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Integrating striga resistant maize and spatial arrangement of intercropped cowpea in the control of *Striga asiatica*

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Abstract

Infestation of maize fields by *Striga asiatica* in coastal Kenya is increasing due to continuous mono-cropping of cereals without replenishment of soil nutrients, hence reducing land productivity. This may therefore lead to food insecurity if a viable solution is not found. A study was conducted to determine if integrating striga resistant maize and cowpea spatial arrangement could offer an effective solution to the striga problem. The study was conducted at KALRO Matuga in 2012 and 2013. A randomized complete block design, with three replications, was used. Maize varieties differed significantly in their stover yield in 2013 LR seasons but the varieties did not show any significant effect on striga stand counts in both seasons. Spatial arrangement of intercropped cowpea significantly influenced maize grain and stover yields in 2013 LR season. Maize variety V_2 showed some tolerance to striga weed. This variety is therefore recommended for multi-locational evaluation under the National Performance Trials (NPTs) to ascertain its superiority to the current commercial maize varieties (Coast Maize Composite, Pwani Hybrid 1 and Pwani Hybrid 4). Within row spatial arrangement of intercropped cowpea gave higher maize yields than the between row arrangement. Farmers are therefore likely to realize improved maize yields by adopting the within row spatial arrangement of intercropped cowpea.

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Introduction

Maize is grown on 99% of the smallholder farms (Saha *et al*., 1993) and is a staple food of the coastal population (Wekesa *et al*., 2003). However, its production is constrained by among other factors weed infestation, especially by *S. asiatica*. Striga is one of the most destructive parasitic weed, parasitizing important economic plants such as cereals and legumes leading to crop losses ranging from 70 to 100% (Ejeta, 2007). According to Gethi *et al*. (2005), *S. asiatica* occupies a large area in the coastal region of Kenya, and infestation by this weed is becoming worse due to soil fertility decline through continuous mono-cropping of cereals.

Striga control using resistant maize varieties will reduce the labor and time needed for physical control, help in environmental preservation and reduce production cost by minimizing the use of chemical control. Host plant resistance is seen as the most promising method of striga control especially in subsistence agriculture (Elzein and Kroschel, 2003). Few sources of resistance among the very large numbers of sorghum and maize genotypes screened to date have been identified (Malcolm and Gurney, 2000; Elzein and Kroschel, 2003). Some crop varieties have been shown to resist striga infestation through reduced production of the required germination stimulant (Olupot, 2011). However, the development of crop plants with resistance to striga has been limited because of the complexity of interactions between host, parasite, and the physical environment (Ejeta, 2007). Some maize varieties in Kenya, such as Katumani Maize Composite, show partial resistance to striga (Gethi *et al.,* 2005). Maize hybrid *Tzi-30* has also been reported to resist *S. hermonthica* infestation (Ransom *et al.,* 1990).

Different mechanisms of resistance to striga have been suggested by various scientists. According to Mohamed *et al*. (2003) and Rich *et al*. (2004), some mechanisms of resistance to striga involved mutant host plants with low germination stimulation and low haustorial induction, formation of necrotic lesions (hypersensitive reaction) when striga first attaches, and incompatibility whereby early post-attachment growth of the parasite is stopped or slowed. Intercropping of the striga resistant maize varieties with legumes has shown potential for the control of striga (Khan *et al*., 2007).

A study by Fujita *et al*. (1992) showed that the distance between the intercrop root systems is important because N is transferred through the intermingling of the root systems of the companion crops. Frankow-Lindberg and Dahlin (2013) have suggested that a major part of the legume root system turnover occurs in the uppermost part of the soil profile. In a study in coastal lowland Kenya, Saha (2015) observed the highest maize root length density in the top 30 cm of the soil profile.

In an unpublished survey (H.S. Shauri, Personal communication), it was observed that some farmers in the striga prone areas of coastal Kenya plant maize and cowpea (*Vigna unguiculata*) in the same planting hole (Fig. 1). The farmers could not clearly explain why they used such a cropping system. It appeared that this system has been passed on from one generation to another without the reason(s) for using it. It was not clear whether this system was meant to minimize labour for digging planting holes or to control striga, probably by confusing the stimulated striga seed by merging the root systems of maize and cowpea.

