

# Soil Maize Cultivar-related Challenges on *Striga hermonthica* Infested Fields in Western Kenya

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## Abstract

Maize production in Western Kenya is constrained by *Striga hermonthica* and declining soil fertility. Integrated *Striga* Management (ISM) packages have been proposed. An ISM field experiment assessed combination of 4 maize varieties with 5 levels of soil fertility amendments. Imazapyr Resistant (IR) maize and local yellow seed *Shipindi* had highest germination percentages of 90% and 81% respectively, compared to commercial white seed *Duma* and local white seed *Rachar*. *Duma* had significantly large plants in terms of leaf size and plant height; and taking least time to silking and tasseling while producing heaviest cobs and grains per plant. Synthetic fertilizer (DAP+CAN) was associated with the least germination percentage, but produced the largest plants with many leaves, took the shortest time to silking, and produced highest cob weight and grain weight, with very low *S. hermonthica* infestations regardless of the maize varieties. Cattle manure (CM) and water hyacinth compost containing cattle manure culture (HCM) and Effective Microbes™ (HEM) had the highest *S. hermonthica* population per unit area. Maize grown with water hyacinth compost containing Effective Microbes™ (HEM) positively influenced cob weight than those receiving cattle manure (CM) and the controls; while being associated with the highest numerical increase in grain yield/area. Alternative soil fertility interventions based on these observations are therefore proposed.

**Keywords:** compost, Imazapyr Resistant, Integrated *Striga* Management, *Striga hermonthica*

## 1. Introduction

Maize production in Western Kenya is being constrained by the hemi-parasitic weed *Striga hermonthica* (Oswald, 2005; Avedi et al., 2014). Some reports indicate that local yellow pigmented maize varieties, such as *Nyamula* and *Shipindi*, exhibit tolerance to *S. hermonthica* (Ojiem, Ransom, & Wakhonya, 1996; Hassan, 1998). This has been raising research interests, especially the relationship between carotenoid expression in yellow maize and the exudation of strigolactones that stimulate the germination of *S. hermonthica* seeds (Matusova et al., 2005; Li, Vallabhaneni, Yu, Rocheford, & Wurtzel, 2008; Jamil, Charnikhova, Verstappen, & Bouwmeester, 2010; Jamil, Kanampiu, Karaya, Charnikhova, & Bouwmeester, 2012). Greater carotenoid expression with concomitant low rate of carotenoid cleavage is suspected to prevent the exudation of carotenoid-derived germination factors for *S. hermonthica*, particularly strigolactones (Matusova et al., 2005; Sun et al., 2008; Floss & Walter, 2009). Besides, carotenes in yellow maize are important in human nutrition as a source of pro-vitamin A (Hwang et al., 2016).

The innovation of Imazapyr Resistant (IR) maize varieties has offered hope to maize farmers affected by *S. hermonthica* in Western Kenya (Kanampiu et al., 2003; De Groote, Wangare, & Kanampiu, 2007; Woomeer, Mulei, & Kaleha, 2016). Such maize varieties have altered genes for acetohydroxyacid synthase (AHAS) production (Tan, Evans, Dahmer, Singh, & Shaner, 2005), making them insensitive to the Imazapyr herbicide (Green, 2007; Menkir, Chikoye, & Lum, 2010), which instead is lethal to *S. hermonthica* (Makumbi, Kanampiu, Mugo, & Karaya, 2015). Unfortunately, IR maize may face challenges performing under conditions of poor soil fertility and acidification that exist in Western Kenya (Vanlauwe et al., 2008). Various organic and synthetic soil

fertility amendments have been used to enhance plant nutrition while mitigating the effects of *S. hermonthica* (Gacheru & Rao, 2001; De Groote et al., 2010). Composts have been developed from water hyacinth (*Eichhornia crassipes*), with potential of promoting bean-*Rhizobium* symbiosis (Naluyange et al., 2014), as well as enhancing maize production (Osoro et al., 2014). The water hyacinth composts are yet to be tested on *Striga*-infested maize and other cereal crops.

