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RHIZOBIUM INOCULANT INTEGRATION WITH ORGANIC AND MINERAL FERTILIZER: IMPACT ON WEED INFESTATION, SOYBEAN GROWTH AND YIELD IN SOUTHERN GUINEA SAVANNA, NIGERIA

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ABSTRACT
To evaluate the effect of integrating Rhizobium inoculant, organic and inorganic fertilizer on weed infestation, growth and yield of soybean, an on-farm experiment was conducted in the 2015 and 2016 rainy seasons in Paikoro Local Government Area of Niger State, Nigeria. The treatments were control (no input), inoculant (I) only, I + phosphorus (P), I + P + potassium (K), I + P + K + micronutrients (M), and I + P + K + M + cow dung (CD) replicated three times in a randomized complete block design. Data collected were weed species composition, weed density and dry weight, nodule dry weight, pods per plant, grain weight and grain yield of soybean. Results indicated that weeds with highest relative density values across all the nutrient combinations were Ageratum conyzoides and Kyllinga sp., and other notable species included Mitracarpus villosus, Oldenlandia corymbosa, Sida rhombifolia, Paspalum scrobiculatum, Cynodon dactylon, Digitaria horizontalis Cyperus rotundus and Cyperus difformis. Years had a significant effect on weed density, weed dry weight, nodule dry weight, number of pods per plant and grain weight, number of pods per plant and grain weight of soybean. Weed density and dry weight, and weight of nodules, number of pods and grain weight of soybean were lower in 2015 compared to 2016. Among the treatments, I + P + K + M reduced weed dry weight better than I + P + K + M + CD. Average over the years, soybean grain yield was enhanced with the integration of I + P, I + P + K, I + P + K + M, I + P + K + M. However, the highest grain yield was obtained with the integration of I + P +K + M + CD which is recommended for soybean production in this agroecology of Nigeria.

Key words: cow dung, mineral fertilizer, Rhizobium inoculant, soybean, weed growth

INTRODUCTION
Soybean (*Glycine max* (L.) Merril) is an important pulse and oilseed crop widely cultivated for cash, food and animal feed in most sub-Saharan countries. It is a vital source of cheap and good quality protein, vegetable oil and raw material for several industries. In Nigeria, it is cultivated mostly in the savannas and rainforest agro-ecologies (Nwofia *et al*., 2015). However, most soils used for its cultivation are poor in fertility, which are characterized by low levels of N, Ca, Mg, P, K, micronutrients like B and Zn, and low population of beneficial soil microorganism like Rhizobia (Nwofia *et al*., 2015). Low soil fertility is responsible for poor soybean yield in farmers' field (Imoloame, 2014). Moreover, weed infestation poses a major challenge to soybean production, reducing yields and causing economic losses.

Weeds are important pest in crop production. In addition to resource competition, weed–density, types of weed species present, their persistence and cultural practices can influence the magnitude of crop yield and losses (Kaur and Verma, 2016). Weeds are the most important biotic constraint for higher soybean productivity in farmers' fields and accounts for 80% loss of potential grain yield in most parts of the world (Imoloame, 2014). Weed infestation in soybean fields could lead to reduced crop yields, poor crop quality, and increased production costs. The moist savanna region of Nigeria is particularly prone to weed growth due to favourable climatic conditions and soil fertility. Traditional weed control methods, such as manual weeding or herbicide application, could be expensive and labour-intensive (Olufemi *et al*., 2020).

The integration of Rhizobium inoculant with organic and mineral fertilizers presents a-promising and sustainable approach to managing weeds, while enhancing soybean growth and yield. Rhizobium is a beneficial soil bacterium that forms a symbiotic relationship with leguminous plants, including soybean. This bacterium colonizes the root nodules of the soybean plant and fixes atmospheric nitrogen, converting it into a usable form for the plant. Organic fertilizers, derived from plant or animal sources, contribute to soil fertility and provide essential nutrients for plant growth. Mineral fertilizers,

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on the other hand, are synthetically produced and contain specific nutrients in concentrated forms. The combination of organic and mineral fertilizers can optimize nutrient availability, improve soil structure, and promote sustainable agriculture.

