American Journal of Plant Sciences, 2023, 14, 1043-1060
https://www.scirp.org/journal/ajps
ISSN Online: 2158-2750
ISSN Print: 2158-2742

Maize-Soybean Integration for Managing *Striga hermonthica* (Del.) Benth in the Sudan Savannah Zone of Ghana

Olivia Aguriboba Akanbelum[1], Israel K. Dzomeku[2], Julius Yirzagla[3]*, Abdul-Karim Alhassan[3], John Bokaligidi Lambon[4], Abdul-Wahab M. Imoro[5], Kwadwo Gyasi Santo[6]

[1]St Vincent College of Education, Yendi, Ghana
[2]University for Development Studies, Tamale, Ghana
[3]CSIR-SARI, P. O., Nyankpala, Ghana
[4]CSIR-Head Office, Accra, Ghana
[5]C.K. Tedam University of Technology and Applied Sciences, Navrongo, Ghana
[6]University of Energy and Natural Resources, Sunyani, Ghana
Email: *yirzagla@yahoo.com

How to cite this paper: Akanbelum, O.A., Dzomeku, I.K., Yirzagla, J., Alhassan, A.-K., Lambon, J.B., Imoro, A.-W.M. and Santo, K.G. (2023) Maize-Soybean Integration for Managing *Striga hermonthica* (Del.) Benth in the Sudan Savannah Zone of Ghana. *American Journal of Plant Sciences*, **14**, 1043-1060.
https://doi.org/10.4236/ajps.2023.149071

Received: July 17, 2023
Accepted: September 24, 2023
Published: September 27, 2023

Abstract

Field experiments were conducted at Gore near Zebila in Bawku West District of the Upper East Region of Ghana during the 2015 and 2016 cropping season on four *Striga* tolerant maize varieties in maize/soybean integration alongside maize monocrop as a means of managing the devastating effects of *Striga*. The study determined the relative *Striga* tolerance of the maize varieties in terms of yield and yield components, as well as the most effective intercrop for the reduction of *Striga* seed bank. The treatment differences were not significant ($p < 0.05$) in affecting plant height, plant population, leaf area index (LAI), *Striga* count and *Striga* biomass. Similarly, yield components of maize such as height of cob attachment, cob length, cob weight, 100 seed weight, grain yield, as well as straw weight were not significantly affected by the treatments. There was no relativity of *Striga* stress tolerance in terms of yield and yield components of the four maize varieties. All the entries efficiently tolerated the biotic stress of *Striga* and further supported growth and grain yield equally. There was reduced *S. hermonthica* seed bank production in the soil in both cropping systems. The four maize varieties are proven tolerant materials to *Striga* infestation and are therefore recommended for long-term *Striga* seed bank depletion in the study area.

Keywords

Striga hermonthica, Seed Bank, Afayak, Suicidal Germination

1. Introduction

Maize [*Zea mays* L.] is a cereal crop that is cultivated world-wide in a wide range of agro ecological zones. It was introduced into Africa in the 1500s and has since become one of Africa's dominant food crops. It is the most important cereal crop of the world, grown in irrigated and rain-fed areas [1]. Maize is considered a very significant cereal crop and probably has the greatest yield potential among crops in sub-Saharan Africa (SSA) as it occupies more than 50% of aggregate land given entirely to crop production [2]. Due to the ease of processing, high yield potential, and low cost of production, maize is considered very significant in ameliorating food insecurity in SSA [3]. In industrialized countries, maize is largely used as livestock feed and as a raw material for industrial product. According to [4], maize is the second most important commodity crop in Ghana after cocoa accounting for more than 45% of the agricultural cash income among smallholder farmers in the country [5]. It is the most widely consumed staple food with increasing production since 1965 [6] and is a major source of food for both urban and rural dwellers in Ghana. It forms part of everyday diet and also serves as an important raw material for animal feed. Maize consumption accounts for more than one-quarter of calories consumed, about double that of the second crop, cassava [7]. Maize consumption is projected to increase due to population growth. Increased rate of population growth coupled with urbanization, poultry keeping and fish farming have contributed to increased demand for maize in Ghana. The poultry industry's demand for maize, used as feed, was estimated to have grown by 10 percent annually between 2000 and 2009. About three-quarters of maize consumption is from own production, suggesting maize has limited appeal as a cash crop [8]. This is set to change as Ghana's Planting for Food and Jobs (PFJ) initiative, launched in 2017, prioritizes maize seed and fertilizer distribution and encourages market participation by smallholders [9].

Despite the importance of maize, there are several biotic and abiotic constraints limiting its production. These include the parasitic weed; *Striga*, causing food scarcity faced by 100 million people, thereby increasing economic challenges that amount to more than 10 billion USD losses yearly [10] [11]. In the Guinea Savannah zone of Ghana, a major threat to maize production is root parasitic weed of the genus *Striga* in the family *Orobanchaceae*, [12]. Itis endemic in the zone causing poor grain yield to poor resource maize farmers, [13]. The threat is aggravated by climate change with concomitant negative effects on food security and the general livelihood of the people in this part of the country. *Striga* infestation flourishes in conditions characterized by low soil fertility, and continuous monocropping with cereals. Crops such as soybean act as false hosts and trap crops. Trap crops stimulate the *Striga* seeds to germinate but the *Striga* seedling cannot successfully attach its roots to the roots of the trap crops in order to feed and hence *Striga* dies in the process. Crop losses due to *Striga* cause yield reduction of up to 100%, excluding the high effect on the agricultural product [14] [15]. *S. hermonthica*, generally known as purple witch weed is a challenging weed to crops in SSA [16]. It is a hemiparasite of grasses belonging to the family *Orobanchaceae*. This species of *Striga* causes a destructive harvest reduction annually and attacks crops, such as sorghum, sugarcane, finger millet, pearl millet, rice, cowpea, and maize, causing a decimating effect on the yield of crops [17]. This parasitic weed depends solely on its host plant for nutrients and growth, which results in substantial damage to crops, such as chlorosis, wilted silk, thin stalk, reduced height, and total loss of crops in farmlands with high invasion [18] [19]. The invasion of this parasite is prominent in places with characteristic poor soils and intense cultivation with poor management practices [16].

