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Metribuzin and 2,4-D as potential herbicides for weed management in sorghum [*Sorghum bicolor* (L) Moench]

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Grain sorghum demand for industrial and domestic uses has triggered increased production of sorghum. Field experiment was conducted at Egerton University Njoro, Kenya to determine the most effective herbicide(s) for weed management in sorghum. The experiment was carried out in a randomized complete block design (RCBD) with nine treatments replicated three times. The treatments consisted of four pre-emergence herbicides namely Lumax® (Mesotrine, Metolachlor, Terbuthylazine), Primagram® (Atrazine, S-metolachlor), Dual gold® (S-Metolachlor) and Sencor® (Metribuzin). In addition, three post-emergence herbicides namely 2,4-D (2,4-D amine salt), Maguguma® (Atrazine, S-metolachlor) and Auxio® (Bromoxnil, Tembotrine) were included. Positive and negative controls comprised of hand weeding and no weeding, respectively. Pre-emergence treatments were applied immediately after sowing while post-emergence treatments were applied 30 days after sowing. Weed density and biomass were determined at 30 and 60 days after sowing. Means were separated according to least significant difference (LSD) whenever the herbicide effects were significant ($P \leq 0.05$). Analysis of variance revealed significant ($P \leq 0.05$) differences in the effect of the treatments evaluated. When used as pre-emergence herbicide, Sencor (Metribuzin) was more effective in reducing weed density by 96 and 79% relative to un-weeded and hand weeding treatments, respectively. The post-emergence 2,4-D herbicide reduced weeds by 90, 43 and 26%. Sencor and 2, 4-D were more effective in managing weeds in sorghum and currently, could be the best option for farmers in Kenya and elsewhere.

Key words: Sorghum, herbicides, Sencor, weeds

INTRODUCTION

Sorghum [*Sorghum bicolor* (L) Moench] production in Kenya is gradually expanding due to increasing demand from brewing and feed industries. Weed management is one of the field operations that influence productivity and determines scale of production. The low production currently being experienced is partly attributed to lack of suitable herbicide for use locally. Herbicides are handy when dealing with increased scale of operation and are effective in managing weeds at critical crop stages, thus avoiding significant crop loss (Tuinstra et al., 2009; Rajcan and Swanton, 2001; Khaliq et al., 2011). It has been suggested that good crop establishment can be achieved by keeping a crop weed-free for about 3-4 weeks after sowing (Chauhan et al., 2012). However, this is dependent on the weed seed bank, which influences weed emergence pattern and stage of crop growth

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(Hoverstad et al., 2014), weeds density, competitiveness and periodicity of emergence (Bystro et al., 2012). Chemical weed management may involve the use of pre-emergence or post emergence herbicides. Grassy weeds are best controlled through application of herbicides at juvenile growth stages when they are most susceptible (Pannacci and Covarelli, 2009). Timing of herbicide treatment is crucial to farmers since fully established weeds may need multiple herbicide application with negative environmental consequences.

An application of pre-emergence herbicide is important for farmers to realize increased yields because it takes care of weeds interference with crops at their most vulnerable stages. However, in the absence of a suitable pre-emergence, properly timed post-emergence herbicide soon after crop emergence can also be effective. The growing interest in sorghum production in Kenya necessitates availability of herbicides for farmers who are expanding their acreages. An effective herbicide would be one that suppresses most of the weeds with little or no injury to the crop.

The study was conducted to determine the most effective herbicides for weed management in sorghum. Locally available pre-emergence and post-emergence herbicides selected based on their use in closely related cereals but with different active compounds were evaluated for their efficacy in sorghum production.

MATERIALS AND METHODS

Experimental site

Experiment was conducted at Egerton University (0°23´ S, 35°35´ E) research field, which is at 2267 m above sea level. The area receives about 1000 mm of rainfall annually and has a mean temperature of 15.9°C. The soils are *mollic andosols* and agro-ecological zone classification is low highland 3 (LH3) (Jaetzold et al., 2005). The environment represents major sorghum growing regions with a rich weed seed bank.

