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Effects of Fallowing and Nitrogen Application on Striga Infestation, Soil Fertility and Maize Performance

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Authors' contributions

This work was carried out in collaboration among all authors. Author MSB designed the study, wrote the protocol, and wrote the first draft of the manuscript. Author MKAA supervised and directed the work and ensure that literature searches were relevant and adequate. Author MGMK scrutinized analyses of the study, cross-checked and fine tune the final manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Striga possesses an ominous obstacle to the African continent that is struggling with food security as it affects the livelihood of more than 300 million people. The control of *Striga* has proved exceptionally difficult. Two fallows, namely natural fallow (NF) and *A. histrix* fallow (AF) were maintained in 2012, such that the field was divided into two parts and each part was further divided into three replicates. Each part was separated from one another by a strip of 2 m width and the fallow factor was randomly assigned to each part which constituted the main plot. In 2013, the inorganic N fertilizer levels (0, 60, 90 and 120 kg ha^{-1}) were applied to the fallow plots and assigned to the sub-plot. These treatments were laid out in a split plot arrangement fitted to a randomized

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complete block design with three replicates. The two fallows significantly (P < 0.05) reduced *Striga* infestation similar to application of N at 60 – 120 kg N ha^{-1}. The two fallows significantly (P< 0.05) increased SOC. Only natural fallow significantly (P<0.05) increased the STN by 36 %. Maize grain yield after natural fallow (1527 kg ha^{-1}) was not significantly (P>0.05) different from that after *A. histrix* (1943 kg ha^{-1}). Inorganic N application had highly significant (P<0.05) effect on grain yield. Lowest grain yield of 1253 kg ha^{-1} was obtained without inorganic N application, which was significantly different from those fertilized with inorganic N. Inorganic N fertilizer rate of 60 kg ha^{-1} seems to be optimum for maize. The Nitrogen Fertilizer Replacement Value of *A. histrix* was low, 13 kg N ha^{-1}. The effect of both fallows on grain yield was due mainly to increased SOC content.

Keywords: Fallows; nitrogen; striga infestation and Maize.

1. INTRODUCTION

Maize is one of the most important cereal crops of the world after rice with respect to cultivated area [1]. The phenomenal increase in maize production in Nigeria over the past few years was attributed to increase in its utilization for various food items, livestock feed and industrial materials, as well as research activities leading to the development of input and management of technologies resulting from increased grain yields [2].

The relatively high N requirement of maize and the inherently low plant available N in the soils of the Guinea savanna of Nigeria, make N to be one of the most important constraints to maize production [3]. Hence, an external input of N is inevitable for maize production. The high cost and poor distribution of inorganic N fertilizer prevent farmers from using them to supply N. The integration of legumes into the cropping system can be an option to improve the N nutrition of maize [4].

One of the commonly used methods to determine N contribution from legumes included in crop rotation is the N fertilizer replacement value (NFRV). The NFRV of a legume is defined as the amount of fertilizer N required by a non-legume in the absence of legumes to obtain grain yields equivalent to those obtained when the non-legume is followed by legume in rotation [5]. Management of the legume residue affects the amount of the NFRV of a legume. Higher values are obtained when the residues are incorporated into the soil than when the residues are exported from the field. NFRV of similar herbaceous legume, *Centrosema pascuorum*, with the residues incorporated, was estimated to be 34 kg N ha^{-1}, in the northern Guinea savanna of Nigeria [6].

Striga possesses an ominous obstacle to the African continent that is struggling with food security as it affects the livelihood of more than 300 million people [7]. [8] stated that *Striga* infests 40 % of arable land in the African Savannah region and two – thirds of the 73 million hectares devoted to cereal production in Africa were affected by *Striga.* Over US $1billion losses per year was estimated for *Striga* infested maize alone in Africa [9]; a major cause of food insecurity in the region. The control of *Striga* has proved exceptionally difficult. In Nigeria, the use of inorganic fertilizers to increase the N content in the soil is not feasible for the peasant farmers due to lack of resources, inaccessibility, low industrial technology and poor road network, among others. One alternative to inorganic fertilizer to increase soil N is by crop rotation with herbaceous legumes especially *A. histrix* or similar ones.