Several methods, such as the traditional, chemical, and biological methods, and host resistance have been used to combat this parasitic weed. Traditional practices including hand pulling, crop rotation, intercropping, trap or catch crop planting, push-pull technology, and soil fertility improvement (nitrogen fertilization) are used. Chemical management practices, for example, weedicide (imazapyr), genetic control, resistant crop varieties, suicidal germination, biological control agents, such as fungi and bacteria, and certain insects have been used [20] [21] [22]. None of these methods have been able to eradicate the incidence of *S. hermonthica* alone, however, the incorporation of two or more methods have proven effective in eradicating it completely. The adverse effect of chemical compounds on soils has led to increased use of microbial inoculants, which are advantageous to plant development by enhancing its secretion of plant growth hormones, increasing nutrient uptake, and reducing plant pathogens [23]. In their efforts to help farmers manage *Striga* infestation on their farms, the Crops Research Institute (CRI) and the Savannah Agricultural Research Institute (SARI), both of the Council for Scientific and Industrial Research of Ghana have developed a range of maize varieties purported to be tolerant/resistant to *S. hermonthica*. SARI also released the soybean variety "Afayak" (*i.e.* TGX 1845-5E) targeted for use as *Striga* trap crop that could accelerate *Striga* germination with the long-term effect of depletion of *Striga* seed banks in *Striga* endemic fields [24]. However, there is no report on the adaptive and relative performance of these varieties in integration with the trap crop (Afayak) in the Guinea and Sudan savannah in Ghana, for which they have been developed. The purpose of this study was to evaluate the effects of integrating soybean (Afayak)-maize on *Striga* management in the Guinea Savannah zone of Ghana. Intercropping *Striga* tolerant maize with soybean will give farmers better and cheaper way to control *Striga hermonthica*. In Ghana intercropping legumes such as soybean with cereals is a common practice by farmers and the practice has been reported to reduce *Striga* seed bank in *Striga* endemic locations of Northern Ghana [25]. The objective of this study was therefore to evaluate the effectiveness of maize-soybean integration in managing the effects of *Striga hermonthica* in the study area. Specifically, the objectives were to:

1) Assess *Striga* tolerance of the four maize varieties in terms of maize-soybeanyield and yield components.

2) Identify the most effective maize variety in combination with the soybean (Afayak) for the reduction of *Striga* seed bank.

2. Materials and Methods

2.1. Experimental Site and Design

The trials were conducted at Gore near Binaba, in Zebila of Bawku West District of the Upper East Region of Ghana on a farmer's farm in the 2015 and 2016cropping seasons. This area was chosen because it is heavenly infested by *Striga hermonhtica*. The experimental site was located on latitude 10˚48"N and 0˚28"W and longitude 0˚33'1"W (IFDC personal communication 2015). The vegetation at the site is savannah grassland which is characterized by shrubs and few scattered trees. The climate is warm, semi-arid with a total average annual rainfall of about 1100 mm [26]. There is a short rainy season followed by a long dry season which is between October and April. The climatic condition is characterized by two air masses, the North East trade winds usually dry and the South West Monsoon winds. The trials were 2 × 4 factorial laid out in Randomized Complete Block Design (RCBD) with three replications. The eight treatments consisted of four drought and *Striga* tolerant maize (Aburohemaa, Omankwa, Bihilifa, and Wang dataa) varieties planted with and without the recommended soybean variety (Afayak) (**Table 1**). A replication was made up of eight plots separated by 0.5 m with the alley between blocks and replications being 1.0 m and 2.0 m respectively. Plot-size of 10 m × 10 m was used with total experimental area of 2780.50 m^2 (67.0 m × 41.5 m).

2.2. Management Practices

During the major cropping seasons (2015 and 2016), the experimental area was ploughed, harrowed and ridged (in July) using bullock-drawn implements. Lining and pegging were done to establish the plots for the treatments. The ridges

Table 1. Entries for researcher-managed trial in 2015 and 2016.

Treatment	Maize Variety	Soybean (Inoculated)	Intercrop/Treatment
1	Bihilifa	Soybean (Afayak)	Bihilifa/Soyabean
2	Bihilifa	-	Bihilifa Monocrop
3	Wang data	Soybean	Wang Data/Soybean
4	Wang data	-	Wang Data Monocrop
5	Omankwa	Soybean	Omankwa/Soybean
6	Omankwa	-	Omankwa Monocrop
7	Aburohemaa	Soybean	Aburohemaa/Soybean
8	Aburohemaa	-	Aburohemaa Monocrop

were separated by a distance of 1 m. At planting, three seeds per hill were sown at an intra-row spacing of 50 cm inter-row spacing of 75 cm. The three seeds per hill were later thinned to one plant per stand. Weed control was done by hoeing twice at 2 WAP and 5 WAP which coincided with fertilization. Fertilizer grade NPK 15-15-15 was applied at 15 kg N/ha, 15 kg P_2O_5/ha and 15 kg K_2O/ha at 2 weeks after planting (WAP) and 5 WAP; (half N was used for top dressing). Fertilizer application targeted maize hills only.

2.3. Data Collection

2.3.1. Soil Analyses

The soil characteristics were determined in order to know nutrients status and *Striga* load of the experimental site before application of the fertilizers. Three composite soil samples were taken for determination of physical and chemical properties. At the beginning of the experiment (in 2015), 15 samples were randomly collected by using an auger and composited. Then, soil samples were also taken from each treatment at harvesting (in 2016). The samples were air dried, crushed with mortar and sieved to pass through 2 mm mesh. The characteristics analyzed for included; Soil pH, organic matter, total nitrogen, exchangeable calcium, magnesium, potassium, sodium and effective cation exchange capacity, and bray No. 2 extractable phosphorus and potassium. The air-dried soil samples were ground at the laboratory and sieved through a 2 mm sieve. Soil pH was determined using a glass electrode (pH meter) in a soil ratio of 1:2.5 as reported by [27] and [28]. Soil organic matter was determined by the wet combustion method [29]. Percentage total nitrogen was determined by the micro Kjeldahl-technique [27]. The available phosphorus was extracted by the Bray method and determined colorimetrically [30]. Potassium was determined by flame emission photometry [27]. The exchangeable cations calcium, magnesium, potassium and sodium were determined as recommended by [27] using EDTA Titration after extraction with 0.1N Ammonium Acetate at pH 7. Effective Cation Exchange Capacity (ECEC) was calculated as the sum of the exchangeable bases and exchangeable acidity [27].

2.3.2. Plant Height

Data were collected on plant height at two weeks interval from 5 WAP to 13 WAP, on five tagged plants in the middle part of each plot. Maize height was determined by measuring from the ground level of the stem to the last emerged leaf using a tape measure.

2.3.3. Number of Leaves of Maize Plants

Maize and soybean leaves were counted on the five (5) tagged plants in each plot. Leaves were counted on each plant starting from the first leaf from the base of the plant to last emerged leaf. Maize leaves were counted 7 and 9 WAP.

