RUFORUM Working Document Series (ISSN 1607-9345), 2018, No. 17 (1): 601-609.
Available from *http://repository.ruforum.org*

Research Application Summary

Comparative effects of soybean, grain amaranth (*Amaranthus* spp) and nitrogen on Striga (*Striga hermonthica*) and maize yield in western Kenya

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Abstract

Western Kenya, the area considered the grain basket of the country, is heavily infested by Striga, reducing maize yields by up to 30-100%. On-farm trials were conducted in two cropping seasons between August 2014 to July 2015 at Ugunja, Siaya County, western Kenya to (i) evaluate the effects of grain amaranth and nitrogen (N) fertilizer on Striga (*Striga hermonthica*) weed control through suicidal germination as compared to soybean; and to (ii) determine treatment effects on grain yields. The treatments consisted of rotational cropping of maize with maize, soybean with maize and grain amaranth with maize at different rates of N i.e. 0, 50, 100, 150, and 200 kg ha^{-1}. The treatments were replicated three times in a randomized complete block design in three different sites. Results showed that soybean-maize rotation at 0 N fertilizer resulted into 41.2% reduction on Striga count while amaranth-maize rotation at the same rate of N fertilizer resulted in 34.4% reduction 12 weeks after planting. These reductions were pegged on the reductions Striga counts in maize-maize rotation. There was significant difference ($P<0.05$) due to crop rotation systems, nitrogen and their interaction on maize yield. Despite the relatively higher counts of Striga under amaranth-maize rotation than the soybean-maize rotation in all N levels, the amaranth-maize rotation treatment gave a generally higher maize yields in treatment with similar N levels. Grain amaranth-maize rotation at 200 kg ha^{-1} N resulted in 10.5 % maize yield increase while soybean-maize system at 200 kg ha^{-1} N resulted in 25.7% maize yield increase. These results show that crop rotation involving maize and grain amaranth can be adopted by farmers as an efficient cropping system strategy to reduce Striga infestation and increase maize yields.

Keywords: Crop rotation, Kenya, *Striga hermonthica,* suicidal germination, weed control

Résumé

L'ouest du Kenya, la zone considérée comme le panier de céréales du pays, est fortement infesté par le Striga, ce qui réduit les rendements de maïs de 30 à 100%. Des essais à la ferme ont été menés pendant deux saisons de culture entre août 2014 et juillet 2015 à Ugunja, comté de Siaya, ouest du Kenya pour (i) évaluer les effets de l'amarante à grains et des engrais azotés (N) sur la lutte contre les mauvaises herbes par Striga (*Striga hermonthic*a) contre les mauvaises herbes par suicide la germination par rapport au soja; et (ii) déterminer les effets du traitement sur les rendements céréaliers. Les traitements consistaient en une culture en rotation de maïs avec du maïs, de soja avec du maïs et d'amarante à grains avec du maïs à différents taux de N, soit 0, 50, 100, 150 et 200 kg ha-1. Les traitements ont été répliqués trois fois dans une conception de blocs complets randomisés dans trois sites différents. Les résultats ont montré que la rotation soja-maïs avec 0 N d'engrais a entraîné une réduction de 41,2% du nombre de Striga tandis que la rotation amarante-maïs avec le même taux d'engrais N a entraîné une réduction de 34,4% 12 semaines après la plantation. Ces réductions étaient liées aux réductions des dénombrements de Striga dans la rotation maïs-maïs. Il y avait une différence significative (P <0,05) en raison des systèmes de rotation des cultures, de l'azote et de leur interaction sur le rendement du maïs. Malgré les dénombrements relativement plus élevés de Striga sous rotation amarante-maïs que la rotation soja-maïs à tous les niveaux de N, le traitement de rotation amarante-maïs a donné des rendements de maïs généralement plus élevés dans le traitement avec des niveaux de N similaires. La rotation grain-amarante-maïs à 200 kg ha-1 N a entraîné une augmentation de 10,5% du rendement du maïs tandis que le système soja-maïs à 200 kg ha-1 N a entraîné une augmentation de 25,7% du rendement du maïs. Ces résultats montrent que la rotation des cultures impliquant le maïs et l'amarante à grains peut être adoptée par les agriculteurs comme une stratégie de système de culture efficace pour réduire l'infestation par le Striga et augmenter les rendements du maïs.

