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Article

Effect of Dicamba and Adjuvant Combination on Parthenium Control, Fodder Yield and Yield Components of Forage Sorghum (*Sorghum bicolor*)

*Efeito do Dicamba e Combinação de Adjuvantes no Controle de Partênio, Rendimento de Forragem e Componentes de Rendimento de Sorgo de Forragem **(Sorghum bicolor)***

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ABSTRACT - Parthenium is an important weed which poses severe threats to yield and quality of sorghum and many other summer season crops, worldwide. As in other field crops, parthenium also reduces yield and quality of forage plants in forage crops so it should be controlled in forage and fodder crops. Parthenium control efficacy of five herbicide treatments (including dicamba at 304.5 g a.i. ha^{-1} (full rate) alone, dicamba at full rate + 1% ammonium sulphate, dicamba at full rate + 2% ammonium sulphate, dicamba at 75% rate + 1% ammonium sulphate and dicamba at 75% rate + 2% ammonium sulphate) was tested in field trials for two consecutive years (2013 and 2014). One manual hoeing three weeks after crop emergence was also performed as a treatment and weedy check was kept as control. Application of the full rate of dicamba with 2% ammonium sulphate showed the lowest parthenium dry weight (16.5 g m^{-2} and 23.5 g m^{-2}) and NPK uptake that seem to be due to the highest parthenium control efficiency of 79.6% and 73.8% during 2013 and 2014, respectively. This weed management strategy also gave maximum values of yield components of forage sorghum, including plant height (261 and 254 cm), stem diameter (0.97 and 0.84 cm), leaf area per plant (3,072 and 3,041 cm^2), fresh fodder yield (63.4 and 60.9 t ha^{-1}) and dry matter yield (17.4 and 15.8 t ha^{-1}) in 2013 and 2014, respectively. Highest net return and marginal rate of return (346 and 356% in 2013 and 2014, respectively) were also found when the full rate of dicamba with 2% ammonium sulphate was applied. In conclusion, tank-mixed application of dicamba at 304.5 g a.i. ha^{-1} with 2% of ammonium sulphate proved to be better for efficient control of parthenium weed in forage sorghum.

Keywords: *Parthenium hysterophorus*, forage, ammonium sulphate, herbicide.

RESUMO - O partênio é uma planta importante que representa uma grave ameaça ao rendimento e qualidade do sorgo e de muitas outras culturas da estação do verão, em todo o mundo. Como em outras culturas de campo, o partênio também reduz o rendimento e a qualidade das forrageiras nas culturas forrageiras, de modo que deve ser controlado nas forragens. A eficácia do controle de partênio de cinco tratamentos de herbicidas, incluindo dicamba a 304,5 g i.a. ha^{-1} (dose completa), dose total de dicamba + 1% de sulfato de amônio, dose total de dicamba + 2% de sulfato de amônio, dicamba at 75% da dose + 1% de sulfato de amônio e dicamba at 75% da dose + 2% de sulfato de amônio, foi testada no campo por dois anos consecutivos (2013 e 2014). Uma capina três semanas após o surgimento da

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colheita e o monitoramento de plantas daninhas foram mantidos como controle. A aplicação da dose total de dicamba com 2% de sulfato de amônio apresentou menor peso seco de partênio (16,5 g m^{-2} e 23,5 g m^{-2}), e a absorção de NPK acompanhou a maior eficiência de controle de partênio, de 79,6% e 73,8% em 2013 e 2014, respectivamente. Essa estratégia de manejo de plantas daninhas também proporcionou valores máximos de componentes de produção de sorgo forrageiro, incluindo altura da planta (261 e 254 cm), diâmetro do caule (0,97 e 0,84 cm), área foliar por planta (3.072 e 3.041 cm^2), rendimento de forragem fresca (63,4 e 60,9 t ha^{-1}) e rendimento de matéria seca (17,4 e 15,8 t ha^{-1}), em 2013 e 2014, respectivamente. Maior retorno líquido e taxa de retorno marginal (346 e 356% durante 2013 e 2014, respectivamente) também foram observados quando a dose total de dicamba com 2% de sulfato de amônio foi aplicada. Em conclusão, a aplicação misturada em tanque de dicamba at 304,5 g i.a. ha^{-1} com 2% de sulfato de amônio mostrou ser melhor para o controle eficiente da planta de partênio em sorgo forrageiro.

Palavras-chave: *Parthenium hysterophorus*, forragem, sulfato de amônio, herbicida.

