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Full Length Research Paper

Role of herbicide (metalachlor) and fertilizer application in integrated management of *Striga asiatica* in maize in Malawi

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The parasitic weed species *Striga asiatica* (L.) Kuntze is one of the major constraints in maize production in Malawi. The effects of metalachlor (as Dual[TM] Magnum 960 EC), a pre-emergence herbicide, with 69N:21:P_2O_5:4S kg ha^{-1} and without fertilizer application, on maize growth and *Striga* suppression, were investigated at 5 sites in 2000/'01 season and 6 sites in 2001/'02. The use of metalachlor at 2.2 kg ha^{-1} gave no considerable phytotoxic effects on maize plants. Application of metalachlor significantly suppressed *Striga* emergence across all sites in 200/'01 and not in 2001/'02. Metalachlor application increased yields from 1448 to 1793 kg ha^{-1} in 2000/'01, and from 1677 to 2077 kg ha^{-1} in 2001/'02. On the overall, the use of fertilizer was superior to herbicide use in increasing maize yields. Yields were generally low as, in most cases, sites with *Striga* are low in productivity. Due to this association between poor site productivity and *Striga*, an integrated approach which tackles both problems is suggested. For example, rotation with legumes is strongly recommended not only to reduce *Striga* seeds in the soil, but to improve fertility. The increased productivity in subsequent years would then allow sufficient yields to cover other inputs such as herbicides, fertilizer and improved seed.

Key words: Witchweed, *Zea mays* L., metalachlor, on-farm fertilizer responses.

INTRODUCTION

Maize is an important cereal crop in Africa, occupying 25.3 M ha (FAO, 2001). The genus *Striga,* of the family *Scrophulariaceae*, is a major parasitic weed affecting cereal production in the grasslands (Musselman, 1987; Pieterse and Verkleij, 1991; Sauerborn, 1991). The species parasitizing cereals are *Striga hermonthica* (Del.) Benth., *Striga asiatica* (L.) Kuntze, *Striga aspera* (Wild.) Benth and *Striga forbesii* (Musselman, 1987). In Malawi and most countries of southern Africa, *S. asiatica* is the most prevalent (Terry and Michieka, 1987). Yield losses depend on infection intensity, time of infection and soil fertility, among other factors, with total loss possible under heavy attack (Kabambe, 1991; Odhiambo and Ransom, 1996; Kim and Adetimirin, 1997). For effective parasitism, the weed seeds need an initial period (10 - 20 days) of warm, moist conditions before they can germinate in response to a chemical stimulant from the host root. Radicle growth and attachment to host roots also require chemical trigger (Riopel and Baird, 1987). Control measures for *Striga* include chemical control (Eplee and Norris, 1987; Eplee et al., 1991; Kanampiu et al., 2003), crop rotations with trap crops (Parkinson et al., 1987; Odhiambo and Ransom, 1996; Kabambe, 1997) soil fertility amendments (Kabambe, 1991; Kim and Adetimirin, 1997), hand pulling (Press et al., 1989), intercropping (Carsky et al., 1994; Kabambe, 1997) and many other cultural practices. The search resistant varieties is underway and promising (Kim and Adetimirin, 1997; Kabambe and Ganunga, 2003; Badu-Apraku and Lum, 2007). An integrated approach is considered most feasible for low input production of most developing countries (Pieterse and Verkleij, 1991). Such an approach would incorporate tolerant genotypes, agronomic practices to delay or reduce emergence, minimize seed return to soil, avoid maximum damage to the host, and general enhancement of crop growth.