Aeschynomene histrix (Poir) (Jointvetch) is a fast growing and decomposing green manure with high potential as legume fallow in the humid tropics [10] [11]. *A.histrix* has the ability to fix large quantities of N, thus enriching the poor tropical savanna soils [12]. It grows wildly and widely in the southern Guinea Savanna of Nigeria. Despite all these attributes, very few studies have been carried out, to evaluate its effect on *Striga* infestation, soil properties and grain yield when rotated with maize in the southern Guinea savanna. Our objectives therefore, were to determine the rotation effect of the legume on *Striga* infestation, soil organic carbon, soil total nitrogen and maize grain yield and estimate its NFRV.

2. EXPERIMENTAL SITE

Field experiment was conducted on a *Striga* infested field in 2012 and 2013 rainy seasons at the Teaching and Research Farm of Niger State College of Agriculture, Mokwa (09^0 18 N; $05^0$50 E), situated in the Southern Guinea savanna agro ecological zone of Nigeria. Rainfall pattern is monomodal with the rainy season starting in

March or April and ending in October. Monthly rainfall during the period of study is shown in Table 1. The field was heavily infested with *Striga hermonthica* which makes it to be sparingly cultivated with maize over the years with no fertilizer application.

2.1 Treatments and Experimental Design

Two fallows, namely natural fallow (NF) and *A. histrix* fallow (AF) were maintained in 2012, such that the field was divided into two parts and each part was further divided into three replicates. Each part was separated from one another by a strip of 2 m width and the fallow factor was randomly assigned to each part which constituted the main plot. In 2013, the inorganic N fertilizer levels (0, 60, 90 and 120 kg ha^{-1}) were applied to the fallow plots and assigned to the sub-plot. These treatments were laid out in a split plot arrangement fitted to a randomized complete block design with three replicates. There were 24 experimental plots with gross plot size of 4 m by 6 m (24 m^2) and net plot size of 13.5 m^2.

2.2 Agronomic Practices

The field was manually cleared and ridged using hoe at 75 cm apart in 2012 and 2013. The maize variety, SUWAN 1, obtained from premier seeds, highly susceptible to *Striga* was manually planted at 3 seeds per hill, spaced 50 cm within rows. The seedlings were thinned to two plants per hill at two weeks after sowing (WAS) to give a plant population of 53, 3333 plants ha^{-1}. Basal application of 30 kg P ha^{-1} as single superphosphate and 30 kg K ha^{-1} as muriate of potash were carried out at 2 WAS after thinning. Inorganic N fertilizer as urea was split – applied to plots that were to receive N fertilizer. At 2 WAS, one- third of the N was applied, while the remaining two- third was applied at 6 WAS. Fertilizers were applied by side banding at about 5 cm away from the seedlings and at about 5 cm deep along the ridge. The first hoe –weeding was carried out at 3 WAS while the second weeding was at 5 WAS followed by careful hand- pulling of weeds other than *Striga.*

2.3 Soil Sampling and Analysis

Prior to land preparation, for initial characterization of the field for both experiments, surface soil (0 – 15 cm) samples were collected with an auger (15 cm length), along four diagonal transects, from ten points each, thoroughly mixed and bulked to give four composite samples. In 2012, for the crop rotation experiments, samples were collected after one year of fallow in both natural and *A. histrix* block from each subplot before planting, at tasselling stage and physiological maturity of the maize. Samples were collected from three points, between two plant stands and furrow, along three diagonal transects, thoroughly mixed together and bulked to give one composite sample per plot. All the soil samples were air-dried, crushed lightly and sieved through a 2 mm sieve and analyzed.

