Effect of sunflower (*Helianthus annuus* L.) on the suppression of some summer weeds at the Field Station of the University of Zambia

Tamala T. Kambikambi[1*], Olusegun A. Yerokun[2] and David D. M. Mbewe[3].

[1]*Department of Crop Science, School of Agricultural Sciences, University of Zambia, P. O. Box 32379, Lusaka. Zambia.*
[2]*School of Agriculture and Natural Resources, Mulungushi University, P. O. Box 80415, Kabwe. Zambia*
[3] *Zambia Open University, P. O. Box 31925 , Lusaka. Zambia.*

ABSTRACT

Weeds present a major challenge to crop production and need to be controlled. Several methods of weed control exist but they have proved to be less than successful especially in the tropics; therefore new ways of using these methods are still being sought. The use of allelopathy, a form of biological weed control, has been proposed. A systematic screening of 6 sunflower varieties, a crop known to have allelopathic activities was done at the Field Station of the University of Zambia in the 2008/09 and 2009/10 rain-fed growing seasons using a RCBD with 2 maize varieties as the control. Weed diversity was observed, while weed density, weed biomass and crop yield were measured and subjected to analysis of variance. Results showed that although there was a wide diversity of weeds present, 15 were most prevalent. Sunflower varieties, generally, had lower weed density and weed biomass than the control maize varieties. But varietal differences among the sunflower varieties were discerned. The yield reduction was higher in maize grown in a weedy environment than for the sunflowers although here again varietal differences were evident among the sunflowers. It was concluded that the use of sunflower varieties Milika, Record and PAN7352 as an alternative crop can help to reduce weeds in the field.

INTRODUCTION

Non-crop plants, normally called weeds, have grown among cultivated crops from the time that systems of food production were developed and have presented a major challenge to crop production and its improvement [(1)]. This is because these weeds compete with crops and are therefore a large economic and environmental cost to crop production[(2, 3, 4, 5)]. Methods of controlling these weeds have evolved and can be categorized into four, namely preventive, cultural, chemical and biological. However, these measures in the current form they are used have largely proved less than successful, motivating weed scientists to seek other ways of using them[(6)].

Biological control, which refers to the suppression of weeds by the action of organisms through natural means or by manipulation of the weed, organism or environment[(1)] is one method that has been singled out[(2)]. This is because it is an environmentally compatible method of weed control that does not leave residues or pollute. It has therefore been suggested that biological control of weeds can be used to maintain sustainability in agriculture and for the protection of natural resources.

Biological control includes control with both vertebrate and invertebrate animals, use of micro-organisms (plant pathogens) and live mulch. Other areas with potential for biological control of weeds are the exploitation of crop canopy, density and the allelopathic effects of both weeds and crop plants[(7)]. Biological control has already been successfully demonstrated in certain situations where it has proved to be both practical and economically affordable[(8,9)].

One such development is the use of allelopathy which permits ecological weed management[(10, 11)]. Allelopathy has been defined as an interaction among plants by chemical pathways; the interaction including both inhibition and promotion[(12, 13, 14, 15)]. Through allelopathy, natural compounds released by crops, weeds and their residues may offer solutions to weed control needs[(16,17)].

There are many crop species known to possess allelopathic activities [(7)] and sunflower is one of them. Sunflower's allelopathic potential has also been reported by Kato *et al* [(18)], Semidey[(19)] and Robinson[(20)]. Sunflower therefore offers potential for biological weed control through production and release of allelochemicals from living and decomposing plant materials[(21)].

***Corresponding Author:**
Ms. Tamala T. Kambikambi,
Department of Plant Science, School of Agricultural Sciences,
University of Zambia, P. O. Box 32379, Lusaka.
Telephone: +260 211 295655 / 250587
Email: tkambikambi@unza.zm, kambikambit@gmail.com

Key words: *Weeds, allelopathy, sunflower.*

The objective of this study was to identify local sunflower varieties with allelopathic potential through systematic screening.

MATERIALS AND METHODS

Field experiments were conducted at the Field Station of the School of Agricultural Sciences, University of Zambia (15°23'S, 28°20'E and 1,225m above sea level) in the 2008/09 and 2009/10 rain-fed growing seasons. A Randomized Complete Block Design was set up with four replications. Plots, 5 x 5m in extent were laid down containing rows 75cm apart with 20cm intra row spacing and one plant left per station. This translated to a plant population of 60,000 plants per hectare equivalent. A distance of 1.5m was allowed between plots while blocks (replications) were laid 2m apart. Treatments were assigned to the plots at random using random numbers in Mead *et al*.[22] and comprised six different sunflower varieties (Chongwe, Milika, PAN7371, PAN7352, Record and Saona) and two maize varieties (MRI514 and MRI455) as the control.