2.3.4. Leaf Area Index (LAI)

Leaf area index of maize was determined once in the 9 WAP and was taken by measuring the length and width of three (3) leaves from the lower part of the plant, in the middle and at the top on each of the 5 tagged plants in each plot. Each leaf area index was estimated using this formula; Leaf area index = 0.75 × LL × LW; where 0.75 is the constant for maize, LL = leaf length, LW = leaf width.

2.3.5. Length of Cob, Height of Cob Attachment and Cob Weight

Height of cob attachment was done by measuring from the base of the plant to the point where the cob attaches to the maize stalk using tape measure. Similarly, a tape measure was used to measure the length of cobs from the point at which the cob attaches to plant to the tip of the cob before the maize was then harvested. Five (5) cobs were selected from the five (5) tagged plants in each treatment and weighed and their averages recorded. An electronic scale was used to determine the cob weight at harvest.

2.3.6. *Striga* Shoot Count

Striga seedlings were counted as they emerged in every two (2) weeks interval, starting from the 7 to 16 WAP. At each *Striga* count, the plants of the parasite were uprooted.

2.3.7. Harvesting

Maize grain and stover were harvested at maturity from a net area of each treatment demarcated after leaving out two rows on each side of the plot and the first two lines of maize/soybean plants on each row to minimize the edge effect. The entire plants on the plots were harvested by cutting at the ground level. Maize cobs were manually separated from the stover, sun-dried, and packed in sacks before threshing. Weights of maize grain yield per plot were taken using a weighing scale. *Striga* count and leave count were transformed using the square root ($\sqrt{n+0.5}$) transformation.

2.3.8. Formulas Used

$$\text{Adjusted yield} = \text{yield measured} \times \frac{100 - \text{sample moisture content}}{100 - \text{s tan dard moisture content}} \quad (1)$$

$$\text{Yield,}\left(\text{kg/ha}\right) = \text{yield measured} \times \frac{10000}{69.12} \quad (2)$$

$$\text{Harvest index}\left(\text{HI}\right)\% = \frac{\text{grain yield, kg/ha}}{\text{total biomass, kg/ha}} \times 100\% \quad (3)$$

$$\text{Transformed} = \sqrt{n+0.5} \quad (4)$$

Postharvest soil samples were also taken for analysis of *Striga* seed bank as a result of soybean-maize intercropping systems.

2.3.9. Analyses of Data

The data were statistically analyzed using the Analysis of variance (ANOVA) for randomized complete block design (RCBD) and the Least Significant Difference (LSD) was used for mean separation ($P \leq 0.05$) following the procedure of Steel and Torrie (1980). Count data were transformed using $\sqrt{x+0.5}$ before subjecting them to analysis of variance.

3. Results and Discussion

3.1. Plant Height of Maize

Plant height of the four maize varieties with or without integration with soybean was not significantly (p > 0.05) different for both 2015 and 2016 cropping seasons at the measured growth stages on all sampling days (**Table 2**). Optimum plant height was attained at 9 WAP, but slight increases were generally observed up to 13 WAP during which the results of plant height, ranged from 145.9 cm (Omankwah) to 161.9 cm (Bihilifa), suggesting that the expected and biotic stress imposed by *S. hermonthica* did not suppress maize height. The maize varieties were bred for drought and *Striga* tolerance, and this could be the reason for the observed expression of this trait. It could also be the genetic makeup of the varieties used for the study. This observation is consistent with reports by [31] who did not find any significant difference in plant height of maize under mono-cropping and intercropping with sugar-beet and groundnuts. Thus, the treatment differences were not significant in affecting maize plant height in the current study implying that presence of *Striga* in the experimental plots did not affect height of maize. Although, *Striga* reduces cell elongation as it takes photosynthesis away from the maize leading to shorter maize internodes and stunted growth, yet these symptoms were not observed on the plants in this study. Thus, *Striga* did not have negative effect on the crops. This agrees with [32] [33] [34], who reported that intercropping sorghum and maize with legume crop especially *Desmodium spp*, significantly enhanced both plant height and grain yield in maize.

Table 2. Plant height of maize during the 2015 and 2016 cropping seasons.

Treatment	Plant Height (cm) Weeks After Planting (WAP)							
	5		7		9		13	
	2015	2016	2015	2016	2015	2016	2015	2016
Wang Data	42.2	43.3	94.8	93.4	153.8	150.2	154.9	156.1
Aburohemaa/Soya	41.6	43.2	94.1	92.4	155.7	153.9	157.1	158.2
Omankwa/Soya	45.8	44.1	102.8	100.2	156.5	154.2	159.4	158.1
Wang data/Soya	38.8	40.1	143.9	145.2	148.7	150.1	153.3	155.2
Bihilifa/Soya	38.9	40.2	88.6	90.1	155.1	156.9	155.9	154.8
Aburohemaa	38.6	38.2	88.5	87.2	154.1	157.2	154.1	158.1
Bihilifa	43.9	44.1	98.9	99.8	158.7	157.8	161.9	159.8
Omankwa	41.9	42.1	90.8	92.1	145.5	144.6	145.9	147.1
Grand Mean	**41.46**	**41.91**	**112.83**	**100.1**	**153.51**	**153.11**	**155.31**	**155.92**
L.S.D (0.05)	**9.11**	**10.2**	**61.67**	**63.50**	**15.62**	**15.62**	**15.55**	**15.55**
CV (%)	**12.6**	**14.1**	**25.1**	**15.1**	**5.8**	**5.8**	**5.7**	**5.7**

3.2. Plant Population of Maize at 9 WAP and at Harvest

Similar to plant height, plant population of the four maize varieties with or without integration with soybean was not significantly ($p > 0.05$) different for both 2015 and 2016 cropping seasons at the measured growth stages on all sampling days (**Table 3**). Results of plant population per unit area at harvest showed no significant effect by treatments. It was observed from field inspection that in plant stand of maize, all the maize varieties used germinated well. Also, it means birds and rodents did not remove the seeds/seedlings at the initial stages. This result was not in agreement with the findings of [33] who reported that both plan population density and variety showed significant difference in final plant population of maize. The differences in the two studies might be as a result of genetic materials used or might also be that, some of the seeds used in the study of [35] were not viable. The eight treatments did not show significant ($p < 0.05$) difference in leave area index (LAI). LAI ranged from 5.0 cm to 5.6 cm. In a similar study, [31] also did not find any significant differences in LAI between maize monocrop and maize intercropped with sugar beans or groundnuts. These findings are consistent with results of [36] who did not find any significant differences in LAI between sole maize and maize intercropped with cowpea. The leaf area (LA) describes the size of the assimilatory apparatus of a plant stand and is the main factor that determines the rate of dry matter production in a closed stand. It also reflects differences in productive efficiency between crop varieties [37]. The non-significant difference of leaf area observed in the present study could be due to the genetic makeup of the varieties, environmental conditions, and cropping systems used. This is in line with [38] that these four maize varieties are resistant/ tolerant to *S. hermonthica* infestation.