It was therefore found necessary that a study be carried out on the integration of striga resistant maize and spatial arrangement of intercropped cowpea in the control of *S. asiatica*. The aim of the study was to determine the effectiveness of integrating striga-resistant maize varieties and spatial arrangement of intercropped cowpea in the control of *S. asiatica*. Tenebe and Petu-Ibikunle (2012) reported low striga populations on plots of sorghum and cowpea sown on the same hill and attributed this to confusion of the parasite on recognition of the appropriate host. Carsky *et al*. (1994) reported highest yield of sorghum in alternating stands of sorghum and cowpea within the same row. A spatial arrangement where cowpea is planted between rows of a cereal crop is known to leave a larger area of soil surface exposed than an arrangement where the legume is planted within the cereal row, leading to higher soil temperature which encourages greater moisture loss from the soil through evaporation (Tenebe and Petu-Ibikunle, 2012).

Materials and methods

Site description

The study was conducted on-station at the Matuga station of the Kenya Agricultural and Livestock Research Organization (KALRO Matuga) in Kwale county, coastal Kenya, during the long rain seasons of 2012 and 2013. The site (KALRO Matuga) lies within coastal lowland agro-ecological zone three (CL3), at an altitude of 132 meters above sea level. It lies between latitude 4°9'52" South and longitude 39°34'23" East. The rainfall pattern is bimodal, with two distinct seasons: the long rains (LR) from March/April to June/July and the short rains (SR) from September/October to December. The amount of rain ranges from 760 mm to 1200 mm per year. The annual mean maximum temperature range is between 26°C and 30°C while the mean annual minimum temperature is 22°C. The relative humidity varies between 60% and 95%.

The soils at KALRO Matuga are sandy, with a substantial amount of clay.

Experimental design

The randomized complete block design was used, with treatments arranged in a factorial manner. The treatments were replicated three times.

Treatments

The following treatments were evaluated in the experiment:

Factor A: Maize variety

1. Commercial variety – Pwani Hybrid 4 (V_1)
2. Striga resistant variety MS 2011-10 CML 312/T2Mi/TzL2/MUG 1-2-4 (V_2)

Factor B: Spatial arrangement of intercropped cowpea

1. Between maize rows (S_0)
2. Within maize row (S_1)
3. Same hill with maize (S_2)

Crop establishment

In the first spatial arrangement of intercropped cowpea (S_0), each plot consisted of three maize rows (spaced at 90x50 cm) and two cowpea rows (each planted between two maize rows). The cowpea was planted at three seeds per hill and spaced at 30 cm within row. In the second spatial arrangement (S_1), maize and cowpea were planted in alternating hills within each row. In the third spatial arrangement (S_2), maize and cowpea were planted in the same hill. To ensure uniform striga infestation in the plots, a mixture of striga seeds and sand (at a 1:2 ratio) was used to inoculate the plots. The mixture was placed beside the maize hills.

Crop management practices

The maize and cowpea were thinned at two weeks after planting (WAP) to two plants per hill. All crops were weeded twice, at four and seven WAP. Re-growth of weeds other than striga was controlled by hand-pulling. Fertilizer was applied to maize at the recommended rates of 60 kg N ha^{-1} and 20 kg P ha^{-1}. The nitrogenous fertilizer was applied four WAP. Bulldock (0.05GR 0.5g/kg Beta cyfluthrin) was applied around the time of first weeding to control maize stem borer and cowpea pests.

Data collected

The following data were collected from the experimental plots:

(a) Grain yield

All the three rows of maize in each plot were harvested for the determination of maize grain yields. At harvest, plot weight was measured after dehusking the cobs. Two cobs were taken at random from each plot, weighed, shelled and the grains weighed to determine the shelling fraction. The shelling fraction was calculated as the grain weight over the initial weight of cobs before shelling.