The soils, which are classified as fine loamy mixed isohyperthermic oxic paleustalf, were ploughed to a depth of 20cm using conventional means and disced to obtain a fine tilth. Basal dressing fertilizer was applied at 200kgha^{-1} equivalent using Compound D (10:20:10 NPK) to supply 20kg N, 20kg K_2O and 40kg P_2O_5, and top dressing using 100kgha^{-1} equivalent (46% N) to supply 46kg N was applied four weeks after planting using the local recommendations [23]. Harvesting was done at maturity.

Data collected comprised the following:

(i) Sunflower and maize emergences were determined as number of plants emerged from the net rows or harvest area at two weeks after planting.
(ii) Weed density and diversity was determined within four 0.25m^2 quadrants on a transect at mid-plot 3, 6 and 9 weeks after planting.
(iii) Weed biomass was obtained by uprooting all weeds from each quadrant and drying them in an oven at 60°C for 48 hours.
(iv) Seed weight for both sunflower and maize were determined. For sunflower, the heads were harvested at petal drop stage and fresh weights of the heads were determined in the field using a balance. These heads were then moved to the shed for drying at room temperature. When the heads were dry enough, they were threshed separately for each plot and seeds weighed. A 100g sample was drawn from each harvest plot for moisture content determination. Using the determined moisture content, data was corrected to 8%. Yield was then expressed in kgha^{-1} equivalent. For maize, the same process was followed except that the cobs were harvested at black layer maturity and the determined moisture was corrected to 12.5%.

Analysis of variance (ANOVA) was the first analytical tool used followed by mean separation with the Least Significant Difference (LSD) test [24].

RESULTS

Weed diversity

A total of 38 weeds were recorded in these field trials (Table 1), of which 15 were more widespread. The first flush of weeds emerged in the first two weeks of planting and later developed alongside the crops. This resulted in 38% weed cover in maize as compared to 24% for the sunflower just before the first weed count, 3 weeks after planting. After six weeks, the figures had gone up to 47 and 31% for maize and sunflower respectively. Data collected at 9 weeks after planting showed a reduction in weed cover to 31 and 18% in maize and sunflower, respectively.

Weed density

The ANOVA for the two seasons combined showed highly significant differences for the interaction among the variety x season x time but not for the other sources of variation (Table 2). Means for the effect variety x season x time showed that for time 1 (T1) in the 2 seasons, Milika and Chongwe in season 1 were significantly different ($P \leq 0.05$) from Record, Milika, Saona, PAN7371 and PAN7352 in season 2 but not from the remaining varieties in both seasons (Record, Saona, PAN7371, PAN7352, MRI514 and MRI455 in season1; Chongwe, MRI514 and MRI455 in season 2). Record, Milika, Saona, PAN7371 and PAN7352 in season 2, were however not significantly different from these varieties (Record, Saona, PAN7371, PAN7352, MRI514 and MRI455 in season 1; Chongwe, MRI514 and MRI455 in season 2). Means for time 2 (T2) in the two seasons showed that there were no significant differences among all the varieties. For time 3 (T3), Saona in season 1 was significantly different from all the varieties in both seasons. The remaining varieties were not significantly different from each other (Table 3; Figure 1).

Weed biomass

Analysis of variance for weed biomass for the two seasons combined showed highly significant differences for variety x season, variety x time and variety x season x time. None were found for the other sources of variation (Table 4).

Table 1: Weed diversity in the study area (combined for two seasons)

	Weed presence			
	Weed species	**3 WAP**	**6 WAP**	**9 WAP**
1.	*Achyranthes aspera*	P	P	A
2.	*Amaranthus hybridus**	P	P	P
3.	*Amaranthus spinosus*	P	P	P
4.	*Amaranthus thumbergii*	A	P	A
5.	*Celosia trigyna**	P	P	P
6.	*Boerhavia diffusa**	A	P	P
7.	*Cleome gynandra*	A	P	P
8.	*Cleome hirta*	A	P	P
9.	*Oxalis latifolia*	A	P	P
10.	*Oxalis obiquifolia*	A	P	P
11.	*Euphorbia hirta*	P	P	A
12.	*Euphorbia heterophylla**	P	P	P
13.	*Corchorus olitorius*	A	P	P
14.	*Hibiscus meeusei*	A	P	P
15.	*Trichodesma zeylanicum**	P	P	P
16.	*Leucas martnicensis*	P	P	A
17.	*Ocimum canum*	A	P	A
18.	*Eragrostis aspera*	A	P	P
19.	*Nicandra physalodes**	P	P	P
20.	*Datura stramonium*	A	P	P
21.	*Sesamum calycinum*	P	P	P
22.	*Acanthospermum hispidum*	P	P	P
23.	*Ageratum conyzoides**	P	P	A
24.	*Bidens pilosa**	P	P	P
25.	*Bidens schimperi**	A	P	P
26.	*Tagetes minuta*	A	P	A
27.	*Galinsoga parviflora**	P	P	A
28.	*Sonchus oleraceae*	A	P	A
29.	*Commelina benghalensis*	P	P	P
30.	*Cyperus rotundus**	P	P	P
31.	*Cyperus esculentus**	P	P	P
32.	*Eleusine indica**	P	P	P
33.	*Rottboellia conchinchinensis**	P	P	P
34.	*Cynodon dactylon**	P	P	P
35.	*Panicum maximum*	P	P	A
36.	*Digitaria milanjiana*	P	P	P
37.	*Digitaria ternata*	A	P	P
38.	*Panicum maximum*	A	P	P

A – absent P – present * most prevalent weeds.