INTRODUCTION

Sorghum (*Sorghum bicolor* L.) is a member of the family Poaceae and cultivated as grain and fodder crop in many parts of the world, including Pakistan. Sorghum is used as grain and in silage preparation, animal feed, sugar and alcohol extraction. Average yield of sorghum in Pakistan is far below its potential, which might be attributed to low quality seeds, low seed rate, imbalance nutrition and weed infestation (Ayub and Shoaib, 2009). Weeds pose a major threat to the natural ecosystem, destroy natural habitats and cause a significant reduction in crop yield and quality. Yield losses caused by weeds in Pakistan range from 17 to 25% in wheat, 20 to 63% in rice, 10 to 35% in sugarcane, 13 to 31% in cotton (Abbas, 2013) and about 90% in fodder crops (Tomado et al., 2002). Major weeds which can reduce growth, yield and quality of sorghum fodder are *Trianthema portulacastrum*, *Cyperus* spp., *Echinochloa* spp., *Amaranthus* spp. and *Digera arvensis*. Recently, parthenium (*Parthenium hysterophorus*) has become a problematic weed of sorghum and other summer season crops in many regions of the world. It has been considered as an invasive weed in agroecosystems of more than 20 countries in the world, including Pakistan (Shabbir and Bajwa, 2007; Nigatu et al.*,* 2010). It is also called white top or white head, carrot grass and rag weed. It belongs to the family Asteracea. Parthenium is now spreading all over Pakistan, especially in two major provinces, namely, Punjab and Khyber Pakhtunkhwa (Shabbir and Bajwa, 2007). Parthenium causes prominent yield losses in oilseed crops, fodder crops and pulses (Tamado et al., 2002; Vivek et al., 2008). Parthenium is noxious and unpalatable for livestock. Parthenium has become a weed of national significance and inspired weeds scientists and agronomists to develop appropriate strategies for management of parthenium in different crops. The use of herbicides is a key component of weed management which is considered to be the most effective, time-saving and economical way to control targeted weeds in agroecosystems (Torra et al., 2010). Post-emergence herbicides are applied directly to the leaf canopy of the targeted weeds. They control the weeds by absorption through leaves, stems, and roots. Dicamba is a selective herbicide which belongs to the family chlorophenoxy and behaves like 2, 4-D amine. When plants are treated with dicamba, it can be absorbed by leaves and roots. Plants grow in abnormal and uncontrollable condition, which leads to plant death. Addition of adjuvants might increase herbicide effectiveness and decrease herbicide application rate, especially for broadleaf weeds (Abouziena et al., 2009). Scherb et al. (2000) reported that adjuvant and herbicide combination enhanced the selectivity and performance of mixture against broadleaf weeds. The recommended dose of ammonium sulphate adjuvant is 1-2% with most herbicides and is reported to enhance the efficacy and absorption of many post-emergence herbicides, including dicamba, 2, 4-D amine (Fabio, 2007). Ammonium sulphate improves the effectiveness of acid herbicides, acting as a buffer compatibility agent. It can also reduce problems associated with hard water during herbicide mixing and application (Hall et al., 1999). Although parthenium poses severe threats to crops, very limited investigation studies have been conducted on the control of this weed, particularly as far as forage crops are concerned. The present study was therefore conducted to find out suitable dicamba-ammonium sulphate adjuvant combinations for cost-effective control of parthenium and improve the forage yield of sorghum.

MATERIALS AND METHODS

The experiment was conducted during the summer season of two consecutive years (2013 and 2014) at the Agronomic Research Area, University of Agriculture Faisalabad, Pakistan. Textural class of the soil is sandy clay loam. Soil analysis showed pH (8.1), organic matter content (0.64%), total nitrogen content (0.0412%), available phosphorus (7.67 ppm) and available potassium (K) (268.5 ppm). During the crop growth season, mean rainfall values of 176.4 mm in 2013 and 67.9 mm in 2014 were recorded. The experimental plan during each study year consisted of six different parthenium management treatments including hoeing after 3 weeks' emergence, dicamba at 304.5 g a.i. ha^{-1} (full rate), dicamba at full rate with 1% ammonium sulphate, dicamba at full rate with 2% ammonium sulphate, dicamba at 75% rate with 1% ammonium sulphate, dicamba at 75% rate with 2% ammonium sulphate. A weedy check without any weed management was also kept as control. The experiment was laid out in a randomized complete block design with net plot size of 6 m × 2.4 m, and each treatment was quadruplicated. Hoeing and application of dicamba alone and in combination with ammonium sulphate as adjuvant were applied 3 weeks after parthenium emergence at the four-leaf stage of sorghum. Pre-soaking irrigation was applied and a uniform seed bed was prepared by using ordinary cultivator and planker when soil attained suitable moisture contents. The seeds of sorghum (variety Hegari) at 75 kg ha^{-1} were sown on June 5th in each year with a hand drill in rows spaced 30 cm apart. Fertilizer was applied at the recommended rate (90 kg N and 60 kg P_2O_5 ha^{-1}), and Whole P and half N were applied at the time of sowing while the remaining half N was applied at the 1st irrigation. Viable seeds (tetrazolium test) of parthenium were equally broadcast in all treatments at the time of crop sowing. All agronomic practices were performed uniformly except the treatments under study. The crop was harvested 70 days after sowing with hand sickle at 50% heading stage. At harvesting, ten plants were randomly selected from each treatment and plant height, plant diameter and leaf area were recorded and then average values per plant were taken for these parameters. Fresh forage yield was determined by harvesting the whole plot and immediately weighing it in the field. Dry matter yield was determined by oven-drying the weighed sample at 72 ^{o}C for 48 hours. For dry weight of parthenium, plants from a one-meter-square area were uprooted at crop harvest and oven-dried. N, P and K uptake by parthenium was determined at crop harvest. N, P and K contents of the parthenium plants were determined and multiplied with parthenium plant dry weight in kg ha^{-1} to get parthenium N, P and K uptake in kg ha^{-1}. Nitrogen (%) in the parthenium sample was determined through the Kjeldhal method by following the standard protocol as suggested by AOAC (1990). Phosphorus content was measured on a spectrophotometer at 470 mu wavelength (Allen et al., 1986). Potassium concentration was measured by using a flame photometer (Jenuary 8505) and a K^+ filter for K determination. These measurements were made for each sample. Weed control efficiency was calculated by using weed dry weight produced in each treatment as proposed by Kondap and Upadhyay (1992) in the following equation:

