Technical Note Series

Kenya Agricultural Research Institute

KARI Technical Note No. 19, March 2006

Options for *Striga* management in Kenya

Esilaba A.O.

Striga (witchweed)

Published 2006

Author
Anthony O. Esilaba
Kenya Agricultural Research Institute,
P.O. Box 57811-00200 Nairobi, Kenya

Technical editing
Rachel Rege and Jane Wamuongo

Copyediting
John Ayemba

Production editing
Mwangi Mwariri

Layout and design
John Ayemba and Phyllis M Alusi

Photographs
Anthony O. Esilaba

Cover photo
Striga-infested sorghum

Publications Unit
Kenya Agricultural Research Institute
P.O. Box 57811-00200 Nairobi, Kenya
Tel: (254 20) 4183301-20
Fax : (254 20) 4183344
E-mail: resource.centre@kari.org
Website: www.kari.org

ISBN: 9966-879-65-X

Publication sponsored by: KARI

Contents

Introduction

Striga (witchweed) is one of the most important pests that affect food production in the tropics. In Kenya, the parasite is a serious pest that mainly threatens maize production. Yield losses are between 65 and 100%. With increasing demographic pressure and demand for food, there has been intensification of land use, monocropping and consequently a decline in soil fertility. This depletion of soil fertility is one of the main causes for the increase in *Striga* incidence (Ransom, 1996).

Research conducted over several years in Africa has provided several control technologies including use of resistant and tolerant varieties, and various agronomic practices, herbicides, fertiliser and manures (Esilaba and Ransom 1997; Esilaba *et al*., 1997a). These technologies have not been widely adopted due to the mismatch between technologies and the farmers' socioeconomic conditions, particularly the non-availability of economically feasible and effective technologies. This is also because of the inadequacy of any one single component for sustainable *Striga* control and the absence of integrated management strategies suitable for the existing farming systems. There is need therefore to adopt a farming systems approach for the development and implementation of integrated *Striga* management strategies suitable for the various agroecosystems.

Origin, occurrence and distribution of *Striga*

Sriga hermonthica (Del.) Benth originated in the Nuba mountains of the Sudan and in parts of Ethiopia. It is most common on heavy soils particularly in the densely populated parts of the Lake Victoria region of western Kenya (Dogget, 1965; Kiriro, 1991; Frost, 1994). It is also widespread in eastern and northern Uganda on sorghum and finger millet (Dogget, 1965; Oryokot, 1994; Ebiyau *et al*., 2000). *Striga asiatica* is found in the Coast Province and seriously damaged upland rice (Kiriro, 1991). Hassan and Ransom (1998) confirmed that *Striga* incidence in maize is increasing in the moist transitional zone in Kenya with a total affected area of about 300,000-500,000 ha.

Economic importance of *Striga*

The effect of *Striga* damage on crops is a reduction in yield. The extent of yield loss is related to the incidence and severity of attack, the host's susceptibility to *Striga*, environmental factors (edaphic and climatic) and the management level at which the crop is produced. Maize yield losses of up to 81% have been recorded in western Kenya (Ransom *et al.*, 1990). About 1000 *Striga* parasites per hectare can cause a grain yield loss of 2-3 kg ha^{-1} of sorghum and probably more on maize (Kiriro, 1991). Arable lands are often abandoned because of the prohibitive parasite populations (Doggett, 1984).

New approaches to *Striga* control and their limitations

Controlling *Striga* and other root parasites is difficult because the weed can do much damage to the host crop before emerging above the ground. Cultural, mechanical, chemical and biological control measures are available to regulate the parasite population. However, few of these techniques can provide complete *Striga* eradication and it is usually necessary to use a combination of these methods (integrated control) most relevant to the farming system (Parker and Riches, 1993).

Cultural and mechanical control methods

Hand-weeding/hand-pulling

Hand-weeding is the most widely practised control method for *Striga* in Kenya (Frost, 1994). Due to high labour costs in repeated hand-pulling of *Striga*, it is recommended that hand-pulling should not begin until 2-3 weeks after *S. hermonthica* begins to flower to prevent seeding (Parker and Riches, 1993). Hand-pulling *Striga* plants before seed set in a maize crop is as effective as trap cropping in restoring the productivity of land infested with *Striga* in western Kenya (Odhiambo and Ransom, 1994). Labour needed for such later hand-pulling is less than half that required for early pulling. Hand-pulling will usually need to be continued for 3-4 years and is most economical on the least infested fields (Parker and Riches, 1993; Ransom, 1996).