Unfortunately, no single weed control measure has been successful in controlling *S. hermonthica* when applied in isolation (Marley, Aba, Shebayan, Musa, & Sanni, 2004). Integrated *Striga* Management (ISM) systems are therefore being encouraged to control *S. hermonthica* in Africa (Schulz, Hussaini, Kling, Berner, & Ikie, 2003; Avedi et al., 2014). The use of IR maize, or yellow maize that is tolerant to *S. hermonthica*, in combination with water hyacinth composts, could be beneficial for ISM in Western Kenya. Evaluating this ISM approach was the objective of the present study. Our goal is to share information that could create awareness and help mobilize research resources for addressing *S. hermonthica* and soil fertility related problems affecting farmers in Western Kenya.

## 2. Materials and Methods

### 2.1 Study Location

This study was conducted on *Striga*-infested farmer's field in Busia County, Western Kenya (N 00° 41.630'; E 034° 12.543'; and 1197 metres a.s.l). This region is among parts of Africa that are heavily infested by *S. hermonthica* (Kilonzi, 2011). Prior to experimentation, soil samples were randomly collected and analyzed for nutrients at the *SoilCares Laboratory*, Bungoma County. The soils contained nitrogen (1.38 %), phosphorus (2.8 ppm), potassium (2.1 cmolkg<sup>-1</sup>), magnesium (8.0 cmolkg<sup>-1</sup>), carbon (11.45 %), calcium (7.5 cmolkg<sup>-1</sup>) and soil pH of 4.75.

### 2.2 Experimental Design

The experiment consisted of a 4 × 5 factorial treatment design comprising four maize seed types and five types of soil fertility amendments, on a piece of land measuring 32.7 m × 15.9 m. The resulting 20 treatment combinations comprised of plots in the form of 8.7 m long lines spaced at 0.7 m; each having 30 planting holes spaced at 0.3 m. These were laid out in a completely randomized block design of 3 blocks (replicates). The blocks that measured 13.3 m × 8.7 m were spaced at 2 m from each other and 1.3 m from the field boundary. The experiment was conducted during the long rain season (May to July 2014) and repeated once in time, during the short rains (August to November 2014). Climatic data (rainfall) for this region during the study period can be found in Midega et al. (2015a).

### 2.3 Maize and *Striga* Seeds

Seeds of Imazapyr Resistant (IR) maize hybrid (FRC 425-IR) (Freshco Seeds, Nairobi, Kenya), pre-treated with the imidazolinone herbicide (De Groote et al., 2007), and those of *Duma* (SC *Duma* 43) white seed maize variety (Agri-Seed Company Ltd, Nairobi-Kenya), were purchased from Agrovets shops in Busia town, Kenya. The local yellow seed *Shipindi* variety and the white seed *Rachar* variety were purchased from the Busia town market in Kenya. Agronomic performances of these local maize varieties have been reported by Ojiem et al. (1996) and Hassan (1998). *S. hermonthica* seeds (0.5 kg) were obtained from *Striga* harvest stocks at KALRO-Kibos station in Kisumu, and formulated into *Striga* seed-sand mixture (1:4) (Berner et al., 1997).

### 2.4 Soil Fertility Amendments

Diammonium phosphate (DAP) sowing fertilizer (18% N and 46% P<sub>2</sub>O<sub>5</sub>), and calcium ammonium nitrate (CAN) topdressing fertilizer (27% N) (MEA Ltd, Westlands, Nairobi-Kenya), were purchased from Agrovets shops in Busia, Kenya. Water hyacinth compost formulated with Effective Microbes™ (HEM) or with cattle manure culture (HCM) were obtained from our MMUST-VicRes research facility at Otonglo in Kisumu, after being prepared as described by Naluyange et al. (2014). HEM is fortified with Effective Microbes™, comprising of photosynthetic bacteria (*Rhodospseudomonas palustris*), lactic acid bacteria (*Lactobacillus plantarum* and *L. casei*), yeast (*Saccharomyces cerevisiae*), molasses, and water (EM Technologies Ltd, Embu, Kenya) (Higa & Parr, 1994; Chandi, 2003). The nutrient composition of the two water hyacinth composts are outlined in Naluyange et al. (2014, 2016). Cattle manure (CM) was obtained from stocks locally composted through heaping by farmers.