Integration of Rhizobium inoculant with organic and mineral fertilizers can potentially reduce reliance on synthetic herbicides, minimizing their environmental impact. Improved understanding of the interactions between Rhizobium inoculant, organic and mineral fertilizers, and weed dynamics would provide valuable insights for farmers, researchers, and policymakers in optimizing soybean production in the Nigerian moist savanna. Therefore, the objective of this study was to determine the effects of combining Rhizobium inoculant with cow dung and mineral fertilizers on weed dynamics, growth and yield of soybean.

MATERIALS AND METHODS

Site Description

On-farm trial was carried out on five different farmers' fields in Paikoro Local Government Area of Niger State (Lat. 9° 12′N - 9° 47′N and Long. 6° 28′E - 7° 22′E) in the Southern Guinea Savanna, Nigeria in 2015 and 2016 rainy seasons. It has a mean annual rainfall of 1,300 mm, a growing period of six months and a mean number of rainy days of 120; and rainy season starts in April/May, peaks in August and ends in October (Danladi, 2014). The weather conditions of the experimental location for the period of 2015 - 2016 are presented (Table 1). The soil from the farmers' fields in 2015 prior to the trial establishment was sandy loam with organic carbon of 5.8 g kg^{-1}, N 0.4 g kg^{-1}, P 3.7 mg kg^{-1}, K 0.11 cmol kg^{-1} and pH of 6.5. In 2016, the soil had organic carbon of 2.3 g kg^{-1}, N 0.6 g kg^{-1}, P 3.9 mg kg^{-1}, K 0.14 cmol kg^{-1} and pH of 6.1. The experimental soil particles were determined by the Bouyoucous hydrometer method, soil pH by the glass electrode, organic carbon by Walkley-Black wet oxidation method, total nitrogen by Micro-kjeldahl method, available phosphorus by Mehlich method and soluble potassium by the Flame Photometer method. These properties were estimated following the procedure described by Okalebo *et al*. (2002).

Treatments and Experimental Design

There were six treatments in each field: (i) control (no input), (ii) Inoculant (I) only (Legumefix, containing *Bradyrhizobium* sp. Strain 532c together with a polymer sticker that allows dry inoculation, Legume Technology Limited, UK) (iii) I + P, (iv) I+P+K, (v) I + P + K + Micronutrients (M), and (vi) I+P+K+M+ Cow dung (CD). These treatments were arranged in a randomized complete block design using each farmer's field as a replication. Gross plot size was 10 m × 10 m, consisting of 14 rows, 10 m long each. The net plot size was 5 m × 5 m. An alley of 1 m^2 was left between the treatments.

Experimental Materials

Soybean seed (TGX 1951-3F, low shattering, tolerant to rust, *Cercospora* leaf spot, bacterial pustule and poor soils, and early maturing), inoculant and inorganic fertilizers were all sourced from IITA, Ibadan. Prior to sowing, soybean seed was moistened with water and thoroughly mixed with the Rhizobium inoculant at the rate of 4 g per one kilogram of seed, until all the seeds were fully coated and air dried for 20 min. under shade.

Agronomic Practices

All the experimental fields were manually cleared and ridged at 75 cm inter-row with a handheld hoe according to the farmers' practice. The inoculated seeds were manually sown at two per hole at 10 cm intra-row spacing on 23 and 27 July, 2015 and 2016, respectively. Plots were manually weeded at 3 and 6 weeks after sowing (WAS). Cured cow dung (2.14 g kg^{-1} N, 0.24 mg kg^{-1} P and 0.44 cmol kg^{-1} K) at the rate of 4 t ha^{-1} was incorporated during ridging two weeks before sowing. Application of P fertilizer (30 kg P ha^{-1} as Single Super Phosphate) and K fertilizer 20 kg K ha^{-1} as Muriate of Potash) was applied at sowing by incorporating into the soil at 5 cm away from the sowing line, and at 5 cm depth with the use of a hoe. Agrolyzer manufactured by Cybernetic Nigeria Limited (containing 20.14% Ca, 1.04% Na, 0.11% Zn, 0.19% Mg, 0.19% Cu, 2.72% S, and traces of Fe, Mn, Bo and Mo) was used to supply micronutrients at 3.3 kg ha^{-1} as a foliar spray with a knapsack sprayer to the crops at 3 and 6 WAS. The farmers' practice of no input use (control) plot did not receive any Rhizobium inoculant, cow dung, inorganic fertilizer or micronutrients.

