STRIGA INFESTATION AND MANAGEMENT IN EAST AFRICA

Paul L. Woomer, George D. Odhiambo and Canon N. Savala

FORMAT, P.O. Box 79, The Village Market, Nairobi, Kenya
Email: plwoomer@gmail.com

ABSTRACT

Striga hermonthica and *S. asiatica* are plant parasitic weeds of maize that cause widespread food insecurity. A review of available information on striga was conducted, and a database developed to assess the coverage, intensity, yield decline and economic loss of striga infestation throughout East Africa. The parasite has infested approximately 446,000 of the 3.84 million ha of maize cropland in East Africa (12%), reducing maize grain yields by 385,000 tons per year and causing economic losses of US $56 million yr^{-1}. The problem is greatest in Kenya (217,000 infested ha), followed by Tanzania (164,000 ha) and Uganda (65,000 ha) and is most severe in the Lake Victoria Basin and surrounding midlands. Maize fields in west Kenya contain an average 161 million striga seeds per ha that form 133,000 shoots ha^{-1} within a maize field. For several decades, small-scale farmers sought to control striga by hand weeding, but this practice failed because striga causes damage before emerging aboveground. Two new technologies offer greater control of striga, 1) imazapyr seed coating of herbicide-resistant maize seeds, and 2) intercropping or rotation of maize with field legumes that suppress striga. On-farm testing of these technologies in west Kenya resulted in yield improvement of 785 and 545 kg maize grain per ha, and reduced striga expression by 84% and 71%, respectively. Striga infestation and its reduction through crop management are important, and often overlooked as determinants of soil health. Scientists with interests in land characterization and soil ecology are encouraged to incorporate striga management into their studies.

Keywords: *herbicide resistance, IR maize, parasitic plants, seed bank, soil health, witchweed*

INTRODUCTION

Striga is a parasitic plant that originates from African grasslands but has now invaded vast areas of its cropland. Native grasses and traditional African cereals have some resistance, but most domesticated cereals have little or no ability to fight off the parasite. Germinated striga seeds infect host roots, feeding on the plant below-ground for several weeks, and then a fast growing shoot emerges that produces prolific flowers and thousands of tiny seeds (Odhiambo and Woomer, 2005). Host plants exhibit a range of symptoms including severe stunting, twisted growth and bronzing, and severely infested plants produce little or no yield. Two species of the parasite affect cereal crops in Africa, *Striga hermonthica*, with lavender flowers and common in East and West Africa, and in the Sahel, and *S. asiatica*, with red flowers that has colonized croplands in Southern Africa (Mohamed *et al*., 2001).

From the plant parasite's point of view, uninformed farmers can become very good friends. First, farmers dig the soil, burying last season's striga seeds to a convenient depth. Then they plant striga's favorite host, maize, and later remove other competitor weeds early in the season. Finally, the farmers move through their fields at harvest, searching for their stunted ears of maize while spreading recently-formed striga seeds to new areas, only to repeat the process the following season. Two other factors greatly reduce the effectiveness of hand weeding: much of the crop damage occurs before the striga emerges above ground and striga continues to mature in the field after maize has been harvested. From the farmer's point of view, it is easy to understand why they do not weed underground pests and failing crops.

Too many farm households have developed a fatalistic attitude toward striga, saying that they were born and expect to die with striga in their fields. The purpose of this paper is to derive estimates of the coverage and economic losses consequences of striga in Sub-Saharan Africa and to explore some avenues for better striga management available to small-scale farmers

MATERIALS AND METHODS

Striga coverage and losses. The coverage of striga infestation of maize croplands were calculated based upon information obtained from FAOSTAT, an online service posted by the Food and Agriculture Organization, Cambridge Economic Policy Associates (CEPA, 2004) and other, site specific sources. FAO STAT provided the coverage, average yields and price of maize in 15 African countries. CEPA provided the proportion of maize affected by striga and the maize yield loss due to striga in those same countries. More detailed information on striga in Kenya was obtained from De Groote *et al*. (2002). These data were entered into a computer spreadsheet and the following parameters were calculated for 15 countries: striga-infested area (ha), striga-affected maize yields (kg ha^{-1}), maize yield loss (kg ha^{-1}) and the total economic value of the loss ($ per year). Countries were then grouped by African sub-region and summary statistics generated.