Table 2: ANOVA for weed density

Source of variation	DF	Mean squares	F ratio	Probability
Variety x Season	15	18739.2	2.08NS	0.023
Variety x Time	16	11893.9	1.32NS	0.213
Variety x Reps	24	12924.2	1.43NS	0.128
Variety x Season x Time	16	19447.3	2.16***	0.016
Season x Time x Reps	15	9617.08	1.07NS	0.403
Variety x Time x Rep	42	9313.31	1.03NS	0.445
Residual	63	9007.07		
TOTAL	**191**	**11495.2**		

SE = 47.453

Table 3: Mean weed density (no./m^2) for the two seasons

		Season 1			Season 2		
No.	**Variety**	**T1**	**T2**	**T3**	**T1**	**T2**	**T3**
1.	Record	194.25^{bcd}	62.00^{defg}	104.50^{bcdefg}	39.75^{efg}	67.00^{cdefg}	31.25^{efg}
2.	Milika	205.25^{b}	43.75^{efg}	75.50^{bcdefg}	40.75^{efg}	75.75^{bcdefg}	16.25^{g}
3.	Saona	196.75^{bc}	51.75^{efg}	382.50^{a}	55.25^{efg}	87.00^{bcdefg}	58.25^{efg}
4.	Chongwe	204.25^{b}	98.25^{bcdefg}	84.00^{bcdefg}	86.50^{bcdefg}	101.25^{bcdefg}	35.00^{efg}
5.	PAN7371	116.75^{bcdefg}	30.75^{efg}	68.50^{cdefg}	46.00^{efg}	97.25^{bcdefg}	90.25^{bcdefg}
6.	PAN7352	100.00^{bcdefg}	27.25^{fg}	86.50^{bcdefg}	56.50^{efg}	134.00^{bcdefg}	36.50^{efg}
7.	MRI514	158.50^{bcde}	64.25^{cdefg}	74.25^{bcdefg}	81.75^{bcdefg}	152.75^{bcdef}	40.00^{efg}
8.	MRI455	140.50^{bcdefg}	39.75^{efg}	130.50^{bcdefg}	74.50^{bcdefg}	101.50^{bcdefg}	59.75^{efg}

Treatment means followed by the same letter in a column and are not significantly different from each other ($P \leq 0.05$)

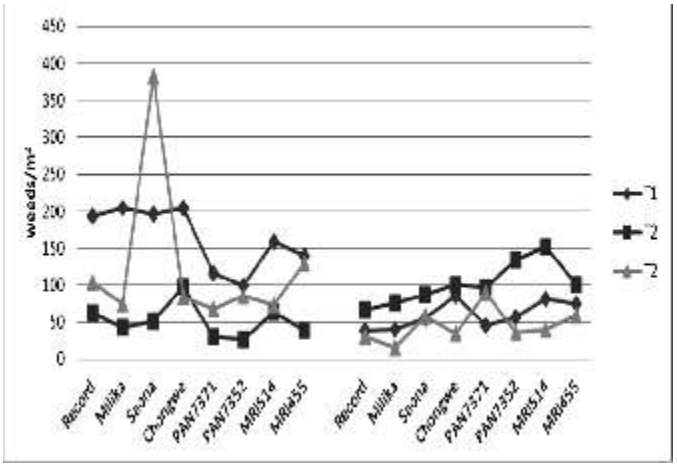
SE = 27.4

Table 4: ANOVA for weed biomass

Source of variation	DF	Mean squares	F ratio	Probability
Variety x Season	15	504.847	3.75***	0.000
Variety x Time	16	288.363	2.14***	0.017
Variety x Rep	24	191.708	1.43NS	0.132
Variety x Season x Time	16	486.223	3.61***	0.000
Season x Time x Rep	15	117.336	0.87NS	0.597
Variety x Time x Rep	42	100.498	0.75NS	0.841
Residual	63	134.505		
TOTAL	**191**	**204.305**		

SE = 3.348 (Variety x season); 4.1 (Variety x time); 5.799 (Variety x season x time)

Figure 1: Mean weed density for seasons 1 and 2



T1, T2 and T3 are the first, second and third time of sampling 3, 6 and 9 weeks after planting, respectively.