Rotation: trap-crops and catch crops

Crop rotation of infested land with non-susceptible crops or fallowing is theoretically the simplest solution. Rotation with non-host crops interrupts further production of *Striga* seed and leads to decline in the seed population in the soil. The practical limitations of this technique are the more than 3 years required for rotation. The choice of rotational crop should therefore be based 1st on its suitability to the local conditions and only secondarily on its potential as a trap crop (Parker and Riches, 1993).

The use of trap and catch crops that induce the germination of *Striga* but are not themselves parasitised is currently one of the best methods to control agricultural root parasites. Roots of cotton, cowpea, jute, soya bean, pigeon pea, chickpea, kenaf and groundnut stimulate the germination of *S. hermonthica* in the Sudan.

Other potential trap crops include sunflower, lablab, lupin, lucerne, phaseolus bean, pea and faba bean. Although cotton, velvet bean, millet, sunflower and mungbean are considered as trap crops, there was little benefit in terms of *Striga* numbers or crop yield from a 5-year rotational treatment in Uganda (Doggett, 1965). Odhiambo and Ransom (1996) also found that trap crops (cowpeas and cotton) were not better than continuous maize in reducing *Striga* numbers in Kenya.

Catch crops are planted to stimulate a high percentage of the parasite seeds to germinate but are destroyed or harvested before the parasite can reproduce. A thick planting of Sudan grass at 20-25 kg seed per hectare should be sown and either ploughed in or harvested for forage at 6-8 weeks before *Striga* seeds. The main crop could then be planted during the main rains (Parker and Riches, 1993).

From the available studies, it can be concluded that trap crops should be cultivated for at least 3 consecutive years in order to reduce parasite seeds (Esilaba and Ransom, 1997). Areas that may require further research include soil fertility management (Odhiambo and Ransom, 1996), appropriate dates of sowing of the component crops, plant arrangement and population density for effective *Striga* reduction.

Time and method of planting

The degree of infestation of the host plant by *Striga* can be affected by the sowing date. Field trials in Kenya indicate that planting date had no consistent effect on mid season *Striga* counts and parasitism of maize or sorghum (Ransom and Osoro, 1991). The selection of the genotype was more important than date of planting in minimising *Striga* related yield losses. Furthermore, in a bimodal rainfall pattern, *Striga* is normally worst in the crops sown in the early rains. Although early planting did not significantly reduce *Striga* emergence, the potential crop yield of the season was realised. Under suitable soil and climate conditions, high planting density in rows should be the goal.

Nitrogen fertiliser

The use of nitrogen to suppress *Striga* has been demonstrated in the East and Central African highlands (Esilaba and Ransom, 1997; Esilaba *et al*., 2000; Gacheru and Rao (2001). Mumera (1983) recorded a 64% reduction in S. hermonthica emergence in maize using 39 kg N ha^{-1} as calcium ammonium nitrate (CAN). Studies in western Kenya show that CAN at 0-140 kg N ha^{-1} had no significant effect on maize yield but reduced *Striga* populations. Increases in maize yield after application of 20 t ha^{-1} and 300 kg N ha^{-1} as ammonium sulphate nitrate were also reported in Kenya. Farmyard manure trials indicated that 100 t ha^{-1} reduced *Striga* counts and increased maize yield. Mumera and Below (1993) found that although *Striga* infection generally declined with increasing N availability, the impact was partially dependent on the severity of infestation.

The results of field trials with basal application of N fertiliser over many years in many countries have not been consistent in terms of either crop yield or *Striga* numbers. However, Ransom and Odhiambo (1994) showed that there was N by organic matter interaction in field studies carried out in Kenya. From the many studies conducted on the effect of fertiliser on *Striga*, it may be concluded that under certain conditions, N may reduce infestation. However, under nutrient depleted soil conditions, fertiliser may stimulate infestation. This increase could be due to an increase in the biomass of host roots enabling more parasite seeds to germinate. The difference in results from various N fertiliser studies may be due to differences among host plants, chemical interactions, micro-organisms, soil texture and moisture. Other factors may include the source of fertiliser N (Mumera and Below, 1993), the time of its availability in relation to crop growth or even transfer of ammonium to nitrate.