Grain moisture content was recorded. Maize grain yield was then calculated based on a storage moisture content of 13% using the following formula:

$$Y = \frac{FW_{ear}\ (kg)}{Area\ (m^2)} * \frac{10{,}000\ (m^2ha^{-1})}{1{,}000\ kg\ t^{-1}} * \frac{100 - MC_{grain}}{100 - MC_{store}} * SF$$

where Y = grain yield (t ha^{-1}); FW_{ear} = Field weight of maize ears; Area = Net plot area; MC_{grain} = Percent grain moisture content; MC_{store} = Percent storage moisture (13%);
SF = Shelling fraction.

(b) Stover yield

Field stover weight was recorded and samples taken for stover dry matter (DM %) determination. The middle row of maize was used to determine stover yield. Two samples, each consisting of two maize plants were taken at random per variety and weighed fresh. The samples were then oven-dried at 105°C for 48 hours for DM determination. DM was calculated using the following formula:

$$DM\ (kg\ ha^{-1}) = \frac{S_{oven}\ (g)}{S_{fresh}\ (g)} * \frac{PW\ (kg)}{A\ (m^2)} * 1{,}000\ m^2ha^{-1}$$

where S_{oven} = sample oven weight; S_{fresh} = sample fresh weight; PW =plot weight;
A = net plot area.

Maize stover yield was then derived using the following formula:

$$Y = \frac{SW\ (kg)}{A\ (m^2)} * \frac{10{,}000\ m^2ha^{-1}}{1{,}000\ kgt^{-1}} * DM$$

where Y = stover yield (t DM ha^{-1}); SW = field stover weight; A = net plot area;
DM = proportion of DM in fresh stover.

(c) Striga weed data

The number of striga plants that had emerged in each plot was taken as the striga emergence counts at 7 and 9 weeks after planting during the 2012 and 2013 cropping seasons. The striga stand counts were used as a measure of striga infestation on the maize plants. Maize yield was used as a parameter to gauge the effectiveness of striga control method.

(d) Striga seed density

Soil samples were collected from all the plots at the end of the 2012 LR and 2013 LR seasons. Striga seed density was then determined using the procedure as described by Berner *et al.* (1997).

Data analysis

Striga stand counts and maize grain and stover yields data collected were subjected to the analysis of variance (ANOVA) using the General Linear Model (GLM) procedure of the Statistical Analysis System (SAS). Because of the high variability observed for the actual striga stand counts, the $\log_{10}$ [n+1] transformations of the original data (n) were performed before analysis so as to improve the normality of the data. Where the F values were significant, treatment means were separated using the Least Significant Difference (LSD) at the 5% level of significance.

The PROC CORR procedure of SAS was used to correlate maize grain and stover yields and striga stand counts. Since treatments were applied to the same plots in both seasons one (2012 LR season) and two (2013 LR season), a paired t-test was performed on the striga seed counts in soil to determine whether there was a significant change in striga seed density in the soil.

Results and discussion

The results of the 2012 LR season showed that maize variety had no significant effect on striga stand counts ($P = 0.95$) (Table 1). The maize varieties also did not differ significantly in their grain and stover yields ($P = 0.14$ and $P = 0.27$, respectively). However, in the 2013 LR season, maize varieties differed significantly in their stover yield. Variety V_2 produced higher stover yield than V_1 ($P = 0.02$) (Table 2). Plots of the two varieties did not differ significantly in their striga stand counts, indicating similar exposure to the weed. This therefore, shows that maize variety V_2 had some tolerance to *S. asiatica* and gave higher stover yield than commercial maize variety (V_1). Correlation analysis of the 2013 LR season data showed moderate negative correlation between striga stand counts and maize stover yield (r^2 = -0.46, P=0.002 for stand count at 7 WAP and r^2 = -0.41, P=0.004 for stand count at 9 WAP). This is an indication that less than 50% of the variations in the yield parameter can be explained by the relationship between striga stand counts and stover yield, implying that there was no meaningful correlation between striga stand count and maize stover yield.

Table 1. Effect of maize variety on striga stand counts and maize grain and stover yields in the 2012 LR season.