Means for effect variety x season showed that Milika in season 1 had significantly higher ($P \leq 0.05$) weed biomass than Saona, PAN7371, PAN7352 and MRI455 in the same season and all the varieties in season 2 but was not significantly different from Record, Chongwe and MRI514 in season 1. However, although Record, Chongwe and MRI514 in season 1 had significantly higher ($P \leq 0.05$) weed biomass than PAN7352 in season 1 and all the varieties in season 2 except PAN7371 and MRI455, they were not significantly different from Saona, PAN7371 and MRI455 in season 1. Saona in season 1, PAN7371 and MRI455 in both seasons had significantly higher weed biomass than Record and Saona in season 2. The remaining varieties were not significantly different from each other ($P \leq 0.05$).

Analyzing the data per variety revealed the following; apart from PAN7371 and MRI455 which had similar weed biomass in both seasons, the remaining varieties (Record, Milika, Saona, Chongwe, PAN7352 and MRI514) had significantly higher weed biomass in season 1 than in season 2 (Table 5).

Table 5: Mean weed biomass (g/m2) in the different varieties for the two seasons

Variety	Season		Mean
	1	2	
Record	27.147^{ab}	8.159^{d}	17.653
Milika	29.981^{a}	12.053^{cd}	21.017
Saona	20.292^{bc}	8.754^{d}	14.523
Chongwe	26.488^{ab}	11.823^{cd}	19.155
PAN7371	19.499^{bc}	19.319^{bc}	19.409
PAN7352	15.701^{cd}	12.257^{cd}	13.979
MRI514	20.681^{b}	13.809^{cd}	17.245
MRI455	18.468^{bc}	20.058^{bc}	19.763

Treatment means followed by the same letter in a column and rows are not significantly different from each other ($P \leq 0.05$)

SE = 3.35

Means for effects due to variety x time showed that at T1, although Milika was significantly different ($P \leq 0.05$) from Record and PAN7352 but not from Saona, Chongwe, PAN7371, MRI514 and MRI455; these latter five varieties (Saona, Chongwe, PAN7371, MRI514 and MRI455) were however not significantly different from both Record and PAN7352 (Table 6). At T2, Chongwe had the highest weed biomass which was significantly different ($P \leq 0.05$) from Saona, PAN7371, PAN7352 and the maize variety MRI455 but not from Record, Milika and MRI514. These varieties (Record, Milika and MRI514) were however not significantly different from each other and from Saona, PAN7352, and MRI455. But they were all significantly different from PAN7371. This variety, PAN7371, had the lowest weed biomass which was significantly different from all the other varieties at T2. At T3, PAN7371 had the highest weed biomass which was significantly different ($P \leq 0.05$) from Saona, PAN7352 and MRI514 but not the rest of the varieties (Record, Milika, Chongwe and MRI455). However, Record, Milika, Chongwe and MRI455 were not significantly different from Saona and PAN7352.

Table 6: Mean weed biomass (g/m^2) in the different varieties at the 3 sampling times (3, 6 and 9WAP) combined for the two seasons

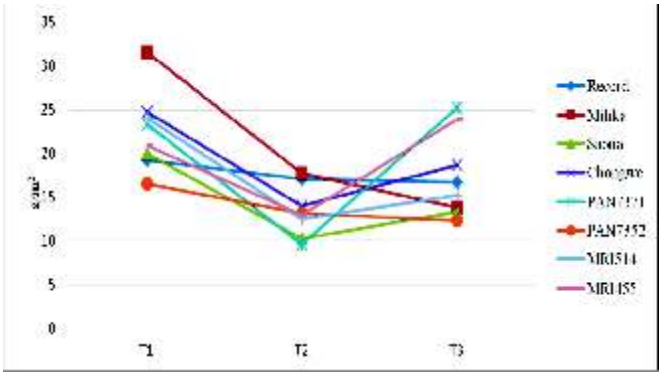
Variety	Sampling time			Mean
	T1	T2	T3	
Record	19.194^{b}	17.090^{bcd}	16.675^{bcd}	17.653
Milika	31.514^{a}	17.753^{bcd}	13.785^{bcd}	21.017
Saona	19.959^{abc}	10.284^{cd}	13.326^{cd}	14.523
Chongwe	24.775^{ab}	13.980^{b}	18.710^{bcd}	19.155
PAN7371	23.370^{abc}	9.623^{e}	25.235^{ab}	19.409
PAN7352	16.515^{bcd}	13.159^{cd}	12.269^{cd}	13.981
MRI514	24.055^{ab}	15.201^{bcd}	12.479^{cd}	17.245
MRI455	20.945^{abc}	12.970^{cd}	23.875^{abc}	19.763

Treatment means followed by the same letter in a column and rows are not significantly different from each other ($P \leq 0.05$)

SE = 4.1; WAP = Weeks after planting

Per variety, Record, Saona, Chongwe, PAN7352 and MRI455 showed no significant differences ($P \leq 0.05$) in weed biomass for all the three times (T1, T2 and T3). Milika had significantly higher weed biomass at T1 than at both T2 and T3. These were then not significantly different from each other ($P \leq 0.05$). PAN7371 showed no significant difference in weed biomass at T1 and T3. Both these times were significantly different from T2 which had significantly lower weed biomass. MRI514 showed no significant difference in weed biomass between T1 and T3 and between T2 and T3. However, there was a significant difference ($P \leq 0.05$) between T1 and T3 (Figure 2).