Experimental design and procedures

Field trials were conducted during the short rains in August-December 2014 and long rains beginning in March-July 2015 to evaluate the efficacy of selected pre- and post-emergence herbicides on weed control and the responses of EUSS 25 line of sorghum. The field was ploughed and harrowed to a fine tilt for good crop emergence and seedling development. The experiment was set up in a randomized complete block design (RCBD) with nine treatments in experimental units measuring 4 m by 2.5 m and replicated three times. A path of 1.5 m separated the blocks with the blocking based on the gradient of the field.

Sorghum was sown in each of the experimental plots having six rows at an inter row spacing of 60 cm by drill with a depth of about 2.5-4 cm and a seed rate of 8 kg per ha which was carried out just before the onset of the rains. During sowing, NPK (20:20:0) fertilizer was applied at a rate of 50 kg P_2O_5 kg and 50 kg N per ha. After crop emergence, sorghum was thinned to intra row spacing of 15 cm. Top dressing using Calcium Ammonium Nitrate (26% N) was done three weeks after seedling emergence at the rate of 20 kg N ha^{-1}. Except for the herbicide treatments, all other crop husbandry practices were uniform across experimental plots.

Herbicide treatments

Nine treatments were evaluated for their effect on weed density, weed biomass and crop growth. Four herbicides, namely Primagram®, Lumax®, Sencor® and Dual Gold®, were applied as pre-emergence while 2,4-D, Maguguma® and Axio® were applied as post emergence herbicides at 30 days after sowing (Table 1). Two hand weedings and an un-weeded treatment were included as positive and negative controls, respectively. Herbicide application was done using a knapsack sprayer with flat fan nozzles on each experimental plots. Pre-emergence herbicide application was done only once, immediately after sowing.

Data collection

Crop emergence and stand count was determined by counting the number of plants in each plot after thinning the crop. Thinning was done by removing excess seedlings to achieve a spacing of 15 cm within rows and 60 cm between the rows and to attain optimum plant population of about 111,000 plants per hectare.

Weed counts and species distribution were done 30 days after application of pre-emergence herbicides which coincided with the three-leaf stage of sorghum. The second weed count was done at 60 days after sowing to capture the effect of the post-emergence herbicides. Sampling for weed count and weed identification was done using a 1-m^2 quadrat thrown randomly in each plot. The weed species in each quadrat were counted and identified through close observation of distinguishing characters and identifying keys (Moody et al., 1984).

Weed biomass was taken at 30 DAS and 60 DAS by harvesting all the above ground growth of weeds within the 1-m^2 quadrat thrown randomly in each experimental plot. The weeds were gathered together and put in a paper bag and later oven-dried at 60°C to attain a constant weight. The oven-dried weight in grams was then converted to kg ha^{-1} for each plot. In addition to weed biomass, sorghum biomass sampling was done at the same time as for weeds, from 0.6 m row length on each of the two border rows. The sorghum shoots were harvested at the crown level and dried in an oven at 60°C to constant weight. Weed control efficiency (WCE) was calculated as the percentage of weed reduction due to the weed control treatments. The WCE is a measure of effectiveness of a control method. Data on WCE (%) were calculated according to the formulae by Mani et al. (1973) as follows;

$$WCE = \frac{DMC - DMT}{DMC} \times 100$$

Where, DMC is the weed dry matter in no weeding treatment and DMT is dry matter in a treatment. Data on crop yield were not collected due to bird damage.

Data analysis

Data collected were subjected to analysis of variance (ANOVA) using Statistical Analysis Software (SAS) version 8.1 (Littell et al., 2002). Treatment means were separated using Tukey's MSD (Minimum significant difference) test at 5% level of significance.

RESULTS AND DISCUSSION

Weed flora

Major weed flora observed in the experimental plots

Table 1. Treatments, trade name, active ingredients and recommended rates.