$$WCE\ (\%) = \frac{W1 - W2}{W1} \times 100$$

W_1 = Dry matter of weeds in control plots

W_2 = Dry matter of weeds in treated plots

An economic analysis was carried out on the basis of prevailing market prices of dicamba, ammonium sulphate adjuvant and fresh fodder of sorghum. A marginal analysis was carried out as suggested by CIMMYT (1988). Calculation of marginal rate of return was based on marginal net benefit (i.e. change in net benefits) and marginal cost (i.e. change in costs) by using the following formula:

$$MRR\ (\%) = \frac{Marginal\ benefit}{Marginal\ cost} \times 100$$

Statistical Analysis

Two years's data was recorded by using standard protocol and analyzed statistically through Randomized Complete Block Design ANOVA (Steel et al., 1997). Significance of treatment means was tested by Tukey's honestly significant difference (HSD) test at 5% probability level. Planned meaningful contrast comparisons for different herbicide treatments using single degree of freedom (df) contrast method (Little and Hills, 1978)was carried out. Statistical analysis was done by Statistix 8.1 (Analytical Software, 2005).

RESULTS AND DISCUSSION

Growth and nutrient uptake of *P. hysterophorus*

Parthenium dry weight reduction

All parthenium management strategies, including herbicide alone and in combination with adjuvant, caused a significant decline in parthenium dry weight compared with the weedy check in both study years (Table 1). Among parthenium management treatments, full dicamba rate tank mixed application with 2% ammonium sulphate adjuvant produced significantly lower parthenium dry weight (16.5 and 23.5 g m^{-2} in 2013 and 2014, respectively) that did not differ significantly from the value recorded with the full rate of dicamba + 1% ammonium sulphate as adjuvant. Contrast analysis revealed a significant difference in all contrasts except in a comparison between 1% ammonium sulphate and 2% ammonium sulphate in both study years (Table 1). The significant contrast between dicamba alone and in mixture with ammonium sulphate adjuvant might be the result of improved absorption of this herbicide with the adjuvant, which enhanced its bio-efficacy against parthenium weed. These results corroborate the findings of Abouziena et al. (2013), who reported a significant reduction in total dry biomass of all weed species in peanut (*Arachis hypogaea*) by bentazon with 2% ammonium sulphate adjuvant as compared to bentazon alone. Naveed et al. (2008) also reported similar results; dry biomass of *Trianthema portulacastrum*, *Coronopus didymus* and *Cyperus rotundus* at harvest in maize was decreased significantly when the full rate of formasulfuron + isoxadifen ethyl was applied with 3% ammonium sulphate as adjuvant as compared to its full dose alone or reduced dose with adjuvant.

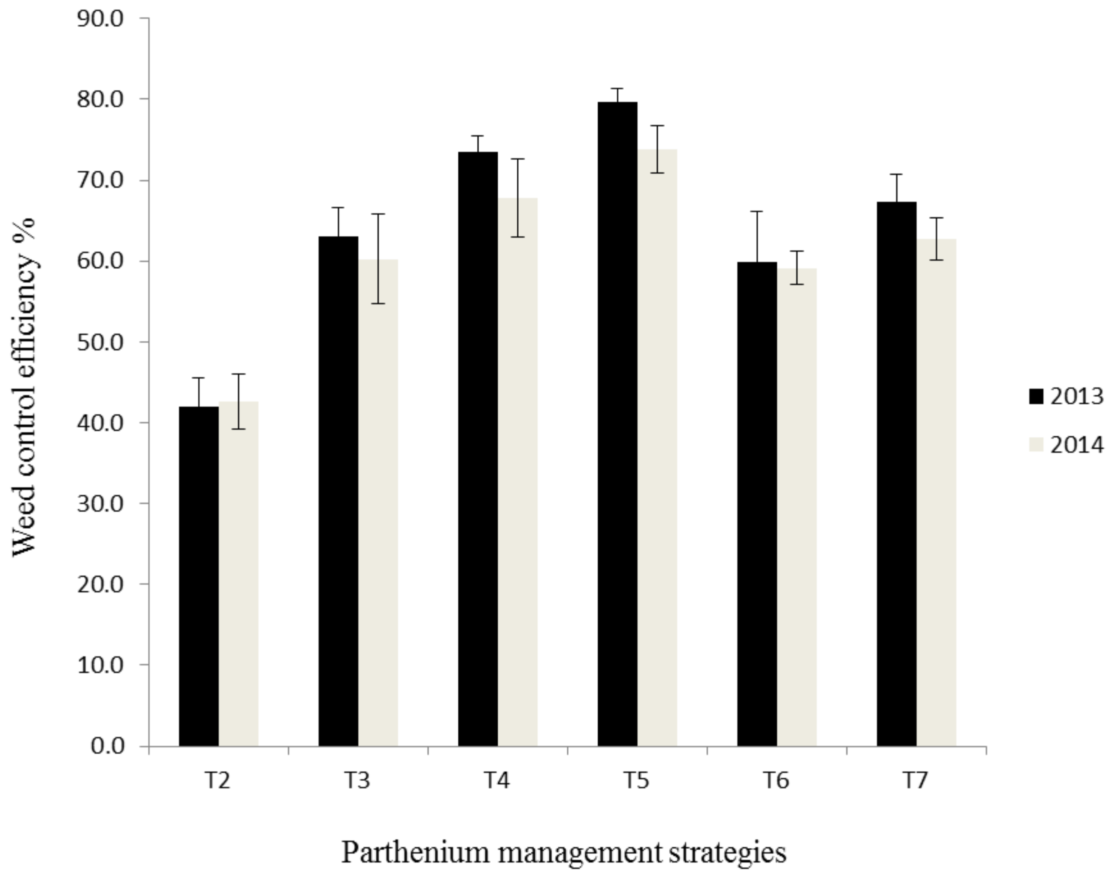
Table 1 - Effect of weed management strategies on dry weight and nutrient uptake of *P. hysterophorus* in forage sorghum in years 2013 and 2014

