STUDY OF PRE AND EARLY POST EMERGENCE ALLELOPATHIC EFFECTS ON SELECTED WEEDS OF SEVERAL SORGHUM [Sorghum bicolor (L.) Moench.] AND PEARL MILLET (Pennisetum glaucum L.) CULTIVARS IN ZIMBABWE

Mukondwa Olivia[1], Rugare Joyful Tatenda[1], Mabasa Stanford[1] and Mandumbu Ronald[2]*

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ABSTRACT
Allelopathy has been identified as potentially a cost effective, natural weed control method which could be exploited by smallholders who have little access to herbicides. The objective of this study was to investigate the potential of sorghum and pearl millet cultivars for their allelopathic effect against several weeds. Water extracts of the stems root and leaves of twelve sorghum and pearl millet cultivars were screened for their ability to suppress germination and dry weight of blackjack (Bidens pilosa L.), upright starbur (Acanthospermum hispidium L.) and goose grass [Eleusine indica (L.) Gaertn)] and by the addition of their plant material to soil under laboratory and glasshouse conditions. A randomized complete block design with three replicates was used and the experiment was repeated twice over time. Results showed that there was a significant ($P < 0.01$) effect of sorghum and pearl millet cultivars on germination / emergence and dry weight of goose grass and blackjack. It was established that sorghum and pearl millet cultivars has no significant ($P > 0.05$) effect on germination of upright starbur and pearl millet landrace. However upright starbur dry weight was significant affected by sorghum and millets plant residues. From this study it can be concluded that all the sorghum and pearl millet cultivars reduced the germination and growth of goose grass and blackjack. Upright starbur was independent of the extracts applied. It can be concluded that incorporation of sorghum and millet residues can work as a tool in the integrated weed management for the rural farmers in Zimbabwe.

Keywords: Blackjack, goose grass, plant residues, integrated weed management, sustainable weed management, upright starbur.

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[1]Crop Science Department, University of Zimbabwe, P.O. Box MP167, Mount Pleasant, Harare, Zimbabwe.
[2]Crop Science Department, Bindura University of Science Education, P.O. Box 1020, Bindura, Zimbabwe.
*Corresponding Author: rmandumbu@gmail.com, Phone +263772919821

INTRODUCTION

Weeds are known to cause enormous losses due to their interference in agroecosystems. Blackjack, goose grass and upright starbur are some of the most common arable weeds in Zimbabwe which adversely affect crop yields (Munguri et al., 1996). Weed control through hand weeding is uneconomical due to higher costs of labour and resultant yields in the communal farming sector of Zimbabwe (Mandumbu et al., 2013). For Zimbabwe, although a lot of energy is expended on removing weeds by hand, crop yields are generally low due to competition as a result of untimely and ineffective weed control. Chivinge (1990) reported that farmers in Zimbabwe spend more than 70% of their time from January to the end of the season for weeding. The operation is done with short handled hoes which makes the operation back breaking. Despite the significant contribution of those weed control methods in improving crop productivity, certain challenges are also associated with them (Jabran et al., 2015). Labour for hand weeding is decreasing in availability and increases costs of labour and inconsistent weed control (Gianessi, 2013).

Allelopathy, which is expressed through release of chemicals by a plant has been suggested as one of the alternative weed control method (Singh et al., 2010). Wise exploitation of allelopathy in cropping systems may be an effective, economical and natural method of weed management and a substitute for hand weeding (Farooq et al., 2010). According to Weston and Duke (2003), sorghum possess a variety of inhibitory constituents such as sorgholeone and dhurrin among other components (Weston and Duke, 2003) which are actually hydrophobic p-benzoquinone phenolics and cyanogenic glucoside, respectively (Weston et al., 2013). Sorgholeone has been characterised as a potent bio-herbicide, which is inhibitory to broadleaf and grassy weeds at concentrations as low as 10 µM in hydroponic assays (Einhellig and Souza, 1992). Field et al. (2006) reported that allelochemicals may influence vital physiological processes such as respiration, photosynthesis, cell division and elongation, membrane fluidity, protein biosynthesis, water tissue status and enzyme activity. Other authors have noted the potential of sorghum seeds and seedlings to interfere with the germination and growth of weed seedlings (Panasuik et al., 1986; Hoffman et al., 1996). Sorgholeone has several modes of action which include a potent inhibitor of the electron transport system in both photosynthesis and respiration (Rasmussen et al., 1992; Rimando et al., 1998).For millet, Radbouane (2014) found that they inhibited the growth of the coleoptile and the inhibition reached 80% for oats. Other authors reported that phenolic compounds in millets inhibited cell division (Cherney et al., 1991); reduced root growth and cell elongation (Bhoumik et al., 2006). It was also reported that millet allelochemicals inhibited gibberellins and indole acetic acid induced growth (Radhouane, 2014).

Allelopathic compounds are non nutritional and can be found in any part of the plant from which they can eventually be released into the environment through the process of volatilisation, root exudation and leaching (Bonanomi et al., 2006). This phenomenon is a potential resolve to resistance development problems and environmental pollution usually caused by synthetic agrochemicals.

Allelochemicals can affect the growth and development of plants by reducing germination, necrosis of the root, curling of the root axis, discoloration, reduced weight accumulation and lowered reproductive capacity (Rice, 1984). Sorghum has been identified to cause allelopathic effects on different weed species (Cheema and Ahmad, 1992). Water extracts of mature sorghum have been reported to reduce the populations and biomass of weeds (Cheema et al., 1997). In other studies done outside Zimbabwe, Cheema and Khaliq (2000) found that sorghum stalks incorporated in the soil could reduce dry weight of weeds.

In Zimbabwe, sorghum and millets are the main crops grown in the communal areas where the farmers are located in the marginal areas and thus there is need to manipulate the by-products of the sorghum and millets genotypes to reduce weed competition. Therefore the objective of this study was to determine the allelopathic effects of distinct sorghum and pearl millet cultivars on germination and early dry matter accumulation of goose grass (Eleucine indica), blackjack (Bidens pilosa) and upright starbur (Acanthospermum hispidium) and pearl millet (Pennisetum glaucum) landraces which are common and problematic weeds for Zimbabwe cropping systems.