Table 3. Plant population of maize at 9 WAP and at harvest and LAI 9 WAP during the 2015 and 2016 cropping season.

S/NO.	Treatment	Plant Stand /Ha		LAI (cm^2)
		9 WAP	**harvest**	**9WAP**
1	Wang Data	124,933	124,933	5.0
2	Aburohemaa/Soya	124,800	124,800	5.5
3	Omankwa/Soya	126,933	126,933	5.6
4	Wang dataa/Soya	127,067	127,067	5.6
5	Bihilifa/ Soya	121,733	121,733	5.3
6	Aburohemaa	124,933	124,933	5.1
7	Bihilifa	127,067	127,067	5.6
8	Omankwa	126,133	126,133	5.1
9	**Grand Mean**	125,450	125,450	**5.3**
10	**L.S.D (0.05)**	4956.4	4956.4	**1.00**
11	**CV (%)**	2.3	2.3	**10.7**

3.3. *Striga* Count

Statistically, no difference ($p > 0.05$) was observed on the impact of the eight treatments on *Striga* count at 7 WAP. Except for the low *Striga* emergence of 7 plants/plot under Bihilifa/Soybean, similar *Striga* count was observed across the cropping systems. Wang dataa supported the highest *Striga* emergence of 52 plants/plot and the intercrop Bihilifa/Soybean the lowest. *Striga* emergence was pronounced in sole Bihilifa and Omankwa/Soybean in the 13 WAP (**Table 4**). The high *Striga* numbers in some of the treatments might be attributed to high initial *Striga* seed bank at the site. This might also be due to variation in soil fertility where some plots might have low soil fertility. *Striga* thrives well in less fertile soils as supported by [39] who reported that one of the witch weed most contributing factors for development is low soil fertility and cropping systems in SSA with no external inputs. Because *Striga* is an obligate parasite, interactions between *Striga* and its host plays a crucial role in survival of the parasite, if this interaction was disrupted, it might be a beneficial approach for integrated management of this parasite. Differences in production of *Striga* stimulants are known to occur between crop cultivars [40], and that may be the cause for reduced *Striga* emergence in some of the treatments in the current study. The low number of *Striga* plants in some of the treatments could be due to their ability to show some levels of resistance to the parasitic weed, which reduced the extent of severity of *Striga* infestation. This is supported by a baseline study carried out by [41] looking at the extent of *Striga* infestation on maize grown in Western and Nyanza provinces. It was also observed that, some maize plots intercropped with soybean resulted in high numbers of *Striga* emergence count than some of the maize plots that were sole cropped. This was probably because of the soybean variety (Afayak) which has the ability to cause germination of *Striga* seeds but do

Table 4. *Striga* count at 7 and 13 WAP for the 2015 and 2016 cropping season.

Treatments	*Striga* Count ($\sqrt{x+0.5}$)		*Striga* Fresh Weight (g/ha)		
	7 WAP	13 WAP	7 WAP	13 WAP	16 WAP
Wang Data	7.18	12.6	203.6	333	50.1
Aburohemaa/Soybean	6.03	15.6	137.2	501	57.1
Omankwa/Soybean	4.60	18.0	52.3	957	43.8
Wang dataa/Soybean	5.16	13.2	109.8	377	63.4
Bihilifa/Soybean	2.59	14.4	51.1	465	64.2
Aburohemaa	3.44	18.3	39.6	746	60.0
Bihilifa	3.89	21.2	53.5	1080	74.1
Omankwa	5.11	11.0	113.8	247	40.7
Grand Mean	**4.75**	**15.5**	**95.1**	**588**	**56.7**
L.S.D (0.05)	**3.886**	**10.61**	**158.43**	**920.2**	**36.43**
CV (%)	**46.7**	**40.3**	**0.42**	**0.464**	**0.552**

not support it subsequent growth and development. This present study is not in line with [42] who reported that the maize varieties grown in Ghana under intercropping supported fewer *Striga* infestation compared to those grown in sole cropping.

At 9 and 16 WAP, *Striga* count varied with treatment ($p < 0.05$) such that Omankwa/Soybean in 9 WAP recorded the highest *Striga* emergence but similar to Wang dataa/Soybean (**Figure 1**). Maize monocrops and intercrops of Aburohemaa/Soybean and Bihilifa/Soybean recorded similar emergence of *Striga* seedlings. It was not clear at this stage which cropping system was outstanding for enhanced or reduced *Striga* seedling emergence. Wang dataa/Soybean slightly had highest percentage (5.3%) *Striga* emergence in the 16 WAP, but not significantly different from Aburohemaa/Soybean (4.9%) and Bihilifa/Soybean (4.8%), sole Aburohemaa (4.5%) and sole Bihilifa (4.5%) which all supported *Striga* emergence. Sole Wang dataa and Omankwa/Soybean equally supported *Striga* emergence with Sole Omankwa recording the lowest *Striga* emergence in the 16 WAP.

It was interesting to note that, the *Striga with* higher numbers in germination or emergence did not show any negative effect on the crops which might be due to maize resistance/tolerance level to the witch weed. On the other hand, some plots with sole maize exhibited resistance to *S. hermonthica* by supporting the lowest number of *Striga* plants germination unlike some of the maize-soybean intercropped with greatest number of *Striga* emergence. Possible reason for this could be due to *Striga* seeds which did not germinate because of absence of chemical stimulant. Also, the *Striga* seeds will not germinate unless they have been conditioned, that is., are no longer dormant and are exposed to the right environmental conditions for germination. This result agrees with [43] who reported that nitrogen reduced the severity of *S. hermonthica*. It also agrees with the findings of [44] who reported that maize resistance to the *Striga* is the eventual expression of a series of interactive events between the parasite and its hosts. Similarly, [45] reported that resistant crop genotypes support significantly fewer

