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Article

ESTIMATING YIELD LOSSES AND ECONOMIC THRESHOLD LEVEL OF *Parthenium hysterophorus* IN FORAGE SORGHUM

Estimativa das Perdas de Rendimento e Nível de Dano Econômico de ***Parthenium hysterophorus*** *em Sorgo Forrageiro*

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ABSTRACT - A field trial was conducted for two consecutive years to evaluate the effect of different parthenium densities (0, 2, 4, 6, 8, 10, 12, 14 and 16 plants m^{-2}) on the yield and yield components of forage sorghum along with parthenium economic threshold level. The experiment was laid out during the summer in a randomized complete block design with four replications. Different parthenium densities reduced yield and yield components of forage sorghum, as the parthenium density increased significant decline in yield and yield components. The highest parthenium density (16 plants m^{-2}) reduced plant height by 17.19% and 15.32%, stem diameter by 31.79% and 28.10%, leaf area per plant by 18.88% and 10.16%, leaf to stem ratio by 51.01% and 45.03% and fresh fodder yield by 24.97% and 26.49% throughout 2013 and 2014, respectively. Parthenium relative competitive index (RCI), dry weight and nutrient uptake (NPK) also increased as parthenium density increased. The suggested economic threshold level of parthenium was 2.2 and 1.6 plants m^{-2} in 2013 and 2014, respectively. Thus, control the parthenium at this density level is suggested for achieving high yield of good quality sorghum fodder.

Keywords: *Sorghum bicolor*, *Parthenium hysterophorus*, weed competition, yield losses, threshold density.

RESUMO **-** *Um experimento em campo foi conduzido por dois anos consecutivos, a fim de estudar o efeito de diferentes densidades de Parthenium (0, 2, 4, 6, 8, 10, 12, 14 e 16 plantas m^{-2}) sobre os componentes de produção e produtividade de sorgo forrageiro, bem como seu nível de dano econômico. O experimento foi realizado durante o verão, em delineamento de blocos completos (DBC) com quatro repetições. Os resultados mostraram que diferentes densidades de Parthenium reduziram o rendimento e seus componentes do sorgo forrageiro. Contudo, o efeito foi menos proeminente em baixa densidade de Parthenium. Com o aumento da densidade de plantas de Parthenium, observou-se declínio significativo no rendimento e seus componentes Além disso, verificou-se redução na altura das plantas de 17,19% e 15,32%; diâmetro do caule, de 31,79% e 28,10%; número de folhas por planta, de 18,88% e 10,16%; colmo, de 51,01% e 45,03%; e rendimento de forragem fresca, de 24,97% e 26,49%, durante 2013 e 2014, respectivamente. O índice competitivo das plantas de Parthenium, a matéria seca e a captação dos principais nutrientes (NPK) também aumentaram à medida que a densidade delas foi aumentada. O nível de dano econômico sugerido de Parthenium foi de 2,2 plantas m^{-2}, sendo recomendado o seu controle a partir dessa densidade, visando obter alto rendimento e boa qualidade de forragem das plantas de sorgo.*

Palavras-chave: *Sorghum bicolor*, *Parthenium hysterophorus*, matocompetição, perdas de rendimento, densidade-limite.

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INTRODUCTION

Sorghum (*Sorghum bicolor*) is a member of the family Poaceae, grown as grain and fodder crop worldwide (Dajue, 2011). In Ethiopia, sorghum is used as staple food, livestock feed, silage making, extraction of alcohol, edible oil and sugar extraction (Dajue, 2011). Fresh sorghum fodder contains about 28.1% dry matter, 33.6% crude fiber, 57.9% neutral detergent fiber, 35% acid detergent fiber, 8.2% crude protein and 9.1% ash contents (Fulkerson et al., 2008). Sorghum fresh fodder average yield is very low and factors which affect yield and quality of sorghum are poor quality seed, low seed rate, inappropriate sowing methods, insufficient nutrition and high infestation of weeds (Zulfiqar et al., 2002). To support increasing population, we have to feed more livestock to fulfill the needs of the population, relying on limited area and resources (Searchinger et al., 2014). Weeds cause huge yield losses in different field crops in Pakistan (Abbas, 2013). Weed control in forage crops is also equally important and should not be ignored especially when their production is associated with high cost of production. Weeds compete with forage crops for resources and reduce yield and quality. Some of the weed flora is poisonous and unpalatable for livestock (Green et al., 2003). Thomas (2008) reported 90% reduction in forage yield due to weed infestation, and infestation is severe at early stages of forage crops. Whereas, Okafor and Zitta (1991) recorded 65% yield loss due to weed-crop competition in sorghum. A number of weeds which affect the growth, yield and quality of sorghum fodder are *Trianthema portulacastrum*, *Cynodon dactylon*, *Echinochloa* spp., *Digera arvensis*, and *Parthenium hysterophorus*. Given the above facts, cultivated fodder as well as pastures and rangelands should be kept weed free to produce quality fodder to maintain the health of livestock.