Table 1. Effects of fallow and nitrogen fertilization on maize population and plant height at 3, 6 and 9 WAS in 2013 rainy season

Treatment	Plant population ha^{-1}			Plant height (cm)		
	3WAS	6WAS	9WAS	3WAS	6 WAS	9WAS
Fallow (F)						
Natural Fallow	2870	2860	2240	36.9	58.5	199.2b
A. histrix Fallow	3290	3120	2630	39.8	59.8	216.9a
SE ±	29.5	23.8	27.2	2.5	2.8	5.1
Significance	NS	NS	NS	NS	NS	*
N Levels(kg ha^{-1}) (N)						
0	2690	2610b	1940b	32.3b	52.7b	181.0c
60	3260	3260a	2640ab	38.3ab	59.7a	203.7b
90	3080	2950ab	2450ab	36.7ab	60.7a	217.5ab
120	3290	2965ab	2730a	44.2a	60.7a	230.2a
SE ±	41.8	33.7	38.5	3.6	3.9	7.1
Significance	NS	*	*	*	*	*
Interaction						
F×N	NS	NS	NS	NS	NS	NS

Means in each treatment column with different letter(s) are significantly different from each other at P < 0.05 using Duncan Multiple Range Test (DMRT)

*WAS – Weeks after sowing; *- Significant at 5 % level; NS- Not significant*

Particle size distribution was determined by Bouyoucos hydrometer method [13]. Soil reaction was determined using potentiometer in 1:2:5 soil 1 to water suspension with the glass electrode pH meter. Organic carbon was determined by the Walkley and Black wet oxidation method [14]. Exchangeable bases were determined by extraction with neutral 1 N NH_4OAc. Potassium and Sodium in the extract were determined with flame photometer, while calcium and magnesium were determined using atomic absorption spectrophotometer. Exchangeable acidity was determined by titrimetric method using 1 N KC1 solution. Effective cation exchange capacity (ECEC) was estimated by summation method of exchangeable acidity and exchangeable bases. Available phosphorous was extracted by the Bray P1 method. The P concentration in the extract was determined colorimetrically using the spectrophotometer. Total N was determined by Kjeldahl digestion method [15].

The NFRV of the *A. histrix* was estimated by the method described by [4]. The response of maize to urea N in the natural fallow plot was fitted to a linear model. The intercept was the grain yield after fallow with no fertilizer and the slope is the response of maize to fertilizer N.

> NFRV = Yield after *A. histrix* with no N fertilizer – Intercept / slope

2.4 *Striga* Infestation Parameters

The number of *Striga* shoots per maize plant was taken by counting each *Striga* shoot present per maize plant stand starting from 6 WAS. The number of *Striga* shoots flowering was taken by counting closely the number that flowered in each plot. The number of *Striga* shoots per meter squared was taken by counting closely the number of *Striga* present in each plot per m^2. Days to 50 % *Striga* shoot flowering was carried out by counting the number of days from the day the first *Striga* shoot emerged to the day that 50 % of *Striga* shoots flowered. The *Striga* reaction score was taken on the scale of 0 – 9 using visual observation to measure mild, severe and very severe or death infestation of *Striga* on maize plant.

2.5 Maize Growth and Yield Parameters

Ten maize plants from each of the net plot were randomly tagged for periodic observation at 3, 6 and 9 WAS. The following observations made were:

The maize plant population was carried out by counting individual plants at 3, 6 and 9 WAS. This is also known as plant population count and expressed in hectare. The maize plant height was observed by tagging ten plants from the inner rows at random which were used throughout for taking the measurements. The plant height was measured using meter rule from the top of the uppermost leaf to the base of the plant at 3 and 6 WAS but from the base to the tip of the tassel at 9 WAS and expressed in centimeters. Days to 50 % maize tasselling was taken through observation by counting the number of days from the sowing date to the day when about 50% of all the maize plants in each plot has tasseled and expressed in percentage. The average cob length of 10 harvested tagged maize plant from the inner row of each plot were taken and measured using meter rule and expressed in centimeters. The number of maize cobs from the inner rows of each plot was counted and estimated per hectare. This was done when the plant attains physiological maturity. The number of maize grain per cob was also obtained by weighing those harvested from the inner rows and shelled at harvest time. This was done by counting. 100 maize grain weights was taken from the ten harvested cobs from each plot, shelled and weighed using a weighing balance, expressed in grams.