Intercropping/mixed cropping

There are conflicting reports on the effect of intercropping cereals (hosts) with legumes (non-hosts of cereal *Striga*). However, studies in Kenya indicate that intercropping with cowpeas between the rows of maize significantly reduced *Striga* numbers when compared to within the maize rows (Odhiambo and Ransom, 1993).On-farm trials show that intercropping of maize and beans in the same hole in *Striga* infested farmers' fields increased maize yields by 78.6% in western Kenya (Odhiambo and Ariga, 2004). Similarly, a push and pull strategy for integrated pest management has shown that fodder legumes (*Desmodium uncinatum* and *D. intortum*) intercropped with maize to repel stem borers reduced *Striga* infestation in western Kenya (Khan *et al*., 1999, 2000, 2002). The effect was significantly greater than that on other legumes such as cowpeas, as were the concomitant yield increases. In screen house studies, there was a highly significant reduction in *S. hermonthica* infestation which was attributed to allelopathic mechanisms of *Desmodium* spp. that involved a germination stimulant for *S. hermonthica* and also an inhibitor for haustorial development (Khan *et al.,* 2002).

A common feature of these reports is that cereal crop yields were significantly reduced by intercropping. The intercrop yield can under favourable conditions compensate for the loss of cereal in economic terms, but the practice may not be acceptable to farmers already suffering reduced cereal yield due to *Striga*. There is therefore a need to conduct research to explain the effect of intercropping on both the above ground and the below ground development of both the host crop and the parasite. In this way, cultural practices that may reduce the damage caused by the parasite can be determined.

Development of *Striga* resistant/tolerant varieties

The development of resistant and tolerant lines of susceptible crops constitutes an important, practical and reliable approach to controlling *Striga*. Host plant resistance is an effective means to reduce the reproduction of the parasite. The main success using this approach has been on sorghum in East and Central Africa.

Sorghum

Serena, a cross between Dobbs and Swaziland variety P127, had a satisfactory level of *Striga* resistance. Further crossing of Serena produced Seredo which had some resistance during screening trials in western Kenya (Kiriro, 1991). Mumera (1983) found Serena and Serenex to have high resistance while MY146 and ZKX were susceptible and MY146 tolerant. Several Machakos/Yatta landraces (MY134, MY183 and MY95-Z) performed well under *Striga* infestation (Kiriro, 1991). Field screening of sorghum cultivars conducted in Kenya identified stable resistance for ICSV 1112 BF, Namonimbri and IS 9830. High *Striga* susceptibility was observed for 88MW 5200, MY 134, SAR 24, Andiwo II, Esuti, Neburomoyi and Othuwa I (Ayiecho and Nyabundi, 2000).

Maize

Screening for resistance to *Striga* in maize was initiated at the International Institute of Tropical Agriculture (IITA) in 1982. Considerable progress has been achieved at IITA and by the International Maize and Wheat Improvement Centre (CIMMYT) in developing open pollinated varieties, inbred lines and hybrids that have both reduced host plant damage symptoms (tolerance) and reduced parasite emergence under artificial infestation with *S. hermonthica* (Kling *et al*., 2000). Resistant varieties have been developed with adaptation to the lowland and mid-altitude ecologies, with a range of maturity, grain colour and grain texture characteristics. The best varieties have been extended to farmers through the efforts of the regional maize and *Striga* networks and several collaborative projects (Kling *et al*., 2000).

In Kenya, Ransom and Odhiambo (1992) investigated the growth and development of *S. hermonthica* on sorghum cv Seredo, Serena and maize cv H511, H512, H622, H632 and Katumani Composite. Maize was more sensitive to *S. hermonthica* parasitism than sorghum. Katumani Composite supported less *Striga* and yielded more than H511 and H622 in a heavily infested field. Further work under field conditions showed that fewer roots were present in the topsoil for Katumani, confirming that avoidance rather than resistance was the mechanism associated with reduced *Striga* attack (Baltus *et al*., 1994). Odhiambo and Ransom (1995) evaluated 15 genotypes of maize with a wide range in days to maturity for the level of *S. hermonthica* parasitism. The results indicated that in some seasons, early maturing genotypes can reduce *Striga* attack in heavily infested areas and yield more than late maturing genotypes. Odongo and Abayo (1999) tested 7 maize varieties in western Kenya and 2 varieties (Nyamula and KTSP94) were found to be tolerant to *Striga* infestation.

Rice

Harahap *et al*. (1993) evaluated 46 upland rice breeding lines in field trials for their resistance to *S. hermonthica* in Kenya. The lines differed markedly in their reaction ranging from highly resistant to extremely susceptible varieties. The genes for resistance to *S. hermonthica* may be easily incorporated into rice.

Sugarcane

Mbogo and Osoro (1991) found that sugarcane variety Co-617, although allowing some infestation, was highly resistant to *S. hermonthica*. Others with nearly equal resistance included KEN-83-1228, KEN-83-538 and KEN-83-1161.