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In Malawi, Striga, commonly known as witch weeds, is a serious constraint to maize production. The recommended approaches in the control of witch weeds include the use of herbicides, high rates of fertilizer, long term trap cropping and hand pulling (Kabambe et al., 2002). Most of, these measures do not offer complete control and may require several seasons for substantial *Striga* reduction (Kabambe, 1991; 1997). Also, these may not be adopted fully by most smallholder farmers in Malawi, who grow maize on over 80% of the arable land. Damage due to witch weeds is very pronounced in Malawi and in some cases farmers abandon fields, mainly due to prevailing low soil fertility, brought about by continuous cultivation of maize with mostly small amounts or no fertilizer application. The damaging effects of *Striga spp*. on cereals are more pronounced under low fertility conditions (Parker, 1984; Pieterse and Verkleij, 1991). It is therefore important to look for options that help reduce witch weed pressure and enable good crop yields. Conventional herbicides such as Dual (metalachlor) suppress *Striga* by preventing attachment of germinated *Striga* seeds (Eplee et al., 1991). These authors reported 80% control with application of 2.2 kg ai ha^{-1} as pre-plant incorporated. Although herbicides are considered beyond the reach of most small holder farmers, there are times that effective control measures are required to control witch weed on prime land such as prison farms, and extension, research or irrigation sites. Also, in 2001/'02 Sasakawa Global 2000, in partnerships with the Malawi Government and Monsanto, initiated extension activities to promote use of herbicides, especially as a conservation farming package (Valencia and Nyirenda, 2003). Some herbicide companies promote herbicides (including metalachlor) to release labour constraints amongst farmers that grow cash crops such as tobacco and cotton.

Another constraint to maize production is poor soil fertility (Kumwenda et al., 1997; Blackie and Mann, 2005). In the five-year period between 1997 and 2002, the area under maize cultivation has ranged between 1.292 to 1.507 M ha, with average yields of 1.09 to 1.65 t ha^{-1}. (MoAIFS, 2005). These yield levels considered low, and Government instituted several strategies to address low soil fertility. These include loan programmes such as the Agricultural Productivity Investment Programme (APIP), the Starter Pack Initiative Scheme (SPIS) and Targeted Inputs Programme (TIP) initiatives (involving free distribution of small fertilizer packages), and the targeted fertilizer subsidy. These schemes have been implement-ted between 1998/99 and 2007/08 seasons (Government of Malawi, 2007). Use of legume rotations and green manures and other organic amendments are also being encouraged (MoAIFS, 2005). To address production constraints in a holistic manner, it is important to evaluate the contribution of more than one factor for the development of a comprehensive management package. Studies in this report were therefore conducted to determine the relative importance of herbicide and fertilizer use in managing *S. asiatica* and enhancing maize yields.

MATERIALS AND METHODS

A trial was conducted in 2000/'01 and 2001/'02 seasons to examine the role of metalachlor (as Dual) and fertilizer application on *S. asiatica* suppression and maize yield.

The trial was a herbicide x fertilizer factorial arrangement with 4 replications and was conducted at 5 sites in 2000/01 as follows: Chitedze station and on-farm, Mbawa on-farm, Mulanje and Katuli. In 2001/02 there 6 sites as follows: Chitedze station and on-farm, Mpingu (near Chitedze) Mbawa on-farm, Mulanje, Tembwe and Mponela. All sites are in the mid altitude ecology in Malawi, lying between 1000 - 1500 masl and with mean annual rainfall of 800 - 1200 mm. The factors comprised two levels of herbicide application (H1= no application and H2 = metalachlor at 2.2 kg ha^{-1}), pre-plant incorporated and two fertilizer rates (F1 = no fertilizer application F2 = 69:21:0+4S kg ha^{-1} N, P_2O_5 and S.

Plots had 6 rows of x 5.00 m x 0.9 m as gross, and 2 ridges x 0.9 x 4.5 m (8.1m^2) apart as net). Stations were 50 cm apart with 3 seeds per station, thinned to 2 at weeks after emergence. A total of 69 kg N and 21 kg P_2O_5 ha^{-1} was applied for the higher level of fertilizer, first as a basal dressing of 23:21:0+4S kg ha^{-1} N:P:K:S applied in a band on the side of the ridge. The remaining 46 kg was applied in the form of urea at 4 weeks after planting. This fertilizer package if one of the recommended options (MoAIFS, 2005). The herbicide was sprayed with a knapsack sprayer and incorporated soon after by means of a light hoeing action of a hand hoe. Due to the need to monitor *Striga* emergence without obstruction, plots were kept free of weeds by hoe weeding at least 2 times within the first 3 weeks in all plots, thereafter weeds (except *Striga*) were controlled by hand pulling. Hand weeding of weeds other than Striga was also done in the herbicide treated plots. Trial planting dates for 2000/'01 season were as follows: December 4, 2000 for Chitedze station; November 28 for Chitedze on-farm; November 23 for Katuli, November 25 for Mulanje and December 5 for Mbawa. The sites in 2001/02 were Chitedze Research Station, Chitedze on-farm, Mpingu, Bunda, Tembwe, Mponela, Mulanje and Mbawa. The 2001/'02 season planting dates were December 20, 2001 for Chitedze station, Chitedze on-farm and Mpingu, December 22 for Mponela and Bunda, December 15 for Tembwe and December 31 for Mbawa.