Herbicide product (trade name)	Active compound (s)	Rate of application (product in l ha^{-1})
Primagram	S-Metolachlor 280 g l^{-1}, Atrazine 370 g l^{-1}	5.6
2 ,4-D	2,4-D amine salt 560 g l^{-1}	3
Sencor	Metribuzin 480 g l^{-1}	1.5
Dual gold	S-metolachlor 960 g l^{-1}	2
Maguguma	S-metolachlor 290 g l^{-1}, Atrazine 370 g l^{-1}	2
Lumax	Mesotrione 37.55 g l^{-1}, Terbuthylazine 125 g l^{-1}, Metolachlor 375 g l^{-1}	4
Auxio	Bromoxynil 262 g l^{-1}, Tembotrine 50 g l^{-1}	1.5

comprised of *Datura stramonium, Bidens pilosa, Pennisetum clandestinum, Digitaria scalarum, Gallinsoga parviflora, Commelina benghalensis, Tagetes minuta, Anagallis arvensis, Oxygonum sinuatum, Oxalis latifolia, Setaria sphacelata and Cyperus rotundus.* Weed distribution in the experimental site recorded 80% annual broad-leaved and 23% narrow-leaved weeds, possibly because most broad-leaved weeds are more persistent in the soil than those of grass-weeds**.** Broadleaf weeds namely *Amaranthus hybridus, B. pilosa and G. parviflora* were among the predominant weed species as shown in Table 2. The *A. hybridus* emerges with crops and has been observed to significantly reduce yield of sorghum, maize and peas (Littell et al., 2002). In order to enhance competitiveness, *A. hybridus* may overtop lower growing vegetables by increasing height, deploying foliage at greater heights to enhance light interception and production of many seeds to increase chances of survival (Nandula et al., 2013). There were two troublesome narrow-leaved weeds; the *D. scalarum* and *C. rotundus*. The Kikuyu grass (*P. clandestinum*) was found but not in all experimental plots. Among the herbicides, 2,4-D was effective in killing all broad-leaved weeds (Table 2). The herbicide is one of the oldest and is widely used to control broad leafed weeds in cereals (Peterson and Hulting, 2004). Metribuzin is a systemic herbicide that is used as pre- and early post-emergence herbicide. It is a broad-spectrum herbicide that is effective on annual broad leaved and grass weeds and has been used to control weeds in maize, potato, tomato and soybean (Volova et al., 2020). In the current study, Metribuzin was effective in control of both narrow and broadleaved weeds as shown in Table 2. Sencor® was applied as pre-emergence and weeds were more susceptible at early stages, moreso, at 4 to 8 true leaves stages (Hugie et al., 2008).

Effect of selected herbicides on weed density

The pre-emergence herbicides significantly reduced the weed density in sorghum compared to the un-weeded check (Table 3); however, weed density varied with the treatment. Amongst the four pre-emergence herbicides, Sencor was the most effective herbicide in reducing the weed density by 98% compared to no weeding at 30 DAS (Table 3).

The positive effect of hand weeding was seen at 60 DAS, where weed density was reduced by 91% compared to ‘un- weeded’ control. The negative attribute to hand weeding is the likelihood of some mechanical injury to the crop. During hand weeding, roots, leaves and stems could be damaged or bruised, thereby affecting growth and development. Also, weeds that grow within crop rows and closer to crop plants may escape mechanical weeding (Peterson and Hulting, 2004) and such weeds culminate in higher losses to crops.

Some of the perennial weeds are persistent and more difficult to control through tillage than annuals due to their underground vegetative structures, which provide carbohydrate reserves that aid in regeneration of several new plants even after being uprooted (Jabran et al., 2012), making hand weeding a less effective option. The use of Sencor recorded lower weed density as compared to hand weeding (Khaliq et al., 2011).

The difference in weed densities among the treatments could be attributed to properties of individual herbicides, which include solubility in the soil, volatilization, photo degradation, microbial breakdown, persistence and weed tolerance. One major challenge with pre-emergence herbicide is that they need to be applied in a moist soil for it to be effective. The pre-emergence herbicides are taken up by roots of germinating weeds (Kaapro and Hall, 2012) or through the coleoptile or meristem of germinating seedling. The uptake by roots will occur when the herbicide is available in soil water. Metribuzin has high solubility (1165 mg/L) followed by S-metolachlor (480 mg/L) while atrazine has the lowest solubility (30 mg/L) all at 20°C (GRDC, 2015). Atrazine can therefore fail to provide good weed control under dry conditions.