Chemical control methods

Germination stimulants

Certain chemicals such as ethylene, ethephon, strigol and strigol analogues can induce germination of *Striga* seeds in the absence of a suitable host and therefore seed reserves in the soil (Esilaba and Ransom, 1997). Ethylene can reduce *S. asiatica,* however, *S. hermonthica* may not be well controlled by ethylene under field conditions in eastern Africa (Ransom and Njoroge, 1991).

Herbicides

Among the chemicals investigated for efficacy in controlling *Striga* is Dicamba which can provide early season control but has not proven to be consistently cost-effective (Odhiambo and Ransom, 1993). However, Imazapyr gives early season *Striga* control in specific varieties with increased maize yields and may offer complete control at an affordable cost for subsistence farmers (Abayo *et al*., 1996 and 1998). Recent on-farm trials in Kenya and Tanzania indicate that seed dressing with Imazapyr and Pyrithiobac offers good *Striga* control and increased maize yields (Kanampiu *et al*., 2004). Many herbicides are useful in preventing the build-up of *Striga* seeds in the soil but may not prevent the damage done by *Striga* plants before emergence. Research efforts should therefore be directed towards identifying herbicides that persist in the soil, allowing the germination of *Striga* seeds but killing the seedlings before attachment to the host. Herbicides must also be compatible with the mixed cropping systems practiced by farmers and be profitable to use with low initial capital outlay.

Biological control methods

Few systematic studies of individual natural enemies of *Striga* and their influence on the population of host plants have been conducted. The genus of greatest interest for biological control is *Smicronyx* of which several species are highly specific to *Striga*. Some fungal pathogens have been isolated from emerged *Striga* plants of which *Fusarium nygamai* and *F. semitectum* var. *majus* reduce germination and/or kill *S. hermonthica*. However, further studies under field conditions need to be conducted.

Integrated control of Striga

Several integrated techniques for the control of *Striga* have been developed and tested. Mumera (1983) investigated the efficacy of 3 herbicides with N fertiliser on maize and sorghum cultivars. Several on-farm trials have been conducted in western Kenya to compare proposed integrated *Striga* management practices with farmer practices. These trials involved the use of FYM at 10 t ha^{-1}), fertiliser (50 kg ha^{-1} and 50 kg P_2O_5 ha^{-1}, normal hand-weeding, and 3 maize varieties (hybrid 511, synthetic Tzi 1 and a local variety). Results showed that long-term repeated application of appropriate packages was required to confirm their cumulative benefit. Odhiambo and Ransom (1994) evaluated long-term effects of trap cropping (cowpea and cotton and other maize management systems (fertiliser, hand-pulling and ethylene) on the restoration of land infested with *S. hermonthica* for 4 seasons. Trap crops were not effective in reducing numbers while ethylene reduced *Striga* infestation but did not increase maize yields as the soil fertility was low. Hand pulling *Striga* before seed set was as effective as trap cropping. However, application of fertiliser to maize and repeated hand-pulling led to the highest infestation and the highest maize yield (Odhiambo and Ransom, 1994). Ransom and Odhiambo (1994) found that incorporation of stover combined with fertiliser and hand-weeding had the highest yield. They recommended that maintenance of soil fertility (fertiliser and crop residues) and the removal of *Striga* before seed set would restore the productivity of lands infested with *Striga.* Ransom and Odhiambo (1994) recommended that maintenance of soil fertility (fertiliser and crop residues) and the removal of *Striga* before seed set would restore the productivity of lands infested with *Striga*. However, the best solution in the control of *Striga* is an integrated approach that includes a combination of methods that are affordable and acceptable by farmers.

The priority in all field projects should be to generate information from which farmers can make optimum decisions on rotation, fallowing, choice of cereal species and variety, time and method of planting, mixed cropping, manuring, herbicide and hand pulling as relevant to the farming system. Long-term integrated systems have to be developed based on sound agronomic principles and involving all options for maintaining and improving soil fertility (Parker and Riches, 1993). Effective preventive measures need to be taken through seed quarantine, *Striga* free equipment, reproduction denial and burning material which may contain viable seeds (Parker and Riches, 1993). There is need to launch an action program to control *Striga* in Kenya. Farmers, relevant government ministries, non-governmental organisations (NGOs) and extension agents need to be alerted on the potential problems of *Striga*. There may be a need to legislate against its spread and also take positive steps to control it. Extension staff should be trained to identify *Striga* symptoms in plants and teach farmers the same skills, so that appropriate control measures may be taken in time.

