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# Response of NERICA Rice to *Striga hermonthica* Infections in Western Kenya

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## ABSTRACT

*Striga hermonthica* (Del.) Benth (hereafter referred to as Striga), an obligate root hemiparasite, poses a serious threat to cereal production in sub-Saharan Africa. Field experiments were conducted in two years at Alupe farm, western Kenya, to investigate the effect of Striga on growth and yield parameters of New Rice for Africa (NERICA) cultivars. A randomized complete block design replicated three times and rice cultivars NERICA 1, NERICA 4, NERICA 10, NERICA 11 and Dourado precoce, a local landrace were used. Striga significantly reduced grain yield and the yield components. Reduction in grain yield and its components were more severe under moisture stress period in 2008. Grain yield loss ranged between 33-90%. NERICA 1 gave the highest yield in the two seasons both in Striga infected and control plants. This was followed by NERICA 10, which was also the most economically viable when infected with Striga. Result showed that both NERICA 1 and NERICA 10 are resistant to *S. hermonthica,* while NERICA 4 is highly susceptible. © 2012 Friends Science Publishers

**Key Words:** *Striga hermonthica*; Resistance; NERICA; Yield; Kenya

## INTRODUCTION

*Striga* weed, a root parasitic flowering plant, is common in sub-Saharan Africa (SSA) causing severe constraints to crop production. It survives by diverting essential nutrients, which are otherwise taken up by cereal crops such as sorghum (*Sorghum bicolor* [L.]), pearl millet (*Pennisetum glaucum* [L.]), finger millet (*Eleusine coracana* [L.] Gaertn), maize (*Zea mays* [L.]) and upland rice (both *Oryza glaberrima* [Steudel] and *O. sativa* [L.]) (Rodenburg *et al*., 2006; Atera *et al*., 2011). These cereals are of utmost significance to African farmers for their home consumption. Underground the weed siphons water and nutrients for its growth, while above the ground, the crop withers and grain yield is reduced (Khan *et al*., 2007). However, most farmers are not aware of the threat *Striga* poses to their land quality and food security as the weed continues to increase its soil seed bank and spreading to new areas.

It has been estimated that the parasite infects some 21.9 million ha (40% of the cereal-producing areas) (Gressel *et al*., 2004) of SSA, where farmers lose about 20–80% of their yield estimated at US$7 billion annually, and affecting livelihood of approximately 300 million people (Scholes & Press, 2008). In Kenya, Striga infects approximately 210,000 ha [of which Western Kenya accounts for 80%] (AATF, 2006) causing annual crop losses of US$ 40.8 million (Gethi *et al*., 2005). The most affected are resource poor subsistence farmers with infertile fields (Gurney *et al*., 2006).

According to Oswald (2005), Striga has been on existence in farmers' fields in Western Kenya since 1936. Poverty level of small scale farmers has enhanced the spread of the parasite through sharing of seeds collected from the previous crop harvest. In addition, Striga pandemic has increased in size and severity as a result of mono cropping and seed dormancy (of more than 10 years in the soil). The parasite produces several seeds, which are incorporated into the soil during tillage. Through the tools used by man for land preparation and weeding, seeds are spread to new areas over time. They are also spread by animals moving from one field to another in search of pasture. This has made it easier for the noxious weed to spread to new areas affecting crop yield.

Research on Striga control has been carried for a long time and a wide range of technologies have been developed (Atera *et al*., 2011). Despite efforts made to control the Striga problem, it has persisted and increased in magnitude. Although research on the parasitic weed has a long history, adoption of the control options is limited (Emechebe *et al*., 2004). This is one of the greatest tests to be addressed by researchers as to why farmers are not embracing the control mechanisms.

The development and integration of more tolerant and resistant crops to Striga into upland production systems (UPS) may be a viable option for attaining optimum yields.