Soybean crop was harvested when the leaves of the plants had turned yellowish brown to brown and had started falling off, and the pods per plant had also turned brown. Soybean plants from the two middle rows (net plot) in each treatment were harvested by carefully hand pulling whole plants. The harvested plants were further sundried, threshed and winnowed.

Data Collection

Weed species composition was recorded from four 50 cm × 50 cm quadrats placed along a diagonal transect in each treatment plot at 9 WAS in each year. The weeds were identified, counted, clipped above the soil surface, then bulked for each plot and oven-dried at 80 °C to a constant weight to obtain the weed dry weight. The prevalent weed species over other species across the treatment plots were determined based on relative density, and expressed in percentage values as described by Devasenapathy *et al*. (2008):

$$\text{Relative density(RD)} = \frac{\text{Absolute density of a given species}}{\text{Total densities of all species}} \times 100.$$

Table 1: The average weather conditions of the experimental region for the period of 2015-2016

Month	Temperature (°C)		Rainfall (mm)	
	2015	2016	2015	2016
April	38.38	39.45	18.76	95.2
May	38.38	38.38	19.51	30.81
June	35.18	36.25	14.61	46.8
July	35.18	35.18	63.86	21.11
August	31.98	31.98	69.51	31.34
September	33.05	33.05	42.11	22.49
October	35.18	35.18	8.53	7.14
Total			236.89	254.89

Source: https://weatherandclimate.com/nigeria/niger/paiko

At 8 WAS, six randomly selected plants from the gross plot were carefully uprooted with a shovel to reduce to the barest minimum any damage to the roots. The roots were dipped in a bucket of clean water to wash off the attached soils. These were further thoroughly rinsed carefully under running water, and subsequently used to obtain the mean number of nodules per plant. It was then oven dried to obtain the mean dry weight of nodules per plant. The number of pods per plant was recorded from six randomly selected plants from each plot. Grain weight was determined by weighing three samples' of 1000 grains taken from the grain lot of each treatment plot. Grain yield (kg ha^{-1}) was weighed from the harvested plants of each net plot.

Data Analysis

The Statistical Analysis System software version 9.2 (SAS, 2008) was used to analyse the data. Means were separated using the least significant difference (LSD) test at the 5 % level of probability.

RESULTS AND DISCUSSION

Weed Infestation

In 2015 rainy season, a total of 25 weed species were found in the field of soybean representing 10 families; nine from *Poaceae,* five from *Asteraceae*, two each from *Rubiaceae, Lamiaceae* and *Cyperaceae*, one from each of *Verbanaceae, Onagraceae, Commelinaceae, Solanaceae,* and *Euphorbiaceae* (Table 2). The relative density of > 10 % of the prominent weeds across the nutrient combinations was in the order of *Ageratum conyzoides* Linn. > *Mitracarpus villosus* (Sw.) DC. > *Paspalum scrobiculatum* Linn. > *Cyperus rotundus* Linn. > *Cynodon dactylon* Linn. Other weeds were of low relative density in this year of study. However, in 2016 rainy season, a total of 29 weed species were found infesting soybean plots representing 15 families; six from *Asteraceae*, three from *Cyperaceae*, two from each of *Poaceae, Amaranthaceae, Malvaceae, Solanaceae, Acanthaceae* and *Euphorbiaceae* and one from each of *Commelinaceae, Sterculiaceae, Tiliaceae, Convolvulaceae, Nyctaginaceae* and *Lamiaceae* (Table 3). *Kyllinga* sp., Thorn, was the only species that had a relative density of > 10.0 % in all the treatments in 2016. Weed species of comparatively high relative density in the field included *Oldenlandia corymbosa* Linn, *Sida rhombifolia* L., *Digitaria horizontalis* (H.B.R. Henr.) *and Cyperus difformis* Linn, in decreasing order. Other weed species were of comparatively lower density.