Striga seed banks. Striga seed banks were characterized by elutriation, density separation and counting under stereo binoculars (Eplee and Norris, 1990). Composite samples were collected from 86 farms in west Kenya using a soil auger to 15 cm depth. At least nine cores per sample taken using a 'W' pattern from each field, mixed and a sub-sample of 500 g obtained for striga characterisation. Soils were air-dried and stored in plastic bags prior to elutriation. A soil sample of 250 g soil was placed within an elutriator overflowing into three sieves of different mesh sizes (850, 250 and 90 µm). Striga seeds were then captured within the 90 µm mesh and washed into a 500 ml glass burette column containing a potassium carbonate solution with a specific density of 1.8 g cc^{-3}. Tap water was applied to the column and seeds were retained between the K_2CO_3-water interface. The K_2CO_3 was then drained away using a burette and the seeds were then drained onto a 100 µm nylon cloth. The seeds were then counted using stereo binoculars (Odhiambo and Woomer, 2005). Seed banks are expressed as number per square meter to a depth of 15 cm by adjusting by bulk density and soil moisture content. Seed counts were entered into a computer spreadsheet and summary statistics generated.

Striga Management. Five management options were evaluated involving 1) striga tolerance (KSTP 94 and WH 502), 2) legume suppression (Push Pull and MBILI), and

3) imazapyr resistance (*Ua Kayongo*). These five management options were installed on 120 farms over four consecutive growing seasons. A widely recommended but susceptible variety (H513) was included as a control. All managements received modest additions of fertilizer, 35 kg N and 10 kg P ha^{-1} during the long rains, and 26 kg N ha^{-1} during the short rains as DAP and/or CAN. The trials were farmer installed and managed, and harvests recovered and striga counts performed by local NGO collaborators (Woomer *et al*., 2005). Information on maize and intercropped legume yield, economic returns and striga emergence was collected. Data were compiled into a computer spreadsheet with data entered as columns and farms entered as rows, imported into a statistics program and summary statistics and ANOVAs performed.

Striga Management Utility. The Striga Management Utility was constructed using a computer spreadsheet. The utility requires user information about the number of participating households, their field areas, fertilizer targets, current fertilizer consumption, planting seed rates and price, current yields, commodity price, planned nutrient additions and agronomic use efficiency (AE) of applied fertilizers under conventional fertilizer and Integrated Striga Management (ISM) conditions. These user queries are shaded in grey and must be completed (or default values used) for the utility to calculate its projections. As user inputs are entered, the spreadsheet then calculates current and projected crop production and values for a fertilizer only scenario and within ISM. Fertilizer agronomic efficiency drives the utility's projected yield improvement. The user queries prompt entries as SI units (kg, tons, ha) and values as US$ but any other units may be used if they are entered in a consistent manner.

The costs of the project intervention are totaled, allowing for an overall Project Investment Summary based upon total returns and all project costs. Finally, a separate analysis is preformed for individual farm households participating in the activity, with benefits calculated at the individual farm level (value of increased production and cost of farm inputs). The utility partitions returns from improving fertilizer management alone (FM, as described by the recent African Fertilizer Summit) and the application of more integrated striga management (ISM) in order to assign value to additional efforts directed toward striga control.

RESULTS AND DISCUSSION

Striga affects about 2.36 million ha of maize cropland resulting in grain loss of 1.62 millions tons resulting in an economic loss of US $383 million per year (Table 1). Annual maize grain losses due to striga are greatest in West Africa (0.79 million tons) followed by East Africa (0.46 million tons) and Southern Africa (0.37 million tons). In East Africa, economic losses in Kenya ($28 million yr^{-1}) are greater than Tanzania ($19 million) and Uganda ($8 million). Large losses are also suffered in Nigeria and Malawi.

Of the eighty-three maize farms sampled in west Kenya, 73% were affected by striga (Table 2). On average, these fields contained 161 million striga seeds per ha resulting in 3.0 parasitic stems per maize plant and 778 kg of striga biomass per ha. Striga infestation was greatest in the Lake Victoria Basin (Bondo and Siaya Districts) and least in the Upper Midlands (Vihiga District). Measurements of striga were extremely variable, with CVs ranging between 0.6 and 2.0. Despite lower striga expression (stems per maize plant), striga biomass was greatest in the Upper Midlands, probably due to the more favorable plant growing conditions within that agro-ecological zone (Sombroek *et al*., 1982).