The efficacy of applied herbicides may decline due to photo degradation resulting in increased weed growth. Adequate rainfall after application of pre-emergence herbicide may also lead to chemical loss through runoff or leaching. Comparing persistence of three herbicides under no tillage, Bedmar et al. (2017) found S-

Table 2. Weed species found in the experimental plot**.**

Weed species	Un-weeded	Primagram	2,4-D	Sencor	dual	Magug	Hand	Lumax	Auxio
Amaranthus hybridus	36	6	0	0	8	2	0	9	30
Datura stramonium	3	1	0	0	2	2	2	0	0
Bidens pilosa	31	4	3	0	9	6	2	4	23
Physalis alkekengi	3	1	0	1	5	0	3	6	15
Pennisetum clandestinum	10	0	5	0	3	7	6	3	2
Chenopodium album	8	0	0	1	4	1	1	9	1
Raaphanistrum raphanistrum	12	5	0	0	1	1	4	1	4
Digitaria scalarum	6	0	3	1	7	6	3	8	3
Gallinsoga parviflora	26	6	0	1	6	2	1	4	4
Commelina benghalensis	3	2	0	0	8	8	0	3	9
Tagetes erecta	2	2	0	1	0	5	1	0	14
Oxygonum sinuatum	7	2	0	1	5	3	1	4	4
Oxalis latifolia	5	2	2	1	3	7	0	1	9
Setaria sphacelata	12	0	3	1	9	1	0	3	7
Cyperus rotundas	3	2	4	3	1	5	2	4	1
Total	171	42	28	8	22	77	56	29	61
Broad leaf	140	40	0	3	15	57	37	18	43
Narrow leaf	31	2	28	5	7	20	19	11	18

metolachlor to have significantly greater persistence of 82 to 141 days compared to atrazine whose persistence ranged from 13 to 29 days. The persistence varies depending on herbicide composition, soil type and rate of breakdown. According to GDRC (2015), S-metolachlor (Dual Gold), and Sencor are non-persistent having DT_{50} value ranging between 11 to 31 days. Since Sencor has low persistence, it was able to clear the majority of weeds within 30 days after planting to create a long lasting effect of low weed density.

The post-emergence herbicides reduced weed density significantly relative to the un-weeded control (Table 3). 2,4-D amine salt was a more effective post-emergence herbicide that resulted in lower weed density compared to un-weeded check, Auxio and Maguguma which was however comparable to hand-weeding. Thirty days after application of the post emergence treatment of 2,4-D hand weeding (Maguguma and Auxio) were used, weed densities were reduced by 97, 91, 68 and 59%, respectively. Although both Auxio and Muguguma were less effective than hand weeding, they reduced weed density significantly by about 58 and 67%, respectively compared to un-weeded check at 90%. Hand weeding was comparable to 2, 4-D indicating that either can be used depending on economic advantage and convenience.

Effect of selected herbicide treatments on weed biomass

Weed biomass was remarkably influenced by weed control treatments at all stages of observation (Table 4). The results showed that the use of Sencor had notable effect on weed biomass at 30 and 60 days after application. The herbicide reduced weed biomass by 85 and 92% compared to no weeding at 30 and 60 days after sowing, respectively. Relative to hand weeding, Sencor reduced weed biomass by 73 and 68% at 30 and 60 days after application, respectively. Primagram, Lumax and Dual gold were not as effective as hand weeding at 30 and 60 days after application.

These results reflect the ability of Sencor in suppressing weeds (Rajcan and Swanton, 2001). Sencor is absorbed by plant roots and transported through the xylem to the target process within the plant (Kennepohl et al., 2010). It is a selective triazinone herbicide acting as an inhibitor of photosynthesis in light reaction stage (Norsworthy et al., 2012). This is done by binding onto the D1 proteins of the photosystem II complex in chloroplast thylakoid membranes blocking electron transport, stopping CO_2 fixation and production of energy needed for plant growth (Azadbakht et al., 2017). This interferes with dry matter accumulation lowering the biomass of a crop. Though sencor was applied as pre-emergence, it is also used as post-emergence herbicide for control of weeds in potatoes, sugarcane and tomatoes.