MATERIALS AND METHODS

Site Description

The experiments were carried out at the University of Zimbabwe Crop Science Department in the weed science laboratory and in greenhouses in Harare from September 2014 to January 2015.

Plant Material

The plant materials that were used for the experiment are as shown in Table-1.

Table-1. Description of sorghum and pearl millet cultivars used.

Sorghum/pearl millet cultivar	Maturity period	Height	Type of variety	Yield potential (t ha^{-1})	Origin	Crop	Colour of grain
SV-1	115 - 125	125 – 180	OPV,	4	ICRISAT	Sorghum	White
SV-2	115 - 125	140 – 160	OPV	6	ICRISAT	Sorghum	White
SV-4	113 - 127	135	OPV	9	DRSS	Sorghum	White
Macia	120	134	OPV	5	ICRISAT	Sorghum	White
PMV-2	95 - 100	170 – 220	OPV	3	DRSS	Pearl Millet	Grey
PMV-3	85 - 90	160 - 200	OPV	4	DRSS	Pearl Millet	Creamy white
Okashana-1	95-100		OPV	4	ICRISAT	Pearl Millet	Dark grey
Red Swazi	100 - 120		Farmer cultivarOPV	5	ICRISAT	Sorghum	Red
Chitichi	95 - 100	135	White,	5	Chiredzi	Sorghum	White
Chibonda			White,	3	Matoposi	Sorghum	White
Kuyuma			White,	4	Mwenezi	Sorghum	White
Mutode			White,	4	Murewa	Sorghum	White

OPV is open pollinated variety, ICRISAT is the International Crop Research Institute for the semi-arid Tropics, DRSS is the Department of Research and Specialist Services of Zimbabwe.

The weed seeds were sourced from Henderson Research Station, from the weed research team for Zimbabwe and they are located 30 Km north of Harare along Bindura road. The seeds were harvested from the farmers' fields in the previous two seasons.

Experimental Trials

1.Laboratory experiment: Effect of plant extracts on the germination of four weed species.

Experimental Design

The experimental design was randomized complete block design (RCBD). Thirteen treatments were randomly arranged in three blocks with each treatment appearing once in each block. The experimental treatments were replicated three times and whole experiment was repeated twice over time.

Experimental Procedure

Growing of Test Crop

Twelve sorghum and pearl millet cultivars to be used for the extraction of allelochemicals were planted in asbestos pots of 40 cm diameter 30 cm depth irrigated with a total volume of 1200 cm^3 per pot. Each pot had 10 plants. . Watering was done with three days interval. The plants were harvested six weeks after planting. The whole plant including roots was uprooted and air dried under the shade. The soil was washed off the roots before extraction. This was done to prevent volatilization of the allelochemicals under direct sunlight. After air drying, the samples were oven dried for at 60^{o}C for 24 hours. Samples were ground into powder using a grinder.

Extraction Of Allelochemicals

The powdered herbage was soaked in distilled water for 24 hours with a ratio of 20 g: 300 ml (Yarnia et al., 2009). Soaking was done for 24 hours at room temperature. The solution was filtered through a single layer of muslin cloth and the filtrate was then again passed through a filter paper to give the final filtrate to be used in seed germination experiment.

Germination Tests

Germination tests were done in petri dishes of 7 cm diameter in the weed science laboratory for a period of two weeks. Petri dishes were firstly disinfected by washing them in hot water. To disinfect, the seeds of test species (Table-1) were soaked in a 0,1% sodium hypochloride solution for three minutes and then rinsed with distilled water. Nine millimetre diameter filter papers were laid in the petri dishes and twenty seeds of each test species were placed in each petri dish. Each petri dish was treated with 5 ml of sorghum and millet water extracts whereas the control treatment received the same volume of distilled water. The petri dishes were placed in an incubator at 25^{o}C until the end of the experiment.

Data Collection

The data was collected regarding germination percentage, root length and shoot length. The following formula was used to calculate the germination percentage:

$$\text{Germination } \% = \frac{\text{Number of germinated seeds}}{\text{Number of seeds planted}} * 100$$

2. Greenhouse experiment: Effect of sorghum and pearl millet powders on the emergence and dry weight of blackjack, upright starbur and goose grass.

Experimental Design

The experiment was carried out using RCBD. Twelve treatments plus the control treatment (untreated soil) were arranged in three blocks. Air flow was the blocking factor. The experiment was repeated twice over time.

Experimental Procedure

Asbestos pots of 400 cm^{3} volume were filled with clay loamy soils with 28 % clay and then thirty grams of powdered sorghum and pearl millet plant material of test species (Table-1) was incorporated and thoroughly mixed within the top 2 cm of the soil in the pot. Thirty seeds of blackjack, three hundred seeds of goose grass and twenty seeds of upright starbur were sown into each pot. Pots with untreated soil were also kept as control. Watering was done with 750 ml at an interval of one day until the weeds were established.

Data Collection

Weed counts were done on 6, 8, 13, 20, 23 and 28 days after sowing. The final weed count was done on the 28th day after sowing which, weeds were harvested and percent weed reductions calculated. Weeds were harvested after four weeks, by uprooting and washing them to remove excess soil from the roots. The weeds were oven dried for 48 hours at 78°C and weighed.

Data Analysis

Data collected from the laboratory and greenhouse experiments were subjected to analysis of variance using Genstat version 14. The general linear model procedure was used to determine the significance at $P \leq 0.05$. Minitab version 16 was also used to calculate the standard errors of the means. Where significant differences were determined with the ANOVA, Fischer's Protected LSD test was used at 5% probability level to separate the means (Steel and Torrie, 1980).