Several management options are available to partially manage striga including resistant varieties (Ejeta and Butler 1993, Woomer *et al*., 2005), intercropping with suppressive legumes (Carsky *et al*., 1994, Khan *et al*., 2005) and the use of herbicide (imazapyr) resistance (Kanampiu *et al*., 2002). In terms of maize yield, there was significant difference in between striga control target approaches and those that were susceptible to the parasite. However, large differences were observed between the long- and short- rains for all the treatments. The economic costs and returns from these different management practices are described in Savala *et al*. (2007).

Hybrid 513 is a widely recommended variety in west Kenya but it appears to be extremely susceptible to striga (2.4 stems per plant). The least striga expression was observed in the imazapyr resistant maize (0.4 stems per plant), followed by systems relying upon legume suppression (0.6 stems per plant) and striga resistance (1.2 stems per plant) (data not presented, see Savala *et al*., 2007). Based upon the expression of striga, we calculate that different management practices result in between 50% and 88% control. Nonetheless, even the best management practice, imazapyr-resistant maize, still contains large numbers of striga stems that must be physically weeded before it sets seed (about 18,000 stems per ha), so none of these control practices may be viewed as a complete success.

Attention is now being directed toward the establishment of striga reduction initiatives (AATF, 2006) that rely upon public-private partnership (Kanampiu *et al*., 2006) and community-based approaches (Otieno *et al*., 2005). The comprehensive and largely successful striga eradication campaigns in the southern USA (Sand *et al*., 1990) offer a promising example but too many differences exist between the methods and investment potentials of African smallholders and US commercial grain farmers for eradication programs to simply be transferred between continents. In addition, some organizations and individuals stand opposed to the widespread introduction and use of imazapyr resistant maize by African farmers based upon ideological reasons (Grain, 2006) and technical misunderstandings (Kim, 2007) and some of this interference has affected donor perceptions. Despite these differences in approach, for the first time technologies exist that permit small-scale farmers to overcome striga and restore maize yields. Striga management does not necessarily result in improved yields, rather it opens the opportunity for maize to respond to other farm inputs, especially fertilizers. Furthermore, many striga managements also affect soil fertility, particularly the use of suppressive legumes that are also symbiotic nitrogen fixers such as soybean, lablab or groundnut.

In keeping with the need for new approaches, a Striga Management Utility was constructed in Microsoft Excel (Table 4). Users enter data on the number of participating farmers, their field size, needed inputs and their costs, current yields, maize price and fertilizer agronomic efficiency and the utility calculates the costs, yield increase, economic value and net returns of a striga management project. The calculations are performed at both the project and participating household level. For example, if 5000 households participate in a project that provides input packages for 0.25 ha and additional funds for extension and information campaigns, then $1.5 million is required. This project would increase maize production by 21,600 tons and result in net returns of $1.9 million. At the household level, each participant would receive 11 kg of fertilizer and 5 kg of seed worth $24. Their food supply would increase by 430 kg and the benefit to cost ratio is 2.8.

The striga management inputs may be extended to households under different terms (e.g. charitable deployment, partial credit, vouchers) and the proceeds generated may be directed toward innovative credit schemes (e.g. revolving funds, community banks), depending upon socio-economic setting and terms of donor investment. For the first time, we can offer African farmers advice and technologies that control striga. It is the responsibility of the research and development community to nest these technologies into collective action programs that bring these assets within the reach of the poorest farmers.

ACKNOWLEDGEMENTS

Information on striga management in west Kenya was provided by Celestine Wekesa (RPK), Dismas Okello (SCODP), Macdonald Wesonga (ARDAP) and George Maina (SACRED Africa) during a collaborative project funded through the African Agricultural Technology Foundation (AATF). All of these individuals and their respective organizations are thanked for their assistance. The authors serve as Coordinator, Striga Ecologist and Farm Liaison Specialist, respectively, within the AATF Striga Management Project operating in west Kenya, and we thank that regional organization for its financial and logistical support.

REFERENCES

AATF (African Agricultural Technology Foundation). 2006. Empowering African Farmers to Eradicate *Striga* from Maize Croplands, AATF, Nairobi.

Cambridge Economic Policy Associates (CEPA). 2004. Striga Control in Africa: Deployment of technologies for eradicating striga infestation in maize fields. EPA, Cambridge, UK. 99 pp.