Parthenium hysterophorus, also called parthenium and known as white top, carrot grass or rag grass in English, is a member of the family Asteraceae (Khan et al., 2012). Parthenium is an annual or short-lived ephemeral plant which normally germinates in spring and early summer, remains in vegetative phase for 4-8 weeks and reaches the reproductive phase in 12-16 weeks (Adkins et al., 1996; Tanveer et al., 2015). In Pakistan, parthenium is spreading throughout the country and considered an exotic or invasive weed species (Shabbir and Bajwa, 2007). Wiesner et al. (2007) reported that parthenium has become a potential colonizer and invaded countries over railway roads, water channels, in field crops and grazing pastures in different growing conditions. Parthenium causes prominent yield losses in sunflower, sorghum, maize, pigeon pea, black grams and fodders (Angiras and Saini, 1997; Tamado et al., 2002; Vivek et al., 2008). Another harmful aspect of parthenium is its noxiousness and unpalatability for livestock and they do not like to eat it (Patel, 2011). Parthenium causes dermatitis with skin lesion, mouth ulcer with excessive saliva, diarrhea due to irritation of gastro intestine, reduction in milk yield, tainting of milk, and in severe cases, haemorrhage and rupture of internal tissues may kill animals (Patel, 2011). Profitable agriculture is based on wise and economic weed management strategies which are possible only by estimation of weed density causing appreciable yield losses (Deines et al., 2004). Weed control beyond threshold level is a key component of integrated weed management for good crop production (Moorthy and Das, 1998; Knezevic et al., 2002) and threshold density may vary with weed species (Onofri and Tei, 2006). Previous studies have shown different threshold level of parthenium in different crops. Morales-Payan (2000) suggested 1 parthenium plant m^{-2} economic threshold level in direct seeded tomato, which caused 63% yield loss and 6 parthenium plant m^{-2} in transplanted tomato, which also caused 63% yield loss. Tomado et al. (2002) also reported 69% reduction in sorghum grain yield at 3 plants m^{-2} of parthenium. In spite of such a severe threat of parthenium to crops, no appreciable research work has been done yet with particular reference to forage crops and its economic threshold level. Therefore, there is a current need to conduct research studies about forage crops so that we may be able to estimate yield losses at different parthenium densities and determine the critical threshold level (CTL) in forage sorghum.