The maize grain yield analysis was carried out by harvesting maize ears in the two central rows leaving out the border plants at both ends (net plot of 13.5 m^2). These were shelled, air- dried and weighed. The grain yield was adjusted to 12 % moisture content for each plot and weighed. The biomass yield of both *A. histrix* and fallow plots were determined from 1 m × 1m quadrant outside the experimental plots.

3. RESULTS AND DISCUSSION

3.1 Maize Growth and Yield Parameter

Effects of fallowing and N fertilization on maize growth parameters are shown in Tables 1 and 2. Plant population was not significantly ($P > 0.05$) affected by fallowing at 3, 6 and 9 WAS (Table 1). N levels had a significant influence on plant population at 6 and 9 WAS only. The application of 60 kg N ha^{-1} at 6 WAS and 120 kg N ha^{-1} at 9 WAS gave rise to highest plant population, than the control. Maize plant height was not significantly ($P > 0.05$) affected by fallowing at 3 and 6 WAS, except at 9 WAS. AF had the tallest plants, which was 9 % higher than NF. The application of 120 kg N at 3 and 9 WAS, and 60 kg N ha^{-1} at 6 WAS produced significantly taller plants compared to 0 kg N ha^{-1}. Days to 50 % tasselling in maize was not significantly (P > 0.05) affected by fallowing and N fertilization (Table 2). However, fallowing had a significant (P < 0.05) effect on the number of maize cobs per plot (Table 2) such that AF had 16 % more cobs than NF. There was no significant (P > 0.05) difference in N fertilizer levels on this parameter. Similarly, cob length was not significantly (P > 0.05) increased by fallowing but by N fertilizer levels. The application at 60 kg N ha^{-1} produced the longest cobs, which were comparable to 90 and 120 kg N ha^{-1}, respectively.

The effects of fallowing and N fertilization on maize grain yields and yield attributes are shown in Table 3. Fallowing and N fertilization had no significant (P > 0.05) effect on 100 grain weight (Table 3). Stover yield was significantly (P < 0.05) increased by fallowing, such that AF produced 35 % more stover yield than NF. N fertilization also had significant (P < 0.05) effects on stover yield. Application at 60 kg N ha^{-1} and beyond resulted in similar higher stovers than plots without fertilizer. Fallowing had a significant (P < 0.05) effect on grain yield (Table 3). AF produced significantly higher grain which was 21 % more than NF. N fertilization levels also had a significant (P < 0.05) effect on grain yield such that application of 60 kg N ha^{-1} and beyond resulted in similar higher grain yield than plots without fertilizer application.

Plant height, days to 50 % tasselling, number of maize cob per plot and cob length were generally increased by both natural and *A. histris* fallows. Maize growth was enhanced with N application at 60 – 120 kg N. Also, there was increase in stover and grain yield in this study. Maize yield was high in *A. histrix* fallow and with the application of 60 – 120 kg N. The grain yields of the fallowing maize were similar in both fallows. Increase in soil organic matter level might have resulted in increase in soil fertility, nutrient supply, porosity, permeability and thus, soil productivity [16] which amounted to higher grain yields. Results obtained are consistent with that of other workers in the same savanna agroecological zone of Nigeria [17].

Grain yield without inorganic N fertilization was significantly lower than the grain yield with inorganic N levels. Similar response to inorganic N fertilizer has been reported in the same area by [18]. The highest grain yield was recorded with application of 60 kg N ha^{-1}, which was however comparable with the other N levels of 90 and 120 kg ha^{-1}. These results suggest that application of between 60 and 90 N kg ha^{-1} seem to be optimum for maize in this area. [18] also reported 90 kg ha^{-1} to be optimum for maize in the area. In the West African savannas, 60- 120 kg ha^{-1} had been recommended by [19]. Series of trials conducted in savanna zone, led to a recommendation of 100- 120 kg ha^{-1} [20]. A rate of N, which usually gives reasonable return, has been put at 60 kg N ha^{-1} [21].