Table 2: Composition and relative density of weed species at 9 weeks after sowing in soybeans as influenced by Rhizobium inoculation in combination with cow dung and mineral fertilizers in 2015 rainy season

Scientific name	Family	Relative Density (%)						
		C	I only	I + P	I + P + K	I + P + K + M	I + P + K + M + CD	Total
Grasses								
Digitaria horizontalis (H.B.R.Henr.)	Poaceae	2.6	2.4	0.9	1.5	1.1	1.4	9.9
Eleusine indica (L.) Gaertn	Poaceae	3.0	2.0	2.3	3.0	2.6	2.4	15.3
Dactyloctenum aegyptium (L.) Beauv.	Poaceae	1.3	1.2	1.8	3.0	1.6	1.4	10.3
Imperata cylindrica Linn.	Poaceae	2.1	0.8	0.9	1.0	1.1	2.9	8.8
Paspalum scrobiculatum Linn.	Poaceae	10.3	8.6	8.1	11.3	11.6	10.0	60.0
Setaria pumila Poir.	Poaceae	1.3	0.8	1.4	1.0	0.5	1.0	5.9
Brachiaria lata Schumach.	Poaceae	0.4	0.0	0.0	0.0	0.0	0.5	0.9
Rottboellia cochinchinensis Lour.	Poaceae	1.7	2.0	2.3	0.0	1.6	1.4	9.0
Cynodon dactylon Linn.	Poaceae	4.7	6.1	10.8	9.9	2.6	6.2	40.3
Broadleaves								
Stachytarpheta jamaicensis Linn.	Verbanaceae	1.7	2.0	7.2	1.0	1.6	3.3	16.9
Conyza sumatrensis Retz.	Asteraceae	1.3	0.4	1.4	1.5	1.6	0.5	6.6
Oldenlandia corymbosa Linn.	Rubiaceae	0.0	3.3	6.8	1.0	5.3	5.7	22.0
Mitracarpus villosus (Sw.) DC	Rubiaceae	8.2	11.8	8.1	12.8	10.6	12.9	64.3
Leucas martinicensis Jacq.	Lamiaceae	3.4	4.5	3.2	2.5	4.2	4.8	22.5
Ludwigia decurrens Walt.	Onagraceae	3.9	0.4	1.4	3.9	0.5	0.0	10.1
Ageratum conyzoides Linn.	Asteraceae	18.9	18.8	21.6	16.7	18.5	15.7	110.3
Acanthospermum hispidum DC.	Asteraceae	8.2	4.5	3.6	5.9	4.8	4.8	31.7
Synedrella nodiflora Gaertn	Asteraceae	3.0	9.8	2.3	8.9	4.8	5.7	34.4
Hyptis suaveolens Poit.	Lamiaceae	6.4	5.3	1.4	2.0	3.2	5.7	24.0
Commelina benghalensis Linn.	Commelinaceae	3.4	0.0	4.1	4.9	3.2	2.9	18.4
Physalis angulata Linn.	Solanaceae	0.0	0.4	0.0	0.0	0.5	0.0	0.9
Tridax procumbens Linn.	Asteraceae	2.1	4.5	0.5	1.0	1.6	1.4	11.1
Euphorbia heterophylla Linn.	Euphorbiaceae	0.0	0.4	0.0	0.0	1.1	1.0	2.4
Sedges								
Cyperus rotundus Linn.	Cyperaceae	11.2	9.0	9.0	7.4	13.2	7.6	57.4
Kyllinga squamuculata Thorn.	Cyperaceae	0.9	0.8	1.4	0.0	2.6	1.0	6.6

C - Control, I - inoculant, P - phosphorus, K - potassium, M - micronutrients, CD - cow dung

Table 3: Composition and relative density of weed species at 9 weeks after sowing in soybeans as influenced by Rhizobium inoculation in combination with cow dung and mineral fertilizers in 2016 rainy season