Mots-clés: Rotation des cultures, Kenya, Striga hermonthica, germination suicidaire, lutte contre les mauvaises herbes

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Introduction

In Kenya, agriculture is an important economic activity and accounts for approximately 26% of GDP (Gok, 2010). The major food crops grown in Kenya are maize, sorghum, sweet potatoes, wheat, rice, beans, finger millet and cassava (Atera *et al.,* 2012b). Cereals play a central role for food supply, but its production has lagged. The production capacity of the country's food systems has not kept pace with the surging demand for food. The low yield recorded in the country is due to constraints of nutrient depletion, loss of organic matter, drought, weeds, and pest among others.

About 1.6 million hectares of land are under maize and 80% is grown by smallholder farmers in Kenya (Mureithi *et al.,* 2006). However, declining soil fertility has led to a reduction in maize production (Karaya *et al.,* 2012) with an average grain yield estimated at 1 t ha^{-1} (Ngome *et al.,* 2011b). Western Kenya is one of the maize producing zones in Kenya. However, maize productivity has been decreasing over the past years, threatening food security in the region and Kenya as a whole. Among the mentioned causes of the decline in production, Striga weed infestation has emerged as the major player.

Striga weeds belong to Orobanchacea family and are the most economically important parasitic plants, a monophyletic group of root parasites with approximately 90 genera and more than 2000 species (Westwood *et al.,* 2010). The common species that attack maize, sorghum and millet and upland rice are *Striga hermonthica* reducing their yield drastically. The weed is common in soils low in plant nutrients especially Nitrogen (N). They are generally dispersed by water, wind, livestock and human activities. Crops such as wheat, barley and Napier grass previously unaffected by Striga are now showing serious infestation in Sahel (Hussein, 2006; Ejeta *et al.,* 2007).

The root parasite is reported to be infecting about 217,000 ha in Kenya, causing annual crop loss of US $53 million (Woomer and Zavala, 2009, Atera *et al.,* 2013). Maize yield losses of up to 81% have been recorded in western Kenya (Ransom *et al.,* 1990) due to Striga infestations. Farmers grow hybrid maize varieties with a potential yield of 10 ton/ha but realize less than 1.0 ton/ha.

Research conducted over several years in Africa has provided several control technologies for Striga weed which include the use of resistant and tolerant varieties, and various agronomic practices, herbicides, fertilizer and manures (Esilaba and Ransom 1997; Esilaba *et al.,* 1997a). However, these technologies have not been widely adopted due to the mismatch between technologies and the farmer's socioeconomic conditions. 0ne of the tested methods of Striga control considered to be the most effective, cost-effective and practical to small-scale farmers is a non-host, also called trap crops (Omanya *et al.,* 2004). Trap crops induce germination of Striga weed but are not parasitized and result in suicidal germination of Striga seeds.

Crop rotation with non-host crops has been reported to disrupt production of Striga that leads to a reduction of the weeds. For example, crop rotation involving soybean and maize was found to be more effective in reducing Striga infestation and gave higher maize grain yield than cowpea in Guinea savanna of Nigeria (Kureh *et al.,* 2006). Schultz *et al.* (2003) achieved 50% seed bank reduction after one year's rotation with soybean and cowpea under farmer managed condition.