MATERIALS AND METHODS

A field experiment was conducted during the summer season of 2013 and 2014 on a sandy clay loam. Soil has pH 8.1, organic matter 0.64%, total nitrogen 0.0412%, available P 7.67 ppm and available K 268.5 ppm. Mean seasonal rainfall was 176.4 mm and 67.9 mm in 2013 and 2014, respectively. The experiment was laid out in randomized complete block design (RCBD) with net plot size 2.4 m x 6 m, and each treatment was replicated four times. Uniform seedbed preparation was attained in all the experimental units. Soaking irrigation of 10 cm depth was applied. When the soil reached appropriate moisture level, the seedbed was prepared by performing three cultivations with the help of a tractor-mounted cultivator followed by planking. The Hegari cultivar of sorghum was sown with a single row hand drill at 30 cm apart rows using a seed rate of 75 kg ha^{-1}. The recommended dose of fertilizer (90 kg N and 60 kg P_2O_5 ha^{-1}) was applied. Whole phosphorus and half nitrogen were applied at the time of sowing while the remaining half of nitrogen was applied at first irrigation. Three irrigations (each 7.5 cm of depth) were performed during the entire growing period of the crop; the first irrigation was applied at 21 days after sowing (DAS) and the second one after 35 DAS and the third at full vegetative stage. Seeds of parthenium (*Parthenium hysterophorus*) were collected at maturity from farmer's fields at the end of summer from the district of Cheniot and Sargodha, Punjab, Pakistan. Parthenium seeds were uniformly distributed in all the experimental units at the time of crop sowing. Desirable parthenium density (0, 2, 4, 6, 8, 10, 12, 14 and 16 plants m^{-2}) was maintained by uprooting its surplus seedlings from each plot at their early growth stage according to the treatment plan, whereas all parthenium seedlings were uprooted in control treatment. All other agronomic operations were kept normal and uniform except those under study. The crop was harvested at 70 DAS with hand sickle when the sorghum reached 50% heading stage. Observations about yield components, fresh forage yield and parthenium weed growth (fresh and dry weight) and NPK uptake at crop harvest were recorded by determination of NPK contents, which are estimated by the method proposed by Williams (1984).

Statistical analysis

Data of both years were recorded using a standard protocol and analyzed statistically by using Fisher's analysis of variance techniques (Steel et al., 1997). Tukey's honest significant difference (HSD) test was applied at 5% probability level to test the significance of treatment means, and trend comparison (linear, quadratic and cubic) was carried out in Statistics 8.1 (Analytical Software, 2005). Fresh fodder estimated yield (Y_0) and weed competitivity (β), whose reciprocal (1/β) is the parthenium density that reduces sorghum yield by 50%, was calculated by nonlinear regression by using Cousens' model to determine the relationship between parthenium density (X) and fodder yield (Y).

ETL of parthenium was also calculated by using Cousens' equation:

$$ETL = (Ch + Ca) / Y_0PLH \text{ (Cousens, 1987)}$$

where Ch is herbicide cost, Ca is herbicide application cost, Y_0 estimated weed free sorghum fodder yield, P per unit crop value, L proportional fodder yield loss at each parthenium density, H herbicide efficacy.

RESULTS AND DISCUSSION

Growth and yield parameters of sorghum fodder

Plant height (cm)

Parthenium densities significantly affected sorghum plant height in both years (Table 1). Sorghum plant height decreased linearly with increased parthenium density; however, the decrease could not reach a significant level at each increment in parthenium density in both years. Maximum plant height (265.60 cm in 2013 and 253.50 cm in 2014) was attained in a plot where no parthenium plant was present (control) and minimum plant height (219.68 cm in 2013, 214.67 cm in 2014) was recorded in plots where 16 parthenium plants m^{2} were kept. Parthenium density of 16 plants m^{-2} decreased plant height by 17.19% and 15.32% as compared to control in 2013 and 2014, respectively. Reduction in plant height with increase in parthenium planting density may be due to increase in interspecies competition for the same resources. These findings are in line with those of Hussain et al. (2011), who observed that fodder maize height decreased with increase in density of *Xantium strumarium* beyond 6 plants m^{-2}.

Table 1 - Effect of varying *Parthenium hysterophorus* densities on the yield and yield components of forage sorghum