Table 2. Effects of fallow and nitrogen fertilization on growth and yield components of maize in 2013 rainy season

Treatment	Days to 50% tasseling	No. of maize Cob/ Plot	Cob length (cm)
Fallow (F)			
Natural Fallow	53	36b	12.4
A. histrix Fallow	53	43a	14.0
SE ±	1.75	4.1	0.72
Significance	NS	*	NS
N Levels(kg ha^{-1}) (N)			
0	55	32	12.1b
60	51	42	15.0a
90	53	42	13.6ab
120	51	41	14.0a
SE ±	2.5	5.8	1.02
Significance	NS	NS	*
Interaction			
F×N	NS	NS	NS

Means in the column with different letter(s) are significantly different from each other at P < 0.05 using Duncan Multiple Range Test (DMRT);
**-Significant at 5 % level, NS- Not significant*

Table 3. Effects of fallow and nitrogen fertilization on maize yields and yield attributes in 2013 rainy season

Treatment	100 grain weight (g)	Stover yield (kg ha^{-1})	Grain yield (kg ha^{-1})
Fallow (F)			
Natural Fallow	25.3	4970b	1527b
A. histrix Fallow	24.2	7690a	1943a
SE ±	1.67	868.2	346.9
Significance	NS	*	*
N Levels(Kg ha^{-1}) (N)			
0	23.3	3996b	1253b
60	25.2	7471a	1915a
90	25.6	6810a	1902a
120	25.0	7038a	1871a
SE ±	2.32	1227.8	490.6
Significance	NS	*	*
Interaction			
F×N	NS	NS	NS

Means in the column with different letter(s) are significantly different from each other at P <0.05
**- Significant at 5 %; NS- Not significant*

3.2 *Striga* Infestation Parameter

The effects of fallowing and N fertilization on *Striga* m^{-2} and *Striga* shoots per maize plant at 9 and 12 WAS in 2013 are shown in Tables 4. There were no significant differences in *Striga* shoots m^{-2} between the fallows and N fertilization levels (Table 4). Application of N at 120 kg N had the least number of shoots, compared to the other treatments. However, N fertilization had significant (P > 0.05) effect on *Striga* shoots per plant at 12 WAS such that 60 kg N ha^{-1} had the least number of shoots similar to 90 and 120 kg N, which were higher than the control. Table 5 shows fallowing and N levels interaction on *Striga* shoots per m^{-2}. Comparing fallowing while keeping N levels constant, *Striga* shoots per m^{-2} was significantly higher at 0 kg N ha^{-1} in both fallows, however, the application of 60 – 120 kg N ha^{-1} in both fallows gave rise to lower *Striga* shoots per m^{-2}. Table 6 shows fallowing and N levels interaction on *Striga* shoots per maize plant. Comparing fallowing while keeping N levels constant, *Striga* shoots per maize plant was significantly higher at 0 kg N ha^{-1} in both fallows, and further increase in N levels from 60 – 120 kg N ha^{-1} resulted in no significant response. However, the use of 60 – 120 kg N ha^{-1} in both fallows produced lower *Striga* shoots per maize plant.

Striga shoot m^{-2}and per plant^{-1} were generally reduced by both natural and *A. histrix* fallows but varied between N fertilizer levels. *Striga* shoots were low in both fallows. This demonstrates that natural and *A. histrix* fallows caused a reduction in *Striga* emergence, similar to the application of N at 60 – 120 kg N ha^{-1}. Also, the application at 120 kg N produced the lowest *Striga* shoots. These might be due to incorporation of green manure to the soil and reduced loss of N by volatilization [22]. Many workers have reported reduced *Striga* infestation with resultant higher grain yield of the host crop when herbaceous legumes are in rotation with the host crop [23]; [3].