Soybean is one of the legume crops being promoted in Kenya for its high protein content, the source of cooking oil and for soil fertility enhancement. Soybean can positively contribute to soil health; human nutrition and health; livestock nutrition; household income; poverty reduction; and the overall improvements in livelihoods and ecosystem services than many others grain legumes (Rakasi, 2011). When rotated with cereals it can contribute to yield increases of cereals by up to 25% (Mahasi *et al.,* 2011). This is because of its ability to fix up to 200 kg N ha^{-1} $year^{-1}$ under optimal field conditions (Cheminingwa *et al.,* 2007). Furthermore, it has been reported to induce abortive germination of Striga seeds with a consequent reduction in infestation (Parker *et al.,* 1988). The use of nitrogen to suppress Striga has been demonstrated in the East and Central African highlands (Gacheru and Rao, 2001). Mumera (1983) recorded a 64% reduction in Striga hermonthica emergence in maize using 39 kg Nha^{-1}. The suppressive effects of N on Striga infestation are attributed to delayed germination; reduced radical elongation, reduced stimulants production and reduction of seeds response to the stimulants (Hassan *et al.,* 2009).

Laboratory screening of Amaranthus lines at growth stages showed that it can induce suicidal germination of Striga seeds and thus could be used as a trap crop to control the parasitic weed (Alabi *et al.,* 2007). However, grain amaranth is still an underexploited crop in Kenya despite its unique nutritional and potential economic value due to a variety of uses and benefits to producers, processors and consumers (Muyonga *et al.,* 2008). The crop is currently being promoted as an important source of protein among the poor. The aim of this study was therefore to evaluate the ability of grain amaranth to cause suicidal germination of Striga weed in maize fields and thus reducing the weed's seed bank.

Materials and Methods

Experimental sites. The on-farm trial was set up in Ugunja, Siaya County during 2014-2015 planting seasons in three sites. Siaya county lies between latitude 0^0 03’ N and latitude 34^0 25’ E. The altitude ranges from 1140 to 1400 M above the sea level. Temperature varies from 27^0C to 30^0C and 15^0C to 17^0 C maximum and minimum ranges respectively. Soils are mainly from volcanic origin, mainly basalt, well developed, deep and friable but shallow with murram in some places. Common soil type is dystric nitisols, orthic ferralsols and acrisols (FAO, 1996 and the Republic of Kenya, 1994). The County receives bimodal rain with long rains March-June and short rains in August-November. Main economic activities in the area are farming and fishing.

Pre-visit to the area was done during the previous cropping season and the farmer sites were selected based on the availability of Striga infestation, the willingness of the farmer to grow the crops in the rotation combinations, and the availability of labour. The selected sites were well drained levelled fields, uniform in fertility and soil type with no termites and soil erosion. Site characterization was conducted to determine the reigning physical and chemical properties of the soils.

Treatment allocations and test crops. The treatments were; grain amaranth-maize, soybean-maize and maize-maize crop rotations and five levels of N (i.e. 0, 50, 100, 150, 200 kg ha^{-1}). The treatments were arranged in a randomized complete block design (RCBD) with three replications. The test crop was Striga tolerant maize variety KSTP 94. The maize variety is tolerant to high temperature and matures fast (in 140 days). The grain amaranth seeds were obtained from KALRO-Kakamega while the nitrogen fertilizer (urea) and phosphorous (P) fertilizer (TSP) was obtained from an agro-dealer in Kakamega.

Soil data. Composited soil samples collected at a depth of 0-30cm were air dried, ground, and sieved using a 2 mm sieve. This was then analyzed at the University of Eldoret soil laboratory for the determination of selected soil physicochemical properties {pH, organic matter (OM), total nitrogen (TN), available P (Ava P) and texture.