Fresh fodder yield (ton ha^{-1})		Leaf/stem ratio		Leaf area/plant (cm)		Stem diameter (cm)		Plant height (cm)		Parthenium weed density (m^{-2})
2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	
54.57 a	56.19 a	0.362 a	0.347 a	3002.4 a	3035.1 a	1.00 a	1.06 a	253.50 a	265.60 a	(Control)
54.00 ab	55.85 a	0.360 a	0.332 ab	2996.0 ab	3006.5 ab	1.00 a	1.02 ab	252.40 a	265.25 ab	2
52.11 abc	53.43 ab	0.339 ab	0.299 ab	2985.7 ab	2982.9 bc	0.975 a	1.01 ab	248.43 ab	253.05 abc	4
50.01 abc	51.18 bc	0.311 bc	0.339 ab	2974.3 bc	2973.1 cd	0.942 ab	0.95 bc	241.55 abc	250.25 abc	6
46.11 abcd	49.13 cd	0.289 c	0.277 b	2962.3 cd	2963.7 cde	0.901 bc	0.92 c	235.67 bc	249.11 bc	8
45.56 bcd	47.15 de	0.243 d	0.209 c	2944.5 de	2950.6 def	0.856 cd	0.872 cd	229.46 cd	240.45 cd	10
43.57 cd	45.84 de	0.232 de	0.213 c	2931.4 ef	2944.4 def	0.821 de	0.808 de	221.67 de	232.40 de	12
40.2 d	43.94 ef	0.201 e	0.189 c	2919.9 f	2933.3 ef	0.757 ef	0.782 ef	219.34 de	220.41 e	14
40.14 d	42.16 f	0.199 e	0.170 c	2909.6 f	2929.4 f	0.719 f	0.723 f	214.67 e	219.68 e	16
8.88	3.47	0.037	0.064	23.05	32.04	0.069	0.075	12.98	16.22	HSD
47.36 B	49.43 A	0.282 A	0.264 B	2958.5 B	2968.8 A	0.886 B	0.903 A	235.19 B	244.02 A	Year
1.348		0.015		7.355		0.014		3.015		HSD
Trend comparison										
**	**	**	**	**	**	**	**	**	**	Linear

Means following the same letter did not differ significantly at $p \leq 0.05$ NS and ** indicates non-significant and significant at $p \leq 0.01$, respectively.

Celebi et al. (2010) reported that plant height of alfalfa (*Medicago sativa*) reduced as weed density was increased. Safdar (2015) also investigated the same results that plant height of maize was declined gradually as parthenium density was increased (5, 10, 15 and 20 plant m^{-2}).

Stem diameter (cm)

Data indicate a linear decrease in plant stem diameter as parthenium density increased (Table 1). Throughout 2013 and 2014, sorghum plant achieved maximum stem diameter (1.06 cm, 1.00 cm) in control and minimum stem diameter (0.723 cm, 0.719 cm) was recorded when 16 parthenium plants m^{-2} competed with sorghum. *Maximum parthenium* density reduced stem diameter by 31.79% and 28.10% over the control treatment. The stem diameter of sorghum at parthenium density of zero, 2 and 4 plants m^{-2} during the first year and zero, 2, 4 and 6 parthenium plants during the second year did not differ significantly from each other. The stem diameter of sorghum plant at parthenium densities of 14 and 16 plants m^{-2} was statistically similar in both years. The effect of year on stem diameter was also significant. Stem diameter was significantly lower in the second year. Among the trend comparison of stem diameter, a linear trend was significant whereas other two were non-significant in both years. The good growth of parthenium plant in the 2nd year may be the cause of lower stem diameter. These investigations had similar results to the findings of EI-Morsey and Badawi (1998). They observed that maize plant diameter was significantly decreased when weeds were present for a complete crop growth period. Gholami et al. (2013) also reported that unweeding treatment reduced stem diameter of forage sorghum plant more than other weeding treatments where weed density was minimum.

Leaf area (cm^2) per plant

The effect of different parthenium densities (plants m^{-2}) on leaf area per (cm^2) plant of sorghum (Table 1) indicated a significant reduction in leaf area due to increased parthenium density. Control treatment produced the highest leaf area of 3035.1 cm^{-2} in 2013 and 3002.4 cm^{-2} in 2014. The leaf area started to decrease as parthenium density increased; finally, sorghum plant showed the lowest plant leaf area 2929.4 cm^2, 2909.6 cm^2 when parthenium population was 16 plants m^{-2}, which was 18.88% and 10.16% lower than control treatment in the years 2013 and 2014, respectively. Leaf area was significantly higher in the first year than in the second year. The differences in crop growing conditions may have been the cause of these differences. A linear trend was only significant in both years. These results are similar to the findings of Rezvani et al. (2012), who reported a decrease in the leaf area of soybean, because the weedy condition of crop and absence of weeds during crop season (unweedy condition) have no significant adverse effects on leaf area. Sarabi et al. (2013) also investigated that density of lambsquarters (0, 4, 8, 12, 16 and 20 plants m^{-2}) significantly reduced the leaf area index of maize and high density (16 and 20 plants m^{-2}) caused maximum reduction in leaf area index.

