# Exploring cost-effective maize integrated weed management approaches under intensive farming systems

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## Abstract

**Several production constraints have led to low yields (< 2.5 t ha$^{-1}$) in maize (*Zea mays* L.) in Uganda, among which are weeds. This study investigated the most cost-effective integrated weed management (IWM) approach in maize in eastern Uganda. An experiment was conducted at Ikulwe station, Mayuge in 2011 and 2012 using nine integrated weed management  (IWM) approaches. Results showed yields (P < 0.001) in decreasing order of three hand-hoe weedings (3hh), two hand-hoe weedings (2hh), pre-emergence application of atrazine, followed by one hand-hoe weeding (pre-Atz+1hh) and post-emergence application of atrazine, followed by one hand hoe weeding (post-Atz+1hh) (5.9 - 6.4 t ha$^{-1}$) and lastly, where no weeding was conducted (2.7 t ha$^{-1}$). Returns on investment (ROI) were highest under pre-Atz+1hh and 2hh (180%), followed by post Atz+1hh (167%). The no weeding treatment registered the lowest value (67%). In 2012 and 2013, the IWM approaches with highest ROI (> 160%) were established on-farm in Bugiri, Kamuli and Iganga districts with one hand-hoe weeding (1hh) as the control.  The pre-Atz+1hh produced the highest grain yield (4.5 t ha$^{-1}$; P < 0.01) and ROI (105%); while 1hh gave the lowest grain yield (3.4 t ha$^{-1}$) and the lowest ROI (60%). Therefore, pre-emergence application of atrazine (2 l ha$^{-1}$), followed by one hand-hoe weeding (28 days after planting) is the most cost-effective IWM option in maize.**

**Key words:**  Atrazine, returns on investment, *Zea mays*

## Introduction

Maize (*Zea mays* L.) is one of the ten priority commodities in Uganda's agricultural sector Development Strategy and Investment Plan 2011-2015 (DSIP, 2010), whose increase in production has been attributed to expansion of cultivated area.

Eastern Uganda contributes almost 50% of the maize produced in Uganda (UBOS, 2011), attributed to large crop area cultivated. This situation is environmentally disastrous and could lead to enormous conflicts with diminishing grasslands and land area for other activities.

Weeds are among the top most hinderances to maize production in Uganda. They have a potential of causing 16-80% maize yield loss (Paller, 2002). They compete with crops for water, soil nutrients, light and space thereby reducing crop yields. According to Maqbool *et al.* (2006), to avoid competition from weeds,

weeding should be conducted within the first 30 days after germination. However, many times, weed control at this stage is costly. Farmers often weed shoddily in order to minimise expenses. The availability and adoption of appropriate cost-effective maize weed management technologies by farmers is one strategy to overcome the limitations to higher on-farm productivity. Successful weed management in maize is dependent upon knowing the characteristics of the weed infestations in individual fields, how the weeds interact with the crop, and understanding the strengths and weaknesses of the control techniques being used.

Weed control is labour intensive when done with the widely used and traditional hand-hoe in sub-Saharan Africa. Most resource-poor households in Uganda face labour constraints, which are seasonal, gender-based and in some areas increased by the impact of HIV/AIDS (Kikafunda, 2000). As a result, the cost of hand-weeding has kept on escalating.

Ileana *et al. (*2007) observed that every maize growing area is characterised by the presence of certain weed species, the specific weed encroachment being influenced by soil conditions and technologies used before and at the time of the maize crop. Thus, each area needs specific integrated weed management strategies (Takim *et al*., 2012). The objective of this study was therefore to determine the most cost-effective integrated weed control practice in maize.