Field agronomy. Maize seeds were planted at a spacing of 75x25 cm to give a plant population of 53,333 shoots ha^{-1}. Soybean variety TGX 1740-2F (SB19) and grain amaranth (golden) seeds were drilled along ridges (and straight lines on the flat) with a spacing of 5 cm and with an inter-row spacing of 75 cm to achieve a population of 266,000 plants ha^{-1}. Sole maize seeds were planted during the second season in all plots using TSP fertilizer at of 26 kg ha^{-1} P. Soybean was harvested when the pods had turned brown (Dugje *et al.,* 2009). Maize was harvested at 12 WAP when the leaves turned yellowish and fallen off which were signs of leaf senescence and cob maturity (Ijoyah and Jimba, 2012).

Data collection and analysis. Data on Striga weed intensity on each experimental unit was collected at the date of planting (DOP), eight weeks after planting (8 WAP) and twelve weeks after planting (12 WAP). The number of Striga was counted in the one-meter-square of each net plot. Data for maize was collected on the date of planting (DOP), germination percentage (GP) at three weeks (TW) of germination and stand count (SCT) at thinning. Stand count at harvesting, crop height (HC) at 8 and 12 weeks after planting, dry weights (DW) of grains and stover at harvesting were also taken.

Data were subjected to analysis of variance (ANOVA) using Genstat statistical software (Payne *et al.,* 2006). Fisher's least significant difference (LSD) test was used to separate the means at P < 0.05.

Results and Discussions

Soil characteristics. The soil of trial site 1 and 3 were moderately acidic with pH 5.32 and 5.44 respectively while those of site 2 was strongly acidic with pH 4.97. Organic carbon of the experimental site was 1.63, 1.58 and 1.91 % for site 1, 2 and 3, respectively. This fall under the medium category according to Fisher (1974) classification. These results correspond with Westerman (1990) who rated organic matter content of soil as very low (<1 %), low (1.0 to 2.0 %), medium (2.1 to 4.2 %), high (4.3 to 6 %), and very high (>6 %). The total N of experimental sites was 0.13 %, 0.12 % and 0.15 % for site 1, 2 and 3, respectively where they all fall in low category according to Havlin *et al.* (1999) who rated total N (%) as very low (<0.1), low (0.1 to 0.15), medium (0.15 to 0.25), and high (> 0.25). According to Tekalign *et al*. (1991), N availability is classified as very low, poor, moderate and high at <0.05 %, 0.05-0.12 %, 0.12-0.25 % and >0.25 respectively. The available P were 8.44, 8.13 and 8.96 ppm for sites 1, 2 and 3 respectively which all fall in medium category according to Olsen *et al.,* (1954) rating, where P (mg kg^{-1}) content is <3 (very low), 4-7 (low), 8-11 (medium) and >11 (high).

Maize stand count and plant height. There was no significant difference (P<0.05) due to crop rotation systems, nitrogen and their interaction on initial and final stand counts. This is because stand count is not affected by the soil fertility. The results indicated that there was a significant difference in plant height among treatments and sites (P<0.05) at 8 WAP and 12 WAP (Table 1). However, there were no significant differences in plant height when treatments interacted with the sites. It was observed that there was an increase in plant height with an increase in N level both at 8 weeks and 12 weeks after planting for all the crop rotation systems. The tallest plant (151.9 cm) at 8 WAP and (238.9 cm) at 12 WAP was recorded from the amaranth-maize rotation at 200 kg N ha^{-1} and the shortest (233.1 cm) at 12 WAP was from the maize-maize rotation at 0 N application. The difference in plant heights in the sites could be due to the varying soil fertility status in the three sites. The higher plant heights in site 3 compared to site 1 and 2 could also be partly due to the lower Striga numbers that did not adversely affect the nutrient absorption status of the crops.