Recommendations

Short-term research strategies

The short-term research areas include identification of pre-emergence herbicides and screening of available post-emergence herbicides for effectiveness in *Striga* control. However, research efforts should be directed towards identifying herbicides that are cheap, persist in the soil and are compatible with the mixed cropping systems practised by most subsistence farmers. Studies indicate that seed dressing with Imazapyr to maize with target site resistance shows promise as a technology for reducing *Striga*-related yield losses for small-scale farmers (Abayo *et al*., 1996 and 1998). The use of glyphosphate with glyphosphate resistant maize should also be evaluated. To control the spread of *Striga*, the mechanisms of dispersal need to be better understood. Increased efforts on developing resistant and tolerant varieties are needed including the use of the recently developed biotechnology approaches.

Long-term research strategies

Long-term research efforts should be directed in areas that reduce the *Striga* seed bank in the soil (Ransom, 1996). The effects of fertiliser, soil structure and soil microbiology on *Striga* in crops should be investigated. The beneficial effects of N fertiliser in controlling *Striga* (Esilaba *et al*., 2000; Gacheru and Rao, 2001) should be utilised. The relationship between ammonium-N and nitrate N as well as the chemical composition of *Striga* infested soils needs to be investigated. This relationship could be influenced by various factors such as bacterial activity, soil moisture, pH, and organic material and could vary seasonally. Therefore laboratory, greenhouse and long-term field research is required to determine the response of *Striga* to different amendments and soil conditions. Long term investigation on the role of organic matter, microorganisms, nematodes and other organisms that influence decomposition and mineralisation needs to be conducted. In other words, a more holistic approach to soil health and activity rather than focus on nitrogen alone.

The use of legumes, locally available organic resources and agroforestry landuse systems that maintain and improve soil fertility through biological N fixation, nutrient cycling and increase soil organic matter need to be explored (Esilaba *et al*., 1999; Rao and Gacheru, 1998; Gacheru and Rao, 2001).

Long-term studies including the effects of trap crops and the health of trap crops, varieties and fertility, among others, in rotation with or without mixed cropping on *Striga* are required. The use of trap crops as an intercrop with susceptible hosts to reduce the seed bank needs prolonged investigations. The appropriate dates of sowing for the component crops, spatial plant arrangement and population density for effective *Striga* reduction should be considered. In addition, there is a need to identify cash and food crops that are already part of the farmers cropping system that can serve as trap crops or that can be economically grown by farmers instead of the susceptible cereals.

The use of resistant varieties is the most appropriate means of combating *Striga* in resource-poor developing countries. Since *Striga* is an obligate parasite, there is scope for the discovery and utilisation of resistant and tolerant crop varieties. Some resistant or partially resistant varieties have not been tested repeatedly in long-term trials to determine the durability of the resistance. Often, the resistant varieties do not have desired characteristics like grain colour, plant height and yield potential. Future research efforts should be directed towards understanding host resistance mechanisms, improvement of field screening and infestation techniques, development of rapid, reliable screening techniques for resistance identification and development of stable high yielding *Striga* resistant varieties that are acceptable to farmers. However, reliance on resistance/tolerance alone for effective control of the parasite is not possible and should be supplemented by other methods.

Certain chemicals induce germination of *Striga* seeds in the absence of suitable hosts, and can therefore be used to deplete the seed bank in the soil. The efficient use of stimulants, formulations that are cheap, easy to apply and are persistent in the soil need to be developed for small-scale farmers. Germination stimulants have been detected in many *Euphorbia* species and it is possible that other common indigenous plants could be exploited as stimulants for *Striga* control.

The development of integrated control measures requires a farming/cropping systems approach. Moreover, few economic evaluations have been conducted on the feasibility of different *Striga* control measures due to the lack of long-term data. Long-term socioeconomic implications of the parasite problem need to be investigated. Component researchers can use this information to develop control measures and provide guidelines on the allocation of resources.

Finally, long-term research efforts should be also directed on the possibilities of using biological control methods for *Striga*, but most particularly those that are directed towards reducing seed banks or that control *Striga* before attachment.

Acknowledgement

This Technical Note has been published with permission from the Director KARI.

References

[1] Abayo, G.O., English, T., Eplee, R.E., Kanampiu, F.K., Ransom, J.K. and Gressel, J. (1998). Control of parasitic witchweeds (*Striga* spp.) on corn (*Zea mays*) resistant to acetolactate synthase inhibitors. *Weed Science 46*, pp 459-466.