3.3 Soil Organic Carbon and Total Nitrogen

The effect of natural fallow and *A. histrix* fallow on SOC and STN are shown in Table 7. The two fallows significantly increase SOC with NF having a higher increase of 44.1 % compared to 31.3 % by AF. Also, NF increased STN by 26.3 % compared to AF that increased it by 20.3 %.

The SOC and STN were increased by both fallows after one year rotation. NF had a higher increase compared to AF. Similarly, NF produced a higher biomass than AF which was incorporated. The increase in SOC is related to the amount of biomass produced by the fallows and incorporated [22]. The relatively lower increase by the AF may also be partly attributed to higher rates of mineralization of legume residues, due to its low C/N ratio [24] and more contact with soil enzymes when incorporated. Costa et al. [25] reported that incorporation of legume residues ensures more contact with soil enzymes, with consequent faster rate of mineralization. NF significantly increased the soil total N (STN) than AF. Similar increase in STN with incorporation of residues of natural fallow and herbaceous in the savanna zone has been reported by other workers [26]; [21]; [3]. The relatively higher increase by NF compared to AF may be ascribed to mineralization of the residues [27], enhancement of soil microbial activity and possibly heterotrophic N_2 fixation and release of N from the breakdown of their roots and nodules [28].

3.4 Nitrogen Fertilizer Replacement Value

The response of maize succeeding natural fallow to urea N is shown in Fig. 1. The estimated nitrogen fertilizer replacement value of the *A. histrix* after one year fallow was 13 kg N ha^{-1}.

Table 4. Effects of fallow and nitrogen fertilization on *Striga* shoots m^{-2} and plant at 9 and 12 WAS in 2013 rainy season

Treatment	*Striga* shoots m^{-2}		*Striga* shoot plant $^{-1}$	
	9WAS	12WAS	9 WAS	12WAS
Fallow (F)				
Natural Fallow	0	2	1	2
A. histrix Fallow	1	4	0	2
SE ±	0.32	0.59	0.32	0.60
Significance	NS	NS	NS	NS
N Levels(kg ha^{-1}) (N)				
0	1	6c	1	4b
60	0	3b	0	1
90	0	2b	0	2
120	0	1a	0	1
SE ±	0.45	0.82	0.45	0.85
Significance	NS	*	NS	*
Interaction				
F×N	NS	*	NS	*

Means in each treatment column with different letter(s) are significantly different from each other at P < 0.05 using Duncan Multiple Range Test (DMRT); WAS – Weeks after sowing
**- Significant at 5 % level; NS- Not significant*

Table 5. Interaction between fallow and nitrogen fertilization on *Striga* shoots m^{-2} at twelve weeks after sowing in 2013 rainy season

N Levels(kg ha^{-1})	*Striga* shoots m $^{-2}$	
	Natural fallow	*A.histrix* fallow
0	3a	8a
60	2bc	2bc
90	2bc	2bc
120	1c	1c
SE±	0.59	

Means in each treatment column with different letter(s) are significantly different from each other at P < 0.05 using Duncan Multiple Range Test (DMRT)

Table 6. Interaction between fallow and nitrogen fertilization on *Striga* shoots per plant at twelve weeks after sowing in 2013 rainy season

N Levels(kg ha^{-1})	*Striga* shoots plant $^{-1}$	
	Natural fallow	*A. histrix* fallow
0	5b	12a
60	3bc	2c
90	2c	2bc
120	1c	1c
SE±	0.92	

Means in each treatment column with different letter(s) are significantly different from each other at P < 0.05 using Duncan Multiple Range Test (DMRT)

Table 7. Effect of natural and *A. histrix* fallows on soil organic carbon and total nitrogen in 2013 rainy season

Treatment	Soil organic carbon (g kg^{-1})			Soil total nitrogen (g kg^{-1})		
	Initial value in 2012	Value at beginning of 2013	Percentage change	Initial value in 2012	Value at beginning of 2013	Percentage change
	3.30(0.05)			**1.77(0.15)**		
Natural F		5.9(0.37)	44.1		2.40(0.25)	26.3
A. histrix		4.8(0.54)	31.3		2.22(0.13)	20.3