Maize yield. There was significant (P<0.05) increase in maize yield on all the crop rotation system with an increase in N levels from 0 to 200 kg ha^{-1}. Soybean-maize rotation interacting with 200 kg $ha^{-1}$of N resulted in the highest yield (5.227 t ha^{-1}) while rotation involving maize-maize at 0 kg ha^{-1} N resulted in the lowest yields (1.852 t ha^{-1}). However, there was no significant difference in grain yield for grain amaranth-maize at 150 kg ha^{-1} and that of soybean-maize rotation systems at 150 kg N $ha^{-1}$and 200 kg N ha^{-1}. This illustrates that for economic purpose, 150 kg N $ha^{-1}$for two cropping system is recommendable. The highest grain yield in sole maize cropping (4.189 t ha^{-1}) was obtained with application of 200 kg N ha^{-1} whereas the lowest grain yield (1.852 t ha^{-1}) was obtained from no nitrogen fertilizer application in the same cropping system. Similar findings on the positive effect of increased rate of N was reported by others (Dugje *et al.,* 2008; Soleymani, 2011).

The possible reason for the increase in grain yield with an increase in N levels application might be due to the increase up of yield attributing characters and nutrient uptake of the crop under these levels as well as reduced Striga infestation at the high application of N levels. N also increases the vegetative growth of the host plant, which strengthens it and protects the plant from Striga parasitism and to have the effect of reducing strigolactone production from the host plants and therefore inhibit germination of Striga hermonthica seeds (Sjogren *et al.,* 2010; Gacheru and Rao, 2011). The lower maize yield in sole maize rotation was due to the high Striga numbers that affect the grain yield of maize. Striga attaches itself to the roots of host plants and syphons the nutrients and water intended for plant growth.

Grain amaranth-maize rotation system interacting with 200 kg N ha^{-1} resulted in 10.5 % maize yield increase while soybean-maize system interacting with 200kg N ha^{-1} resulted in a 25.7 % increase in maize yield. This could be attributed to a reduction in Striga intensity in soybean/amaranth-maize crop rotation systems that consequently increased maize yield. Similarly, Sanginga *et al.* (2002) reported maize yield increases relative to maize grown after maize ranging from 20 to 130 %, depending on the soybean genotype incorporated in the rotation. The high Striga count in the maize- maize treatment could have been responsible for the low maize yield. Striga weed attachments on crops cause high levels of yield reduction, (Abdul *et al.,* 2012). Grain amaranth and soybean could have caused suicidal germination of Striga weeds during the first season reducing their seed bank and reduction in their population in the second season. There was a significant difference ($P<0.05$) due to crop rotation systems, nitrogen and their interaction on the yield of maize stover (Table 1). All the treatments, sites and their interactions varied which could be attributed to variation in soil fertility.

Striga intensity. Soybean-maize rotation at no N fertilizer resulted to 41.2% reduction on Striga count while amaranth-maize rotation at no N fertilizer resulted in 34.4% reduction on Striga at 12WAP as compared to that produced from the maize-maize rotation at no N fertilizer. The highest striga number (31.44/ m^2) at 12WAP was observed on maize-maize crop rotation system at no N fertilizer while the lowest (6.89/ m^2) at 12WAP was observed on soy bean-maize crop rotation system. There were no significant differences on treatment and site interaction on Striga count. Similarly, the sites differed significantly in influencing the numbers of Striga populations at 8WAP and 12WAP. There was a significant decrease in the population of Striga weed with an increase of N rates from 0-200 kg ha^{-1} for all the crop rotation systems. Similarly, the decrease in Striga was observed to increase maize grain yield in all the crop rotation systems and vice-versa. This could have been due to decreased parasitism on maize plants and vice-versa. This indicated that both soybean and grain amaranth caused suicidal germination of Striga reducing their seed bank and hence reducing their population in the second planting season.

The highest number of Striga weeds (31.44/m^2) was recorded where no nitrogen was applied (control) at 12 WAP and the lowest (16.00/ m2) at 200 kg ha^{-1}on nitrogen. This agrees with findings of Gacheru and Rao (2011), Lagoke and Isah (2010) and Sjögren *et al.* (2010) who reported that N has the effect of reducing strigolactone production from the host plants and therefore also inhibits germination of *S. hermonthica* seeds and hence their severity. Similarly, the sites differed significantly in influencing the numbers of Striga populations at 8WAP and 12WAP. However, treatment interacting with site did not differ, showing that their contribution to the Striga population is insignificant.