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Whereas some studies report resistance, attachment and effect of Striga weed on upland rice growth and yield (Harahap *et al*., 1993; Johnson *et al*., 1997; Gurney *et al*., 2006; Swarbrick *et al*., 2009), only a limited number of cultivars have been evaluated. For instance, the interspecific hybrids known as NERICA have not been evaluated for Striga resistance/tolerance since introduction in the farmers' fields. NERICA rice is slowly becoming an alternative cereal crop in the moist savanna areas of sub-Saharan Africa, where Striga problem has been most severe. Its adoption by smallholder farmers may depend in part if they can withstand the Striga scourge as well as high yield potential. NERICAs should be evaluated in different Striga infected agro-ecosystems to determine any level of exhibition of resistance. Some studies have shown high level of variation existing within and between the Striga populations from Kenya, Mali and Nigeria (Gethi *et al*., 2005). The objective of this study was to assess the performance of NERICA rice cultivars infected with *Striga hermonthica* in western Kenya.

## MATERIALS AND METHODS

**Site description:** Field studies were conducted in the long rains of March to August and short rains of September to January in 2008 and 2009 at Alupe farm of Lake Basin Development Authority, near Busia town (0$^o$ 29′ N, 34$^o$ 07′ E) in western Kenya, where *S. hermonthica* is a serious limitation to cereal crop production. The experimental site receives approximately 1148 mm of rainfall per annum, has mean annual temperature of 29°C and is located at an altitude of 1189 meters above sea level. The soil characteristics at the beginning of the experiment were 4.22 mg $g^{-1}$ of soil organic content, 4.29 mg $kg^{-1}$ Olsen P, 0.099% of N, 0.007% of P and pH of 5.9. The proportions of sand, silt and clay in the soil were 68%, 19% and 13%, respectively. Prior to the trials, the site was under cultivation of local rice varieties.

**Experimental design:** A completely randomized block design was used with three replications in two sites of the farm. Striga infected cultivars were planted on one block, which had been under continuous cultivation of cereals, while controls plants were planted in another block, a recently opened field for cultivation. Five cultivars namely NERICA 1, NERICA 4, NERICA 10, NERICA 11 and Dourado precoce, a local landrace were sub-plots. The characteristics of the cultivars are as shown in Table I. Plots were 2.5 m x 5 m in size. Natural conditions were relied upon at each site. Five seeds were sown by hill at spacing of 30 x 12.5 cm and later thinned to three. To allow Striga to thrive, minimum fertilizer was applied at rate of 60 kg N $ha^{-1}$ (30 kg $ha^{-1}$ at basal and the rest after the first weeding). The infected fields were weeded once with a hoe, after which the weeds were pulled by hand other than Striga to avoid damaging young Striga seedlings. Control fields were weeded three times. The rice seeds were treated with murtano fungicide/insecticide before planting according to label instructions.

**Striga infections:** For purposes of Striga infestation uniformity, the plots were artificially inoculated with Striga seeds. The seeds were obtained from Kenya Agricultural Research Institute, Alupe, harvested from rice field in 2004. Tetrazolium red was used to test seed viability as described by Berner *et al.* (1997). The seeds were mixed with sand sieved through a screen of pore diameter of 250 µm at a ratio of 1:39 by weight to obtain germination of about 3000 seeds per station. The Striga seeds in the mixture were uniformly sprinkled in rows trenches, which were half buried with soil. Rice seeds were planted in hills along the rows as recommended in Kenya.

**Economic yield loss:** Crop yield loss can be defined as the difference between potential yield and actual yield. In this study the actual yield was obtained from the Striga infected area while the potential yield was from uninfected Striga area (control plants). To estimate the economic value of Striga infection losses, the actual loss was measured. Striga economic evaluation (SEE) was determined when crop loss due to the weed was multiplied by the area and the price.

Crop yield loss in the study was presented as the potential yield denoted as $Y_p$ and actual yield as $Y_s$. The crop loss difference was expressed as potential yield proportion represented by $Y_r$, which can easily be used to estimate loss in yield in Striga infected areas if actual yield is known.

$$Y_r = \frac{Y_p - Y_s}{Y_p}$$

The ratio "s" was determined from the representative sample in the field. If the ratio "s" is known, then losses due Striga can be derived using the following formula:

$$Y_p - Y_s = Y_s \frac{s}{1 - s}$$

Similarly, crop loss for a region or country can be determined by using the same formula when potential yield is known. However, Striga in the field is not uniformly distributed and therefore, there are prone to be error margins in the estimates. It is possible to obtain a function that can estimate crop loss within the error margins. In our study, we estimated the economic losses due to Striga using the formula above.