Carsky, R.J., Singh, L., Ndikawa, R. 1994. "Suppression of *Striga hermonthica* on sorghum using a cowpea intercrop" *Experimental Agriculture* 30: 349-358.

De Groote, H., Wangare, L. and Kanampiu, F. 2002. Potential impact of herbicide resistant maize for Striga control in Kenya. Presented to the *Herbicide–coated IR Maize Promotional Workshop*, Imperial Hotel, Kisumu, Kenya, 4-6 July 2002. CIMMYT, Nairobi. 8 pp.

Ejeta, G. and Butler, L.G. 1993. "Host-parasite interactions throughout the *Striga* life cycle and their contributions to *Striga* resistance". *African Crop Science Journal* 1: 75-80.

Eplee, R.E. and Norris, R.S. 1990. Soil sampling collection equipment and equipment to separate seeds from soil. In: P.F. Sand et al. (Eds) Witchweed Research and Control in the United States. Weed Science Society of America. Champaign, USA. pp. 136-140.

Grain (Pseudonym). 2006. Swapping Striga for patents. Seedling (October). pp 5-9.

Kanampiu, F., Omanya, G., Muchiri, N., Nang'ayo, F., Werehire, P., Tyrell, D., and Sthamer, V. (2006), Launch of *STRIGA*WAY® (IR-maize) technology for *Striga* control in Africa, Proceedings of the launch of the *STRIGA*WAY® (IR-maize) technology. 5-7 July 2005, Kisumu, Kenya.

Kanampiu, F.K., Ransom, J.K., Friesen, D. and Gressel, J. (2002), 'Imazapyr and pyrithiobac movement in soil and from maize seed coats to control Striga in legume intercropping', *Crop Protection* 21: 611-619.

Khan, Z.R., Muyekho, F.N., Njuguna, E., Pickett, J.A., Wadhams, L.J., Dibogo, N., Ndiege, A., Gemga, G. and Lusweti, C. 2005. A Primer on Planting and Managing Push-Pull Fields for Stemborer and *Striga* Control in Maize: A Step-by-Step Guide for Farmers. ICIPE Science Press, Nairobi.

Kim. S.K. 2007. Why Striga and other parasitic weed problems have not been solved in Africa and World for a century? Keynote presentation and paper delivered to the Consultation Meeting "Alliance for Striga Research and Control for Enhanced Food Security in Africa", Ouagadougou, Burkina Faso. Organized by the African Union-SAFGRAD, 20-21 June 2007. 7 pp.

Mohamed, K.L., Musselman, L.J. and Riches, C.R. 2001. The genus *Striga* (Scrophulariaceae) in Africa. Ann. Missouri Botanical Garden 88: 60-103.

Odhiambo, G. and Woomer, P.L. 2005. "Striga emergence and seed bank dynamics under different maize management practices in western Kenya". African Crop Science Conference Proceedings 7:473-477.

Otieno, H., Maina, J., Omare, M.N., Omanya, G. and Woomer, P.L. 2005. "Field testing imazapyr-resistant maize to control *Striga* in western Kenya". African Crop Science Conference Proceedings 7: 461-465.

Sand, P.F., Eplee, R.E. and Westbrooks, R.G. (Eds). 1990 Witchweed Research and Control in the United States. Weed Science Society of America, Champaign, USA.

Savala, CEN, Odhiambo, G.D. and Woomer, P.L. 2007. Integrated Striga Management in Kenya. Presented at the TSBF-CIAT African Green Revolution Conference, Arusha Tanzania, 18 to 22 September 2007 (in press).

Sombroek, W.G., Braun, H.M.H. and van der Pouw, B.J.A. 1982. Exploratory Soil Map and Agro-climatic Zone Map of Kenya. Kenya Soil Survey Report E1. National Agricultural Research Laboratories, Nairobi. 56 pp + maps.

Woomer, P.L., Tungani, J., Odhiambo, G. and Mwaura, F.M. 2005. Striga management options in western Kenya. African Crop Science Conference Proceedings 7: 479-484.