## Materials and methods

In the rainy seasons of 2011B (August-November) and 2012A (April-July), two experiments were conducted at Ikulwe,

Mayuge district (1209 m asl. 00º 26' 23.2'' N. 033º 28' 40.9'' E) in a randomised complete block design (RCBD), with three replicates, using nine randomly applied integrated weed management (IWM) treatments. The treatments were as follows: pre-emergence application of 2.0 liters of atrazine (Primextra Gold 720-SC) per hectare, followed by one hand hoe weeding (Pre-Atz+1hh); pre-emergence application of atrazine, followed by two hand-hoe weedings (Pre-Atz+2hh); post-emergence application of atrazine followed by one hand-hoe weeding (Post Atz+1hh); pre- and post-emergence application of atrazine (Pre-Atz+post-Atz); pre-emergence application of atrazine, followed by post-emergence application of 2,4-D (2 l ha$^{-1}$); (Pre-Atz+post 2,4-D); post-emergence application of 2,4-D, followed by one hand-hoe weeding (post 2,4-D+1hh); no weeding; two hand-hoe weedings (2hh); and three hand hoe weedings (3hh).

Where applicable, the first hand-hoe weeding, and post-emergence application of herbicides were conducted when the weeds were at 2 - 3 leaf stage (Muhammad *et al.,* 2009), approximately 14 days after planting (DAP). The second hand-hoe weeding was conducted at 28 DAP, whereas the third hand-hoe weeding was done at 42 DAP. Two seeds of Longe 6H hybrid maize variety were planted per hill, spaced 75 cm x 30 cm in plots of 5 m x 10 m to give a plant population of 44,400 plants per hectare. The recommended fertiliser dose of NPK (80:40:20 kg ha$^{-1}$) was applied as basal in all plots and the crop was top dressed at knee height stage and at anthesis with 40 kg N ha$^{-1}$.

In seasons 2012B and 2013A, the IWM approaches/treatments with highest

ROI (>160%) were established on farmers' fields in Bugiri, Kamuli and Iganga districts, in the subcounties of Buluguyi (1080 masl, 00° 45'N; 033° 53'E), Nawanyago (00° 74.0' N, 33°14.9'E) and Nawandala (1082 masl, 00° 82.3'N, 033° 82.3'E), respectively. They included 2hh, Pre-Atz+1hh, Post Atz+1hh in comparison with one hand-hoe weeding (1hh), a common practice in eastern Uganda. The design used was RCBD, and in all experiments, data on the following variables were collected: plant height, days to anthesis (DTA), days to silking (DTS), anthesis-silking interval (ASI), percentage of lodged plants, weed biomass, number of leaves, 500 seed weight, ear girth, ear length, number of ears per plant (EPP) and grain yield.

The on-station and on-farm data were pooled and tested for normality using the Proc Univariate normal plot procedure in Statistical Analytical System (SAS) software. As a result, some variables such as weed biomass, lodging percentage and grain yield were $\log_{10}(x+1)$ – transformed. The data were then subjected to analysis of variance (ANOVA) using the General Linear Model (Proc GLM) in SAS to enable separation of the variance components (Steel and Torrie, 1980). Differences between means were compared using Tukey's studentised range test at P = 0.05. A simple linear regression analysis was conducted in SAS software using Proc Reg to determine the relationship between maize grain yield and the other variables. Net returns were calculated as Gross Returns – Production costs. Returns on investment (ROI) were calculated as (Net returns/Production costs) x 100 (Zivenge *et al.,* 2013).

## Results

### On-station trials

Differences in season had no significant effects (P > 0.05) on variables except grain yield, number of leaves and plant height (Table 1). However, the treatments had significant effects (P < 0.05) on all variables measured except number of leaves and ear length. Season x Treatment interaction had no significant effects for all variables. Significantly high grain yields (P < 0.001) were recorded at 3hh (6.4 t ha⁻¹), 2hh (5.9 t ha⁻¹), pre-Atz+1hh (5.9 t ha⁻¹) and post-Atz+1hh (5.9 t ha⁻¹) compared to no weeding (2.7 t ha⁻¹) (Table 1).