**Data collection and statistical analysis:** Striga emergence counts were done at 8 weeks after seeding. Due to high variability of emerged Striga plants both within and among the treatments, data was transformed using natural logarithms, log (x + 1) to stabilize the variance for the analysis (Johnson *et al*., 1997). Rice plant height and tiller number were estimated from 10 plants per plot at every 14

DASE. The grains were harvested when 80% turned golden brown. Yield was estimated from 20 hills in each plot and corrected to 14% moisture content. All data were subjected to analysis of variance (ANOVA). Whenever significance differences were detected ($\alpha = 0.05$), the means were compared using the Tukey's HSD test at 5% levels of significance.

## RESULTS

**Striga growth and dry matter accumulation:** There were significant effects of Striga infections on growth and yield parameters of cultivars. The first Striga plant emerged 42 days after rice seed emergence. The minimum time taken by Striga to complete the life cycle from emergence was 56 days. Striga plants emerged even after harvesting of the plants. More Striga plants were sighted on plots that were planted with Dourado Precoce and NERICA 4 compared to NERICA 1 and NERICA 10.

Dry matter (DM) accumulation at 30, 60 and 90 days after sowing (DAS) of infected rice cultivars is as shown in Fig. 1. NERICA 10 had higher DM accumulation at 30 and 60 DAS and NERICA 1 at 90 DAS. Our results showed effects on reduction in plant height (Table IV) and biomass of the cultivars. Striga influenced dry matter between different parts (allometry) thereby modifying the architecture of infected plants. The parasite significantly reduced the growth of Dourado precoce and NERICA 11 after 60 DAS. Infected plants produced 42% of the total biomass of uninfected plants.

**Yield components of Striga infected cultivars:** The main effects of the year, interaction of Striga and cultivar significantly influenced panicle production. Average panicles were 213 $m^{-2}$ in 2008 and the corresponding value in 2009 was 202 $m^{-2}$ of Striga infected cultivars (Table III) compared to 280 $m^{-2}$ of the control plants (Table II). Over the years, NERICA 1 produced more number of panicles (262 $m^{-2}$) and the least were recorded in Dourado precoce among the infected plants. Results showed that the simple effects of the treatment factors were significant ($P \leq 0.02$) in 2009. NERICA 10 was ranked lowest in grain size as determined by 1000-grain weight (24.8 g $1000^{-1}$) (Table III). Grain size is ranked highest (29.5–31.1 g) in Dourado both in infected and control plants. There were no significant differences in the grain filling ratio among the cultivars. However, the ratio was lower in NERICA 4 compared to other cultivars.

**Grain yield and economic analysis:** In Striga infected cultivars, there was a significant difference in grain yield. Seasonal difference in paddy yield was noted in response to infections among the cultivars. The mean paddy yield was highest in the infected plots in 2009 compared to 2008 by 24.3%. This was attributed possibly to the amount of rainfall received in the two seasons. The average yield of NERICA 1 for the two seasons was 2243.9 kg $ha^{-1}$, while NERICA 4 was 373.4 kg $ha^{-1}$ in the infected fields (Fig. 2). Relative grain yield loss as result of infections ranged between 33-90% (Table IV). The losses were highest in NERICA 4 and Dourado precoce. Grain yield was highly correlated (R=0.763) with dry matter accumulation in infected plants (Fig. 3).