Data reported are maize emergence m^{-2}, grain yield (kg ha^{-1}) adjusted to a storage moisture of 12.5% *Striga* emergence m^{-2}. Two to 4 Striga counts were taken, but the data used in the analysis was from the count reflecting peak emergence for a particular site.

The analysis of variance was done on all data. Statistical significance is quoted at the 5% level unless otherwise stated. Mean comparisons were between pertinent treatment means using the least significance difference.

RESULTS AND DISCUSSION

2000/01 season

A summary of significances for the analysis of variance across all sites is given in Table 1. There were site effects for maize emergence count, grain yield and peak *Striga* emergence (Table 2). Yield was highest at Chitedze Research Station and Mbawa. The use of herbicide significantly reduced maize emergence count, but only marginally in magnitude, from 4.16 to 4.05 plants m^{-2}. For grain yield, there was significant herbicide, fertilizer and site*fertilizer effects. Herbicide increased (p = yield

Table 1. Summary of F probabilities from analysis of variance across all sites for maize emergence count, grain yield and peak *Striga* emergence, 2000/'01 season.

Source of variation	Degrees of freedom	F probability x Variable		
		Maize establishment, as plants m^{-2}	Yield, kg ha^{-1}	Peak *Striga* as plants m^{-2}
Site	5	0.0001	0.0009	0.0001
Rep(site)	8	0.125	0.9	0.0001
h-rate	1	0.037	0.245	0.0001
f-rate	1	0.321	0.0001	0.656
Site*f-rate	5	0.348	0.0066	0.048
Site*h-rate	5	0.281	0.613	0.0001
h-rate*f-rate	1	0.498	0.85	0.757
Site* hrate*f-rate	5	0.236	0.961	0.972
CV%	54	4.6	33.4	64.7

Table 2. Effect of site on maize establishment, grain yield and peak *Striga* emergence, 2000/'01 season.

Site	Variable		
	Maize emergence plants m^{-2}	Grain yield kg ha^{-1}	Peak *Striga* count m^{-2}
Chitedze stn	4.17	2305	8.56
Chitedze farmer	4.23	1856	6.91
Katuli	4.14	983	2.8
Mulanje	4.30	1342	1.97
Mbawa	3.72	1618	2.04
SED	0.05	211	2.7

Table 3. Effects of site x fertilizer application (frate) on maize yield (kg ha^{-1}), 2000/'01 season.

Site	Fertilizer rate	
	0	69:21:0+4S
Chitedze station	1276	3336
Chitedze farmer	1454	2258
Katuli	274	1691
Mulanje	479	2204
Mbawa	1670	1567
SED	299	

Table 4. Effects of site x herbicide application peak *Striga* emergence (plants m^{-2}), 2000/'01 season.

Site	Dual application rate	
	0	2.2 kg ha^{-1} ai
Chitedze station	12.2	4.9
Chitedze farmer	10.9	2.9
Katuli	4.11	1.38
Mulanje	2.27	1.73
Mbawa	1.77	2.33
SED	3.7	

(p=0.07)

from 1448 to 1793 kg ha^{-1}. The site*fertilizer effect on yield arose due to differences in yield levels between sites and within a fertilizer rate (Table 3). The best yielding site was Chitedze station, where yields increased from 1276 to 3336 kg ha^{-1}, and the poorest site was Katulie, where yields increased from 274 to 1691 kg ha^{-1}. For *Striga* emergence data, there were significant Site*H and S*F effects detected. The S*H effect showed that for the sites with high pressure, application of Dual significantly suppressed emergence (Table 4). The S*F interaction came about due to the differences in *Striga* pressure between sites (Table 5).

In summary, results in this season show negligible phyto-toxic effects of herbicide application. The herbicide was effective in suppressing *Striga* emergence and increasing yield. Fertilizer application had no consistent effect on *Striga* emergence.

2001/02 season

Table 6 gives a summary of significances for the analysis of variance across all sites. The analysis showed signifi-

Table 5. Effects of site x fertilizer application peak *Striga* emergence (plants m^{-2}), 2000/'01 season.