Scientific name	Family	Relative Density (%)						Total
		C	I only	I + P	I + P + K	I + P + K + M	I + P + K + M + CD	
Grasses								
Digitaria horizontalis (H.B.R.Henr.)	Poaceae	11.3	13.7	7.4	7.2	7.2	3.3	50.2
Pennisetum polystachion Linn.	Poaceae	0.7	0.5	0.4	0.1	2.5	0.0	4.2
Broadleaves								
Acanthospermum hispidum DC.	Asteraceae	3.7	5.0	4.3	3.2	2.2	3.2	21.4
Melochia corchorifolia Linn.	Sterculiaceae	7.3	6.2	2.6	2.4	3.3	7.0	28.9
Tridax procumbens Linn.	Asteraceae	0.2	0.0	2.6	0.0	0.0	0.0	2.8
Alternanthera sessilis Linn.	Amaranthaceae	2.0	3.0	2.0	2.5	1.4	3.2	14.2
Desmodium scorpirius (SW.) Desv.	Euphorbiaceae	1.2	1.4	3.5	4.6	1.0	2.9	14.6
Spermococe ocymoides (Burm. F.)	Rubiaceae	0.0	0.2	4.3	0.0	0.0	0.0	4.4
Oldenlandia corymbosa Linn.	Rubiaceae	15.0	18.7	15.9	22.1	21.5	8.4	101.6
Croton lobatus L.	Euphorbiaceae	0.0	0.0	0.2	0.0	0.0	0.0	0.2
Boerhavia diffusa L.	Nyctaginaceae	0.2	0.0	0.0	0.0	0.0	0.0	0.2
Sida acuta Burn.F	Malvaceae	6.2	5.9	3.0	8.9	2.0	8.4	34.3
Physalis angulata Linn.	Solanaceae	0.0	0.0	0.2	0.0	0.0	0.5	0.7
Mimosa pudica Linn.	Solanaceae	0.0	0.0	0.0	0.0	1.0	0.0	1.0
Ipoemoea sp. Forsk.	Convolvulaceae	0.0	0.0	0.4	0.6	0.0	0.0	0.9
Chrysanthellum indicum Linn.	Asteraceae	0.2	0.8	0.6	0.1	0.0	0.0	1.7
Sida rhombifolia L.	Malvaceae	8.5	10.2	7.6	9.7	11.0	12.7	59.7
Amaranthus spinosus Linn.	Amaranthaceae	0.7	0.0	0.4	0.6	0.0	1.0	2.6
Senna obtusifolia L.	Commelinaceae	0.0	0.0	0.0	0.0	0.0	1.4	1.4
Gomphrena celosioides Mart.	Amaranthaceae	0.2	0.0	0.0	0.0	0.0	0.0	0.2
Ageratum conyzoides Linn.	Asteraceae	0.8	0.3	0.2	0.3	1.8	0.8	4.2
Hyptis lanceolata Poir.	Lamiaceae	0.5	0.0	0.0	0.0	0.0	0.0	0.5
Aspillia bussei D. Hoffm.	Asteraceae	0.0	0.3	0.0	0.0	0.0	0.0	0.3
Belpharis maderaspatensis Linn.	Acanthaceae	0.0	0.3	0.0	0.0	0.0	0.0	0.3
Senna occidentalis (L.) Link	Acanthaceae	0.0	0.0	0.4	0.6	0.8	0.0	1.7
Emilia coccinea (Sims.) G. Don.	Asteraceae	0.0	0.0	1.8	0.0	0.0	0.0	1.8
Sedges								
Kyllinga sp. Thorn.	Cyperaceae	31.8	26.7	35.7	31.6	28.2	36.6	190.6
Cyperus difformis Linn.	Cyperaceae	8.8	4.8	5.7	5.2	12.9	9.6	47.0
Fimbrystilis littoralis Linn.	Cyperaceae	1.0	1.9	1.1	0.3	3.3	1.0	8.6

C - Control, I - inoculant, P - phosphorus, K - potassium, M - micronutrients, CD - cow dung

The result of the analysis of variance on weed density and weed dry weight at 9 WAS exhibited significant effects for the two planting years of 2015 and 2016 (Table 4). Furthermore, the test integrated nutrient management differed significantly for weed dry weight only; and the interaction between year and integrated nutrient management was not significant for weed density and dry weight (Table 4). Fewer and lighter weeds were produced in the soybean field in 2015 growing season than 2016 growing season (Table 5). However, integrated application of inoculant + phosphorus + potassium + micronutrients produced significantly lighter weeds compared to the plots with inoculant + phosphorous + potassium + micronutrients + cow dung (Table 6).

Soybean Growth and Yield Attributes

Based on the results of the analysis of variance, with the exception of grain yield, the effect of year on nodule dry weight, number of pods per plant and 100 grain weight was highly significant (Table 7). The effect of integrated nutrient was highly significant on nodule dry weight, number of pods per plant, 100 grain weight and grain yield in this study (Table 7). The interaction between year and integrated nutrient was highly significant on nodule dry weight and number of pods per plant (Table 7).