**Table I: Characteristics of upland rice cultivars used for the trials in 2008 and 2009**

| Cultivars | Stature | Maturity days |
|---|---|---|
| Dourado Precoce | Tall | 95-110 |
| NERICA 1 | Semi dwarf | 95-100 |
| NERICA 4 | Tall | 95-100 |
| NERICA 10 | Tall | 95-100 |
| NERICA 11 | Semi dwarf | 85-95 |

**Table II: Yield parameters of control rice plants in 2008 and 2009**

| Cultivar | Panicle $m^2$ | panicle$^{-1}$ | Grain filling (%) | 100 grain weight (g) | Panicle length (cm) |
|---|---|---|---|---|---|
| Dourado Precoce | 274.3±18.3 | 41.7±6.7 | 83.8±0.9 | 31.1±1.5 | 21.4±1.4 |
| NERICA 1 | 287.9±33.6 | 60.3±4.5 | 84.8±0.9 | 29.8±0.5 | 20.3±1.1 |
| NERICA 4 | 282.4±32.5 | 58.7±6.1 | 84.5±1.9 | 28.7±0.4 | 20.9±0.7 |
| NERICA 10 | 273.4±27.4 | 51.4±2.5 | 88.3±1.2 | 25.9±0.8 | 20.2±0.9 |
| NERICA 11 | 281.6±26.9 | 50.7±5.9 | 82.5±0.3 | 30.3±0.8 | 19.3±0.3 |

All values are mean ± SE for two years

**Table III: Yield parameters in 2008 and 2009 of Striga infected rice cultivars**

| Cultivar | Panicle $m^2$ | Spikelets panicle$^{-1}$ | Grain filling (%) | 100 grain weight (g) | Panicle length (cm) |
|---|---|---|---|---|---|
| **2008** | | | | | |
| Dourado precoce | 160.5 | 13.9 | 59.2 | 30.3 | 17.7 |
| NERICA 1 | 259.6 | 34.0 | 61.1 | 27.6 | 19.0 |
| NERICA 4 | 197.8 | 16.8 | 58.7 | 26.6 | 19.3 |
| NERICA 10 | 234.9 | 35.8 | 62.7 | 23.8 | 17.1 |
| NERICA 11 | 210.0 | 26.5 | 62.6 | 26.9 | 17.4 |
| Mean† | 212.6a | 25.4a | 60.9a | 27.0a | 18.1a |
| LSD (0.05)‡ | 36.9 | 4.5 | 9.6 | 1.2 | 1.1 |
| P-Value | 0.041 | 0.004 | 0.290 | 0.003 | 0.029 |
| **2009** | | | | | |
| Dourado Precoce | 148.2 | 21.5 | 57.1 | 29.5 | 17.1 |
| NERICA 1 | 264.7 | 46.2 | 69.9 | 28.3 | 18.7 |
| NERICA 4 | 161.4 | 17.7 | 50.0 | 25.3 | 18.5 |
| NERICA 10 | 230.3 | 41.2 | 61.6 | 25.9 | 19.2 |
| NERICA 11 | 205.8 | 27.3 | 53.7 | 27.5 | 19.4 |
| Mean† | 202.1a | 30.8b | 58.4a | 27.3a | 18.6a |
| LSD (0.05)‡ | 27.3 | 7.1 | 11.0 | 2.2 | 1.2 |
| P-Value | 0.002 | 0.021 | 0.214 | 0.033 | 0.008 |

†Means of cropping year with the same letters are not significantly different according to LSD at P=0.005. ‡LSD values are for comparison of cultivars for each parameter in each year

**Table IV: Relative plant height and yield loss (%) of rice cultivars due to Striga infection**

| Cultivars | LY† | LPH‡ |
|---|---|---|
| Dourado Precoce | 86.2 | 52.5 |
| NERICA 1 | 46.3 | 12.3 |
| NERICA 4 | 90.2 | 48.8 |
| NERICA 10 | 33.4 | 16.4 |
| NERICA 11 | 72.8 | 21.7 |

†Loss in yield, ‡Loss in plant height. Values are average of two years.