Maize variety	Striga stand counts		Maize grain yield (t ha^{-1})	Maize stover yield (t ha^{-1})
	Count 1 (7 WAP)	Count 2 (9 WAP)		
V_1	1.51	11.40	3.26	2.21
V_2	1.97	22.17	4.15	2.60
LSD	1.551	12.863	1.241	0.764
CV	152.1	59.5	31.9	30.3

V_1 = PH4 maize variety; V_2 = striga resistant maize variety

Column means followed by same superscript are not significantly different at P<0.05.

Table 2. Effect of maize variety on striga stand counts and maize grain and stover yields in the 2013 LR season.

Maize variety	Striga stand counts		Maize grain yield (t ha^{-1})	Maize stover yield (t ha^{-1})
	Count 1 (7 WAP)	Count 2 (9 WAP)		
V_1	14.97	39.11	1.67	4.30^{b}
V_2	9.29	25.71	2.07	5.42^{a}
LSD	7.993	15.591	0.530	0.890
CV	66.7	34.9	27.0	17.5

V_1 = PH4 maize variety; V_2 = striga resistant maize variety

Column means followed by same superscript are not significantly different at P<0.05

Spatial arrangement of intercropped cowpea had no significant effect on striga stand counts and maize grain and stover yields in the 2012 LR season (Table 3).

Table 3. Effect of spatial arrangement of intercropped cowpea on striga stand counts and maize grain and stover yields in the 2012 LR season.

Spatial arrangement	Striga stand counts		Maize grain yield (t ha^{-1})	Maize stover yield (t ha^{-1})
	Count 1 (7 WAP)	Count 2 (9 WAP)		
Between row	3.61	20.22	3.95	2.58
Within row	1.95	22.02	3.64	2.31
Same hill	0.86	11.18	3.53	2.33
LSD	3.226	11.059	1.520	0.936
CV	152.1	59.5	31.9	30.3

Column means followed by same superscript are not significantly different at P<0.05.

The results of the 2013 LR season also showed that spatial arrangement of intercropped cowpea had no significant effect on striga stand counts. These results are contrary to the findings by Tenebe and Petu-Ibikunle (2012), who reported low striga populations on plots of sorghum and cowpea sown on the same hill and attributed this to confusion of the parasite on recognition of the appropriate host. Unlike in the 2012 LR season, spatial arrangement of intercropped cowpea significantly influenced maize grain (P = 0.04) and stover yields (P = 0.02) in the 2013 LR season (Table 4).

Table 4. Effect of spatial arrangement of intercropped cowpea on striga stand counts and maize grain and stover yields in the 2013 LR season.

Spatial arrangement	Striga stand counts		Maize grain yield (t ha^{-1})	Maize stover yield (t ha^{-1})
	Count 1 (7 WAP)	Count 2 (9 WAP)		
Between row	35.87	63.70	1.42^{b}	3.98^{b}
Within row	16.14	28.63	2.27^{a}	5.67^{a}
Same hill	8.45	18.50	1.92^{ab}	4.94^{ab}
LSD	28.137	47.025	0.650	1.090
CV	66.7	34.9	27.0	17.5

Column means followed by same superscript are not significantly different at $P<0.05$.

Plots in which cowpea was planted within the maize row had significantly higher maize grain and stover yields than those in which the legume was planted between maize rows. The results of this study are in line with those of Carsky *et al.* (1994) who reported highest yield of sorghum in alternating stands of sorghum and cowpea within the same row. The observed high maize yields where cowpea was planted within the maize row is probably due to nitrogen transfer between the cowpea and maize root systems, as well as the improved ground cover within the maize rows effected by the legume.

Fig. 1. Maize and cowpea planted in same hole on a farmer's field.

The relatively high ground cover within the maize row probably led to moisture conservation for longer periods than in plots in which cowpea was planted between maize rows.

A spatial arrangement where cowpea is planted between rows of a cereal crop is known to have a larger area of soil surface exposed than an arrangement where the legume is planted within the cereal row, leading to higher soil temperature which encourages greater moisture loss from the soil through evaporation (Tenebe and Petu-Ibikunle, 2012). The observed high maize yields where cowpea was planted within the maize row was probably the result of reduced temperature and moisture conservation effected by the overlapping maize and cowpea canopies. Nutrient uptake is known to increase with improved soil moisture. Maize that had been intercropped with cowpea within the row probably responded to soil moisture conservation by increasing its nutrient uptake, leading to increased yields.