RESULTS

In the laboratory experiment, blackjack and goose grass germination was successfully suppressed by extracts of both sorghum and pearl millet cultivars. However, it was not the case for pearl millet landraces and upright starbur (Table-2). The varieties PMV3, Macia, Red Swazi and Mutode

completely suppressed germination of blackjack whereas Kuyuma, Chitichi, Cibonda, SV4, PM3, Macia, Red Swazi and Mutode completely suppressed goose grass (Table-2). Whilst the germination percentage of pearl millet landrace(s) was not affected by sorghum and millet cultivars. However, the shoot length was significantly affected by some genotypes i.e. Okashana-1, Macia, Chibonda and Kuyuma (P≤0.05) with them being the best potent inhibitors (Figure 1). All the sorghum and millets varieties reduced root length of pearl millet landraces (Figure 2). PMV-2, SV-2, SV-1, Chibonda, Red Swazi and SV-4 did not significantly differ from each other in their suppression ability. PMV3 significantly reduced root length of pearl millet although it was the least effective in its ability to reduce root length when compared to others (Figure 2). The best root inhibitor was Okashana1 (Figure 2).
For blackjack all the sorghum and millet genotypes suppressed the number of emerged weeds (Figure 3) but the best suppressors were Chitichi, PMV-3 and Chibonda.

Table-2. Effects of sorghum and pearl millet water extracts on germination percentage of blackjack, goose grass, pearl millet landraces and upright starbur.

Variety	Blackjack	Goose grass	Upright starbur	Pearl millet landraces
	Mean ± SE	Mean± SE	Mean±SE	Mean ± SE
SV-1	5.00 ± 5.00[ab]	3.33 ± 1.67[ab]	16 ± 3	57.5± 11.1
Okashana-1	26.70 ± 14.80[c]	6.67 ± 6.67[a]	13 ± 0.45	81.25± 5.15
SV-2	1.67 ± 1.67[a]	6.67 ± 3.33[ab]	8 ± 2.1	57.5± 13
PMV-2	8.33 ± 4.41[ab]	5.00 ± 2.89[a]	5 ± 0.56	65 ± 7.36
Control	80.00 ± 2.89[d]	20.00 ± 5.77[b]	16± 1.33	93.75 ± 2.39
Kuyuma	13.33 ± 3.30[bc]	0.00 ± 0.00[a]	9 ± 1.73	65 ± 8.42
Chitichi	1.67 ± 1.67[a]	0.00 ± 0.00[a]	11 ± 3.84	70 ± 13.1
Chibonda	5.00 ± 2.89[a]	0.00 ± 0.00[a]	13 ± 4	50 ± 10.2
SV-4	10.00 ± 5.00[abc]	0.00 ± 0.00[a]	14 ± 4.37	60 ± 4.56
PMV-3	0.00 ± 0.00[a]	0.00 ± 0.00[a]	13 ± 4.75	61.25± 6.88
Macia	0.00 ± 0.00[a]	0.00 ± 0.00[a]	6 ± 0.67	66.25± 6.88
Red-Swazi	0.00 ± 0.00[a]	0.00 ± 0.00[a]	9 ± 3.06	46.33 ± 11.3
Mutode	0.00 ± 0.00[a]	0.00 ± 0.00[a]	13 ± 3.46	62.5 ± 5.15
P value	0.001	0.001	0.114	0.07
CV %	43.2	47.8	21	28.1

Means with the same letters are not significantly different according to the LSD test at p≤0.05 probability level.