Weed biomass at harvest was significantly higher in the control (4.9 t ha⁻¹) and Pre-Atz+post 2,4-D (3.1 t ha⁻¹), compared to Pre-Atz+1hh, Pre-Atz+2hh, Post 2,4-D+1hh, Pre-Atz+post-Atz and 3-hh (0.6-0.7 t ha⁻¹). The predominant weed species in the experimental area, arranged in decreasing order of magnitude, were *Amaranthus* spp., *Commelina benghalensis* L. and *Echinochloa colona* L.

One hand hoe weeding following post-emergence application of 2,4-D effectively controlled the weeds. There were no significant differences across treatments for the variables; number of leaves, 500 seed weight, and cob girth and length. Plant height differed between the treatments with post Atz+1hh (261 cm) and the control (232 cm) as tallest and shortest, respectively. Returns on investment (ROI) were highest at pre-Atz+1hh and 2hh (180%), followed by post Atz+1hh (167%), corresponding to net returns of Ush. 1,949,325, 1,850,198 and 1,814,655 per hectare, respectively

194 — M. Kaiira *et al.*

Table 1. Mean effects of different IWM approaches on growth and yield of maize at Ikulwe Station, Mayuge District (N=6)

| Treatments | Plant height (cm) | Number of leaves | 500 g seed weight (g) | Ear girth (cm) | Ear length (cm) | Weed biomass (t ha⁻¹) | Yield (t ha⁻¹) |
|---|---|---|---|---|---|---|---|
| No weeding | 232 c | 11.9b | 169.6a | 16.1b | 18.4a | 4.9a | 2.7b |
| Pre-Atz+1hh | 253 ab | 13.3ab | 175.3a | 17.0ab | 18.2a | 0.6c | 5.9a |
| Pre-Atz+2hh | 249 abc | 12.7ab | 178.8a | 16.5ab | 17.3a | 0.6c | 5.7a |
| Pre-Atz+post-Atz | 235 bc | 12.8ab | 176.8a | 16.7ab | 17.4a | 0.7c | 4.8a |
| Pre-Atz+post 2,4-D | 247 abc | 13.4ab | 173.9a | 16.9ab | 18.2a | 3.1ab | 5.5a |
| Post Atz+1hh | 261 a | 13.0ab | 175.3a | 17.6a | 18.7a | 1.8bc | 5.8a |
| Post 2,4-D+1hh | 242 abc | 13.1ab | 180.1a | 16.5ab | 17.5a | 0.7c | 5.5a |
| 2-hh | 251 abc | 13.3ab | 183.0a | 16.9ab | 17.6a | 1.3bc | 5.9a |
| 3-hh | 258 ab | 13.9a | 177.7a | 17.1ab | 18.4a | 0.6c | 6.4a |

(Table 2). The lowest ROI was recorded under no weeding (67%), corresponding to a net return of USh. 542,308 per hectare.

### On-farm trials

Similar to on-station results, season had no significant effect (P > 0.05) for most growth variables such as plant height, ear height and DTA. However, the IWM practices had significant effects (P≤ 0.05) across locations for all variables, except DTA. Significant effects were also recorded for ear height, DTS, ASI; weed biomass, number of rotten cobs and grain yield across treatments. No significant location x treatment interaction effects were recorded, except for ear height. Across treatments, Pre-Atz+1hh had the highest grain yield (4.5 t ha⁻¹), whereas 1hh had the lowest (3.4 t ha⁻¹) (Table 3).

There were no significant differences in number of lodged plants, ears per plant and days to anthesis. Significant differences were recorded for weed biomass, with 1hh having a very high weed biomass (7 t ha⁻¹) compared with the rest of the treatments (3.9-4.0 t ha⁻¹). Plant height was also significantly lower for 1hh (165 cm), compared to the rest of the treatments (180-182 cm). Application of pre-emergence atrazine significantly (P ≤ 0.05) reduced the weed biomass as effectively as an early hand weeding. A single hand weeding, however, did not control the weeds to enhance plant growth and grain yields. The longest ASI was recorded under 1hh, whereas the shortest ASI was observed under Pre-Atz+1hh.

