}	1.54^{b}	2.95^{b}	**1.25**	0.06^{a}	1.46^{cd}	2.33^{b}	**1.28**
Sole Rice (Control)	0.05^{a}	2.78 a	3.25^{a}	**2.03**	0.07^{a}	3.11^{a}	3.54^{a}	**2.24**

Values having the same superscript within the column are not significantly different at P≤ 0.05 probability (DMRT test)

In the second cropping season, the effect of some of the treatments evaluated was felt early in the plant's vegetative growth. At 4 WAS, rice plants under Cowpea and Mucuna bean green manures produced plants that were as tall as the sole crop, both of which were significantly taller than the other treatments evaluated, while at 12 WAS all green manures produced significantly (P≤) taller rice plants than the various intercrop combinations studied, with all test legumes making equally good green manures.

The leaf area index (LAI) of rice generally followed the same pattern with plant height with Cowpea green manure performing better than other treatments involving legumes in both cropping seasons (Table 5). However, tiller production during the early vegetative growth stage was not significantly influenced by the various treatments evaluated (Table 6), but Cowpea green manure and inorganic N fertilization were found to significantly (P≤) increase tillering when assessed at a later 12 WAS.

3.3 Effect of Cropping System on Rice Yield and Yield Components

Compared to green manuring and relay intercropping, sole cropping produced a significantly higher number of panicles/plant, grain yield/ha, and straw yield/ha in both cropping seasons (Table 7), probably because the amount of N accumulated from atmospheric fixation and mineralization of legume biomass over the two-year period may not have been as much as the 60 kg N/ha received by the sole crop. Relative to sole rice, green manuring with Bebi bean, African yam bean, Bambara groundnut, Cowpea (Ife brown), Mucuna bean, and Cowpea (Ife BPC), resulted in an average rice grain yield reduction of 14.6, 6.6, 4.8, 1.9, 7.4 and 2.4 %, in the first cropping season, and by 13.9, 6.7, 5.1, 0.1, 3.4 and 0.1 %, respectively the following year, while the consequence of relay cropping rice with legumes was even more profound, with rice grain yield being reduced by as much as 47 %. The Cowpea (Ife brown)/Rice relay intercrop with an average yield decrease of 8.9 % in 2015 and 5.4 % the following year was clearly the best performing system, while the worst was the Bebi bean/Rice combination which resulted in a rice grain yield loss of 47 and 37.6 % in 2015 and 2016, respectively. The relative poor performance of the legume/rice relay intercrop system was probably due to competition for growth resources (especially light) between the component crops as has been explained by Akanvou et al. [13], while Cowpea (Ife brown) was apparently more compatible with upland rice due to its determinate growth habit as previously reported by Ramakrishna and Ong [35]. The failure of the various legume/rice relay intercrop combinations to produce rice grain yield comparable to the monocrop in the two-year duration of this study suggests that this system cannot, in the short-term, be a substitute for inorganic fertilizer N in the cultivation of upland rice in the rainforest region of Nigeria, and in such situations, the combined use of organic and mineral fertilizers could be more effective in maintaining higher productivity [36].

Although all leguminous species evaluated in this study had C: N ratios less than the critical 20: 1as has been reported previously (Binang et al. [29]), the superior performance of Cowpea and Mucuna green manures are attributable to their lower C: N ratio of 7:1, which probably allowed the earlier commencement of the process of mineralization of incorporated biomass in these genotypes. Miller and Donahue [37] have

Table 6. Effect of cropping systems on number of tillers per plant in 2015 and 2016 cropping seasons