Treatment	Dry weight (gm^{-2})		Nitrogen uptake (kg ha^{-1})		Phosphorus uptake (kg ha^{-1})		K uptake (kg ha^{-1})	
	2013	2014	2013	2014	2013	2014	2013	2014
Weedy check	81.0 a	89.9 a	37.2 a	31.6 a	3.35 a	3.99 a	24.44 a	26.17 a
Hoeing after 3 weeks' emergence	47.0 b	51.6 b	20.9 b	18.6 b	2.41 b	2.57 b	14.53 b	15.43 b
Dicamba at 304.5 g a.i. ha^{-1}	29.8 c	35.7 cd	13.1 c	13.8 c	1.72 cd	2.02 c	9.45 c	10.77 c
Dicamba at 304.5 g a.i. ha^{-1} + 1% AMS	21.4 de	28.9 de	9.0 de	11.3 cd	1.29 de	1.81 cd	6.81 de	9.03 cd
Dicamba at 304.5 g a.i. ha^{-1} + 2% AMS	16.5 e	23.5 e	6.5 e	9.3 d	1.08 e	1.51 d	5.38 e	7.38 d
Dicamba at 228.4 g a.i. ha^{-1} + 1% AMS	32.5 c	36.7 c	11.4 cd	14.1 c	1.84 c	2.03 c	10.21 c	11.14 c
Dicamba at 228.4g a.i. ha^{-1} + 2% AMS	26.5 cd	33.5 cd	14.1 c	13.1 c	1.58 cd	1.88 cd	8.50 cd	10.40 c
HSD	6.45	6.92	2.99	2.89	0.468	0.438	2.228	2.360
Contrast comparison								
Weedy check vs all	**	**	**	**	**	**	**	**
Hoeing vs chemical control	**	**	**	**	**	**	**	**
Dicamba 304.5 g vs dicamba 228.4 g	**	*	**	**	NS	NS	**	NS
Dicamba with adjuvant vs dicamba without adjuvant	*	*	**	**	NS	NS	NS	NS
1% AMS vs 2% AMS	NS	NS	**	**	NS	NS	NS	NS

AMS: Ammonium sulphate. Means sharing the same letter in a column did not significantly differ at 5% probability level, NS and ** indicate non-significant and significant at $p \leq 0.01$ level of probability, respectively.

Parthenium control efficiency

Figure 1 shows a comparison of weed control efficiency (WCE) of all parthenium mangement strategies used in both study years (2013 and 2014). The treatments differed in their parthenium control effciciency, ranging from 41.9 to 79.6% in 2013 and from 42.6 to 73.8% in 2014. Maximum weed control efficiency of 79.6% in 2013 and 73.8% in 2014 was recorded in plots where dicamba at full rate + 2% ammonium sulphate was sprayed, followed by dicamba at full rate + 1% ammonium sulphate with WCE of 73.51 % in 2013 and 67.71% in 2014. The lowest WCE (41.9% in 2013 and 42.6% in 2014) was found with hoeing after 3 weeks' emergence. The highest WCE with dicamba at full rate with 2% ammonium sulphate was attributed to higher absorption of the herbicide by parthenium plants. Woznica and Idziak (2010) compared the WCE of different post-emergence herbicides in forage maize and reported increased WCE from 92 to 99% by spraying trisulfuron + dicamba in maize.



T_2= Hoeing after 3 weeks' emergence T_3= Dicamba at 304.5 g a.i. ha^{-1} T_4= Dicamba at 304.5 g a.i. ha^{-1} + 1% ammonium sulphate T_5= Dicamba at 304.5 g a.i. ha^{-1} + 2% ammonium sulphate T_6= at 228.4 g ha^{-1} + 1% ammonium sulphate T_7= Dicamba at 228.4 g a.i. ha^{-1} + 2% ammonium sulphate.

Figure 1 - Weed control efficiency (WCE) of different parthenium management strategies in forage sorghum in years 2013 and 2014.