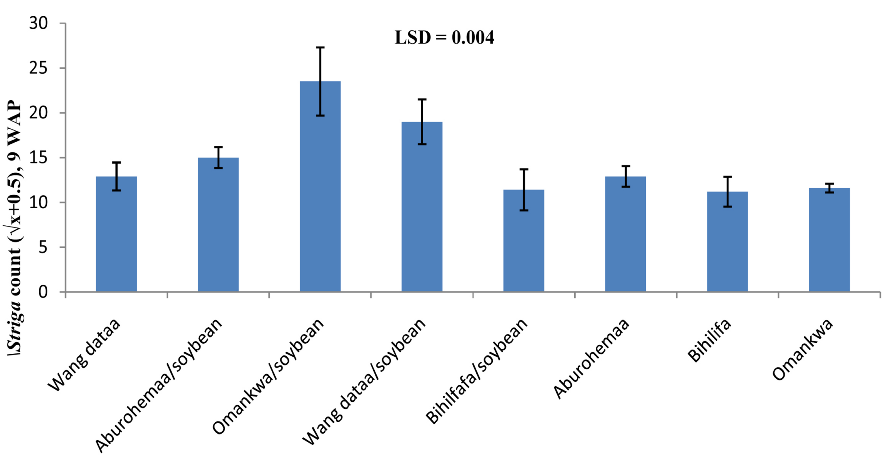

Figure 1. *Striga* count at 9 WAP during the 2015 and 2016 cropping season.

emerged of *S. hermonthica* plants. This study confirms the findings of [44] who reported that resistant varieties effectively reduce the *Striga* count with or without other options, indicating that host plant resistance alone could be used in situations where integration of all options is impossible.

3.4. *Striga* Biomass Production

Striga biomass production at 7, 13, and 16 WAP was not significantly different (P > 0.05) among treatments (**Table 5**). The highest biomass produced was recorded in the 13 WAP during which sole Bihilifa produced (422 kg/ha), Omankwa/soybean (360 kg/ha), and Aburohemaa (285 kg/ha). The lowest biomass (17.0 g/ha) was produced in the 16 WAP by Omankwa (**Table 5**). Greater number of *Striga* biomass was observed in sole Wang dataa, Wang data intercropped with soybean, sole Bihilifa, and sole Omankwa. The greater *Striga* biomass might be due to initial *Striga* seed bank variations at the site and the more the seed bank the more seeds will germinate with suitable hosts, hence, translating to greater *Striga* biomass. The greater *Striga* biomass might also be due to high crop density with high host and soybean root surface area. According to [46], the level of *Striga* biomass on a host influences host productivity, but added that the relationship is non-linear; that is a point is reached where host grain production is independent of parasite biomass. The greater *Striga* biomass in some of the plots could also be due to variation in soil fertility status of the site as *Striga* thrives well in soils with poor fertility. The reduction in *Striga* biomass in some of the treatments could be due to reduction in number of *Striga* plants emerged which might also be due to the differences in the initial *Striga* seed bank, and soil fertility. Here again, though *Striga* emerged in all the plots, yet treatments did

Table 5. *Striga* biomass production at 7, 13, 16 WAP during the 2015 and 2016 cropping season.

Treatment	*Striga* Biomass (g)		
	7 WAP	13 WAP	16 WAP
Wang Data	83.7	125	20.6
Aburohemaa/Soybean	53.4	192	23.7
Omankwa/Soybean	19.4	360	19.7
Wang Dataa/Soybean	48.0	148	26.4
Bihilifa/Soybean	24.7	181	28.6
Aburohemaa	15.1	285	25.0
Bihilifa	23.6	422	32.6
Omankwa	45.5	98.	17.0
Grand Mean	**39.2**	**226**	**24.2**
L.S.D (0.05)	**62.04**	**352.3**	**13.92**
CV (%)	**20.4**	**18.9**	

not have any *Striga* symptoms. It implied that these treatments had more tolerance level to *S. hermonthica* infestation. This result agrees with [46] who observed that highest *Striga* infestation did not necessarily translate into yield reduction. Generally, the results indicated reduction of *Striga* biomass in intercrop maize and increase for the sole maize which might be due to the shading effects in the intercrop. This observation is in line with [47] who reported that *striga* biomass reduction may be due to shading effects from the maize-soybean intercropped plots. In a similar work, [48] observed that intercropping reduced the *Striga* biomass by 25% - 65% and 10% - 80% during the first and second season respectively. In fresh weight of *Striga*, sole Wang Dataa had 46 g/ha, followed by Omankwa/soybean (36 g/ha) similar to Aburohemaa/soybean (36 g/ha) whilst sole Aburohemaa had the least (12 g/ha). The dry weight of *Striga* followed a similar trend in the treatments in fresh weight of *Striga*. It still means that those treatments were highly tolerant to *Striga* negative effects because crop growth was not affected.

3.5. Percent Reduction in *Striga* Seed Bank

Percent reductions in soil *Striga* seed bank varied across treatments ($p < 0.05$), ranging from 30.3% (Aburohemaa) to 52.8% (sole Omankwa) (**Figure 2**). Though, *S. hermonthica* seed bank was high at the initial stage, yet at the post-harvest *S. hermonthica* seed bank reduced between 5% - 26% across all the treatments. The high seed bank load before planting or harvest might be due to the level of *S. hermonthica* plants that flowered and produced seeds previously. This is in line with [49] who reported that *Striga* seed bank is determined by the level of *Striga* plants that flower and produce seeds, coupled with lack of suicidal germination. The high seed bank load may also be favoured by mono cropping because mono cropping of cereal hosts with little or no specific measures against *Striga* would lead to huge amounts of seeds accumulating in the seed bank.

The decreased number of *S. hermonthica* seed bank in the maize/soybean intercrop may be attributed to the suicidal germination caused by the germination

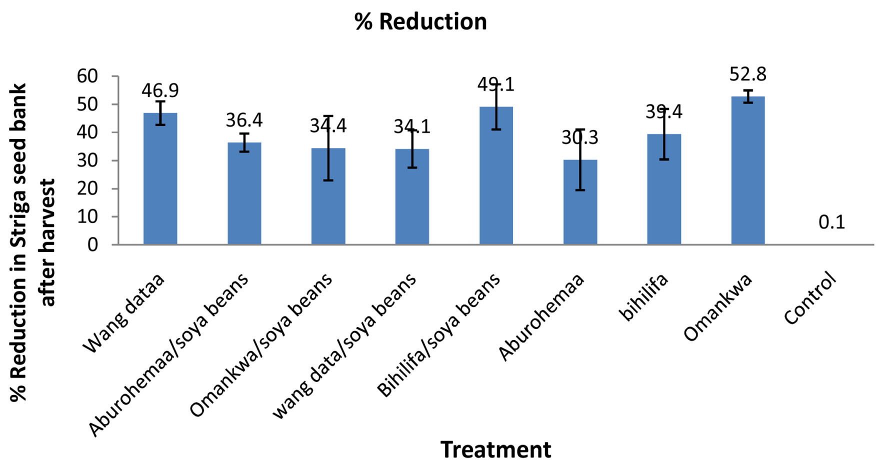

Figure 2. Percent reduction in *Striga* seed bank after harvest.