Site	Fertilizer rate	
	0	kg ha^{-1} 69:21:0+4S
Chitedze station	6.87	10.27
Chitedze farmer	8.09	5.69
Katuli	2.58	2.92
Mulanje	1.43	2.56
Mbawa	2.6	1.49
SED	3.7	

Table 6. Summary of F probabilities from analysis of variance across all sites for emergence count (ec), grain yield and peak *Striga* emergence, 2000/'01 season.

Source of variation	Degrees of freedom	F probability x Variable		
		Ec	Yield, kg/ha	Peak *Striga*
Site	6 (7)b	0.0001	0.0001	0.0001
Rep(site)	21 (24)	0.46	0.0045	0.276
h-rate	1	0.979	0.031	0.509
f-rate	1	0.117	0.0001	0.0001
Site*f-rate	6 (7)	0.344	0.0001	0.019
Site*h-rate	6 (7)	0.166	0.557	0.255
h-rate*f-rate	1	0.782	0.840	0.491
Site* hrate*f-rate	6 (7)	0.694	0.6887	0.646
CV %	63	6.7	47	89.8

'b figures in brackets are for *Striga* data, which was from 7 sites.

Table 7. Effects of site on emergence count, grain yield and peak, *Striga* emergence, 2001/'02 season.

Site	Variable		
	Maize emergence count, plants m^{-2}	Yield, kg/ha	Peak *Striga* m^{-2}
Chitedze stn	4.28	2862	19.0
Chitedze farmer	3.68	1787	10.0
Mpingu	4.27	2345	18.5
Bunda	3.88	597	2.1
Tembwe	4.29	1429	1.0
Mponela	4.41	2240	14.1
P	0.0001	0.0001	0.0001
SED	0.05	159	1.8

site effect for emergence count, grain yield and peak *Striga* emergence. Unfertilized grain yields were poor, especially at Mpingu, Mbawa and Bunda, but yields were doubled with fertilizer application (Table 7). Results on maize plant stand show that plant establishment was quite near to the targeted 4.44 plants m^{-2} at most sites. Maize establishment was only significantly affected by site, meaning that herbicide and fertilizer use had no phytotoxic or other direct impact on establishment. There was no significant three way interaction for all variables reported. Application of herbicide significantly increased cant yield from 1677 to 2077 kg ha^{-1}. There was significant Site*F-rate interaction for yield (Table 8), arising mainly from yield variation between sites within a fertilizer rate.

In this season, there was no significant H effect on *Striga* emergence. There was a significant S*F effect on *Striga* emergence. Fertilizer application generally promoted *Striga* emergence, except in low pressure sites where

Table 8. Effects of Site*fertilizer application on maize yield, kg ha^{-1}, 2001/'02 season.

Fertilizer kg ha^{-1} N:P_2O_5:K:S	Site						
	Chitedze Station	Chitedze Farmer	Mpingu	Bunda	Tembwe	Mponela	Mbawa
0	1621	1214	229	704	1663	402	402
69:21:0+4S	4102	3477	964	2153	2818	3858	3858
SED	275						

Table 9. Effects of Site*fertilizer application on peak *Striga* count m^{-2}, 2001/'02 season.

Fertilizer kg ha^{-1} N:P_2O_5:K:S	Site						
	Chitedze Station	Chitedze Farmer	Mpingu	Bunda	Tembwe	Mponela	Mbawa
0	18.48	4.97	7.4	1.42	0.07	4.32	13.47
69:21:0+4S	19.63	15.0	29.6	2.77	1.99	14.95	19.42
SED	3.15						

there was no fertilizer effect (Table 9).

The highlight of the second season results is that herbicide had no effect on *Striga* suppression, but significantly increased maize yield. Fertilizer also gave the greatest positive impact on yield.