NPK uptake

Nutrient uptake by parthenium weed as affected by different management strategies. Table 1 shows that dicamba at full rate with 1% and 2% ammonium sulphate adjuvant significantly gave the lowest values of N (6.5-11.4 kg ha^{-1}), P (1.0-11.3 kg ha^{-1}) and K (5.3-9.0 kg ha^{-1}) uptake. Percent N, P and K uptake reductions over weedy check through application of dicamba at full rate + 2% ammonium sulphate were 82.51 and 70.64% for N uptake, 67.7 and 62.1 for P uptake, and 78 and 71.8% for K uptake, in years 2013 and 2014, respectively. Contrast analysis showed that all contrast combinations were significant for N uptake in both years of study (Table 1), while in the case of P and K uptake by parthenium weed, contrast between weedy check and all, hoeing and chemical control remained significant in both study years whereas dicamba at full rate and 75% rate were statistically significant in year 2013 only. The decrease in NPK uptake by parthenium in response to herbicide application was due to high mortality rate and lower survival of parthenium plants as compared to hand hoeing and weedy check treatments, in which more parthenium plants were survived to absorb more NPK from soil. Anjum et al. (2007) reported maximum NPK uptake (29.64 kg ha^{-1}, 2.45 kg ha^{-1}, 15.14 kg ha^{-1}) by weeds in cotton when they were not controlled. Glowacka (2011) also reported higher (24.0 kg ha^{-1}) K uptake by weeds in maize when they were not fully controlled. Similarly, Sonawane et al. (2014) reported maximum NPK uptake by weeds (25.4 kg ha^{-1}, 3.2 kg ha^{-1}, 18 kg ha^{-1}) in maize where they were not controlled by any practice. They all recorded significant reductions in NPK uptakes as compared to the weedy check in crops when weeds had been controlled by herbicide application.

Yield and yield components of forage sorghum

Plant height (cm)

The different parthenium management strategies showed significant effects on plant height of sorghum (Table 2). In both study years, maximum plant height (261.5 and 254.1 cm in 2013 and 2014, respectively) of sorghum was recorded when parthenium weed was managed by the application of dicamba at full rate in mixture with 2% ammonium sulphate. However, this treatment did not differ significantly from dicamba at full rate + 1% ammonium sulphate regarding this parameter in both experimental years. Minimum plant height was found in both years in the treatment in which no weed control practice had been applied. The increase in plant height of sorghum by treatment dicamba at full rate + 2% ammonium sulphate over weedy check was 11.54% and 13.26% in 2013 and 2014, respectively. All contrast combinations were significant except for dicamba with and without adjuvant in 2014 and dicamba with 1% and 2% ammonium sulphate in year 2013. Enhanced plant height of sorghum as a result of herbicide application was probably the best result for crop growth under less severe parthenium-sorghum competition because of control of parthenium. These results are in line with the findings of Farid (2014), who reported that Valent (bromoxynil + MCPA + metribuzin) 470 EW at 1000 mL ha^{-1} + Bio-enhancer at 400 mL ha^{-1} (alkyl ether sulfate) significantly increased plant height of forage sorghum compared with the recomended rate of herbicide alone. Khan et al. (2002) also reported similar results in maize.

Table 2 - Effect of weed management strategies on yield and yield components of forage sorghum in years 2013 and 2014

Treatment	Plant height (cm)		Stem diameter (cm)		Leaf area per plant (cm)		Fresh fodder yield (t ha^{-1})		Dry matter yield (t ha^{-1})	
	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
Weedy check	234.4 d	224.3 d	0.765 e	0.699 d	3014.2 e	2973.3 e	50.5 e	47.9 d	11.8 e	11.4 d
Hoeing after 3 weeks of emergence	250.3 c	233.4 c	0.822 de	0.794 c	3039.6 d	2991.8 d	56.5 d	53.1 c	14.1 d	12.8 cd
Dicamba at 304.5 g a.i. ha^{-1}	254.1bc	240.5bc	0.850 cd	0.812 abc	3047.6 c	3007.1 bcd	58.7 c	55.4bc	14.9 c	13.9 bc
Dicamba at 304.5 g a.i. ha^{-1}+ 1% AMS	257.0 ab	247.5 ab	0.947 ab	0.831 ab	3060.1 b	3024.1 b	60.3 b	58.3 ab	15.7 b	15.0 ab
Dicambaat 304.5 g a.i. ha^{-1}+ 2% AMS	261.5 a	254.0 a	0.975 a	0.841 a	3072.6 a	3041.8 a	63.4 a	60.9 a	17.4 a	15.8 a
Dicambaat 228.4 g a.i. ha^{-1} + 1% AMS	252.6bc	234.9 c	0.890 bc	0.805 bc	3045.9 cd	3002.0 cd	58.1 c	54.7bc	14.6 c	13.7bc
Dicambaat 228.4 g a.i. ha^{-1} + 2%AMS	253.6bc	242.4 b	0.875 cd	0.821 abc	3048.7 c	3011.7 bc	60.1 b	56.3 bc	15.5 b	14.3 ab
HSD	4.60	7.46	0.063	0.031	7.20	17.27	1.30	4.31	0.49	1.56
Contrast comparison										
Weedy check vs all	**	**	**	**	**	**	**	**	**	**
Hoeing vs chemical control	**	*	**	NS	**	**	**	**	**	*
Dicamba 304.5 g vs dicamba 228.7 g	**	*	**	NS	**	**	**	NS	**	NS
Dicamba with adjuvant vs dicamba without Adjuvant	*	NS	NS	NS	**	NS	**	NS	**	NS
1% AMS vs 2% AMS	NS	*	NS	NS	**	**	**	NS	**	NS

AMS: Ammonium sulphate. Means sharing the same letter in a column did not significantly differ at 5% probability level, NS and **indicate non-significant and significant at $p \leq 0.01$ level of probability, respectively.