Table 4: Analysis of variance of the influence of integrating Rhizobium inoculant and organic and inorganic fertilizers on weed density and weed dry weight at 9 weeks after sowing in soybean (2015 and 2016 mean)

Source of Variation	DF	*F* value for	
		Weed density (no. m^{-2})	Weed dry weight (g m^{-2})
Year (Y)	1	109.27**	29.40**
Error (A)	4	51.48	1.22
Nutrient (N)	5	0.71	1.17*
Y x N	5	1.01	1.08
Error (B)	40	-	-
Total	59	-	-
CV (%)	-	20.06	37.10

CV - coefficient of variation, DF - degree of freedom
*significant at $p \leq 0.05$, **highly significant at $p \leq 0.01$

Table 5: Weed density and weed dry weight in soybean as influenced by integrating Rhizobium inoculant, organic and inorganic fertilizers during the trial years of 2015 - 2016

Year	Weed density at 9 WAS (no. m^{-2})	Weed dry weight at 9 WAS (g m^{-2})
2015	48.50	49.51
2016	84.50	84.23
$LSD_{(0.05)}$	6.96	12.95

LSD - least significant difference, WAS - weeks after sowing

Table 6: Average weed density and weed dry weight in soybean as influenced by integrating Rhizobium inoculant, organic and inorganic fertilizers

Integrated nutrient	Weed density at 9 WAS (no. m^{-2})	Weed dry weight at 9 WAS (g m^{-2})
Control (no input)	70.70	71.96
I only	69.20	65.71
I + P	60.80	66.07
I + P + K	65.80	63.33
I + P + K + M	67.80	54.45
I + P + K + M + CD	64.70	79.71
$LSD_{(0.05)}$	12.06	22.42

I - Inoculant, P - Phosphorus, K - Potassium, M - Micronutrients, CD - cow dung LSD - least significant difference, WAS - weeks after sowing

In 2016 growing season, significantly heavier nodules, more pods per plant and heavier grains of soybean were produced compared to the 2015 growing season (Table 8). Furthermore, the integrated application of inoculant + phosphorus, inoculant + phosphorus + potassium, and inoculant + phosphorus + potassium + micronutrients produced similar heavier soybean nodules compared to the other nutrient combinations (Table 9). These nutrient combinations also produced more pods per plant, heavier grains and higher grain yield which were in turn similar with inoculant + phosphorus + potassium + micronutrients + cow dung (Table 9).

The significant interaction between year and integrated nutrient management on nodule dry weight and pods per plant indicated that this parameter varied within the years (Table 10). The integrated application of inoculant + phosphorus only, inoculant + phosphorus + potassium, inoculant + phosphorus + potassium + micronutrients in 2016 recorded similar heavier nodules compared with the other treatment combinations (Table 10). In the same vein, in 2016, these nutrient combinations produced more pods per plant similar with inoculant + phosphorus + potassium + micronutrients + cow dung in this study (Table 10).

DISCUSSION

On the basis of the relative weed density, the weed species that were dominant in the soybean field were *Agretum conyzoides, Kyllinga* sp., *Mitracarpus villosus, Oldenlandia corymbosa, Sida rhombifolia, Paspalum scrobiculatum, Cynodon dactylon, Digitaria horizontalis, Cyperus rotundus* and *Cyperus difformis* all through the 2015 and 2016 growing seasons. This suggest that the development of these weed species was enhanced with the application of these nutrients. Thus, the application of these integrated nutrients could have resulted to

Table 7: Analysis of variance of the influence of integrating Rhizobium inoculant and organic and inorganic fertilizers on nodule dry weight, pod per plant, 100 grain weight and grain yield of soybean (2015 and 2016 mean)

Source of variation	DF	*F* value for			
		Nodule dry weight (g)	Number of pods per plant	100 grain weight (g)	Grain yield (kg ha^{-1})
Year (Y)	1	203.71**	77.11**	199.75**	2.38
Error (A)	4	2.67	2.70	2.78	11.09
Nutrient (N)	5	17.34**	11.02**	2.75*	9.00**
Y x N	5	10.60**	3.67*	2.13	1.13
Error (B)	40	-	-	-	-
Total	59	-	-	-	-
CV (%)	-	33.74	29.00	10.70	35.90