Figure 2: Weed biomass in the different varieties (g/m^2) combined for the two seasons



T1, T2 and T3 are the first, second and third time of sampling 3, 6 and 9 weeks after planting, respectively

Means for effect variety x season x time showed that at T1 for both seasons, Milika, Saona, Chongwe and PAN7371 in season 1 had significantly higher weed biomass than PAN7352, MRI514 and MRI455 in the same season, and all the varieties in season 2 but not Record in season 1 (Table 7). Record in season 1 was only significantly different ($P \leq 0.05$)

from Record and Saona in Season 2. It was not significantly different from the rest of the varieties. At T2 no significant differences were discerned for all varieties in both seasons. At T3, Chongwe in season 1 had the highest weed biomass which was significantly different from Milika, Saona, PAN7371, PAN7352 in season 1 and Record, Milika, Saona, Chongwe, PAN7352, MRI514 and MRI455 in season 2 but not Record, MRI514, MRI455 in season 1 and PAN7371 in season 2. Record, MRI514, MRI455 in season 1 and PAN7371 in season 2 were not significantly different from each other and from Milika, Saona, PAN7371, PAN7352 in season 1 and MRI455 in season 2 but were significantly different from Record, Milika, Saona, Chongwe, PAN7371 and PAN7352 in season 2. These latter six varieties (Record, Milika, Saona, Chongwe, PAN7371 and PAN7352 in season 2) were not significantly different from each other and from Saona, PAN7371, and PAN7352 in season 1 and MRI455 in season 2.

Table 7: Mean weed biomass (g/m2) in the different varieties at the 3 sampling times for the two seasons

Variety	Season							
	1				2			
	T1	T2	T3	Mean	T1	T2	T3	Mean
Record	28.730^{ab}	23.998^{bc}	28.716^{ab}	27.147	9.658^{c}	10.183^{bc}	4.638^{c}	8.159
Milika	43.523^{a}	20.380^{bc}	26.043^{b}	29.982	19.505^{bc}	15.125^{bc}	1.528^{c}	12.053
Saona	32.285^{a}	5.693^{c}	22.898^{bc}	20.292	7.633^{c}	14.875^{bc}	3.755^{c}	8.754
Chongwe	37.285^{a}	9.480^{c}	32.698^{a}	26.488	12.265^{bc}	18.480^{bc}	4.723^{c}	11.822
PAN7371	34.588^{a}	2.850^{c}	21.060^{bc}	19.499	12.153^{bc}	16.395^{bc}	29.410^{ab}	19.319
PAN7352	22.160^{bc}	5.255^{c}	19.688^{bc}	15.701	10.870^{bc}	21.063^{bc}	4.840^{c}	12.258
MRI514	25.875^{bc}	8.988^{c}	27.180^{ab}	20.681	22.235^{bc}	15.970^{bc}	3.223^{c}	13.809
MRI455	21.295^{bc}	5.775^{c}	28.335^{ab}	18.468	20.595^{bc}	20.165^{bc}	19.415^{bc}	20.058

Treatment means followed by the same letter in a column and rows are not significantly different from each other (P≤0.05)
SE = 5.8

Across varieties, Record showed no significant differences at T1, T2, T3 in season 1 and T2 in season 2. However, T2 season 1 and T2 season 2 were also not significantly different from T1 and T3 season 2. Only T1 and T3 season 1 were significantly different (P≤0.05) from T1 and T3 in season 2. Milika showed significant differences between T1 season 1 and T2, T3 season1 and all the three times (T1, T2, T3) in season 2. T3 season 1 and T3 season 2 were also significantly different from each other. For Saona also, there were significant differences between T1 season 1 and T2, T3 season 1 and all the three times in season 2. There were however no significant differences among these five times.

Chongwe followed a different trend; T1 and T3 in season 1 were not significantly different from each other but were significantly different from T2 season 1 and all the three times (T1, T2, T3) in season 2. These last four times were however not significantly different from each other. PAN7371 showed no significant difference between T1 season 1 and T3 season 2. However, T3 season 2 was also not significantly different from T3 season 1 and both T1 and T2 in season 2 while T1 season 1 was significantly different from them. T3 season 2 was however significantly different from T2 season 1 just like T1 season 1. No significant differences were observed among T2, T3 season 1, T1 and T2 season 2. For PAN7352, no significant differences were found among the six times across the two seasons.