Stem diameter (cm)

Stem diameter of sorghum showed significant results in both years (Table 2) and the treatment dicamba at full rate + 2% ammonium sulphate resulted in maximum stem diameter (0.947 and 0.841 cm) of sorghum, which was 27.5 and 20.3% higher than weedy check in years 2013 and 2014, respectively. These values remained statistically at a par with those found for dicamba at afull rate with 1% ammonium sulphate in both study years. The contrast between weedy check vs all management strategies was significant in both years, while the contrasts of hoeing vs chemical control and dicamba t full rate vs dicamba at 75% rate were significant in 2013 only. The highest stem thickness of sorghum forage plants in response to full dicamba rate mixed with 2% ammonium sulphate adjuvant was presumably due to efficient parthenium weed control, which allowed sorghum stems to increase their height and width under reduced weed competition and environmental stress. Orson et al. (1998) also reported that wheat plants attained more stem diameter when their weeds were controlled by chemicals as compared to other means and to a weedy check treatment.

Leaf area per plant (cm)

All weed management strategies resulted in significant enlargement in leaf area per plant compared with the weedy check. Among treatments, application of dicamba at full rate + 2% ammonium sulphate significantly gave the highest leaf area per plant (3072.6 and 3051.8 cm^2 in 2013 and 2014, respectively), followed by dicamba at full rate + 1% ammonium sulphate. The percent increase shown by dicamba full at rate + 2% ammonium sulphate was1.94 and 2.30% over the weedy check in 2013 and 2014, respectively. All the contrast combinations in both years were significant except for dicamba with adjuvant vs without adjuvant, which was not significant in 2014. Better control of parthenium by the application of dicamba with adjuvant decreased severity of weed competition, and led to the best utilization of resources from soil and environment. Subsequently, it resulted in better leaf development and growth. These investigations are in line with the findings of Khaliq et al. (1999), who reported significant improvement in leaf area per plant of sorghum in response to better weed control by pendimethalin. Chattha et al. (2007) also found maximum leaf area per plant of cowpea with chemical weed control treatment. Hassan et al. (2010) found that leaf area per plant of maize was maximum with full rate of atrazine and pendimethalin over their reduced doses and weedy check.

Fresh fodder yield (t ha^{-1})

The data on fresh fodder yield of sorghum as affected by different parthenium management strategies (Table 2) showed that all weed control treatments significantly enhanced fresh fodder yield of sorghum. The most efficient weed control was shown by the application of dicamba at full rate + 2% ammonium sulphate, and this treatment also produced maximum fresh fodder yield (63.4 and 60.9 t ha^{-1}) in both consecutive years, respectively. The yield increment resulting from this treatment over the weedy check was calculated to be 19.14% in 2013 and 19.15% in 2014. All contrast combinations were significant in 2013 and only two contrasts i.e. weedy check vs all, hoeing vs chemical control in 2014, were found to be significant. The highest fresh fodder yield of sorghum in plots receiving dicamba at full rate in combination with 2% ammonium sulphate was due to the highest plant height, stem diameter and leaf area of sorghum found in them. These findings are in line with those of Chattha et al. (2007), who reported a 40% increase in cow-pea fresh biomass by chemical weed control integrated with hand weeding over the weedy check. Munsif et al. (2009), Khan et al. (2014) and Mahadi (2014) also reported an increase in biological yield of maize in response to chemical weed control (post emergence application) over the control (weedy check). Idziak et al. (2013) found the highest fresh fodder yield of sorghum when mesotrione was applied in combination with methylated seed oil and urea and ammonium nitrate than in the other treatments. Tanveer et al. (2015) found a 66.7% enhancement in grain yield of maize as a result of improvement in the number of grains per cob and 100-grain weight by Valent-470EW (bromoxynil + MCPA + metribuzin) at 1,250 mL ha^{-1} + 2% ammonium sulphate adjuvant.

Dry matter yield (t ha^{-1})

Table 2 shows dry matter yield of sorghum forage as affected by different parthenium management strategies. The data revealed that except for hoeing, all treatments significantly increased dry forage yield of sorghum compared with the weedy check in both years of study. Among herbicide treatments, the highest dry matter yield (17.4 and 15.8 t ha^{-1} in year 2013 and 2014, respectively) was found from plots sprayed with dicamba at full rate along with 2% ammonium sulphate, which were 46.51 and 39.18% higher over the weedy check in 2013 and 2014, respectively. However, statistically similar dry matter yields of 15.1 and 14.3 t ha^{-1} were found with dicamba at full rate + 1% ammonium sulphate and dicamba at 75% rate + 2% ammonium sulphate in the year 2014. All contrast combinations were significant in 2013 and only the weedy check vs all and hoeing vs chemical control were significant in 2014. This increase in dry matter yield in dicamba + adjuvant treated plots could be attributed to better weed control and reduced competition between weeds and crop plants for nutrients and water. Amiri et al. (2013) found maximum dry matter yield of sainfoin (*Onobrychis sativa)* grass when imazethapyr at full rate alone as well as imazethapyr 75% rate in combination with an adjuvant (ammonium sulfate) were applied for weed control. Farid (2014) found maximum dry weight of sorghum plant when a mixture of Valent 470 EW (bromoxynil + MCPA + metribuzin) at 1,125 mL ha^{-1} in a mixture with bio-enhancer at 400 mL ha^{-1} was applied for weed control. Mahadi (2014) found the highest total dry matter of maize when atrazine + metolachlor at 2.6 kg a.i. ha^{-1} was applied to control weeds.