CV - coefficient of variation, DF - degree of freedom, *significant at $p \leq 0.05$, **highly significant at $p \leq 0.01$

Table 8: Nodule dry weight, number of pods per plant, 100 grain weight and grain yield of soybean as influenced by integration of Rhizobium inoculant, organic and inorganic fertilizers during the trial years of 2015 - 2016

Year	Nodule dry weight per plant (g)	Number of pods per plant	100 grain weight (g)	Grain yield (kg ha^{-1})
2015	1.45	49.16	8.84	1585.90
2016	6.20	97.33	13.13	1374.30
$LSD_{(0.05)}$	0.67	11.09	0.61	277.25

LSD - least significant difference

Table 9: Comparison of the average nodule dry weight, pods per plant, 100 grain weight and grain yield of soybean as influenced by integrating Rhizobium inoculant, organic and inorganic fertilizers (mean of 2015 and 2016)

Integrated nutrient	Nodule dry weight (g)	Pods per plant	100 grain weight (g)	Grain yield (kg ha^{-1})
Control (no input)	1.72	51.60	10.22	897.80
I only	2.14	40.58	10.26	791.90
I + P	5.90	97.36	11.69	1646.80
I + P + K	4.86	80.43	11.40	1808.40
I + P + K + M	5.04	79.52	11.33	1765.00
I + P + K + M + CD	3.28	89.98	11.03	1970.60
$LSD_{(0.05)}$	1.17	19.21	1.06	480.22

I - Inoculant, P - Phosphorus, K - Potassium, M - Micronutrients, CD - cow dung, LSD - least significant difference

Table 10: Interaction between year and integration of Rhizobium inoculant, organic and inorganic fertilizers on nodule dry weight and number of pods per plant (mean of 2015 and 2016)

Integrated nutrient	Nodule dry weight (g)		Number of pods per plant	
	2015	2016	2015	2016
Control (no input)	0.54	2.90	47.0	56.0
I only	1.22	3.05	29.0	52.0
I + P	1.51	10.29	62.0	133.0
I + P + K	2.12	7.59	51.0	110.0
I + P + K + M	1.81	8.27	51.0	108.0
I + P + K + M + CD	1.47	5.08	55.0	125.0
$LSD_{(0.05)}$	1.65		27.1	

LSD - least significant difference, WAS - weeks after sowing, I - Inoculant, P - Phosphorus, K - Potassium, M - Micronutrients, CD - cow dung the presence of the different weed species in the soybean field. The variation could be attributed to the response of the different weed species to the various nutrients applied, the seasonal variation and their adaptability to the ecological condition. This finding is in agreement with Khaliq *et al*. (2014) who noted that the presence of some weed species with high density suggests their adaptation ability to the local climatic condition of the study site which favoured their growth. Also, the relative density of some of the weed species could be linked to the perennating organs or seed production from the seedbank which might have been enhanced by their ability to efficiently use the available soil nutrients (Fabunmi *et al*., 2018). For example, *A. conyzoides* Linn., and *Kyllinga* sp.*,* Thorn.*,* had the highest relative density in each year in this study. While the former can shed high number of seeds, the latter can proliferate by a complex of its underground structures.

Response to Year

Weed density and dry weight were generally lower in 2015 compared with the other year. This might likely be attributed to the rainfall amount which was lower in the 2015 growing season than the other year. This finding agrees with Gandía *et al*. (2021) that the changes in rainfall patterns in a rainfed crop can affect the weed biology, and weed community, which could in turn have an influence on the crop-weed interactions, and crop growth patterns.

Heavier nodules, more pods per plant, heavier grains and higher grain yield of soybean were obtained in the 2016 than 2015 growing season. This may be attributed to the higher rainfall amount recorded in the former than the latter. Onyenali *et al*. (2019) who also worked in 2015 and 2016 attributed a similar observation among five soybean varieties to slightly contrasting weather conditions, especially the total annual rainfall recorded during the two years. Nwite (2022) equally observed that rainfall and temperature during seed development and plant maturation could contribute to variations in biological and seed yield of soybean. A rather more important factor than rainfall pattern is water stress during the crop's critical growth stages. Besides the possibility of more yield-relevant water stress in 2015 than 2016, soybean usually performs poorer in the first than the second year of cropping when the crop benefits from the nodulation in the first year (Obalum *et al.,* 2011).