stimulant produced by the soybean (Afayak) roots. This is in line with report by [50] that the use of trap crop such as soybean triggers suicidal germination of *Striga* and therefore reduces the *Striga hermonthica* seed bank in the soil when intercropped with maize. In addition to being a trap crop, soybean provides shade which smothers the *Striga* thereby reducing its vigour. This result indicates that these *Striga* tolerant maize varieties when planted sole can help reduce *Striga* seed bank in *Striga* endemic areas. The reduced *S. hermonthica* seed bank in the soil in both cropping systems during the cropping seasons means a reduced potential for overall flower and capsule production and, consequently, a reduced capacity of increasing the *S. hermonthica* seed bank in the soil. The *Striga* infestation did not affect yield significantly. This result indicates that these *Striga* tolerant maize varieties when planted sole can help reduce *Striga* seed bank in *Striga* endemic areas in the near future, as more will germinate whose growth and development are not supported. The reduced *S. hermonthica* seed bank in the soil in both cropping systems means a reduced potential for overall flower and capsule production and, consequently, a reduced capacity of increasing the *S. hermonthica* seed bank in the soil. An effective management approach for *Striga* should therefore aim, among other things, to reduce and eventually deplete the soil seed bank.

3.6. Cob Weight, Grain Yield, Harvest Index

These parameters were not statistically affected by treatments. This could be so as a result of inherent ability of the four maize varieties in performance in terms of yield and yield components. It could also be as a result of the low fertilizer application, which was recommended so that fertilizer will not have impact on *Striga* emergence. *In-vitro* experiments have shown that nitrogen in form of ammonium or nitrate inhibits germination and extension of radicle length of *Striga* as a result of inhibition of production of chemical stimulants by host plants [51]. Studies have also shown a toxic effect of nitrogen on *Striga* development following attachment [52]. This research was targeting the cheapest *Striga* control method for resource poor farmers who cannot afford fertilizer for its control. It was therefore important not to make fertilizer to suppress the parasite in order to see the actual effect of Afayak as well as the *Striga* resistant maize varieties. Notwithstanding the insignificance across treatments, the maize varieties in integration with and without Afayak demonstrated potentials in yield in *Striga* endemic area, with sole Wang dataa recording the highest grain yield (1067 kg/ha) and Aburohemaa the lowest (153 kg/ha).

4. Conclusion

The results showed that, there was no relativity of *Striga* stress tolerance in terms of yield and yield components of the four maize varieties. All the entries efficiently tolerated the biotic stress of *Striga* and further supported growth and grain yield equally. There was reduced *S. hermonthica* seed bank production in the soil in both cropping systems. This has the positive implication of reducing the capacity of the *S. hermonthica* seed bank production in the soil. The performance of the maize varieties in integration with and without Afayak demonstrated a potential in yield in *Striga* endemic areas.

5. Recommendations

Considering the results of this trial, it is recommended that resource-poor farmers in *Striga* endemic areas can use the four tested *Striga* tolerant maize varieties (Omankwa, Wang dataa, Aburohemaa, and Bihilifa) mono crop or intercrop with Afayak to manage *Striga hermonthica*. The four *Striga* tolerant maize varieties (Omankwa, Wang dataa, Aburohemaa, and Bihilifa) can be planted sole or intercrop with Afayak to deplete *Striga* seed bank in *Striga* endemic areas in the Guinea Savannah zone of Ghana. However, it must be noted that to avoid replenishment of *Striga* seed bank in the soil, farmers should combine this method with cultural practices such as hand pulling or weeding of emerged *Striga* seedlings.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Hussan, W.U., Haqqani, A.M. and Shafeeq, S. (2003) Knocking the Doors of Balochistan for Fodder Crops Production. *Agridigest—An In House Journal*, **23**, 24-30.

[2] Gasura, E., Setimela, P., Mabasa, S., Rwafa, R., Kageler, S. and Nyakurwa, C. (2019) Response of IITA Maize Inbred Lines Bred for *Striga hermonthica* Resistance to *Striga asiatica* and Associated Resistance Mechanisms in Southern Africa. *Euphytica*, **215**, Article No. 151. https://doi.org/10.1007/s10681-019-2467-5

[3] Stanley, A.E., Menkir, A., Ifie, B., Paterne, A.A., Unachukwu, N.N., Meseka, S., Mengesha, W.A., Bossey, B., Kwadwo, O., Tongoona, P.B., Oladejo, O., Sneller, C. and Gedil, M. (2021) Association Analysis for Resistance to *Striga hermonthica* in Diverse Tropical Maize Inbred Lines. *Scientific Reports*, **11**, Article No. 24193. https://doi.org/10.1038/s41598-021-03566-4

[4] Akramov, K. and Malek, M. (2012) Analyzing Profitability of Maize, Rice, and Soybean Production in Ghana: Results of PAM and DEA Analysis. International Food Policy Research Institute, Washington DC, Ghana Strategy Support Program (GSSP) GSSP Working Paper No. 0028.

[5] IITA (1979) Selected Methods for Soil and Plant Analysis. Manual Series No. 1. IITA, Ibadan.

[6] Food and Agriculture Organisation Statistical Databases (2008) FAOSTAT: Agriculture Data. http://faostat.fao.org

[7] GSS (Ghana Statistical Services) (2018) Ghana Living Standards Survey (GLSS7): Poverty Trends in Ghana; 2005-2017. GSS, Accra.

[8] Gage, D., Bangnikon, J., Abeka-Afari, H., Hanif, C., Addaquay, J., Antwi, V. and Hale, A. (2012) The Market for Maize, Rice, Soy, and Warehousing in Northern

Ghana. This Report Was Produced by USAID's Enabling Agricultural Trade (EAT) Project, January, 2012.

[9] Pauw, K. (2021) A Review of the Ghana Planting for Food and Jobs Program: 2017-2020: Implementation, Impact, and Further Analysis. https://doi.org/10.2499/p15738coll2.134353

[10] Dafaallah, A.B., Babiker, A.G.T and Zain El Abdeen, M.H. (2016) Assessment of the Damage Caused by Striga hermonthica (Del.) Benth: On the Performance of Cereals Hosts in Gadarif State, Eastern Sudan, University of Khartoum Agriculture. *Journal of Agricultural Sciences*, **24**, 99-121.