Economic analysis

Treatments differed in their economic benefit (Table 3). Maximum net benefit in fresh forage yield (U$ 554.83 in 2013 and U$ 581.43 in 2014) was calculated in the treatment in which dicamba at full rate with 2% ammonium sulphate was sprayed to control parthenium weed, followed by dicamba at full rate with 1% ammonium sulphate. Treatments with dicamba at 75% rate with 2% ammonium suphate, dicamba at 75% rate alone, and dicamba at 75% rate with 1% ammonium sulphate could rank 3rd, 4th and 5th, respectively, on the basis of net benefit. A similar trend among treatments can be found in the case of benefit cost ratio (BCR) and marginal rate of returns (MRR). Maximum BCR was calculated in dicamba at full rate with 2% ammonium sulphate with values of 3.47 in 2013 and 3.57 in 2014, followed by dicamba at full rate with 1% ammonium sulphate. The same treatment gave maximum MRR (346.93% in 2013 and 356.66% in 2014) and was followed by dicamba at full rate with 1% ammonium sulphate.

Table 3 - Effect of weed management strategies on economic returns of forage sorghum in years 2013 and 2014

Treatment	Gross income (US$ ha^{-1})		Total variable Cost (US$ ha^{-1})		Net benefits (US$ ha^{-1})		Marginal net benefit (US$ ha^{-1})		Benefit cost ratio		MRR (%)	
	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
Weedy check	462.61	479.90	-	-	462.61	479.90	0.00	0.00	-	-	-	-
Hoeing after 3 weeks of emergence	517.84	531.10	23.36	28.04	494.48	503.06	31.86	23.16	1.36	0.83	136.38	82.61
Dicamba at 304.5 g a.i. ha^{-1}	538.36	554.30	20.09	21.98	518.27	532.32	55.65	52.42	2.77	2.38	276.96	238.47
Dicamba at 304.5 g a.i. ha^{-1} + 1% AMS	552.37	583.40	23.34	25.22	529.04	558.18	66.42	78.28	2.85	3.10	284.62	310.32
Dicamba at 304.5 g a.i. ha^{-1} + 2% AMS	581.41	609.90	26.58	28.47	554.83	581.43	92.21	101.53	3.47	3.57	346.93	356.66
Dicamba at 228.4 g a.i. ha^{-1} + 1% AMS	532.96	547.70	20.07	21.65	512.89	526.05	50.27	46.15	2.51	2.13	250.55	213.10
Dicamba at 228.4 g a.i. ha^{-1} + 2% AMS	551.00	563.70	23.31	24.90	527.69	538.80	65.07	58.90	2.79	2.37	279.19	236.58

AMS: Ammonium sulphate. Price of sorghum fodder: 15 U$ per metric ton in year 2013 and 10.0 U$ per ton in year 2014; Price of dicamba=13.08 U$ in year 2013 and 14.27 U$ in year 2014; Labor costs of spray = 7.0 U$ in year 2013 and 7.71 U$ in year 2014; Labor charges for hoeing 23.36 U$ ha^{-1} in 2013 and 28.0 U$ ha^{-1} in 2014 (Rs.107 = 1 US dollar).

Based on these results, it can be concluded that application of dicamba at 304.5 g a.i. with tank-mixed 2% ammonium sulphate as an adjuvant proved to be the most efficient and cost-effective combination for the management of parthenium weed in sorghum forage crops. This management strategy consistently gave the best control of parthenium weed along with the highest fresh and dry forage yield of sorghum as well as the highest benefit cost ratio in both study years.

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REFERENCES

Abbas MA. General agriculture. 7th. ed. Pakistan: Emporium Publishers Lahore; 2013.

Abouziena HF, El-Wahed MSAA, Eldabaa MAT, El-Desoki ER. Effect of sowing date and reduced herbicides rate with additives on peanut (*Arachis hypogaea* L.) productivity and associated weeds. J Appl Sci. Res. 2013;9(3):2176-87.

Abouziena HFH, Sharma SD, Singh M. Impact of adjuvants on bentazon efficacy on selected broad leaf weeds. Crop Prot. 2009;28(12):1081-5.

Allen SE, *Grimshaw HM, Rowland AP. Chemical analysis*. In: Moore PD, Chapman SB, editors. Methods in plant ecology. Oxford: Blackwell; 1986. p.285-344.

Amiri S, Karimmojeni H, Majidi MM, Boromand A. Evaluation of post-emergence herbicide to control weeds of newly planted sainfoin (*Onobrychis sativa* L.). Evaluation. 2013;2(4):145-9.

Analytical Software. Statistix 8.1 for Windows. Analytical Software. Tallahassee: 2005.

Anjum FH, Tanveer A, Nadeem MA, Tahir M, Aziz A. Effect of split application of nitrogen and integrated weed management on nutrient uptake by *Trianthema portulacastrum* (Itsit) in cotton. Pak J Agric Sci. 2007;44(3):423-9.

Association of Official Analytical Chemists – AOAC. Official methods of analysis. 15th. ed. Arlington: 1990.