MRI514 showed that T3 in season had significantly higher weed biomass than T2 but not T1 in the same season; and T3 in season 2 but not T1 and T2 in that season. T1, T2 season 1, T1, T2 and T3 in season 2 were all not significantly different from each other. This was the same trend observed for MRI455 except that T3 season 2 was not significantly different from T3 in season 1

Yield

Analysis of variance for yield for the two seasons combined showed significance for all sources of variation (Table 8). No mean separations were done for variety x replication, season x time x replication and variety x time x replication because significance for these justified the use of the experimental design, RCBD.

Table 8: ANOVA for crop yield

Source of variation	DF	Mean squares	F ratio	Probability
Variety x Season	15	5555900	28.77***	0.000
Variety x Time	16	0.151145	0.00***	0.000
Variety x Rep	24	1176780	6.09***	0.000
Vari x Season x Time	16	0.591178	0.00***	0.000
Season x Time x Rep	15	606821	3.14***	0.001
Variety x Time x Rep	42	0.641623	0.00***	0.000
Residual	63	193125		
TOTAL	**191**			

SE = 126.861 (Variety x Season); 155.373 (Variety x Time); 179.409 (Variety x Replication); 219.73 (Variety x Season x Time); 179.409 (Season x Time x Replication); 310.745 (Variety x Time x Replication).

For the combined seasons 1 and 2, means for effect due to variety x season revealed that the two maize varieties (MRI514 and MRI455) in both seasons yielded significantly higher (P≤ 0.05) than all the sunflower varieties (Record, Milika, Saona, Chongwe, PAN7371 and PAN7352). However, MRI455 in season 1 was significantly lower than both MRI514 and MRI455 in season 2 but not significantly different from

MRI514 in season 1. MRI514 in season 1 was however not significantly different from both MRI514 and MRI455 in season 2 (Table 9).

Table 9: Mean seed yield (kg/ha) for the different crop varieties for the 2 seasons

Variety	Season 1	Season 2	Mean
Record	878.200^{d}	455.700^{fg}	666.950
Milika	1305.70^{c}	798.125^{de}	1051.913
Saona	1239.25^{c}	614.230^{ef}	926.740
Chongwe	407.000^{fg}	0.0000^{h}	203.500
PAN7371	771.075^{e}	272.700^{g}	521.837
PAN7352	993.875^{d}	264.600^{g}	629.237
MRI514	1947.30^{ab}	2090.93^{a}	1519.115
MRI455	1849.53^{b}	2005.56^{a}	1927.545

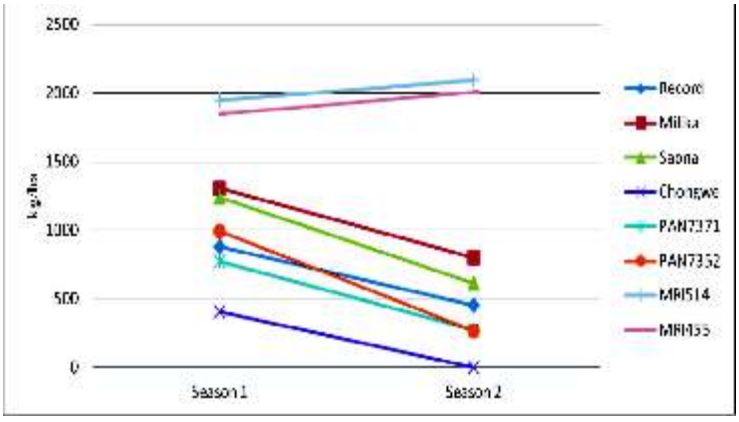
Treatment means followed by the same letter in a column and rows are not significantly different from each other (P≤0.05)

SE = 219.7

For the sunflower varieties in season 1, Milika and Saona were not significantly different from each other but were significantly higher (P≤ 0.05) than Record, Chongwe, PAN7371 and PAN7352. Record, PAN7371 and PAN7352 were not significantly different from each other but they were significantly different from Chongwe, the lowest yielding variety. In season 2, Milika and Saona were not significantly different from each other, again. However, Milika was significantly different from Record, Chongwe, PAN7371 and PAN7352 while Saona was not significantly different from Record but was significantly different from Chongwe, PAN7371 and PAN7352. Record was not significantly different from PAN7371 and PAN7352 but all these latter three sunflower varieties were significantly different from Chongwe.

Analysis across the two seasons showed that there were no significant differences between MRI514 in the two seasons. All the sunflower varieties yielded significantly better in season 1 than season 2. MRI455 performed contrary. It yielded better in season 2 than in season 1 (Table 9; Figure 3).