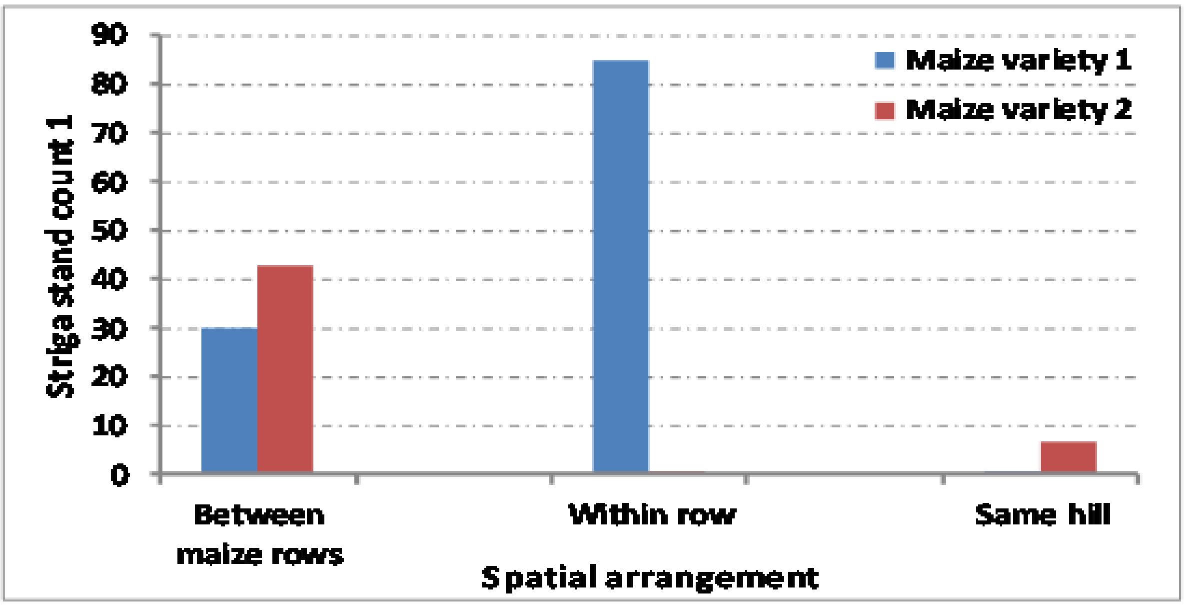

Fig. 2. Effects of maize variety and spatial arrangement on striga stand count at 7 WAP in the 2013 LR season.