Standard error of means in parenthesis
a-By t-test between each treatment and initial value indicates significant difference at p< 0.05
NS -Not sig. different from initial value at p < 0.05

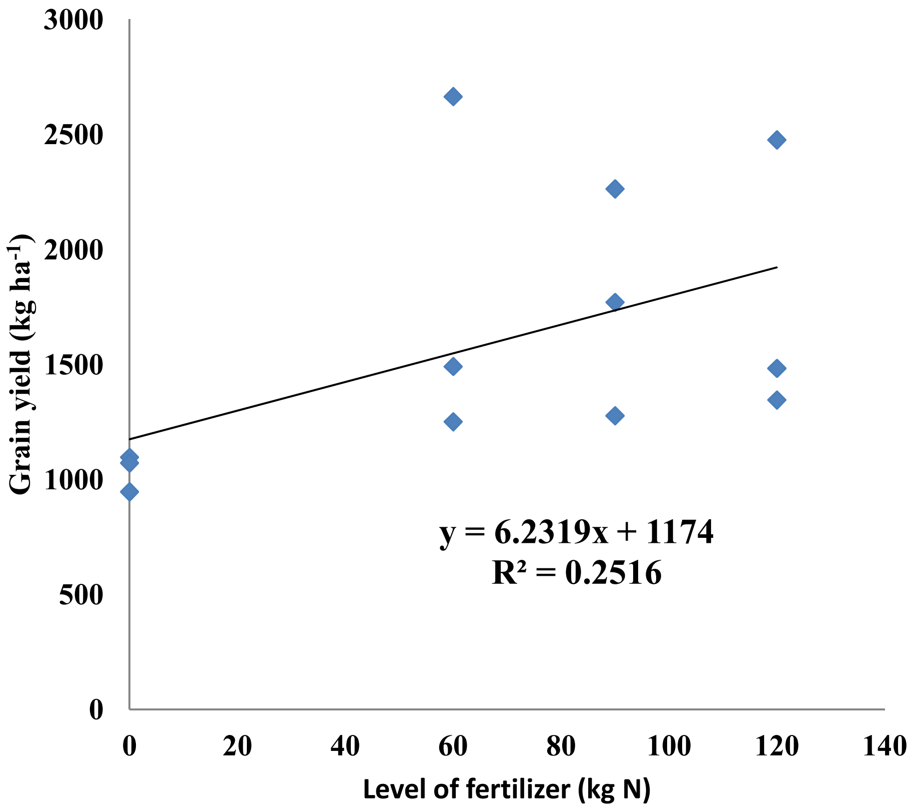

Fig. 1. Response of maize yield to inorganic nitrogen fertilizer after fallowing

The estimated N fertilizer replacement value (NFRV) of *A. hixtrix* was 13 kg N ha^{-1}. This value is lower than 34 kg N ha^{-1} recorded for similar herbaceous legume, *Centrosema pascuorum* in the same savanna agroecological zone by Adeboye [6]. However, most of the N could have been leached beyond the maize roots zone, due to rapid mineralization of the *A. histrix* residues that could have resulted in lack of synchrony between N availability and maize uptake. The significant increase in SOC, which not only improve the soil nutrient content, but improve soil physical properties, by natural fallow, resulting in good growth and yield of maize may also have contributed to the low NFRV.

4. CONCLUSION

From the results of this study, fallowing maize with *A. histrix* has the potential of reducing *Striga* parasitism with respect to *Striga* shoots per m^{-2} and plant^{-1}, thus, enhancing maize grain yield.

Maize rotation with natural fallow was as equally good as rotation with *A. histrix*, with respect to plant height, days to 50 % tasseling, number of cob per plot, cob length, stover and maize grain yields. There was response to inorganic N fertilizer application, suggesting the need for N application to maize for optimum grain yield. Nitrogen rate of 60 kg ha^{-1} was optimum for maize yield.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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