### 2.5 Planting and other Agronomic Practices

Land was prepared by hand-digging, and planting holes (~10 cm diameter and 5 cm deep) excavated using a hoe. The HCM, HEM and CM composts were applied volumetrically using containers of 150 mL per hole as per the

respective treatments and mixed with soil (Naluyange et al., 2014). The water hyacinth composts therefore supplied approximately 0.9 g N, 0.02 g P, and 0.99 g N, 0.03 g P, for HEM and HCM, respectively (Naluyange et al., 2016). DAP fertilizer was applied at the rate of 2 level teaspoonfuls per planting hole (~10 g) and mixed with soil; supplying approximately 2.1 g N and 2.3 g P. One maize seed per hole was planted at a depth of ~3 cm, together with a table spoonful of *S. hermonthica* seed-sand mixture (approx. 1000 seeds) in every planting hole as described by Berner et al., (1997). The DAP treated plants were later top-dressed with CAN once as per the respective treatments at the rate of 2 level teaspoonfuls per maize plant (~10 g), 42 days after planting, supplying ~1.3 g N. Hand weeding was done after every two weeks for all weeds, except *S. hermonthica* (Avedi et al., 2014).

### 2.6 Data Collection

Number of days taken for each maize seed per planting hole to emerge was recorded. The number of emerged maize seedlings out of the total planted seed population per treatment was used to calculate germination percentage. Maize plant growth-related parameters that included plant height, leaf length, leaf width and number of leaves were scored every two weeks until tasseling (10 weeks). Maize plant height from the base of the stem to the apex of the youngest leaf was recorded. The number of open leaves per maize plant, as well as length (base to apex) and width (widest part) of the youngest open leaves were recorded. The number of days from planting to silking, tasseling and physiological maturity of each maize plant was recorded. Cob weights per plant were recorded. Yield-related data that included average grain weight per plant was recorded and expressed as grain weight per unit area.

Number of days from planting to the emergence of the first *S. hermonthica* seedling per host plant was recorded. Population of the parasitic weed per maize plant was recorded daily and used to calculate *Striga* weed population per unit area (counts per m<sup>2</sup>) (Berner et al., 1997); the number of days to flowering of *S. hermonthica* was recorded when the first flower appeared per host plant.

### 2.7 Statistical Analysis

Data was analyzed using SAS 9.1 software (SAS Institute Inc.) at  $P < 0.05$  significance level. Proc Means was used in generating means and standard errors for maize germination percentage, developmental time, plant size and yield-related parameters, as well as *S. hermonthica* developmental time, population per maize plant and per unit area. The two-week scores for plant height, leaf number and size were averaged. Mean germination percentage for maize was computed from individual percentages of the three treatment replicates per season generated by Proc Freq. *S. hermonthica* population was expressed as mean counts/m<sup>2</sup> using sums from the three treatment replicates per season, divided by the 6.3 m<sup>2</sup> plot size (0.7 m × 0.3 m × 30 planting holes). Analysis of variance (ANOVA) between treatments and between seasons was done using Proc GLM with mean separation by Tukey's Studentized Range (HSD) test when there were significant differences.

## 3. Results

### 3.1 Germination Percentage and Developmental Time

Germination percentage was high in IR maize (90 %) and *Shipindi* (81 %) compared to *Rachar* (73 %) and *Duma* (72 %) ( $P < 0.05$ ). Maize germination percentage was lowest in DAP (68 %) compared to the other treatments (CM=77 %, Control = 81 %, HCM = 83 %, HEM = 84 %) ( $P < 0.05$ ). Germination percentage did not vary between the two seasons ( $P > 0.05$ ).

Number of days to maize seed emergence did not vary between the four maize seed varieties and the five soil fertility amendments ( $P > 0.05$ ) (Table 1). DAP+CAN treated maize plants took the shortest period in days to silking, while the controls took the longest period ( $P < 0.0001$ ) (Table 1). Duration to silking (days) was shortest in *Duma* variety and longest in IR maize ( $P < 0.0001$ ) (Table 1). Total days to maturity did not vary between the maize varieties and the soil fertility amendments ( $P > 0.05$ ) (Table 1).