Figure 3: Mean yield (kg/ha) for the different varieties in the two seasons



Means for effect due to variety x time showed that the two maize varieties (MRI514 and MRI455) yielded highest. They were significantly different (P≤0.05) from all the sunflower varieties but not significantly different from each other. Among the sunflowers, Milika was significantly higher than all the other sunflower varieties, followed by Saona which was significantly different from Record, Chongwe, PAN7371 and PAN7352. Record and PAN7352 were not significantly different from each other. However, while Record was significantly different from Chongwe and PAN7371, PAN7352 was not significantly different from PAN7371 but was significantly different from Chongwe. PAN7371, in turn, was also significantly different from Chongwe.

Means for effect due to variety x season x time showed that the two maize varieties (MRI514 and MRI455) yielded significantly higher in both seasons compared to all the sunflower varieties but were not significantly different (P≤ 0.05) from each other. Among the sunflower varieties, in season 1, Milika, Saona and PAN7352 were not significantly different from each other. However, while Milika was significantly different from Record, Chongwe and PAN7371; Saona and PAN7352 were only significantly different from Chongwe but not from Record and PAN7371. PAN7371 was in turn significantly different from Chongwe but Record was not. In season 2, Record, Milika and Saona were not significantly different from each other. However, while Record and Milika were then significantly different from Chongwe, PAN7371 and PAN7352, Saona was only significantly different from Chongwe but not from PAN7371 and PAN7352 (Table 9).

DISCUSSIONS

Weed diversity

The Field Station is an experimental station where research and some commercial activities are conducted. It is intensively used both during the rain-fed season as well as off-season with irrigation. Its weed flora is hence diverse as weeds thrive all year round. The top 5 common weeds in the Field Station were *Cynodon dactylon, Eleusine indica, Amaranthus hybridus, Bidens pilosa* and *Cyperus* spp. Apart from *Cynodon dactylon*, the rest are listed to be among the ten most common weeds in Zambia[25]. There were more weeds in maize on average than in sunflower. Further there were fewer weed species in sunflower than in maize. *Rottboellia conchinchinensis, Eluesine indica, Cyperus* spp., *Digitaria milanjiana, Nicandra physalodes* and *Bidens pilosa* were fewer in the sunflower plots than in the maize ones. These species could have been the ones that were more sensitive to the

allelochemicals released by sunflower which were not present in the maize plots.

Weed density

Weed intensity was generally higher in maize than in sunflower as evidenced through both the weed density and weed biomass. Many weeds emerged and grew fast in the maize plots. This is probably because they had access to different growth resources and also due to the absence of allelochemicals. From the study, the combined average for the two seasons showed that sunflower had lower weed density (91.305/m^2) than for maize (93.167/m^2). These findings agree with the postulations of Semidey[19]; Morris and Parish[26] and Leather[27] who reported that sunflower plots tended to have fewer weeds than plots with other crops. Cultivated sunflower has been shown to contain a series of heliannuols, which show more subtle effects and seem to be signals influencing the germination and growth of competitive seeds[28].

However, varietal differences were observed amongst the sunflower varieties. Saona and Chongwe had significantly higher weed density than the other sunflower varieties and the maize varieties too. Since allelopathy is an interaction that includes both inhibition and promotion [12, 13, 14], this is not surprising. It is therefore imperative that those varieties that have an inhibitory effect are identified and used.

Weed biomass

In this study, significant differences were observed between the test crop (sunflower) and the control (maize). Plots with sunflower varieties had lower weed biomass than the maize plots (17.623 and 18.504g/m^2, respectively). Differences were also observed within the sunflower varieties for weed biomass in the plots. This is in line with what Semidey[19], Morris and Parish[26] and Leather[27] who reported that sunflower plots tended to have fewer weeds and the weeds that were present had lower biomass even in the absence of herbicide application.

Leather[27] conducted field studies to determine if season long weed control could be achieved by combining the use of a herbicide with the natural allelochemicals produced by cultivated sunflower and found that weed biomass was reduced equally in plots planted with sunflowers, whether or not the herbicides was applied. However, varietal differences can be discerned[29]. Anjum *et al*.[30] also reported that the expression of allelopathic effects by sunflowers was highly dependent upon the particular variety. Further, the growth habit of sunflower, which has broad leaves and is a fast growing crop that helped cover the inter row spaces faster than maize also probably helped to suppress emerging weeds or emerged but small weeds. This is in agreement with Wang *et. al*.[31] who explained that the growth habit of a crop and competing weed species are important determinants of crop-weed interference. The lower weed numbers in sunflower are probably due to both allelopathy as well as the growth habit of the plant. Therefore, allelopathic properties of plants can be utilized for weed control as allelochemicals suppress plant growth and regulate species diversity (like herbicides) in the natural habitat of the producer plant[21]. Several authors conducted well designed field experiments and chemical analyzes to provide convincing evidence of allelopathy[32, 33, 34].