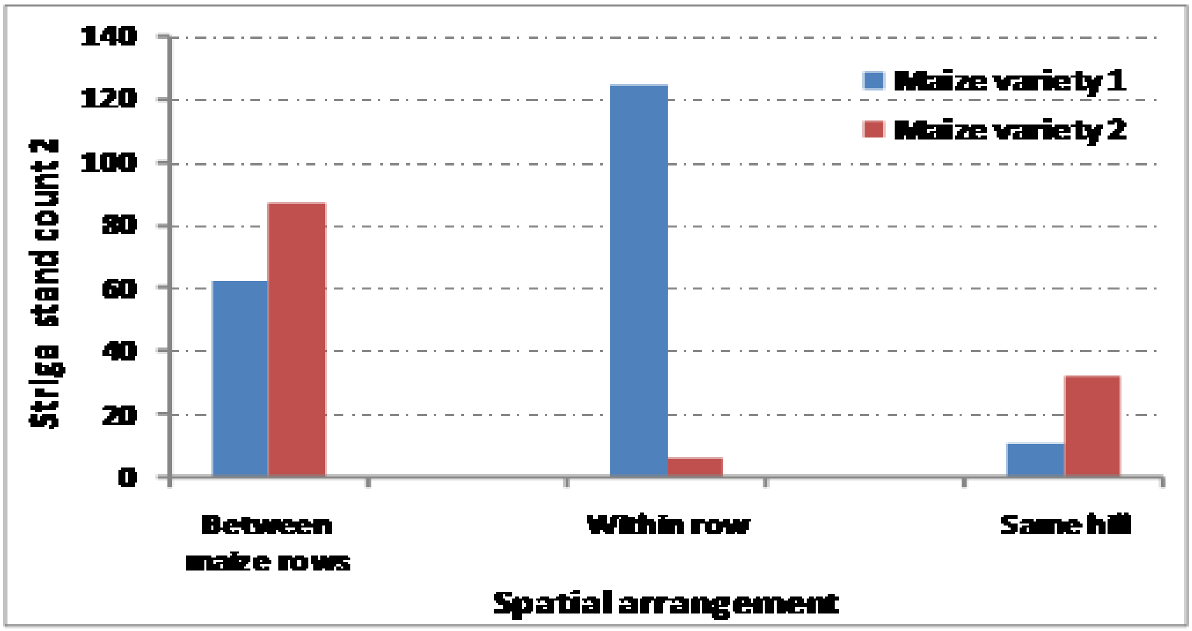

Fig. 3. Effects of maize variety and spatial arrangement on striga stand count at 9 WAP in the 2013 LR season.

Plots in which cowpea was planted within the maize row probably had the highest volume of active maize root hairs in close proximity with cowpea roots where biological N fixation was taking place. A study by Fujita *et al.* (1992) showed that the distance between the intercrop root systems is important because N is transferred through the intermingling of the root systems of the companion crops. Hanegraaf (1987) reported the following three important routes for the transfer of nitrogen from legumes to soil; release of nitrogen from droppings of animals that fed on legumes, decomposition of aerial parts of leguminous plants, and decay of legume root tissues and nodules. The maize that had been intercropped with cowpea within the row most likely benefited from the cowpea root system turnover. Frankow-Lindberg and Dahlin (2013) have suggested that a major part of the legume root system turnover occurs in the uppermost part of the soil profile. In a study in coastal lowland Kenya, Saha (2015) observed the highest maize root length density in the top 30 cm of the soil profile. Therefore, intercropped maize is likely to benefit from the root system turnover of cowpea planted within the same row.

The results of the experiment on maize variety and spatial arrangement of intercropped cowpea also showed that maize variety and legume spatial arrangement had no effect on striga seed density in soil at the end of both seasons one (2012 LR season) and two (2013 LR season). This shows that striga-resistant maize variety V_2 and the commercial variety PH4 (V_1) had similar effect on striga seed density in soil. Since suicidal germination plays a key role in the reduction of striga seed load in soil, the results of this study show that suicidal germination of striga seed by cowpea is not affected by the spatial arrangement of the legume.

The results of the 2013 LR season showed a significant interaction effect of maize variety and spatial arrangement of intercropped cowpea on striga stand count at 7 WAP ($P = 0.04$) and at 9 WAP ($P = 0.02$) (Fig. 2 and 3). This shows that the effect of spatial arrangement of intercropped cowpea on striga stand count will most likely be influenced by maize variety.

Conclusion

The study showed that maize variety V_2 had some tolerance to striga weed. This variety therefore could be recommended for multi-locational evaluation under the National Performance Trials (NPTs) to ascertain its superiority to the current commercial maize varieties. If proved superior, the maize variety may then be multiplied for use by farmers in the *S. asiatica* prone areas of coastal lowland Kenya.

Results of the correlation analysis showed no evidence of meaningful correlation between striga stand counts and maize grain and stover yields since the coefficient of determination (r^2) was less than 0.5, implying that less than 50% of the variations in the yield parameters can be explained by the relationship between striga stand counts and maize grain and stover yields.

Spatial arrangement of intercropped cowpea was found to influence maize yield under maize-cowpea intercropping. The within row legume spatial arrangement of intercropped cowpea gave higher maize yields than the between row arrangement. It is therefore recommended that farmers adopt the within row spatial arrangement of intercropped cowpea for improved maize yields.

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