### 3.2 Maize Plant Size and Grain Yields

DAP+CAN treated maize plants were the largest in terms of height, number and size of leaves; the controls produced the smallest plants ( $P < 0.05$ ) (Table 1). There was no difference in number of leaves per plant between the four maize varieties ( $P > 0.05$ ) (Table 1); with the maximum number of leaves at 10 weeks being 17, 16, 17 and 15, for IR maize, local yellow *Shipindi*, local white *Rachar* and improved white *Duma* respectively. *Duma* maize variety had the largest leaves in terms of length and width, followed by the local white *Rachar*, while IR maize and the local yellow *Shipindi* had the smallest leaves ( $P < 0.0001$ ) (Table 1). The maximum size of leaves (length/width) at 10 weeks being 64/10, 69/10.5, 75/9 and 78.3/8.5 for IR maize, local yellow *Shipindi*, local white *Rachar* and improved white *Duma* respectively. IR maize variety had the shortest plants while the other

three varieties were of similar height ( $P < 0.0001$ ) (Table 1); with the maximum height at 10 weeks being 164.5, 220, 220 and 180 centimeters, for IR maize, local yellow *Shipindi*, local white *Rachar* and Improved white *Duma* respectively. Plants in the second season were larger than those in the first season in terms of height, number and size of leaves ( $P < 0.05$ ) (Table 1).

Table 1. Growth and yield of maize varieties grown under different soil fertility amendments on *Striga hermonthica* infested field in Western Kenya

Source of variation	df	Emergence duration	Tasseling duration	Silking duration	Maturity duration	Leaf number	Leaf width	Leaf length	Plant height	Cob weight per plant	Grain weight per plant	Grain weight per unit area
F values												
Season	1	0.80	2.19	5.71	na	33.8**	31.15**	52.3**	201.4***	na	na	na
Variety	3	1.15	14.45***	19.65***	0.42	0.38	9.52***	6.64***	23.37***	7.11***	7.37***	2.57
Fertilizer	4	1.14	1.52	8.25***	0.34	4.44**	26.23***	24.14***	24.27***	13.39***	4.04**	2.28
Fertilizer*Variety	12	1	1.13	1.43	0.55	0.89	1.34	0.77	1.98	0.8	1.39	1.1
Means												
		days	days	days	days	count	centimeters	centimeters	centimeters	grams	grams	Tonnes/ha
Overall mean		6.57±0.45	63.09±0.37	68.81±0.55	107.22±0.29	7.27±0.16	5.16±0.09	43.43±0.13	48.22±0.51	17.11±0.67	69.75±3.55	1.37±0.09
Seasons	First	6.19±0.86 a	64.14±0.34 a	66.9±1.06 a	na	6.59±1.89 b	4.65±0.15 b	40.15±0.65 b	34.79±1.16 b	na	na	na
	Second	6.96±0.08 a	62.33±1.17 a	69.92±0.65 a	107.22±0.29	7.95±1.14 a	5.67±0.11 a	46.70±0.63 a	61.66±1.50 a	17.11±0.67	69.75±3.54	1.37±0.08
Varieties	<sup>d</sup> Duma	6.39±0.08 a	58.24±1.01 c	64.77±0.70 c	106.79±0.71 a	7.08±0.19 a	5.29±0.20 a	43.33±1.60 a	53.80±2.05 a	20.39±1.33 a	86.43±4.63 a	1.35±0.16 a
	<sup>i</sup> IR maize	7.91±1.71 a	68.98±0.87 a	73.46±0.80 a	107.37±0.31 a	7.34±0.43 a	4.74±0.16 bc	37.30±1.33 c	41.36±1.83 b	15.75±1.24 b	44.13±3.80 c	1.11±0.14 a
	<sup>c</sup> Rachar	6.08±0.08 a	62.42±0.87 b	68.59±0.88 b	107.49±0.32 a	7.01±0.15 a	4.88±0.16 b	40.73±1.56 ab	52.57±2.36 a	16.85±0.99 b	82.58±14.44 ab	1.37±0.16 a
	<sup>d</sup> Shipindi	5.91±0.07 a	62.71±1.79 b	68.41±1.51 b	107.27±0.24 a	7.21±0.17 a	4.53±0.18 c	39.91±1.71 bc	56.41±2.93 a	15.45±1.04 b	65.87±4.18 b	1.67±0.15 a
Fertilizers	<sup>h</sup> NON	5.85±0.09 a	65.87±2.60 a	72.08±1.30 a	107.06±0.25	6.38±0.10 c	4.00±0.08 c	33.40±0.85 c	40.76±2.17 c	13.82±1.0 c	55.68±7.45 b	1.00±0.11 a
	<sup>f</sup> CM	6.03±0.08 a	61.81±1.03 a	68.08±1.00 b	107.44±0.28 a	7.45±0.52 ab	4.78±0.14 b	38.94±1.35 b	49.66±2.41 b	15.63±0.97 bc	63.66±6.10 b	1.43±0.20 a
	<sup>g</sup> DAP+CAN	6.20±0.09 a	62.28±1.15 a	65.18±1.45 c	106.77±0.94 a	7.89±0.20 a	5.67±0.11 a	48.19±1.63 a	61.87±3.24 a	22.82±1.33 a	96.83±17.71 a	1.30±0.21 a
	<sup>h</sup> HEM	6.42±0.07 a	62.60±2.05 a	68.41±1.00 b	107.48±0.29 a	7.09±0.09 bc	5.02±0.23 b	40.99±1.12 b	52.83±2.13 b	17.76±1.11 b	69.83±4.69 b	1.64±0.17 a
	<sup>i</sup> HCM	8.35±2.13 a	62.88±1.29 a	70.27±1.65 ab	107.38±0.32 a	6.99±0.07 bc	4.84±0.12 b	40.08±0.91 b	50.07±1.77 b	15.54±0.95 bc	62.77±4.79 b	1.50±0.14 a