[11] Oula, D.A., Nyongesah, J.M., Odhiambo, G. and Wagai, S. (2020) The Effectiveness of Local Strains of *Fusarium oxysporium* f. Sp. *Striga*e to Control *Striga hermonthica* on Local Maize in Western Kenya. *Food Science & Nutrition*, **8**, 4352-4360. https://doi.org/10.1002/fsn3.1732

[12] Olmstead, R.G., DePamphilis, C.W., Wolf, A.D., Yound, N.D., Elisons, W.J. and Reeves, P.A. (2001) Disintegration of the Scrophulariaceae. *American Journal of Botany*, **88**, 348-361. https://doi.org/10.2307/2657024

[13] Gressel, J., Hanafi, A. and Head, G. (2004) Major Heretofore Intractable Biotic Constraints to African Food Security That May Be Amenable to Novel Biotechnological Solutions. *Crop Protection*, **23**, 661-689. https://doi.org/10.1016/j.cropro.2003.11.014

[14] Akaogu, I.C., Badu-Apraku, B., Tongoona, P., Ceballos, H., Gracen, V., Offei, S.K. and Dzidzienyo, D. (2019) Inheritance of *Striga hermonthica* Adaptive Traits in an Early-Maturing White Maize Inbred Line Containing Resistance Genes from *Zea diploperennis*. *Plant Breeding*, **138**, 546-552. https://doi.org/10.1111/pbr.12707

[15] Kamara, A.Y., Menkir, A., Chikoye, D., Tofa, A.I., Fagge, A.A., Dahiru, R., Solomon, R., Ademulegun, T., Omoigui, L., Aliyu, K.T. and Kamai, N. (2020) Mitigating *Striga hermonthica* Parasitism and Damage in Maize Using Soybean Rotation, Nitrogen Application, and *Striga*-Resistant Varieties in the Nigerian Savannas. *Experimental Agriculture*, **56**, 620-632. https://doi.org/10.1017/S0014479720000198

[16] Gowda, M., Makumbi, D., Das, B., Nyaga, C., Kosgei, T., Crossa, J., Beyene, Y., Montesinos-López, O.A., Olsen, M.S. and Prasanna, B.M. (2021) Genetic Dissection of *Striga hermonthica* (Del.) Benth. Resistance via Genome-Wide Association and Genomic Prediction in Tropical Maize Germplasm. *Theoretical and Applied Genetics*, **134**, 941-958. https://doi.org/10.1007/s00122-020-03744-4

[17] Mudereri, B.T., Dube, T., Niassy, S., Kimathi, E., Landmann, T., Khan, Z. and Abdel-Rahman, E.M. (2020) Is It Possible to Discern *Striga* Weed (*Striga hermonthica*) Infestation Levels in Maize Agro-Ecological Systems Using *In-Situ* Spectroscopy? *The International Journal of Applied Earth Observation and Geoinformation*, **85**, Article ID: 102008. https://doi.org/10.1016/j.jag.2019.102008

[18] Mbuvi, D., Masiga, C., Kuria, E., Masanga, J., Wamalwa, M., Mohamed, A., Odeny, D., Hamza, N., Timko, M. and Runo, S. (2017) Novel Sources of Witchweed (*Striga*) Resistance from Wild Sorghum Accessions. *Frontiers in Plant Science*, **8**, Article No. 116. https://doi.org/10.3389/fpls.2017.00116

[19] Menkir, A., Crossa, J., Meseka, S., Bossey, B., Muhyideen, O., Riberio, P.F., Coulibaly, M., Yacoubou, A.M., Olaoye, G. and Haruna, A. (2020) Stacking Tolerance to Drought and Resistance to a Parasitic Weed in Tropical Hybrid Maize for Enhancing Resilience to Stress Combinations. *Frontiers in Plant Science*, **11**, Article No. 166. https://doi.org/10.3389/fpls.2020.00166

[20] Parker, C. and Riches, C.R. (1993) Parasitic Weeds of the World: Biology and Control.

[21] Aly, R. (2007) Conventional and Biotechnological Approaches for Control of Parasitic Weeds. *In Vitro Cellular & Developmental Biology. Plant*, **43**, 304-317. https://doi.org/10.1007/s11627-007-9054-5

[22] Naoura, G., Amos, D.N., Reoungal, D. and Alfred, D. (2021) Assessment of Traditional Methods of Controlling *Striga* on Cultivated Crops in Sudanian Agricultural Zone of Chad. *International Journal of Applied Sciences and Biotechnology*, **9**, 242-249. https://doi.org/10.3126/ijasbt.v9i4.41889

[23] Magallon-Servín, P., Antoun, H., Taktek, S., Bashan, Y. and De-Bashan, L. (2020) The Maize Mycorrhizosphere as a Source for Isolation of *Arbuscular mycorrhizae*-Compatible Phosphate Rock-Solubilizing Bacteria. *Plant and Soil*, **451**, 169-186. https://doi.org/10.1007/s11104-019-04226-3

[24] Denwar, N.N. (1999) Identification of Soyabean Genotypes with Superior Trap-Cropping Capacity for the Control of *Striga hermonthica* in Ghana. Mphil. Thesis, University of Ghana, Accra.

[25] Labrada, R. (2008) Farmer Training on Parasitic Weed Management. In: Labrada, R., Ed., *Progress on Farmer Training in Parasitic Weed Management*, FAO, Rome, 1-5.

[26] MOFA (2015) Agriculture in Ghana Facts and Figures. Accra.

[27] Weil, R., Islam, K.R., Stine, M.A., Gruver, J.B. and Samson-Liebig, S.E. (2003) Estimating Active Carbon for Soil Quality Assessment: A Simplified Method for Laboratory and Field Use. *American Journal of Alternative Agriculture*, **18**, 3-17.

[28] Mclean, E.O. (1982) Soil pH and Lime Requirement. In: Page, A.L., Miller, R.H. and Keaney, D.R., Eds., *Methods of Soil Analysis* (*Number* 9 *Part* 2), American Society of Agronomy, Madison, 199-224.

[29] Walkley, A. and Black, A. (1934) An Examination of the Method for Determining Soil Organic Matter and Proposed Modification of the Chronic Acid Titration Method. *Soil Sciences*, **37**, 29-38. https://doi.org/10.1097/00010694-193401000-00003

[30] Bray, R.H. and Kurtz, L.T. (1945) Determination of Total, Organic, and Available Forms of Phosphorus in Soils. *Soil Science*, **59**, 39-46. https://doi.org/10.1097/00010694-194501000-00006

[31] Twala, M.G. and Ossom, E.M. (2004) Legume-Maize Association Influences Crops Characteristics and Yields. 4*th International Crop Science Congress*, Brisbane, 26 September-1 October 2004.