**Fig. 1: Trends of shoot dry matter weight of infected plants in 2009**
Each data point is the mean of three replications of each cultivar

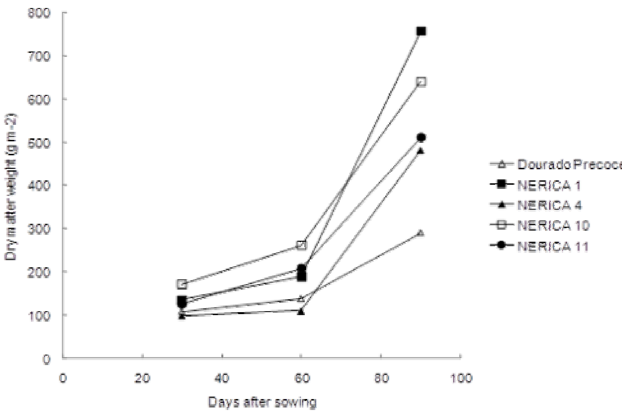
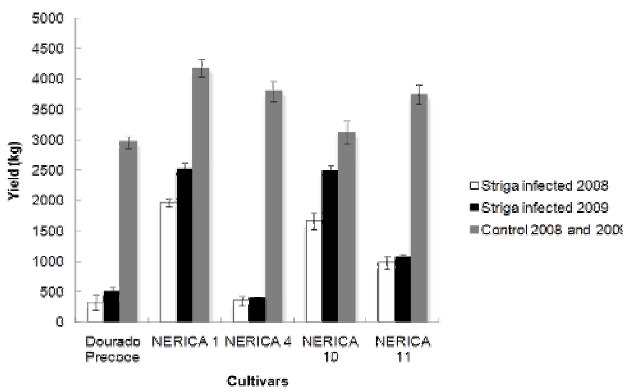



**Fig. 2: Grain yield of Atriga infected and control rice plants at LBDA-Alupe in 2008 and 2009**




Economic yield loss due to infections was highest in NERICA 4 in the two years (Fig. 4). NERICA 10 (US$ 351.7 $ha^{-1}$) was the most economically profitable with the least yield loss followed by NERICA 1 (US$ 652.8 $ha^{-1}$). Dourado precoce, the local landrace known to be susceptible to Striga, performed better than NERICA 4 and NERICA 11. It is important to note that the market prices for the different cultivars used for estimation in Fig. 4 were the same thus, differences in losses were largely due to variations in yield levels of the cultivars.

## DISCUSSION

Mono-cropping has led to continuous mining of nitrogen from the soil resulting into poor soil, which favors Striga infestation. This has played role in the increase of Striga seed densities calling for an innovative and more proactive measures aimed at reducing seed banks. African smallholder farmers depend on cereals as their main source of food which is readily infected by Striga. Dugje *et al.* (2006) studied the effect of Striga infections on maize, sorghum, rice and pearl millet in the savannas of Northern Nigeria and reported that losses resulting from Striga ranged

**Fig. 3: Relationship of grain yield with Biomass accumulation at maturity of infected rice plants in 2009**
Each data point is the mean of three replications for each cultivar

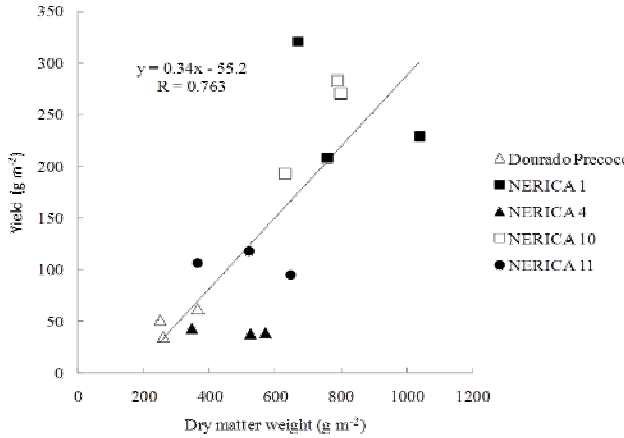
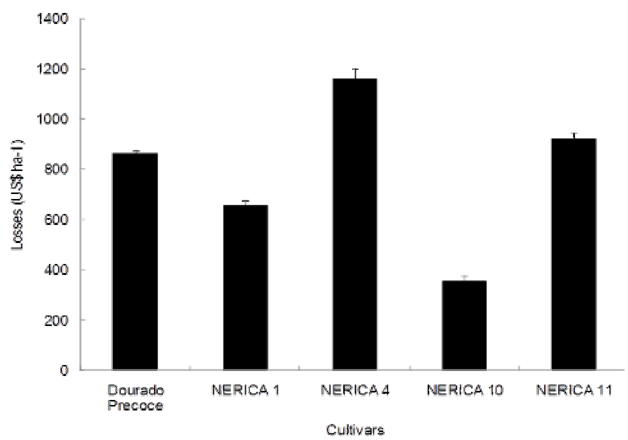