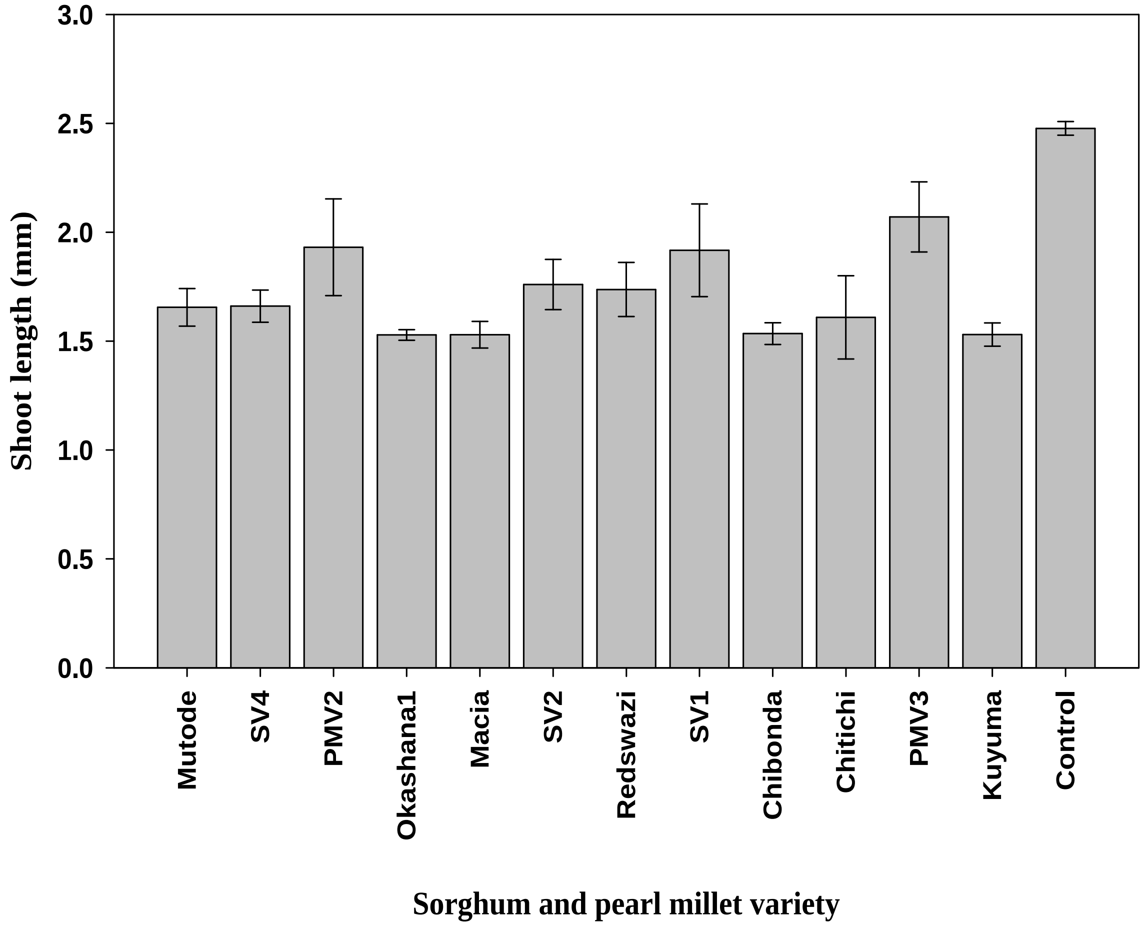

Fig 1 Effects of sorghum and pearl millet water extracts on shoot length of pearl millet land race. Vertical bars are error bars.

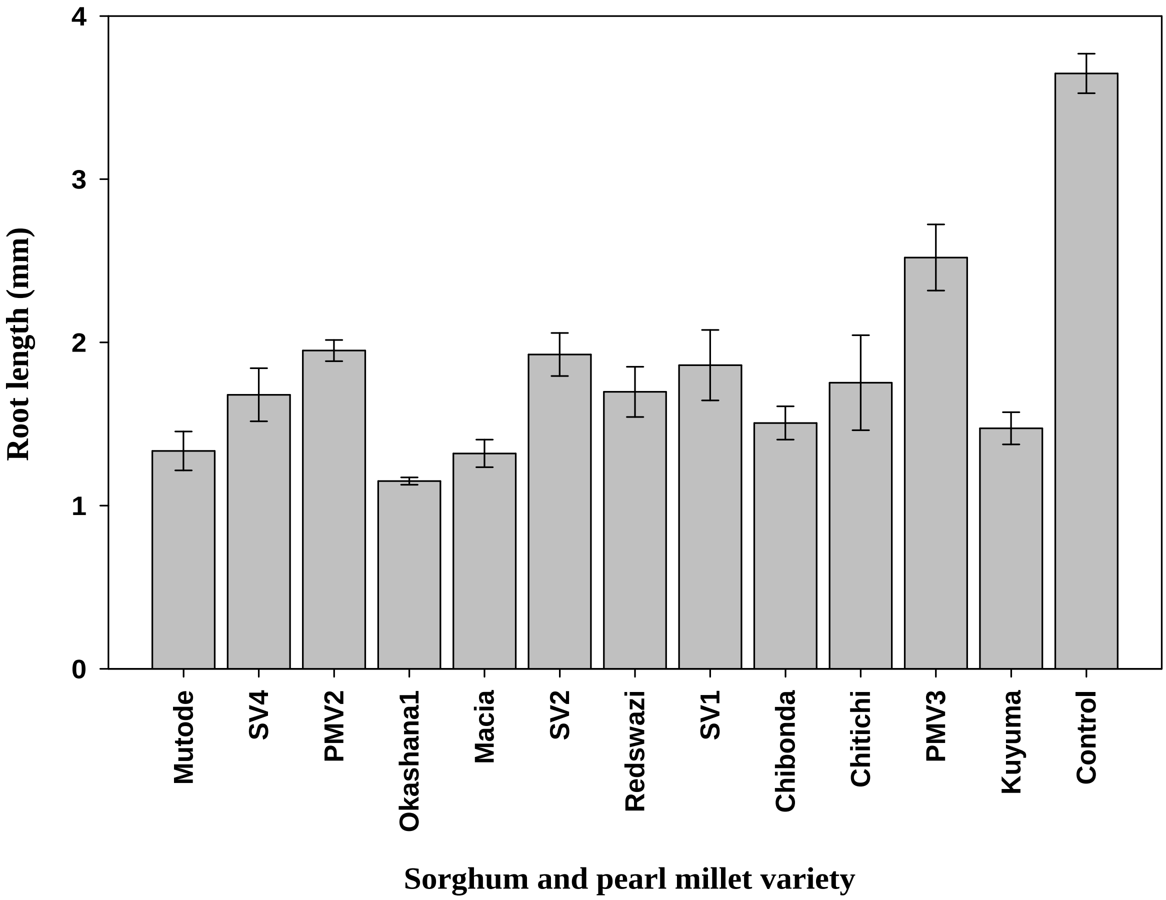

Fig 2 Effects of sorghum and pearl millet water extracts on root length of pearl millet land race.Vertical bars are standard errors.

Comparison of sorghum and pearl millet cultivars on successive weed counts of blackjack, goose grass and upright starbur.

Sorghum and pearl millet cultivars had a significant (P≤0.001) effect on the germination of blackjack, with Chitichi, Chibonda, PMV-3, Okashana -1 and Mutode showing greater suppressive effect on germination compared to the all (Fig. 3). Kuyuma and SV-1 appeared not to reduce blackjack counts. Sorghum and pearl millet varieties significantly (P≤ 0.001) affected weed count of goose grass. All the twelve sorghum and pearl millet varieties significantly suppressed the germination of goose grass (Figure 4). Chitichi and PMV-3 were significantly different from the other varieties with a lower effect.