Results from regression analysis showed no significant linear regression between grain yield and the variables (DTA, EPP, weed biomass and plant height) across all treatments (Data not presented). However, DTS and ASI

**Table 2.  Net returns to investment in the various IWM approaches conducted on-station at Ikulwe, Mayuge District**

| Treatments | Maize production costs (U.shs ha$^{-1}$) | Gross returns from maize sales (U.shs ha$^{-1}$) | Net returns (U.shs ha$^{-1}$) | *ROI (%) |
|---|---|---|---|---|
| No weeding | 804,000 | 1,346,308 | 542,308 | 67 |
| Pre-Atz+1hh | 1,082,000 | 3,031,325 | 1,949,325 | 180 |
| Pre-Atz+2hh | 1,158,000 | 2,856,159 | 1,698,159 | 147 |
| Pre-Atz+post-Atz | 1,008,000 | 2,405,188 | 1,397,188 | 139 |
| Pre-Atz+post 2,4-D | 1,034,000 | 2,641,783 | 1,607,783 | 155 |
| Post Atz+1hh | 1,084,000 | 2,898,655 | 1,814,655 | 167 |
| Post 2,4-D+1hh | 1,050,000 | 2,634,913 | 1,584,913 | 151 |
| 2-hh | 1,104,000 | 2,954,198 | 1,850,198 | 180 |
| 3-hh | 1,240,000 | 3,179,639 | 1,939,639 | 156 |

Note: 1 US Dollar was approximately U. Shs. 2500.   *Returns on investment computed as percentage of net returns/production costs

showed a negative significant regression (P < 0.05) with grain yield at 1hh and Post Atz+1hh (Table 4). Lodging also had a negative significant regression relationship upon grain yield at 1hh. The DTS negatively impacted grain yield for 1hh weeding due to the stress effect of the weeds to the crop. This eventually resulted in a longer ASI; consequently leading to low grain yields for 1hh. Net returns to investment in the various IWM approaches in the farmer's field showed Pre-Atz + 1hh to have the highest ROI (105%), followed by 2hh (67%); whereas 1hh had the lowest ROI (60%) (Table 5).

## Discussion

Plots where effort to control weeds was conducted had significantly higher grain yields compared to the non-weeded plots, with yield differences as high as 3.7 t ha$^{-1}$. Findings from this study show that hand-hoe weeding following application of pre-emergence atrazine is important in keeping the weed population at bay. Takim

et al. (2012) and El-Metwally et al. (2012) also reported that a combination of hand-hoe weeding with pre- and post-emergency herbicides led to the most effective way for controlling weeds in maize. However, the highest grain yield emanating from three hand-hoe weedings attracted a lot of labour, therefore, was not cost-effective to the smallholder farmer. According to Forcella (2000), hand hoeing is efficient in eradication of weeds, but Eddowes and Harpur (2006) observed that pre-emergence herbicide application at 2-3 l ha$^{-1}$ controls annual weeds in maize in a superior manner compared to other control measures. The results obtained on-station, that is the significantly lower weed biomass at Pre-Atz+1hh, Pre-Atz+2hh, Post 2,4-D+1hh, Pre-Atz+post-Atz  and 3-hh  (0.6-0.7 t ha$^{-1}$) compared with the control are in agreement with observations by Khan et al. (2012). Kandil and Kordy (2013) similarly observed lower weed biomass in treatments with two hand-hoe weedings and one hand hoe weeding with