**Fig. 4: Economic losses due to striga at LBDA-Alupe**
Values used represent mean of 2 years. Kenyan shilling was converted to US dollars by using exchange rate of Ksh 81 to US$ 1.00




from slight to total crop failure in heavily infested areas. These results corroborate with our findings, which showed 33-90% of yield loss as a result of infections on the NERICAs. Research conducted in western Kenya to evaluate the tolerance and resistance of rice cultivars also revealed that severe Striga infestation led to complete crop failure (Kouko *et al*., 1992).

Striga infections affect dry matter weight. The Striga reaction on the biomass of the NERICAs expressed as percentage of susceptible Dourado precoce ranged between 40-66%. Dry matter of infected plots was lower compared to uninfected. Similar results have been reported in infected sorghum's biomass (CSH-1 & Ochuti) being lower that of uninfected plants (Frost *et al*., 1997). In addition, Aflakpui *et al*. (2002) showed that shoot biomass of infected maize before any Striga had emerged above ground (at four-leaf stage) was about 93% that of uninfected maize but by the 18-leaf stage it was only 37% that of uninfected maize. NERICAs infected with Striga exhibited changes in growth and allometry when compared with uninfected plants. These included severe stunting of the host lower leaves and stem biomass. The changes in plant hormonal imbalances may be responsible for the differences in allometry observed (Taylor *et al*., 1997). The cultivars supported different levels of Striga densities and tolerance. This variability not only depended on their genetic makeup but also to some extent to the prevailing climatic conditions.

NERICA 1 and NERICA 10 exhibited resistance to *S. hermonthica* infections. The cultivars supported few number of Striga plants in the field. A pot experiment conducted by Kaewchumnong and Price (2008) showed that CG14 had no Striga emergence and is considered highly resistant to *S. hermonthica*. Furthermore, Johnson *et al*. (1997) reported that *O. glaberrima* was less affected by Striga as compared to susceptible *O. sativa* cultivars. NERICA 1 and NERICA 10 being the progenies of CG14 might have inherited resistant genes. However, it has been shown that heritability of traits for Striga infected plants (61-70%) is higher compared to control (37-45%) (Kaewchumnong & Price, 2008). Gurney *et al*. (2006) reported robust resistance in Nipponbare rice cultivar to *S. hermonthica* in post-attachment experiment. In this cultivar, the parasite failed to form xylem to xylem connection to the host plant root. Studies have shown Nipponbare having low numbers of *Striga* and emerging late (if at all) thus concluding that the variety is resistant (Swarbrick *et al*., 2009). However, it was significantly affected by *Striga* as revealed in several traits at harvest (stem dry weight, flower+grain dry weight & plant dry weight) (Kaewchumnong & Price, 2008). These are in agreement with our results as Striga reduced harvest traits of infected NERICAs (Table III). The results clearly indicated that Striga can impose effects on the hosts even in its early and underground stage of development, which might be attributed to the production of toxins by the parasite affecting growth and physiology of the hosts (Press *et al*., 1999).

NERICA rice cultivars evaluated in the present study apparently shared the same parents but they supported different levels of tolerance. Further studies are being carried to investigate the rationale of their variability through genetic mapping and identify genomic regions for Striga tolerance especially in NERICA 1 and NERICA 10. To our knowledge, this is the first of such resistance reported among the NERICAs with this devastating parasite. Similar studies are desirable in different environments to assess Striga reaction with the NERICAs in an array of soil types under different Striga densities and moistures levels.

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