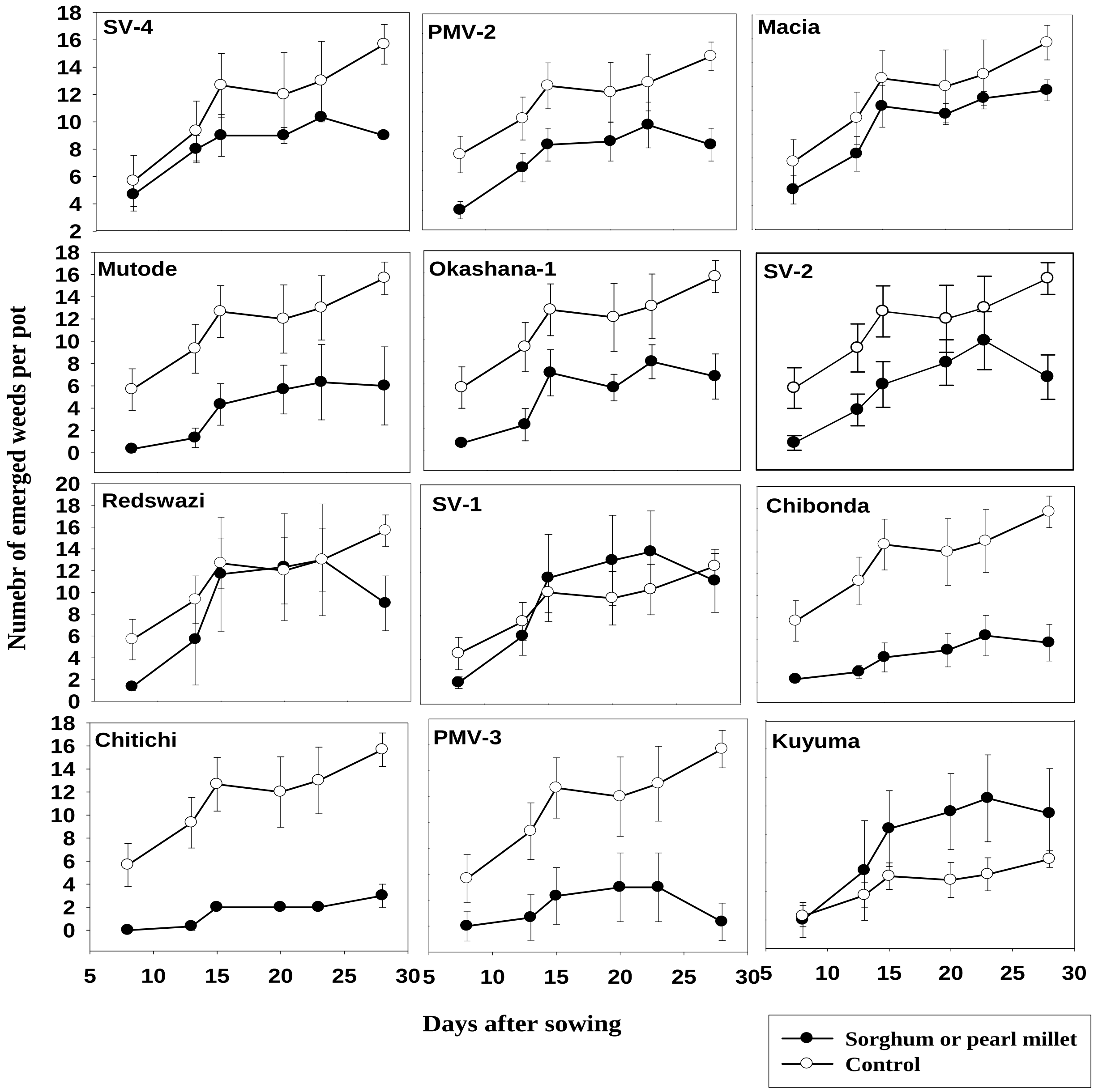

Fig 3 Effect of sorghum and pearl millet plant extracts on weed counts of blackjack in a pot experiment under glasshouse conditions.Vertical bars are standard errors.