Cropping system	2015				2016			
	Weeks after sowing				Weeks after sowing			
	4	8	12	Mean	4	8	12	Mean
Green manure/Rice								
Bebi beans	4.03^{a}	5.13^{ab}	5.47^{b}	5.22	3.12^{a}	5.12^{b}	6.50^{b}	4.57
African yam beans	3.17^{a}	5.53^{ab}	5.83^{b}	4.96	3.19^{a}	5.71^{b}	6.17^{b}	4.91
Bambara groundnut	3.80^{a}	5.70^{ab}	5.60^{b}	5.09	3.73^{a}	5.51^{b}	5.77^{b}	4.95
Cowpea (Ife BPC)	3.43^{a}	5.20^{ab}	5.41^{ab}	5.13	4.01^{a}	5.91^{b}	6.77^{ab}	5.44
Mucuna bean	3.13^{a}	5.00^{ab}	5.84^{b}	4.73	4.68^{a}	5.83^{b}	6.07^{b}	5.45
Cowpea (Ife brown)	4.47^{a}	5.83^{a}	5.47^{b}	**5.74**	3.82^{a}	5.45^{b}	6.93^{ab}	**4.91**
Legume/Rice intercrop								
Bebi beans	2.47^{a}	3.93^{b}	4.21^{c}	3.80	3.83^{a}	4.19^{b}	3.63^{bc}	4.57
African yam beans	3.37^{a}	3.63^{b}	5.00^{bc}	4.28	3.74^{a}	4.84^{b}	5.83^{bc}	4.53
Bambara groundnut	3.60^{a}	4.07^{b}	4.75^{c}	4.28	3.67^{a}	4.69^{b}	5.17^{c}	4.37
Cowpea (Ife BPC)	2.70^{a}	3.60^{b}	4.20^{c}	**4.04**	3.68^{a}	4.93^{b}	5.83^{bc}	**4.60**
Mucuna bean	3.20^{a}	4.40^{b}	4.53^{c}	**4.52**	2.93^{a}	4.50^{b}	5.97^{bc}	**3.99**
Cowpea (Ife brown)	2.77^{a}	4.43^{b}	5.94^{b}	**4.50**	4.12^{a}	4.86^{b}	6.30^{b}	**4.64**
Sole Rice (Control)	3.83^{a}	6.27^{a}	8.53^{a}	**6.17**	4.26^{a}	7.41^{a}	8.40^{a}	**6.73**

Values having the same superscript within the column are not significantly different at P≤ 0.05 probability (DMRT test)

Table 7. Effect of cropping systems on yield components and yield of rice in 2015 and 2016 cropping seasons

Cropping system	2015							2016						
	No. of panicles per plant	No. of spikelets per panicle	No. of grains per panicle	1000 grain weight (g)	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Harvest index	No. of panicles per plant	No. of spikelets per panicle	No. of grains per panicle	1000 grain weight (g)	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Harvest. index
Green manure/Rice														
Bebi bean	4.70^{bc}	10.87^{a}	116.3^{a}	29.30^{a}	3518^{c}	3084^{bc}	0.53^{a}	4.96^{b}	10.73^{a}	115.2^{a}	28.10^{a}	3660^{d}	4010^{b}	0.48^{a}
African yam bean	4.87^{bc}	10.87^{a}	110.2^{a}	27.90^{a}	4004^{b}	3413^{bc}	0.54^{a}	5.02^{b}	10.81^{a}	116.1^{a}	27.80^{a}	3964^{c}	5187^{b}	0.43^{a}
Bambara groundnuts	4.93^{bc}	10.63^{a}	118.7^{a}	26.10^{a}	4083^{b}	4449^{b}	0.49^{a}	5.03^{b}	10.64^{a}	117.3^{a}	28.10^{a}	4034^{c}	5000^{b}	0.45^{a}
Cowpea (Ife BPC)	5.37^{b}	10.97^{a}	114.7^{a}	27.80^{a}	4209^{b}	5226^{ab}	0.45^{a}	5.18^{b}	11.11^{a}	117.1^{a}	26.86^{a}	4210^{b}	5308^{b}	0.44^{a}
Mucuna bean	5.00^{b}	11.23^{a}	113.2^{a}	25.80^{a}	3973^{b}	4095^{b}	0.49^{a}	5.01^{b}	10.83^{a}	118.1^{a}	26.80^{a}	4106^{b}	5170^{b}	0.44^{a}
Cowpea(Ife brown)	5.27^{b}	10.90^{a}	116.7^{a}	28.30^{a}	4186^{b}	5182^{ab}	0.45^{a}	5.03^{b}	10.95^{a}	119.1^{a}	28.23^{a}	4201^{b}	5352^{b}	0.44^{a}
Legume/Rice intercrop														
Bebi bean	2.63^{d}	10.93^{a}	107.1^{a}	26.40^{a}	2272 ^{d}	2730c	0.45^{a}	2.93^{c}	10.54^{a}	104.7^{a}	27.80^{a}	2653^{f}	5132^{b}	0.34^{a}
African yam bean	2.83^{d}	10.77^{a}	111.7^{a}	26.60^{a}	2429^{d}	3019^{bc}	0.45^{a}	3.04^{bc}	10.88^{a}	109.3^{a}	26.90^{a}	3005^{e}	5557^{ab}	0.35^{a}
Bambara groundnuts	2.3 9^{d}	10.53^{a}	115.9^{a}	25.90^{a}	2760^{d}	3297^{bc}	0.46^{a}	3.02^{bc}	10.93^{a}	108.9^{a}	28.60^{a}	3041^{e}	5032^{b}	0.38^{a}
Cowpea (Ife BPC)	4.03^{c}	10.57^{a}	113.2^{a}	28.90^{a}	3404^{c}	4093^{b}	0.47^{a}	4.83^{b}	10.64^{a}	111.3^{a}	26.70^{a}	3787^{d}	5007^{b}	0.43^{a}
Mucuna bean	3.60^{cd}	10.87^{a}	117.0^{a}	26.20^{a}	3301^{c}	3098^{bc}	0.52^{a}	4.02^{bc}	10.79^{a}	108.3^{a}	28.30^{a}	3577^{d}	4534^{bc}	0.44^{a}
Cowpea(Ife brown)	4.07^{c}	10.70^{a}	118.9^{a}	26.90^{a}	3908^{b}	5128^{ab}	0.46a	4.92^{b}	10.87^{a}	114.0^{a}	28.10^{a}	4020^{c}	4492^{bc}	0.45^{a}
Sole Rice (Control)	7.01^{a}	10.83^{a}	119.7^{a}	28.30^{a}	4289^{a}	5594^{a}	0.43^{a}	7.19^{a}	10.97^{a}	116.3^{a}	28.12^{a}	4250^{a}	6580^{a}	0.39^{a}