[32] Khan, Z.R., Picket, J.A., Wadhams, L. and Muyekho, F. (2001) Habitat Management Strategies for the Control of Cereal Stem Borers and *Striga* in Maize in Kenya. *Insect Science and Its Application*, **21**, 375-380. https://doi.org/10.1017/S1742758400008481

[33] Khan, Z.R., Hassanali, A., Overholt, W., Khamis, T.M., Hooper, A.M., Pickett, J.A., Wadhams, L.J. and Woodcock, C.M. (2002) Control of Witchweed *Striga hermonthica* by Intercropping with Desmodium spp., and the Mechanism Defined as Allelopathic. *Journal of Chemical Ecology*, **28**, 1871-1885. https://doi.org/10.1023/A:1020525521180

[34] Khan, Z.R., Pickett, J.A., Wadhams, L.J., Hassanali, A. and Midega, C.A.O. (2006) Combined Control of *Striga hermonthica* and Stemborers by Maize Desmodium spp. Intercrops. *Crop Protection*, **25**, 989-995. https://doi.org/10.1016/j.cropro.2006.01.008

[35] Ahmed, S. and Rao, M.R. (2002) Performance of Maize-Soybean Intercrop Combination in the Tropics: Results of a Multilocation Study. *Field Crop Research*, **5**, 147-161. https://doi.org/10.1016/0378-4290(82)90015-6

[36] Filho, J.M.L. (2000) Physiological Responses of Maize and Cowpea to Intercropping. *Plant Physiology*, **35**, 915-921. https://doi.org/10.1590/S0100-204X2000000500008

[37] Kvet, J., Ondok, J.P., Necas, J. and Jarvis, P.G. (1971) Methods of Growth Analysis. In: Sestak, Z., Catsky, J. and Jarvis, P.G., Eds., *Plant Photosynthetic Production*: *A Manual of Methods*, Dr. W. Junk N.V., The Hague, 343-391.

[38] Adu, G.B., Badu-Apraku, B. and Akromah, R. (2021) Strategies for Selecting Early Maturing Maize Inbred Lines for Hybrid Production under Low Soil Nitrogen and *Striga* Infestation. *Agronomy*, **11**, Article No. 1309. https://doi.org/10.3390/agronomy11071309

[39] Cardoso, C., Ruyter-Spira, C. and Bouwmeester, H.J. (2010) Strigolactones and Root Infestation by Plant-Parasitic *Striga*, Orobanche and Phelipanches pp. *Plant Science*, **180**, 414-420. https://doi.org/10.1016/j.plantsci.2010.11.007

[40] Hesse, D.E., Ejeta, G. and Butler, L.G. (1992) Selecting Sorghum Genotypes Expressing a Quantitative Biosynthetic Trait That Confers Resistance to *Striga*. *Phytochemistry*, **31**, 494-497. https://doi.org/10.1016/0031-9422(92)90023-J

[41] Ndwiga, J., Pittchar, J., Musyoka, P., Nyagol, D., Marechera, G., Omanya, G. and Oluoch, M. (2013) Integrated *Striga* Management in Africa Project. Constraints and Opportunities of Maize Production in Western Kenya: A Baseline Assessment of *Striga* Extent, Severity and Control Technologies. Integrated *Striga* Management in Africa (ISMA). 34 p.

[42] Abdulai, M.S., Denwar, N.N. and Haruna, M. (2006) Combating the Menace of *Striga hermonthica* Infestation: An Integrated Approach Adopted in North-Eastern Ghana. *Journal of Agronomy*, **5**, 617-620. https://doi.org/10.3923/ja.2006.617.620

[43] Lagoke, S.T.O., Parkinson, V. and Agunbiade, R.M. (1991) Parasitic Weeds and Control Methods in Africa. In: Kim, S.K., *et al*., Eds., *Combating Striga in Africa*: *Proceedings of an International Workshop on Striga*, IITA, Ibadan, 3-14.

[44] Ejeta, G. (2007) The *Striga* Scourge in Africa: A Growing Pandemic. In: Ejeta, G. and Gressel, J., Eds., *Integrating New Technologies for Striga Control*: *Towards Ending the Witch-Hunt*, World Scientific, Singapore, 3-16. https://doi.org/10.1142/9789812771506_0001

[45] Doggett, H. (1988) Sorghum. 2nd Edition, Longmans, London.

[46] Gurney, A.L., Press, M.C. and Scholes, J.D. (1999) Infection Time and Density Influence the Response of Sorghum to the Parasitic Angiosperm *Striga hermonthica*. *New Phytologist*, **143**, 573-580. https://doi.org/10.1046/j.1469-8137.1999.00467.x

[47] Kureh, I., Kamara, A.Y. and Tarfa, B.D. (2006) Influence of Cereal-Legume Rotation on *Striga* Control and Maize Grain Yield in Farmers' Fields in the Northern Guinea Savanna of Nigeria. *Journal of Agriculture and Rural Development in the Tropics*, **107**, 41-54

[48] Odhiambo, J.A., Vanlauwe, B., Tabu, I.M., Kanampiu, F. and Khan, Z. (2011) Effect of Intercropping Maize and Soybeans on *Striga hermonthica* Parasitism and Yield of Maize. *Archives of Phytopathology and Plant Protection*, **44**, 158-167. https://doi.org/10.1080/03235400902952194

[49] Ejeta, G. and Gressel, J. (2007) Integrating New Technologies for *Striga* Control: Towards Ending the Witch-Hunt. World Scientific, Singapore. https://doi.org/10.1142/6470

[50] De Groote, H., Rutto, E., Odhiambo, G., Kanampiu, F., Khan, Z., Coe, R. and Vanlauwe, B. (2010) Participatory Evaluation of Integrated Pest and Soil Fertility Management Options Using Ordered Categorical Data Analysis. *Agricultural Systems*,

103, 233-244.

[51] Raju, P.S., Osman, M.A., Soman, J.P. and Peackock, J.M. (2000) Effects of N, P and K on *Striga asiatica* (L.) Kuntze Seed Germination and Infestation of Sorghum. *Weed Research*, **30**, 139-144. https://doi.org/10.1111/j.1365-3180.1990.tb01697.x

[52] Pieterse, A.H. and Verkleij, J.A.A.C. (2001) Effect of Soil Conditions on *Striga* Development—A Review. In: Ransom, J.K. Musselman, L.J., Worsham, A.D. and Parker, C., Eds., *Proceedings of the* 5*th International Symposium on Parasitic Weeds*, CIMMYT, Nairobi, 329-339.