From this study, PAN7352 had the lowest weed biomass followed by Saona. These had lower weed biomass than both control maize varieties. Record and Chongwe had lower weed biomass than one maize variety (MRI455) but not the other (MRI514) while Milika and PAN7371 had weed biomass higher than the control maize varieties.

Yield

Maize yields in this study were drastically reduced as compared to sunflower yields grown in the same weedy environment probably due to the effect of weeds in comparison to their potential. This was indicated by the high number of weeds and weed biomass for these treatments. Akobundu[1] reported that weeds are more efficient in resource use and will therefore have a competitive edge over less efficient crops like maize. The presence of large number of weeds had a negative effect on the growth of maize probably due to inequitable partitioning of a disproportionate amount of growth resources to the weeds.

Sunflower on the other hand had fewer weeds because of its known allelopathic activities but also its growth habit. Sunflowers (*Helianthus* species) are allelopathic in nature and exhibit autotoxicity[27]. They can actively influence the growth of surrounding plants and have demonstrated selective phytotoxicity of their residues towards weeds[35]. Plants in Asteraceae family, genus *Targetes* can produce a variety of allelopathic agents and the polyacetylene and alpha-terthienyl components, which are photo-active biocides can exert potent effects[28]. *Helianthus millani* produces the highly phytotoxic 8, β-sarracinoyloxycumambranolide. The cultivated sunflower (*Helianthus annuus* L.) was reported to be allelopathic to invading weeds in old fields[36] and reduced crop yields as a weed component in agroecosystems[37, 38, 39].

Results from this study showed that between the maize varieties, MRI514 yielded lower than its counterpart MRI455. Among the sunflower varieties, Milika yielded highly (1,052kgha^{-1}), not significantly lower than its normal yield of around 1,200 kgha^{-1}. This was followed by Saona, Record and

PAN7352 in that order with PAN7371 and Chongwe being the lowest yielding sunflower varieties.

Triangulating the three parameters measured, it can be deduced that PAN7352 and Record had low weed biomass and weed density, making them good candidates for varieties with good allelopathic activities. However, their yields were on the low side. Saona had very high weed density but low weed biomass. This is coupled with fairly high yield. It can therefore be deduced that the weeds present, although high in number, were probably the small statured ones mostly leading to a low weed biomass. This would also mean that this variety has high allelopathic potential which acts on growing weeds instead of germinating weed seeds. PAN7352 had average weed density and weed biomass but very low yield. Chongwe had high weed density and average weed biomass but very low yield. The deduction would be that these varieties have low allelopathic activities which did not help in the control of weeds. Milika showed a very interesting trend where although it had the average weed density, it had the highest weed biomass and also the highest yield among the sunflower varieties. This would suggest that Milika had low allelopathic activities.

The issue of the critical period also comes to bear. This has been defined as the time interval between two separately measured crop-weed competition components: (1) the critical timing of weed removal or the maximum amount of time early season weed competition can be tolerated by the crop before the crop suffers irrevocable yield reduction, and (2) the critical weed-free period or the minimum weed free period required from the time of planting to prevent unacceptable yield reductions[40, 41]. Table 3 illustrates this point since the critical period for most crops is known to be between 4 – 8 WAP[42, 43, 44]. Record, Saona, Chongwe and PAN7352 showed no significant difference in weeds among the three sampling times (T1, T2 and T3). Milika had lower weed biomass at T2 and T3 compared to T1. PAN7371 had the lowest weed biomass at T2 compared to T1 and T3. Milika and PAN7371, hence had the lowest weed biomass during the critical period and this is desirable since this is the period when yield is lost.

CONCLUSIONS

The study has shown that the use of sunflower as an alternative crop reduces the number of weeds in the field, both number (diversity) and amount (biomass).

Using these two factors of weed diversity and weed biomass, the study revealed that varietal differences among the sunflower varieties occurred with PAN7371, PAN7352 and Record having fewer weed types and numbers compared to Saona, Milika and Chongwe. This is probably an indication that the latter three varieties (PAN7371, PAN7352 and Record) have more allelopathic activity than Saona, Milika and Chongwe.

When the critical period for weed control was also taken into consideration, it was observed that PAN7352 and Record continued to have fewer weed types and numbers throughout the times of sampling while PAN7371 had higher numbers in the second sampling. It was therefore dropped to join the other "non-desirable" varieties (Saona and Chongwe). Milika, on the other hand had fewer weeds at sampling time two (T2) and was thus upgraded to join PAN7352 and Record.

Sunflower yielded better in the presence of weeds (with the group leader Milika yielding only 17% lower than its potential) than maize which yielded up to 80% lower than its potential while in a weedy field.

The use of sunflower, varieties Milika, PAN7352 and Record, as an alternative crop to help reduce weeds is therefore recommended.

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