Values having the same superscript within the column are not significantly different at P≤ 0.05 probability (DMRT test)

Table 8. Land equivalent ratio (LER) of different legumes and rice grown at Akamkpa in 2015 and 2016 cropping seasons

Treatment	2015			2016			
	Relative yield total of legumes	Relative yield total of rice	LER	Relative yield total of legumes	Relative yield total of rice	LER	LERs Mean
Bebi bean	0.91	0.78	1.69	0.96	0.86	1.82	1.76
African yam bean	0.88	0.82	1.70	0.93	0.87	1.80	1.75
Bambara groundnut	0.98	0.90	1.88	0.95	0.95	1.90	1.89
Cowpea (Ife BPC)	0.88	0.96	1.78	0.85	0.94	1.79	1.79
Mucuna bean	0.86	0.88	1.74	0.86	0.89	1.75	1.75
Cowpea (Ife brown)	0.94	0.98	1.92	0.82	0.95	1.77	1.85

reported that the critical C: N ratio for the release of mineral N early in the decomposition process is 20: 1, and plant materials with ratios of 20:1 or lower make good manures due to their ability to supply sufficient nitrogen to other plants and microorganisms, while those with a ratio greater than 30: 1 results in nutrient immobilization during the initial process of composting. Although intercropping significantly reduced rice grain yield, similar to reports of Ramakrishna and Ong [35], there was a high intercropping advantage, given that the land equivalent ratio of all legume/rice combinations evaluated in this study was greater than unity (Table 8).

4. CONCLUSION

In the short-term, leguminous crop species can be integrated into upland rice-based cropping systems in the rainforest region of Nigeria as intercrops, but preferably as green manure crops. The choice of leguminous species for inclusion is an important consideration as those with a lower carbon to nitrogen ratio appear to give better results as green manures, while those with a determinate growth habit are more compatible when intercropped with rice. Under conditions of moderate soil fertility, low-input agriculture, and low to medium cropping intensity, the contribution of residual nutrients from atmospherically fixed N and mineralized legume biomass incorporated as green manure the preceding season could supplement for inorganic N fertilizer in upland NERICA rice cultivation. Longer-term studies on the inclusion of legumes in these systems are being conducted with a view to assessing their contributions to sustainable soil management and crop productivity.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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