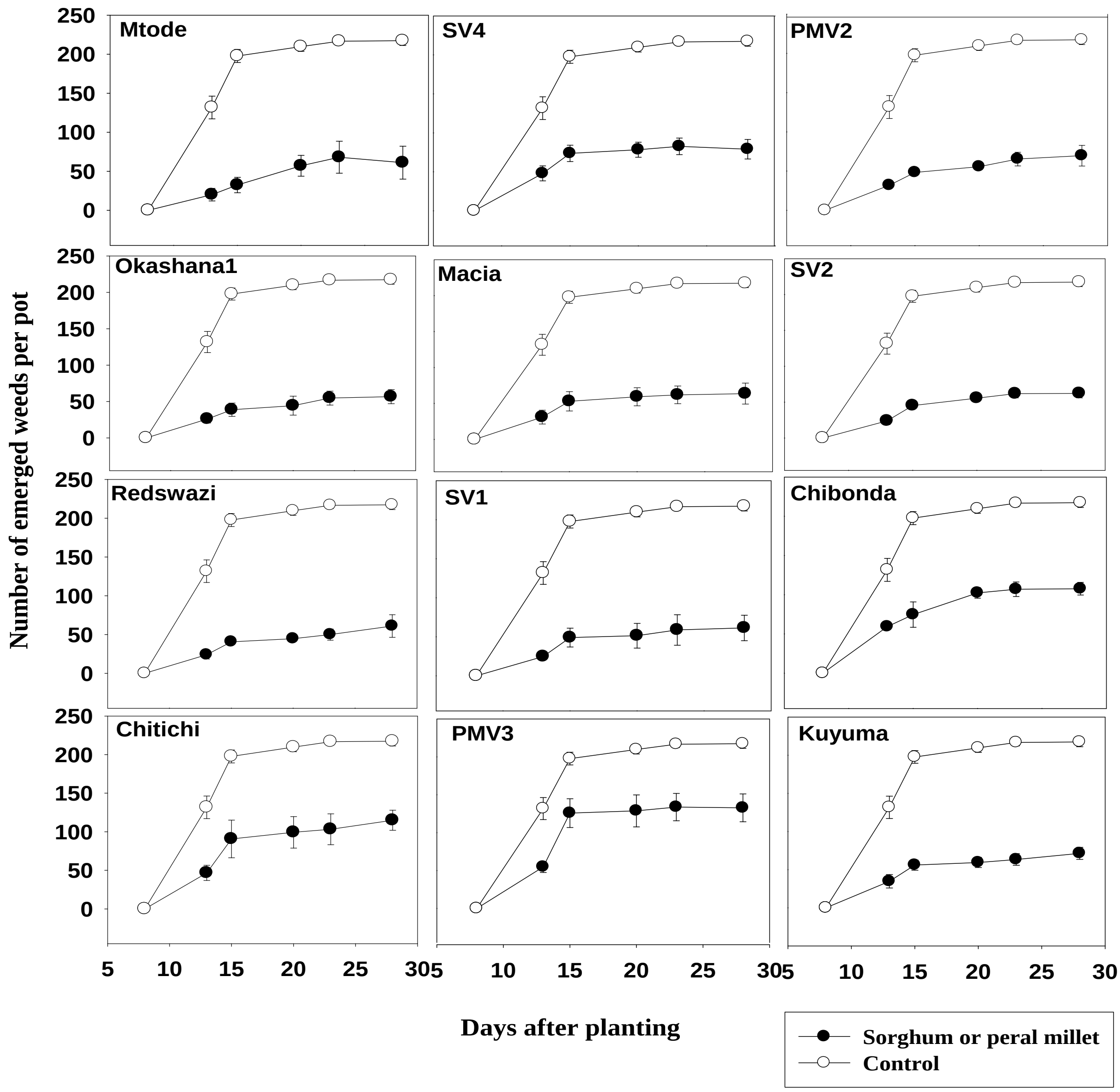

Fig 4 Effects of sorghum and pearl millet plant extracts on weed counts of goose grass in a pot expriment under glasshouse experiments. Vertical bars are standard errors.

There was no significant ($P>0.05$) effect of sorghum and millet varieties on germination of upright starbur. Most of the sorghum and pearl millet cultivars did not suppress germination of upright starbur. However, PMV2 and Macia showed some degree of suppression on day 28 (data not shown).

There was a significant ($P\leq0.001$) response to soil treatment for allelopathy with respect to dry weight of blackjack plants. All varieties except Kuyuma significantly reduced the dry weight of blackjack compared to the control (Figure 5).

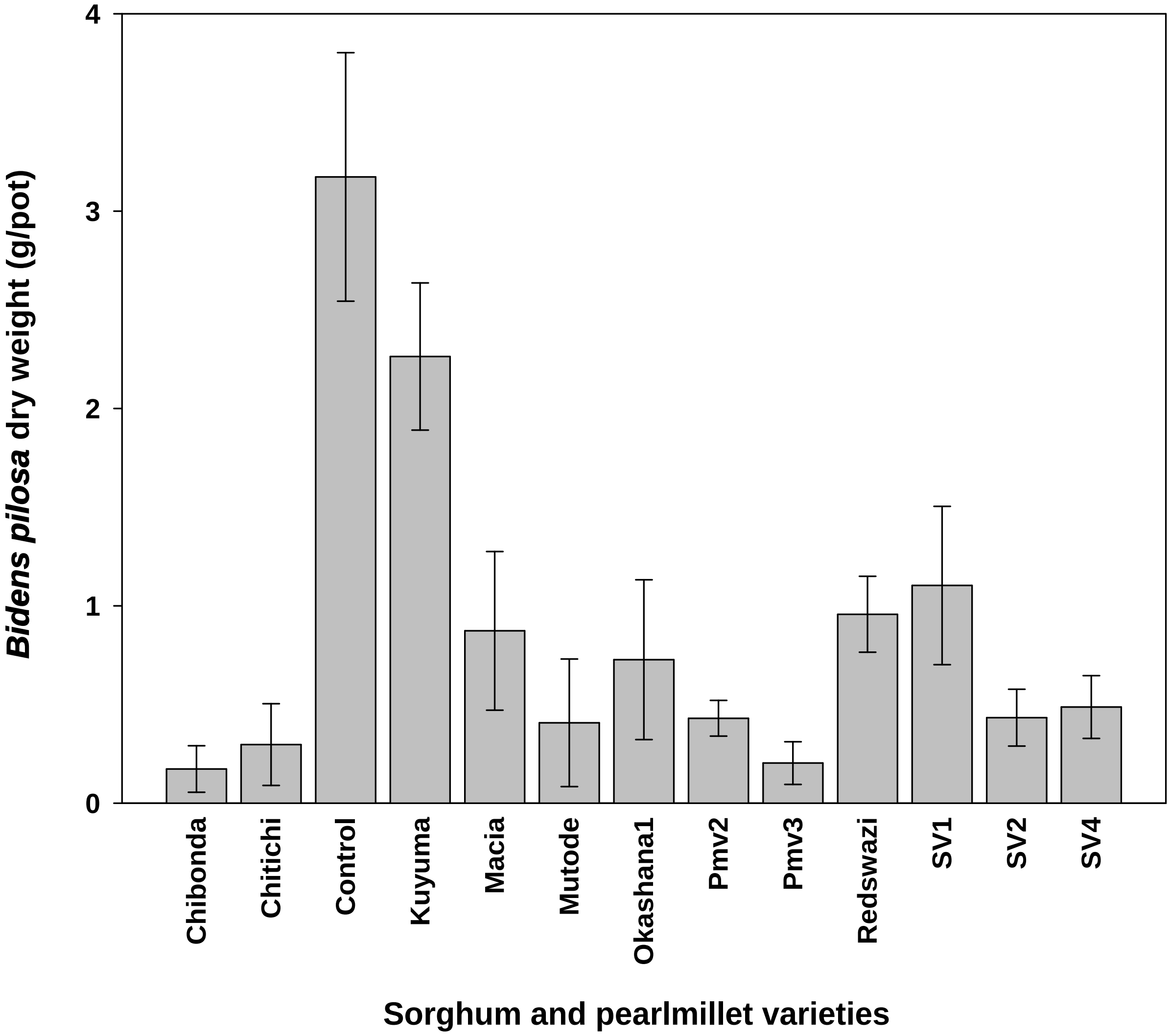

Fig 5 Effcet of sorghm and pearl millet plant residues on dry weight of *B. pilosa* under glasshouse conditions. Vertical bars are standard errors.