Asterisk indicate the significant effect, \*\*\* $p \leq 0.001$ , \*\* $p \leq 0.01$ , \* $p \leq 0.05$ . Means with the same letter(s) are not significantly different ( $p > 0.05$ ); those with more than one letter are intermediate. Interactions are considered over main effects where there were significant <sup>a</sup>Improved white; <sup>b</sup>Imazapyr resistant; <sup>c</sup>Local white; <sup>d</sup>Local yellow; <sup>e</sup>Control; <sup>f</sup>Cattle Manure; <sup>g</sup>Diammonium phosphate; <sup>h</sup>Hyacinth+effective microbes; <sup>i</sup>Hyacinth+cattle manure culture; <sup>na</sup> parameter scored for only one season

DAP+CAN treated plants produced the heaviest cobs, while the controls had the lowest cob weights ( $P < 0.0001$ ) (Table 1). DAP+CAN treated maize plants produced the heaviest grain weight per plant compared to plants from the other four soil amendments, which had similar grain weights ( $P = 0.0077$ ) (Table 1). However, these differences in seed weight between soil fertility amendments were not reflected per unit area ( $P > 0.05$ ; Table 1).

*Duma* maize variety produced the heaviest cobs compared to the cob weights of the remaining three varieties, which were similar ( $P = 0.0006$ ) (Table 1). Grain weight per plant was highest in *Duma* variety and lowest in IR maize, while the two local varieties were intermediate ( $P = 0.0005$ ) (Table 1). However, these differences in grain weight between maize varieties did not reflect in weights per unit area ( $P > 0.05$ ; Table 1).

### 3.3 *Striga Hermonthica* Growth and Population

Per unit area, *S. hermonthica* population was low on plots that received DAP+CAN and high when the CM, HCM and HEM were applied, regardless of the maize variety ( $P < 0.0001$ ) (Figure 1). *S. hermonthica* population per unit area did not vary between seasons ( $P > 0.05$ ). Duration between planting and *Striga* emergence ( $54.3 \pm 1.8$  days) did not vary between the treatments ( $P > 0.05$ ), but was shorter in the first season ( $44.1 \pm 1.9$  days) than in the second season ( $61.5 \pm 0.9$  days) ( $P < 0.0001$ ). Duration between *Striga* emergence and flowering ( $31.3 \pm 0.7$  days) did not vary between treatments and seasons ( $P > 0.05$ ).