Response to Integrated Nutrient Management

Weed dry weight was generally low with the combined application of inoculant + phosphorus + potassium + micronutrients thereby resulted in a decrease in the weed community as observed in the soybean field. The reduction in weed dry weight in these treatments suggest that lower growth resources were captured by weed species in these treatments. By contrast, the soybean plants in this plot efficiently used the growth factors for vigorous growth which enabled them to smother the weed species. In a similar study, Apon and Nongmaithem (2022) reported that with integrated application of 75% recommended dose of fertilizer (RDF) + 25% organic fertilizer through farmyard manure + phosphate solubilizing bacteria (N_2) and 50% RDF + 50% organic through Rhizobium + phosphate solubilizing bacteria (N_3), weed productivity can be greatly reduced in soybean.

The production of heavier nodules and grains of soybean with the combined application of inoculant + phosphorus, inoculant + phosphorus + potassium, and inoculant + phosphorus + potassium + micronutrients demonstrated the favourable effects of combining inoculant with organic and mineral fertilizers in enriching the Rhizobia population in the soil. An improvement in nodule number is the outcome of improvement in the growth environment (soil pH, nutrient availability, microbiological activity, physical and chemical properties of soil) among other factors (Onyenali *et al*., 2019). Also, Sinclair and Vadez (2002) and Ogutu (2013) stated that moderate doses of N and P could enhance nodulation, and P fertilization can promote nodule number and mass, as well as greater N-fixation capacity per plant. The heavier grains obtained in this study, might be attributed to the high nitrogen and phosphorus content available to the soybean crop during its reproductive stage (Musa *et al*., 2011). The supply of adequate amount of N to soybean plants may have resulted in the production of heavier biomass, more photosynthetic and greater assimilate of N to produce more yield and yield attributes (Kubar *et al*., 2021). Similarly, Khan *et al*. (2020) reported that the application of adequate amount of phosphorus can promote soybean crop growth, seed formation and crop productivity.

The production of more pods and higher grain yield of soybean with the combined application of inoculant + phosphorus, inoculant + phosphorus + potassium, inoculant + phosphorus + potassium + micronutrients, and inoculant + phosphorus + potassium + micronutrients + cow dung could be attributed to the availability of essential mineral nutrients in balanced quantity especially N and P, which in turn translated into the production of more pods. This finding agrees with Adjei-Nsiah *et al*. (2022) that the co-application of phosphorus and inoculation increased soybean grain yield by 88% and 108%, respectively over the control. Also, our finding showed that inoculation alone cannot increase soybean grain yield without the addition of P fertilizer because it is the ultimate source of energy for Rhizobium. This finding is in agreement with the work of Ronner *et al*. (2016) who reported an increase in grain yield of soybean in plots treated with inoculant + phosphorus fertilizer.

Year and Nutrient Management Interaction

The significant interaction between year and integrated nutrient management on nodule dry weight and number of pods per plant highlights the importance of integrating nutrient for enhancing soybean production in a given environment which differs in space and time. This is consistent with the findings of Dipak *et al.* (2018) who noted that adequate supply of inorganic fertilizers with organic sources like farm yard manure can improve the physical, chemical and biological condition of the soil which could in turn improve soybean growth and yield contributing characters.

CONCLUSION

The most prevalent weed species of soybean were *Ageratum conyzoides, Kyllinga sp., Mitracarpus villosus, Oldenlandia corymbosa, Sida rhombifolia, Paspalum scrobiculatum, Cynodon dactylon, Digitaria horizontalis, Cyperus rotundus* and *Cyperus difformis*. Weed infestation in terms of weed density and dry weight were generally lower in 2015. Soybean growth and yield attributes in terms of number of nodules, pods and grain weight were higher in 2016. Weed dry weight was generally lowest with the integrated application of inoculant + phosphorus + potassium + micronutrients. However, the complete package of the integration of inoculant + phosphorus + potassium + micronutrient + cow dung produced the best grain yield and is recommended for adoption by soybean farmers in the Southern Guinea Savanna of Nigeria.

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