[2] Abayo, G.O., Ransom, J.K, Gressel, J. and Odhiambo, G.D. (1996). *Striga hermonthica* control with acetolactate synthase inhibiting herbicides dressed to maize with target site resistance. *In*: Advances in Parasitic Plant Research. Moreno, M.T., Cubero, J.I., Berner, D., Joel D., Musselman, L.J. and Parker, C. eds). Proceedings, 6th Parasitic Weed Symposium. Cordoba, Spain. April 16-18 1996. pp 761-768.

[3] Ayiecho, P.O. and Nyabundi, J.O. (2000). Field screening of sorghum cultivars for *Striga* resistance. *In*: Breeding for *Striga* resistance in cereals Haussmann, B.I.G. (Hess, D.E., Koyama, M.L., Grivet, L., Rattunde, H.F.W. and Geiger, H.H. eds). Proceedings of a Workshop held at IITA, Ibadan, Nigeria. 18-20 August 1999. IITA, Ibadan, Nigeria. Margraf Verlag, Wiekersheim, Germany. pp 299-304.

[4] Baltus, P.C.W., Ransom, J.K., Odhiambo, G.D., Egbers, W.S., ter Borg, S.J., Verkleij, J.A.C. and Pieterse, A.H. (1994). A comparative study on the defence mechanism(s) of the maize variety Katumani against *Striga hermonthica* under field conditions in Kenya. *In*: Biology and management of Orobanche (Pieterse, A.H., Verkleij, J.A.C and ter Borg S.J. eds). Proceedings, 3rd International Workshop on *Orobanche* and Related *Striga* Research. Royal Tropical Institute, Amsterdam, The Netherlands. pp 373-381

[5] Doggett, H. (1965). *Striga hermonthica* on sorghum in East Africa. *Journal of Agricultural Science 65*, pp 183-194.

[6] Doggett, H. (1984). *Striga*: Its biology and control - An overview. *In*: *Striga* Biology and Control. (Ayensu E.S., Doggett, H., Keynes, R.D., Marton-Lefevre, J., Musselman, L.J, Parker, C. and Pickering, A. eds). ICSU Press, Paris. pp 27-36.

[7] Ebiyau, J., Eselle, J.P. and Oryokot, J. (2000). *Striga* research activities in sorghum at Serere Agricultural and Animal Production Research Institute (SAARI), Uganda. *In*: Breeding for *Striga* Resistance in Cereals (Haussmann, B.I.G.,Hess, D.E., Koyama, M.L., Grivet, L., Rattunde, H.F.W. and Geiger, H.H. eds). Proceedings of a workshop held at IITA, Ibadan, Nigeria. 18-20

August 1999. IITA, Ibadan, Nigeria. Margraf Verlag, Wiekersheim, Germany. pp 307-311.

[8] Esilaba, A.O. and Ransom, J.K. (1997). *Striga in the Eastern and Central African Countries:A Literature Review.* Technical Report Series No. 1. African Highlands Initiative, ICRAF, Nairobi. 39pp.

[9] Esilaba, A.O., Reda, F., Ransom, J.K., Wondimu Bayu, Gebremehdin Woldewahid and Beyenesh Zemichael. (1999). The potential for relay cropping and improved fallows for soil fertility improvement and *Striga* control in northern Ethiopia. Proceedings of the Seventeenth Soil Science Society of East Africa Conference, 6-10 September 1999, Kampala, Uganda. pp 54-62.

[10] Esilaba, A.O., Reda, F., Ransom, J.K., Wondimu Bayu, Gebremehdin Woldewahid and Beyenesh Zemichael. (2000). Integrated nutrient management strategies for soil fertility improvement and *Striga* control in northern Ethiopia. *African Crop Science Journal*, *8*, pp 403-410.

[11] Frost, H.M. (1994). *Striga Research and Survey in Kenya*. National Agricultural Research Project, KARI/ODA Crop Protection Project. Final Report. 61pp.

[12] Gacheru, E. and Rao, M.R. (2001). Managing *Striga* infestation on maize using organic and inorganic nutrient sources in western Kenya. *International Journal of Pest Management 47, pp* 233-239.

[13] Harahap, Z., Ampong-Nyarko, K. and Olela, J.C. (1993). *Striga hermonthica* resistance in upland rice. *Crop Protection 12*, pp 229-231.

[14] Hassan, R.M. and Ransom, J.K. (1998). Determinants of the incidence and severity of *Striga* infestation of maize in Kenya. *In*: Maize technology development and transfer: A GIS application for research in planning in Kenya (Hassan, R.M. and Ransom, J.K. eds). CABI, Wallingford, UK. pp 163-174.