Table 1. Effects of treatment and site on Striga count, maize yield and maize yield parameters

	Maize height (cm) at 12 WAP			Maize stover (t ha^{-1})			Maize grain yield (t ha^{-1})			Striga population (m^2) at 12 WAP		
	site			site			site			site		
Treatment	1	2	3	1	2	3	1	2	3	1	2	3
MMN$_0$	197	195	204	8.187	8.663	8.203	1.403	1.953	2.2	33.00	34.67	26.67
MMN$_1$	206	197	210	9.143	9.927	10.787	2.4	1.75	2.633	30.00	28.00	24.00
MMN$_2$	214	213	222	11.343	11.28	11.503	3.19	2.4	3.407	18.00	20.00	14.00
MMN$_3$	238	220	241	12.573	11.44	12.58	3.47	3.483	4.61	18.00	32.33	16.00
MMN$_4$	217	236	246.0	13.06	12.99	13.44	4.027	3.91	4.63	16.00	21.00	11.00
AM N$_0$	199	193	203	8.56	9.753	8.433	2.56	2.53	2.96	18.00	23.00	15.00
AMN$_1$	217	213	218	10.077	9.903	11.013	3.31	3.22	3.46	20.00	24.00	14.00
AMN$_2$	194	218	214	11.503	11.72	11.613	3.99	3.73	4.107	18.00	20.00	14.00
AMN$_3$	210	231	238	11.453	11.907	12.083	4.407	4.373	4.710	19.00	8.00	17.00
AMN$_4$	222	250	245	12.897	12.897	12.897	4.59	4.37	4.93	9.67	13.00	6.00
SMN$_0$	192	214	222	11.593	11.393	11.647	3.42	3.33	3.48	20.00	22.00	14.00
SMN$_1$	198	223	228	10.08	11.677	12.543	3.67	3.57	3.677	17.00	20.00	10.00

SMN_2	236	223	240	11.707	12.497	13.543	4.34	3.967	4.41	13.00	15.00	7.00
SMN_3	242	239	245	13.373	13.033	13.877	5.26	5.02	5.177	11	13.00	6.00
SMN_4	248	242	247	13.577	13.967	14.627	5.11	5.463	5.227	1.33	15.33	4.00
F value	<0.001			<0.001			<0.001			<0.001		
CV (%)	5.4			1.2			12.4			29.7		
LSD (0.05)	4.97			0.1866			0.1942			2.214		

M=maize, A=amaranth, S=soybean and N=Nitrogen. 0=0 kg,1=50 kg,2=100 kg,3=150 kg and 4=200 kg ha^{-1} of N.

Conclusion

Soybean-maize rotation demonstrated the highest maize yield and yield parameters followed by grain amaranth-maize rotation. From the results obtained, therefore, use of grain amaranth and N fertilizer is also effective in the control of Striga. The study showed that soybean-maize rotation at no N fertilizer resulted into 41.2 % reduction on Striga count while amaranth-maize rotation at no N fertilizer resulted in 34.4 % reduction and hence can be adopted as alternative Striga trap crop due to its nutritional importance and adaptability to many ecological zones. Monocropping of maize in Western Kenya has greatly contributed to increased Striga population in the area. This has led to parasitism on maize crop hence reduced yields that threaten national food security.

Acknowledgements

We acknowledge the Kenya Agricultural and Livestock Research Institute for providing financial support for this research. Many thanks also go to the University of Eldoret, Soil Science Department Laboratory staff for the support they offered during soil analysis. We also thank the farmers in Ugunja, Siaya County who provided us with their farms sites for setting up the field experiments. This paper is a contribution to the 2018 Sixth African Higher Education Week and RUFORUM Biennial Conference.

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