DISCUSSION

Herbicide effects

These results confirm that metalachlor (as Dual) can suppress *Striga*. Metalachlor suppresses *Striga* by preventing attachment of germinated *Striga* seeds (Eplee et al., 1991). The authors reported 80% control with application of 2.2 kg active ingredient ha^{-1} pre-plant incorporated application. In this study the herbicide significantly suppressed Striga emergence in the first season only and there were also significant site x herbicide effects. Suppression was greater at sites with high *Striga* pressure, hence the interaction. In the second season *Striga* numbers were high at some sites such as Chitedze, Mponela and Mbawa (Table 9), but no significant suppression was recorded. There is no clear explanation available for this, considering that herbicide application increased yields. Due to the need to observe *Striga* emergence, weeds other than *Striga* were controlled in both herbicide treated and untreated plots, as such, yield increase cannot be attributed to control of other weeds. A probable reason for the yield increase is that the herbicide suppressed attachment of *Striga* to host roots early in the season. It is normal for herbicides to control weeds only in earlier part of the season (Kanampiu et al., 2003). Herbicides would be particularly important to bring *Striga* infection down to levels that can be managed through other agronomic measures. Dual is being promoted aggressively by herbicide companies in Malawi. This study was designed specifically to study herbicides effects on *Striga*, and hence results cannot be used to infer on economic feasibility of Dual. However, for busy and diversified farmers, the capital cost of facilities such as knapsack sprayers is shared amongst several enterprises.

Fertilizer effects

Yield increases due to fertilizer applications in maize under *Striga* infection are well reported (Parker, 1984; Kabambe, 1991; Pieterse and Verkleij, 1991). Nitrogen suppresses some development stages of *Striga* such as stimulant production or activity (Parker, 1984; Chechin and Press, 1993) germination and radicle elongation (Okonkwo, 1991; Eplee and Norris, 1994), attachment to host, emergence time and number of *Striga* plants flowered. It is important to have a high concentration of nitrogen at the time of germination and attachment (Parker, 1984; Kabambe and Drennan, 2005). Maintaining high levels of soil N depends on factors which affect the dynamics of soil nitrogen, such as inherent fertility, and soil type and rainfall. Hence, the effectiveness of N in *Striga* suppression increases with higher application rates (Parker, 1984; Kabambe, 1991; Kabambe and Drennan, 2005). The lack of fertilizer effects on *Striga* suppression in these studies can be attributed to the low application rate and general low inherent levels of nitrogen in soils. Several reports have shown that N is more suppressive to *Striga* germination when applied at 2 - 3 weeks after crop planting rather than at earlier or later times (Verkliej et al., 1994; Kim and Adetimirin, 1997; Kabambe and Drennan, 2005). In many of the studies, suppressive N applications have been more than 100 kg ha of N. The application rate used in the study is one of the official fertilizer recommendations (MoAIFS, 2005). It has been proposed that initial N applications seem to promote *Striga*, by means of promoting more crop roots, but further applications increase the concentration of N in soil and roots, thereby suppressing germination and attachment (Okonkwo, 1991; Odhiambo and Ransom, 1996). In this report, fertilizer application promoted *Striga* emergence, particularly in the second year two. The fertilizer recommendations in Malawi were reduced from a blanket of 112 kg ha-1 N to a three options of 35 kg, 6 and 92 kg ha^{-1} (MoAIFS, 2005). Thus these results are important in that they show that the recommended levels of fertilizer may have no impact on *Striga* suppression, and that it is important to call for the use of other sources of fertility enhancements, such as green manures and crop rotations with legumes.

Interactions and general conclusions

It is interesting to note that there was no herbicide x fertilizer interaction effects on *Striga* emergence observed in both seasons. The expectation was that the combined suppressive roles of fertilizer and herbicide would give greater suppression, resulting into interactions. Without this interaction the role of herbicides would be to suppress *Striga,* and possibly reduce seed bank and enhance yield. The profitability of any crop enterprise depends on obtaining high yields through sound management practices. Yield levels were generally low in the trials even with fertilizer application. This could be attributed to the fact that trials were located in *Striga* hot spots. In most cases Striga sites are poor in productivity. Due to this association between poor site productivity and *Striga*, an integrated approach which tackles both problems is suggested. For example, rotation with legumes is strongly recommended not only to reduce *Striga* seeds in the soil (Parkinson et al., 1987; Odhiambo and Ransom, 1996), but also to improve fertility. Other practices such as legume intercropping also reduce *Striga* emergence (Carsky et al., 1994; Kabambe, 1997). The increased productivity in subsequent years would then allow sufficient yields to cover other inputs such as herbicides, fertilizer and improved seed. The nitrogen harvest from green manure is high. Kumwenda et al. (2001) reported dry matter yields of 4 to 8 t ha^{-1} from *Mucuna pruriens* with a nitrogen content of 19.7 kg per tonne. The authors also reported yields of 3.8 to 8.5 8.5 t ha^{-1} from sunhemp (*Crotalaria juncea*).

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