Sorghum and pearl millet varieties significantly (P≤0.001) affected weed growth with respect to dry matter accumulation of goose grass. All varieties successfully reduced goose grass dry weight. SV2 and Chitichi had the lowest effect on growth rate of goose grass and they significantly differed from all other varieties in their suppression ability (Figure 6). Despite the failure of sorghum genotypes to suppress germination, root and shoot length of upright starbur, the sorghum and millet genotypes significantly reduced the dry matter of upright starbur (Figure 7).

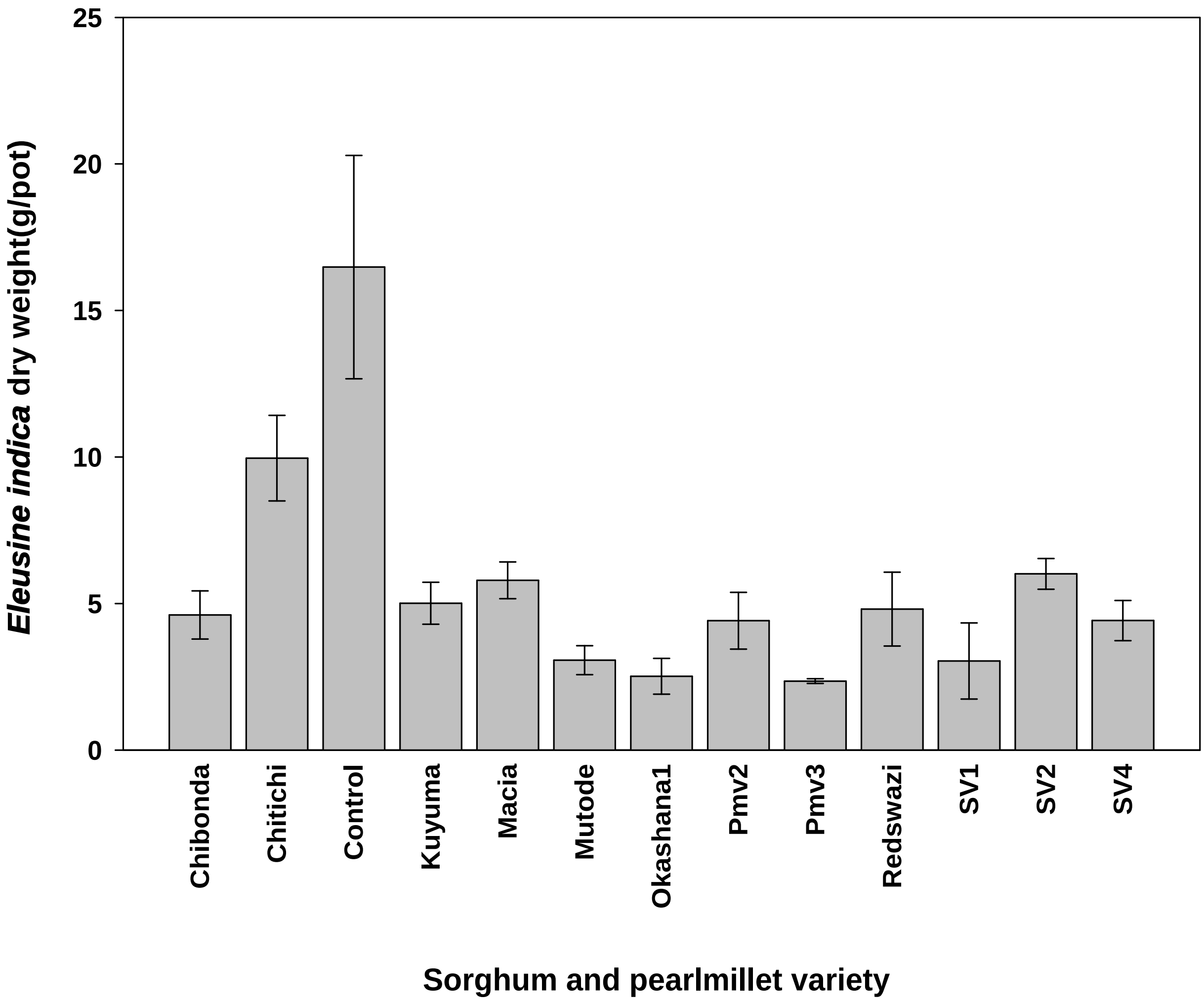

Fig 6 Effect of sorghum and pearl millet plant residues on dry weight of *E. indica* under glasshouse conditions. Vertical bars are standard errors.