Tables

Table 1. *Striga* coverage, yield reduction and economic loss in Africa's maize croplands, by sub-regions and for selected countries

Area	Coverage (x 1000 ha)	Maize grain loss (tons per year)	Economic loss (US $ per year)
Sub-Saharan Africa	2,363	1,623,838	$383,290,000
Southern Africa	589	372,802	$69,708,000
Malawi	291	208,221	$27,900,000
West Africa	1,243	790,084	$250,095,000
Nigeria	835	505,308	$205,660,000
East Africa	446	384,540	$55,920,000
Kenya	217	182,227	$28,610,000
Tanzania	164	141,145	$19,050,000
Uganda	65	61,168	$8,260,000

Table 2. The incidence, seed bank, expression and biomass of *Striga hemonthica* on 86 maize farms in west Kenya (CV in parentheses).

Zone	Sample (farms)	Frequency	Seed Bank (x 10^6)	Expression (stems/plant)	Field biomass (kg ha^{-1})
Lake Basin	30	0.87	259 (1.6)	4.9 (0.7)	569 (1.4)
Midlands	36	0.59	124 (2.0)	2.9 (1.0)	na
Upper Midlands	20	0.75	77 (1.4)	2.3 (0.6)	1109 (0.6)
Overall	86	0.73	161 (1.9)	3.0 (0.9)	778 (1.0)

Table 3. Maize and bean yields during the long and short rains and striga expression after two years of striga control.

Management	Long Rains		Short Rains	
	Maize yield	Bean yield	Maize Yield	Bean Yield
	-------------------------- kg ha^{-1} --------------------------			
Susceptible hybrid[1]	1694	422	1218	209
Resistant hybrid[2]	3201	159	1488	251
Resistant OPV[3]	3031	474	1315	250
Push Pull [4]	2783	na	1141	na
MBILI Push Pull[5]	2778	639	1225	362
IR maize untreated[6]	2340	437	997	249
IR maize treated[7]	2929	404	1553	222
$LSD_{0.05}$	527	96	511	63

[1]Recommended hybrid H513 intercropped with bean. [2]WH502 intercropped with bean. [3]KSTP94 intercropped with bean. [4]WH502 intercropped with desmodium. [5]WH502 intercropped in staggered rows with bean and desmodium. [6]*Ua Kayongo* hybrid not treated with imazapyr intercropped with bean. [7]*Ua Kayongo* hybrid treated with imazapyr intercropped with bean.

Table 4. A projection by the Striga Management Utility based upon 50,000 households in west Kenya establishing striga control on 0.25 ha.

Scenario: **West Kenya Maize Project**

Project clients and area

1	number of households (no)	50000
2	area per household (ha)	0.25
3	total project area (ha)	**12500**

Input and extension costs

4	current fertilizer use (kg/ha)	8
5	target fertilizer use (kg/ha)	50
6	fertilizer price ($/kg)	$1.12
7	fertilizer nutrient cost ($/household)	**$11.76**
8	seed planting rate (kg/ha)	20
9	seed cost ($/kg)	2.5
10	seed costs ($/household)	**$12.50**
11	total input costs ($)	**$1,213,000**
12	ISM services ($/household)	$6.00
13	ISM project costs ($)	**$300,000**
14	total project costs ($)	**$1,513,000**

Baseline yields and returns

15	Current yield (t/ha)	0.84
16	Current production (t)	**10500**
17	Commodity price ($/t)	$157
18	Current value ($)	**$1,648,500**

Fertilizer management yields and return

19	FM AE (kg/kg)	3
20	FM yield (t/ha)	**0.97**
21	FM increased production (t)	**1575**
22	FM increase value ($)	**$247,275**
23	FM baseline benefit:cost ratio	**0.42**

Integrated Striga Management yield and return

24	ISM AE (kg/kg)	32
25	ISM organic inputs (kg FE/ha)	12
26	ISM yield (t/ha)	**2.57**
27	ISM increased production (t)	**20025**
28	ISM increase value ($)	**$3,143,925**
29	ISM benefit:cost ratio	**3.40**

Project investment summary

30	Fertilizer increase (MT)	**525**
31	Total increased production (MT)	**21,600**
14	Total project costs ($)	**$1,513,000**
32	Gross returns ($)	**$3,391,200**
33	Net return ($)	**$1,878,200**
34	Overall benefit to cost ratio	**2.24**

Benefits per household (HH)

35	HH additional fertilizer inputs (kg)	**10.5**
36	HH additional seed inputs (kg)	**5**
37	HH input costs ($)	**$24.26**
38	HH crop increase (t)	**0.43**
39	HH increased crop value ($)	**$67.82**
40	HH net return ($)	**$43.56**
41	HH benefit to cost ratio	**2.80**