[15] Kanampiu, F., Mbogo, P. and Massawe, C. (2004). Multilocational testing of herbicide-resistant maize to control *Striga*. *In*: Integrated approaches to higher productivity in the new millennium (Friesen, D.K. and Palmer, A.F.E. eds). Proceedings of the 7th Eastern and Southern Africa Regional Maize Conference. 5-11 February 2002. Nairobi, Kenya. CIMMYT (International Maize and Wheat Improvement Centre) and KARI (Kenya Agricultural Research Institute). pp 169-172.

[16] Khan Z.R., Hassanali, A., Overholt, W.A., Khamis, T.M., Hooper, A.M., Pickett, J.A., Wadhams, L.J. and Woodcock, C.M. (2002). Control of witchweed *Striga hermonthica* by intercropping with *Desmodium* spp. and the

mechanisms defined as allelopathic. Journal of Chemical Ecology, *28*, pp 1871-1885.

[17] Khan Z.R., Overholt, W.A., Hassanali, A., Chiliswa, P., Wandera, J., Muyekho, F., Pickett, J.A., Smart, L. E. and Wadhams, L.J. (1999). An integrated management of cereal stem borers and *Striga* weed in a maize based cropping system in Africa. *In*: Maize Production Technology for the Future: Challenges and Opportunities: Proceedings of the 6th Eastern and Southern Africa Regional Maize Conference. CIMMYT (International Maize and Wheat Improvement Centre) and EARO (Ethiopian Agricultural Research Organisation). 21-25 September 1998, Addis Ababa, Ethiopia. pp 190-193.

[18] Khan Z.R., Pickett, J.A., Van den Berg, J., Wadhams, L.J. and Woodcock, C.M. (2000). Exploiting chemical ecology and species diversity: stem borer and *Striga* control for maize and sorghum in Africa. *Pest management Science, 56*, pp 957-962.

[19] Kiriro, F.H. (1991). The *Striga* problem in Kenya. *In*: Combating Striga in Africa. Proceedings, International Workshop organised by IITA, ICRISAT and IDRC. Kim, S.K. ed). 22-24 August 1988. IITA, Ibadan, Nigeria. pp 15-17.

[20] Kling, J.G., Fajemisin, J.M., Badu-Apraku, B., Diallo, A., Menkir, A. and Melake-Berhan, A. (2000). *Striga* resistance breeding in maize. *In*: Breeding for *Striga* Resistance in Cereals (Haussmann, B.I.G., Hess, D.E., Koyama, M.L., Grivet, L., Rattunde, H.F.W. and Geiger, H.H. eds). Proceedings of a Workshop held at IITA, Ibadan, Nigeria. 18-20 August 1999. IITA, Ibadan, Nigeria. Margraf Verlag, Wiekersheim, Germany. pp 103-118.

[21] Mbogo, J.O. and Osoro, M.O. (1991). Reaction of sugarcane clones to *Striga hermonthica* infection in Kenya. *In*: Proceedings, 5th International Symposium on Parasitic Weeds (Ransom, J.K., Musselman, L.J., Worsham, A.D. and Parker, C. eds). 24-30 June 1991. CIMMYT, Nairobi, Kenya. pp 310-312.

[22] Mumera, L. (1983). *Striga* infestation in maize and sorghum relative to cultivar, herbicidal activity and nitrate. *In*: Proceedings, 9th East African Weed Science Society Conference, Nairobi, 1983, pp 82-104.

[23] Mumera, L.M. and Below, F.E. (1993). Role of nitrogen in resistance to *Striga* parasitism of maize. *Crop Science 33*, pp 758-763.

[24] Odhiambo, G.D. and Ariga, E.S. (2004). Effect of intercropping maize and beans on *Striga* incidence and grain yield. *In*: Integrated Approaches to Higher Productivity in the New Millennium (Friesen, D.K. and Palmer, A.F.E. eds). Proceedings of the 7th Eastern and Southern Africa Regional Maize

Conference. 5-11 February 2002, Nairobi, Kenya. CIMMYT (International Maize and Wheat Improvement Centre) and KARI. pp 183-186.

[25] Odhiambo, G.D. and Ransom, J.K. (1993). Effect of dicamba on the control of *Striga hermonthica* in maize in western Kenya. *African Crop Science Journal 1*, pp 105-110.

[26] Odhiambo, G.D. and Ransom, J.K. (1994). Preliminary evaluation of long-term effects of trap cropping and maize management on *Striga. In*: Biology, and management of *Orobanche* (Pieterse, A.H., Verkleij, J.A.C. and ter Bora, S.J. eds). Proceedings of the 3rd International Workshop on *Orobanche* and related *Striga* research. Royal Tropical Institute, Amsterdam, The Netherlands. pp 505-512.