Amongst the post emergence treatments, 2, 4-D (2, 4-D amine salts) and hand weeding had over 80% weed control efficiency. These two proved more effective in reducing weed growth as indicated by reduced dry weight compared to other treatments (Table 4). Hand weeding and use of 2, 4-D did not differ significantly ($p \leq 0.05$).

Table 3. Effect of selected herbicides on weed density in sorghum.

Treatment	Weed density (number m^{-2})	
	At 30 DAS	At 60 DAS
No weeding	2542[a*]	2705[a]
and-weeding	2303[a]	251[cde]
Auxio	1948[a]	1122[b]
2,4-D amine salt	1712[ab]	83[de]
Maguguma	2192[a]	871[bc]
Primagram	378[c]	713[bcd]
Sencor	48[e]	59[e]
Dual Gold	832[bc]	591[bcde]
Lumax	460[c]	934[b]
Tukeys $MSD_{0.05}$	890.4	389.54

*Means with same letter in the column do not differ significantly ($P≤0.05$), DAS – Days after sowing.

Table 4. Effect of selected herbicides on weed biomass in sorghum.

Treatment	Weed biomass (kg/ha)		Weed control efficiency (WEC)
	30 DAS	60 DAS	
No Weeding	1542.7[a^]	1888.7[a]	0
Hand Weeding	809.0[ab]	323.7[d]	82.9
Primagram	1303.2[ab]	716.4[c]	62.1
Sencor	121.2[c]	82.09[d]	95.7
Lumax	525.5[bc]	735.9[bc]	61.1
Dual Gold	917.2[ab]	945.8[bc]	49.9
2,4-D	1004.7[ab]	245.4[d]	87.0
Maguguma	937.1[ab]	858.8[bc]	54.5
Auxio	1026.5[ab]	1001.8[b]	47.0
Tukeys $MSD_{0.05}$	540.6	267.5	91.6

*Means with same letter in the column do not differ significantly ($P≤0.05$), DAS – Days after sowing.

However, considering the initial weed biomass at the time of application of the treatment, 2, 4-D reduced the weed biomass by 60.7% while hand weeding reduced the biomass by 42.8%, which also acted as a positive control. 2, 4-D herbicide is among the first herbicide compounds that are selectively effective against dicot but less effective in monocot plant species (Grossmann, 2003). The 2, 4-D amine salts differ from corresponding esters in that ester formulations tend to volatilize more than amines. Secondly, though esters have wider weed control, they tend to cause crop injury since they are readily soluble rendering easy absorption (Grossmann, 2003). When applied at high dose, effect on plant growth is manifested through cupping and stunting of leaves, brittleness, stunting and twisting of stems, and general abnormal growth, which eventually kills the plant (Kennepohl et al., 2010).

The use of herbicides in crop management has been suggested as a technological alternative of hand weeding to obtain increased crop yields. In an experiment where predominant weed species were Bermuda grass (Cynodon dactylon), horse purslane (Trianthema portulacastrum), Jungle rice (Echinochlova colona), nutsedge (C. rotundus), crow foot grass (Dactyloctenum aegyptium), field bind weed (Convolvulus arvensis) and goose grass (Eleusine indica), a significant weed density was observed when S-metolachlor and atrazine were applied for weed management in maize (Abuzar et al., 2011). Therefore, this demonstrates that atrazine and S-metolachlor are ineffective where the afore-mentioned weeds are predominant. The present study showed that 2, 4-D and Sencor obtained above 85% weed biomass suppression and hence, can be adopted as an alternative for efficient weed management approach in sorghum.

CONCLUSIONS AND RECOMMENDATIONS

The application of herbicides for weed control resulted in significant reduction in weed density and weed biomass. The most effective pre- and post-emergence herbicides for sorghum were Sencor and 2, 4-D, respectively. Optimum application rate and influence of its efficacy by soil type, if any, need to be established.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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