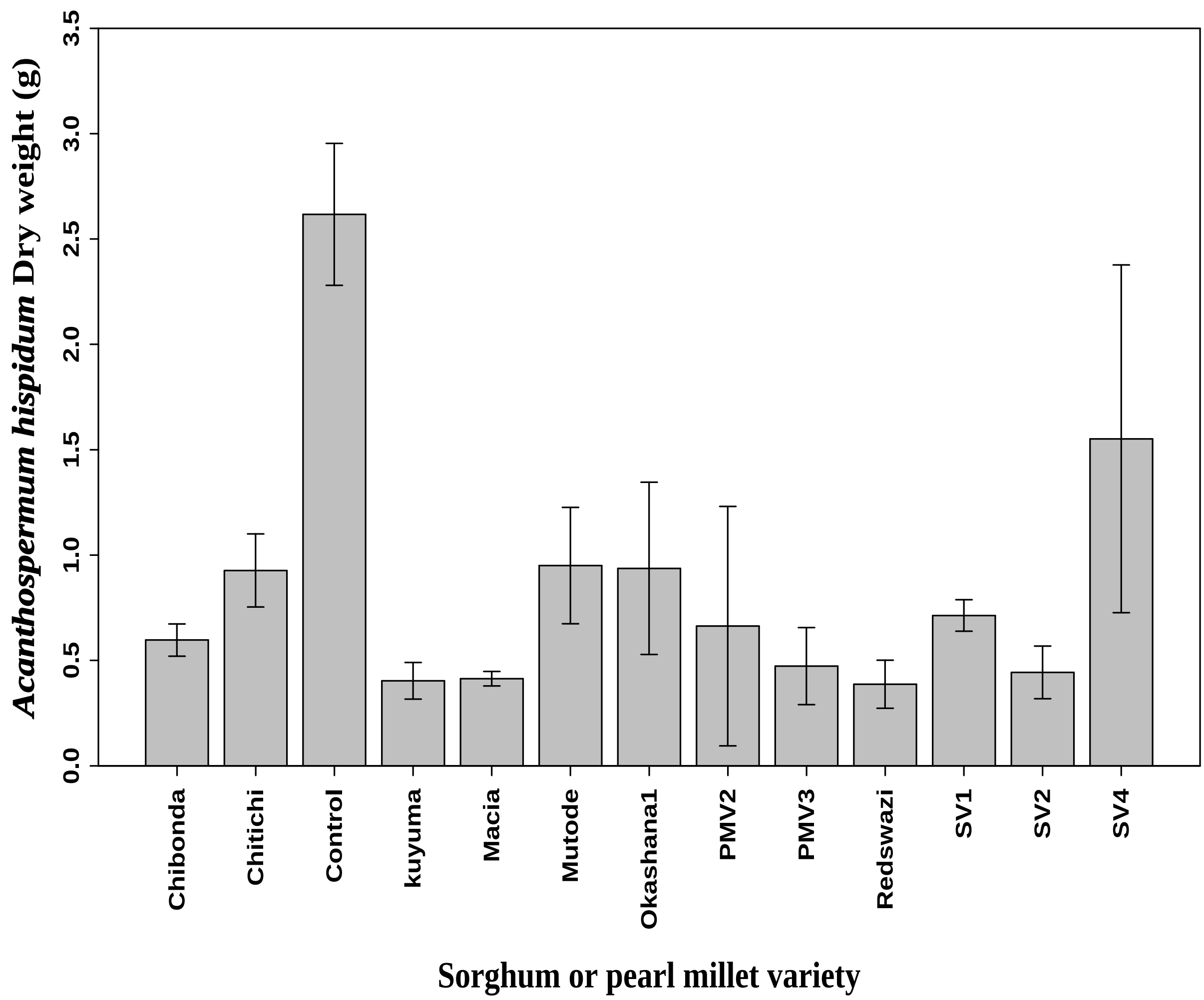

Fig 7 Effects of sorghum or pearlmillet on dry weight of *A. hispidum* under glasshouse conditions. Vertical bars are standard errors.

DISCUSSION

Our results showed that germination of blackjack and goose grass was suppressed by sorghum and millet cultivars. The extracts of all the cultivars of sorghum and millet reduced the germination of both weeds. Sorghum residues produce sorgholeone, dhurrin and a number of breakdown products such as phenolics which suppress weeds (Putnam, 1988). Similar results were found by Field et al. (2006), Cheema et al. (1997), Cheema and Khaliq (2000) and Farooq et al. (2010) whose results confirmed the weed suppressive effects of sorghum and millet extracts. Ability to prevent the germination was an indication that sorghum and millet extracts may act as pre-emergence herbicides for the two weeds which are common in the smallholder farming sector of Zimbabwe. On the contrary, upright starbur and pearl millet landraces resisted the effects of the sorghum and pearl millet extracts and maintained their germination rates irrespective of extract application. Cheema et al. (1997) reported that small seeded crops and weeds are susceptible to allelochemicals under field conditions and this has been attributed to the greater surface area to volume ratio resulting in more exposure of such seeds to allelochemicals. This implies that weeds with bigger seeds such as upright starbur is less susceptible to allelochemicals. The pearl millet landraces were not affected by sorghum and millet extracts. This illustrated the lack of auto-toxicity for germination with respect to the millet landrace.

Shoot and root length of pearl millet landraces were suppressed by all millets and sorghum cultivars. Similar results were also found by Field et al. (2006) who found that allelochemicals in sorghum and millet may affect cell division, elongation, protein biosynthesis. Growth results from cell division and cell elongation and once these processes are inhibited together with photosynthesis and respiration, growth potential may not be realised. Autotoxicity results were also shown by Saxena et al. (1994) who found that pearl millet was found to inhibit seed germination and shoot length in millets.
Similar results were found by Al-Tawaha and Odat (2010) who established that sorghum plant extracts reduced radicle and plumule length of wild barley seedlings with a range of 16 and 47%, compared to those treated with water. The results were further explained by Saxena et al. (1996) who reported that pearl millet extracts affected the germination of pearl millet, a phenomenon known as autotoxicity. The fact that sorghum and pearl millet affects germination of pearl millet may have an impact on crop rotation

In the greenhouse experiment, it was clear that sorghum and pearl millet cultivars suppressed the density of blackjack and goose grass. Although upright starbur density was not influenced by plant residues of sorghum and pearl millet cultivars, its dry matter was greatly reduced.

The dry weight of upright starbur was reduced by most sorghum and millet genotypes except SV4. The results are intriguing in the sense that the upright starbur germination was not affected by sorghum and millets exudates. This finding agrees with the findings of Putnam and DeFrank (1983) who found that residues of sorghum reduced the number and biomass of common purslane (Portulaca oleracea L.) and smooth crabgrass (Digitaria isochaemum) in the field by 70 and 98%, respectively. These products could interfere with nutrient uptake and photosynthesis which are processes for dry matter accumulation. Reduction in dry matter implies reduced competitiveness that is advantageous in the field as the crops may gain resource acquisition advantage and be more competitive against the upright starbur.

CONCLUSION

Our study showed that sorghum and pearl millet varieties have the ability to suppress germination of goose grass and blackjack but not the upright starbur. The study also revealed that auto-toxicity exists between pearl millet cultivars and the pearl millet landraces. Dry matter accumulation in upright starbur however was reduced by the sorghum and millet genotypes illustrating that once germinated, the upright starbur did not resist the effects of allelopathy. Therefore, the studied genotypes could be used by small holder farmers in reducing the germination of goose grass and blackjack as well as competitiveness of upright starbur

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