[27] Odhiambo, G.D. and Ransom, J.K. (1995). Long-term strategies for *Striga* control. *In*: Maize research for stress environments. Proceedings of the 4th East and Southern Africa Maize Workshop. Jewell, D.C., Waddington, S.R., Ransom, J.K. and Pixley, K.V. eds). 28 March-1 April 1994. Harare, Zimbabwe. CIMMYT, Mexico. pp 263-266.

[28] Odhiambo, G.D. and Ransom, J.K. (1996). Effect of continuous cropping with trap crops and maize under varying management systems on the restoration of land infested with *Striga hermonthica*. *In*: Advances in Parasitic Plant Research (Moreno, M.T., Cubero, J.I., Berner, D., Joel, D., Musselmann, L.J. and Parker, C. eds). Proceedings, 6th Parasitic Weeds Symposium. April 16-18 1996. Cordoba, Spain. pp 835-841.

[29] Odongo, M.O. and Abayo, G. (1999). Performance of maize varieties under *Striga* and *Striga* free environments in western Kenya. Proceedings of the 6th Biennial Kenya Agricultural Research Institute (KARI) Scientific Conference. Agronam Services Ltd. (eds). November 9-13 1998, Nairobi, Kenya. Kenya Agricultural Research Institute, Nairobi, Kenya. pp 390-394.

[30] Oryokot, J. (1994). *Striga*: strategies for its control-a review. *African Crop Science Conference Proceedings 1*, pp 224-226.

[31] Parker, C and Riches, C.R. (1993). *Parasitic weeds of the world: Biology and control*. CAB International, U.K. 332pp.

[32] Ransom, J.K. (1996). Integrated management of *Striga* spp. in the agriculture of sub-Saharan Africa. *In*: Proceedings of the 2nd International Weed Control Congress. Copenhagen. pp 623-628.

[33] Ransom, J.K. and Njoroge, J. (1991). Seasonal variation in ethylene-induced germination of *Striga hermonthica* in western Kenya. *In*: Proceedings,

5th International Symposium of Parasitic Weeds (Ransom, J.K., Musselman, L.J., Worsham, A.D. and Parker, C eds). Nairobi, Kenya. CIMMYT, Nairobi. June 24-30 1991. pp 391-396.

[34] Ransom, J.K. and Odhiambo, G.D. (1992). Development of *Striga hermonthica* on maize and sorghum in western Kenya. *In*: Proceedings, 1st International Weed Control Congress, Melbourne, Australia, Weed Science Society of Victoria.

[35] Ransom, J.K. and Odhiambo, G.D. (1994). Long-term effects of fertility and hand-weeding on *Striga* in maize. *In*: Proceedings, 3rd International Workshop on *Orobanche* and related *Striga* research (Pieterse, A.H., Verkleij, J.A.C. and ter Borg, S.J. eds). Amsterdam, The Netherlands, Royal Tropical, Institute. pp 513-519.

[36] Ransom, J.K. and Odhambo, G.D. (1995). Effect of corn (*Zea mays*) genotypes which vary in maturity length on *Striga hermonthica* parasitism. *Weed Technology 9*, pp 63-67.

[37] Ransom, J.K. and Osoro, M.O. (1991). Effects of planting date and genotypes on *Striga hermonthica* parasitism of maize and sorghum in Kenya. A paper presented at the 12th International Plant Protection Congress in Rio de Janeiro, Brazil. August 11-16, 1991.

[38] Ransom, J.K, Wawire, N.W.O. and Thomas Compton, M.A. (1990). Yield losses due to *Striga*. *In*: National *Striga* Weed Workshop, Kisumu, Kenya, 18-21 June 1990. 8p.

[39] Rao, M.R. and Gacheru, E. (1998). Prospects of agroforestry for *Striga* management. *Agroforestry Forum 9*, pp 22-26.

The ***KARI Technical Note Series*** was launched to provide an outlet for the enormous amounts of technical work generated by KARI, some of it dating many years back, that has not been published in any of the institute's existing publications that include the *East African Agricultural and Forestry Journal,* the *KARI Annual Report,* the *Highlighter* and the *KARI updates.* The articles may be on completed or on-going work. The series carries advisory technical information intended to benefit various stakeholders on research findings generated by the institute. Contribution to the series is limited to KARI staff and collaborators. Manuscripts should be submitted to the Publications Unit, KARI, PO Box 57811-00200, City Square, Nairobi.