Ayub M, Shoaib M. Studies on fodder yield and quality of sorghum grown alone and in mixture with guara under different planting techniques. Pak J Agric Sci. 2009;46:25-9.

Chattha MR, Jamil M, Mahmood TZ. Yield and yield components of cowpea as affected by various weed control methods under rain-fed conditions of Pakistan. Int J Agric Biol 2007;9(1):120-4.

Fabio S. A review of the factors influencing the absorption and efficacy of lipophilic and highly water soluble post emergent herbicide. *Europ J Plant Sci Biotechnol*. 2007;1:22-35.

Farid G. Impact of herbicide (bromoxynil + MCPA + metribuzin) alone and along with adjuvant (Alkyl Ether Sulfate) on weeds, forage yield and quality of sorghum crop [thesis]. Faisalabad: University of Agriculture: 2014.

Glowacka A. Dominant weeds in maize (*Zea mays* L.) cultivation and their competitiveness under conditions of various methods of weed control. Acta Agrobot. 2011;64:119-26.

Hall GJ, Hart CA, Jones CA. Twenty-five years of increasing glyphosate use: the opportunities ahead. Pest Manag Sci. 1999;56:351-8.

Hassan G, Tanveer S, Khan NU, Munir M. Integrating cultivars with reduced herbicide rates for weed management in maize. Pak J Bot. 2010;42(3):1923-9.

Idziak R, Skrzypczak W, Waligora H, Woznica Z. The effect of mesotrione applied with adjuvants on weed control efficacy and forage sorghum tolerance. Turk J Agric For. 2013;37:265-70.

Khaliq A, Cheema ZA, Mukhtar MA, Ahmad SM. Evaluation of sorghum (*Sorghum bicolor* L.) water extract for weed control in soybean. Int J Agric Biol. 1999;1:23-6.

Khan MA, Marwat KB, Hassan G, Khan N. Impact of weed management on maize (*Zea mays* L.) planted at night. Pak J Weed Sci Res. 2002;8:57-62.

Khan H, Marwat KB, Khan MA, Hashim S. Herbicidal control of parthenium weed in maize. Pak J Bot. 2014;46(2):497-504.

Kondap S, Upadhyay UC. A practical manual on weed control. New Dehli: Oxford and IBH Publishing; 1992.

Little TM and Hills FJ. Agricultural Experimentation. John Wiley and Sons, New York, 1978.

Mahadi MA. Growth, nutrient uptake and yield of maize (*Zea mays* L.) as influenced by weed control and poultry manure. Int J Sci Nature. 2014;5:94-102.

Munsif F, Ali K, Khan I, Khan HU, Anwar M. Efficacy of various herbicides against weeds and their impact on yield of maize. Pak J Weed Sci Res. 2009;15:191-8.

Naveed M,Ahmad R, Nadeem MA, Nadeem S, Shahzad K, Anjum MA. Effect of a new post emergence herbicide application in combination with urea on growth, yield and weed control of maize (*Zea mays* L.) J Agric Res. 2008;40:157-69.

Nigatu L, Hassen A, Sharma J, Adkins SW. Impact of Parthenium hysterophorus on grazing land communities in north eastern Ethiopia. Weed Biol Manag. 2010;10(3):143-52.

Orson JH, Blair AM, Caseley JC Integration of row widths and chemical and mechanical weed control in winter wheat. HGCA-Project Report, United Kingdom; 1998. **(Project Report, 161)**

CIMMYT. From Agronomic Data to Farmer Recommendations: An Economics Training Manual. Completely revised edition. Mexico, DF: 1988. p.13-33.

Scherb W, Ebbinghaus D, Schlotter P.Fregate - a new adjuvant for improvement of leaf active herbicides uptake. J Plant Dis Prot. 2000;17:619-22.

Shabbir A, Bajwa R. Parthenium invasion in Pakistan – a threat still unrecognized. Pak J Bot. 2007;39(7):2519-26.

Sonawane RK, Dandge MS, Kamble AS, Shingrup PV. Effect of herbicides on nutrient uptake and yield of kharif maize (*Zea mays* L.). Bioinfolet. 2014;11:136-8.

Steel RGD, Torrie JH, Dickey DA. Principles and procedures of statistics. A biometrical approach. 3rd. ed. Singapore: McGraw Hill Book; 1997. p.172-7.

Tamado T, Ohlander L, Milberg P. Interference by the weed *Parthenium hysterophorus* L. with grain sorghum: Influence of weed density and duration of competition. Int J Pest Manag. 2002;48:183-8.

Tanveer A, Ahmad S, Abbas RN, Zafar M, Ali HH, Buriro M. Field validation of ammonium sulphate as an activator adjuvant on bromoxynil + MCPA + metribuzin efficacy against maizeweeds. Pak J Weed Sci Res. 2015;21(2):283-93.

Torra J, Cirujeda A, Taberner A, Recasens J. Evaluation of herbicides to manage herbicide-resistant corn poppy (*Papaver rhoeas*) in winter cereals. Crop Prot. 2010;29(7):731-6.

Vivek NSR, Singh R, Tomar SS. Effect of weed interference on weeds and productivity of blackgram (*Phaseolus mungo* L.). Indian J Weed Sci. 2008;40:65-7.

Woznica Z, Idziak R. Influence of herbicide application timings, rates and adjuvant type on weed control and yield of maize grown for forage. Acta Sci Polonorum. Agric. 2010;9:77-84.