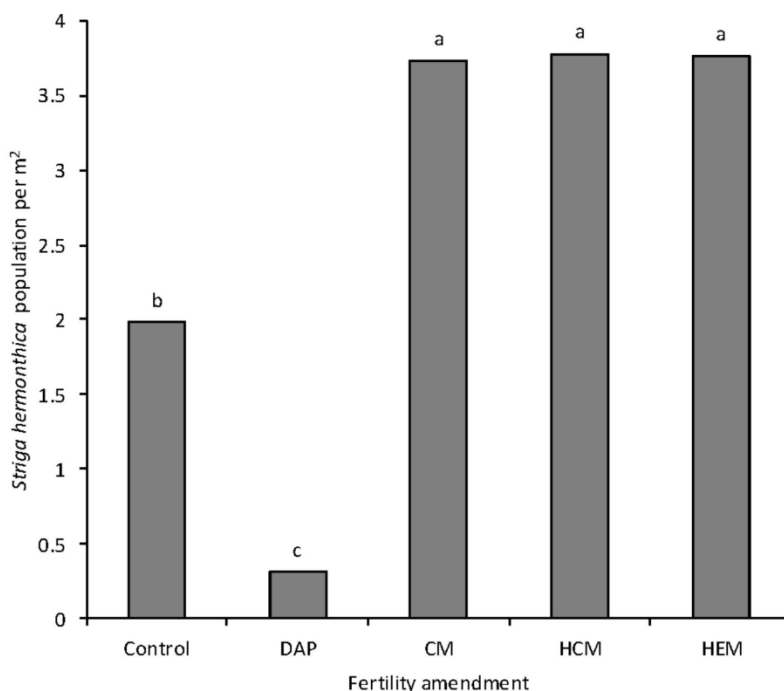


Figure 1. *Striga hermonthica* populations per unit area on maize varieties under different soil fertility amendments in Western Kenya. Bars with the same letter(s) are not significantly different ( $P > 0.05$ ). (DAP= diammonium phosphate with calcium ammonium nitrate topdress, DAP+CAN, CM=cattle manure, HCM= hyacinth +cattle manure culture, HEM= hyacinth +effective microbes)

#### 4. Discussion

Maize varieties in the present study yielded quite below their inherent potential. For instance, IR maize only attained 1.1 ton/ha, yet under ideal soil fertility conditions on farmers' fields, this variety has been found to yield 2.5 ton/ha (Kanampiu & Friesen, 2004). The application of DAP+CAN fertilizers showed potential of improving the size of maize plants. For example, DAP+CAN treated maize plants were 62cm tall, had 8 leaves, with leaf size of 48cm long and 8cm wide; while the controls had the smallest and shortest plants. However, the relevance of the stimulative effect of the DAP+CAN was not reflected in the yield per unit area. The water hyacinth composts and the farmer-produced cattle compost did not offer immediate effect on yield per unit area. Water hyacinth composts have been found to improve maize production (Osoro et al., 2014).

Options for improving maize production on *Striga*-infested fields in Western Kenya are still being sought (Woomer et al., 2016). Despite the fact that the four maize varieties have their varying advantages, IR maize seeds remain ideal for suppressing *S. hermonthica* in Western Kenya (Kanampiu et al., 2003; De Groote et al., 2007). This is because the herbicide kills *S. hermonthica* hence reducing the seed bank of this parasitic weed in the soil (Kanampiu & Friesen, 2004). However, the success of IR maize will greatly depend on the mitigation of the soil fertility problem (Jamil et al., 2012; Larsson, 2012). Alternative soil fertility interventions based on these observations are therefore proposed.

#### 5. Conclusion

IR maize seeds remain ideal for suppressing *S. hermonthica* in Western Kenya. Combined use organic and inorganic fertilizers such as DAP+CAN with water hyacinth compost enhanced with effective microbes (HEM) or cattle manure culture (HCM) could be a viable option for farmers. While DAP+CAN fertilizers offer instant nutrients for maize plant growth, water hyacinth composts on the other hand will improve soil carbon, microbial colonization and diversity, soil fertility and reduce soil acidity in the long run.

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