**Table 3. Mean effects of different IWM approaches on growth and yield of maize at three sites in eastern Uganda**

| Treat | Plant height (cm) | DTA | DTS | ASI | Lodging (%) | Weed biomass (t ha$^{-1}$) | EPP | Grain yield (t ha$^{-1}$) |
|---|---|---|---|---|---|---|---|---|
| 1hh | 165 | 64 | 70 | 5.3 | 39.0 | 7.0 | 0.76 | 3.4 |
| 2hh | 181 | 66 | 71 | 3.8 | 34.2 | 3.9 | 0.82 | 3.8 |
| Pre-Atz+1hh | 182 | 65 | 69 | 3.0 | 34.9 | 3.9 | 0.76 | 4.5 |
| Post Atz+1hh | 180 | 66 | 71 | 4.1 | 33.9 | 4.0 | 0.74 | 3.7 |
| LSD $_{(P=0.05)}$ | 21.0 | NS | 2.3 | 1.6 | NS | 2.7 | NS | 0.7 |

NS = Not significant

herbicides, compared with non-weeded plots and plots where only herbicides were applied. Maqbool *et al. (*2006) reported weeds to cause the highest economic damage to the maize crop at a time when the highest biomass density has been reached.

Field observations in the present study showed that 2,4-D causes temporary injury to the maize plants when applied 14 days after planting, unlike atrazine. Similarly, pre-emergence application of atrazine was superior to post-emergence application of both atrazine and 2,4-D in weed control, and the former was more effective that the latter. Khan *et al.* (2012) observed that herbicides do not significantly affect the maize plant height; therefore, the higher plant height recorded at Post Atz+1hh.

The lower height for maize in the control treatment may be attributed to competition for the available growth factors namely; light, water and nutrients with the weeds. The longest ASI recorded under 1hh in the on-farm trial may be associated with crop stress which prevailed when the weed biomass was high, subsequently leading to the lowest grain yield. However, shortest ASI under Pre-Atz+1hh corresponded to the lowest biomass and highest grain yield.

**Conclusion**

Weeds prolong the ASI, thereby reducing the maize grain yields. From the regression analysis, DTS negatively impacts on grain yield at 1hh weeding due to the stress effect of the weeds on the crop. This eventually results in a longer ASI, consequently leading to low grain yields at 1hh.

The low ROI under no weeding (67%) in the on-station trials is a result of the

**Table 4. Linear regression relationship between grain yield and other variables across the three sites in eastern Uganda**

| *Treatment | Regression equation | Adj R-Square (%) | P-value |
|---|---|---|---|
| 1-hh | | | |
| DTS | $Y = 17.2 - 0.204x$ | 53.3 | 0.0042 |
| ASI | $Y = 4.81 - 0.32x$ | 41.1 | 0.0271 |
| Lodged | $Y = 4.24 - 0.0001x$ | 2.90 | 0.0293 |
| | | | |
| Post Atz+1hh | | | |
| DTS | $Y = 11.8 - 0.12x$ | 29.0 | 0.0503 |
| ASI | $Y = 5.01 - 0.39x$ | 42.4 | 0.0341 |

*Only treatments with significant regression effects for a particular variable are presented

**Table 5. Net returns to investment in the various IWM approaches conducted on-farm in eastern Uganda**

| Treatments | Production cost | Gross returns | Net returns | ROI (%) |
|---|---|---|---|---|
| Pre (Atz) + 1 hh | 1,488,000 | 3,045,000 | 1,557,000 | 105 |
| Post (Atz)+ 1 hh | 1,452,000 | 2,415,000 | 963,000 | 66 |
| 2hh | 1,464,000 | 2,450,000 | 986,000 | 67 |
| 1hh | 1,375,000 | 2,205,000 | 830,000 | 60 |

low grain yields obtained in plots with maize plants competing with weeds for nutrients and space. The high ROI at Pre-Atz + 1hh both on-station and on-farm, emphasizes that application of pre-emergence atrazine followed by one hand hoe weeding is the most cost-effective approach to weed control in maize. Therefore, farmers can integrate herbicide application with hand-hoe weeding in a cost-effective manner.

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