Leaves to stem ratio on dry weight basis

The effect of parthenium density on leaf to stem ratio of sorghum showed that weed density significantly affected the leaf to stem ratio. Initially, the effect of parthenium density was less prominent because of the lower number of parthenium plants, and the effect was prominent as weed density increased (Table 1). There was maximum leaf to stem ratio (0.347 in 2013 and 0.362 in 2014) when weed to crop competition was not allowed (no parthenium). The parthenium densities of 2, 4, 6 plants m^{-2} in 2013 and 2, 4 plants m^{-2} in 2014 were statistically at a par with control. Minimum leaf to stem ratio (0.170 in 2013, 0.199 in 2014) was recorded when maximum parthenium density (16 plants m^{-2}) was maintained. Parthenium density of 16 plants m^{-2} produced 51% and 45% less leaf to stem ratio as compared to the control treatment in 2013 and 2014, respectively. The density of 16 plants m^{-2} did not differ significantly from parthenium densities of 10, 12 and 14 plants m^{-2} in the year 2013 and planting densities of 12 and 14 plants m^{-2} in the year 2014. Increase in leaf to stem ratio was linear. Leaf to stem ratio was significantly higher in the year 2014 than in the year 2013. These results are in line with those of Gholami et al. (2013), who reported that weed competition caused heavier stem, and decreased weight of leaves ultimately decreased the leaf to stem ratio of forage sorghum. Mohammed (2013) also reported that leaf to stem ratio of *Clitoria ternatea* (Butterfly pea) was low when it was left unweeded whreas the ratio was higher when weed density was lower as a result of weeding.

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

Fresh fodder yield showed a decreasing trend as parthenium density was increased during the year 2013 and 2014 (Table 1). Maximum fresh fodder yield of 56.19 tha^{-1} and 54.57 ton ha^{-1} were recorded when no parthenium plant was present in 2013 and 2014, respectively. Fresh fodder yield decreased as parthenium plants m^{-2} were increased and reached the lowest yield 42.16 ton ha^{-1}, 40.14 ton ha^{-1} in 2013 and 2014, respectively at 16 plants m^{-2} density level. The highest parthenium density (16 plants m^{-2}) decreased fresh fodder yield by 24.97 and 26.44% over control in 2013 and 2014, respectively. Analysis of trend comparison showed that only linear trend was significant. Fresh fodder yield was significantly higher in the first year than in the second year. These differences can be attributed to variation in soil fertility status and climatic conditions. Decrease in fresh fodder yield with increasing parthenium densities may be attributed to decrease in growth parameters such as plant height, stem diameter, leaf area and leaf number. These results confirm the findings of Celebi et al. (2010). They observed that green forage yield of alfalfa (*Medicago sativa*) was minimum where the highest weed density was present and yield was the highest where minimum weeds were present to compete with alfalfa. Massinga et al. (2004) also reported a significant decrease in maize fodder yield with increased weed density.

Growth and nutrient uptake of *P. hysterophorus*

Parthenium dry weight (g m^{-2})

The dry biomass of *Parthenium hysterophorus* in forage sorghum showed a linear increase in dry biomass of parthenium with increased parthenium density level in both the years (Table 2). Maximum dry weight 104.75 g m^{-2} and 115.98 g m^{-2} of parthenium was found at density level of 16 plants m^{-2} in 2013 and 2014, respectively. There was minimum dry biomass (25.50 g m^{-2}) of parthenium at density level of 2 plants m^{-2} in 2013 whereas in 2014, parthenium density of 2 and 4 plants m^{-2} produced weed dry biomass of 31.76 g m^{-2} and 43.67 g m^{-2} which were statistically similar with each other. Dry weight was significantly higher in the second year than in the first year. In trend comparison, only linear trend was significant. These results confirm the findings of Cortes et al. (2010). They observed a linear increase in dry weight (kg m^{-2}) of velvetleaf (*Abutilon theophrasti*), a broad leaf weed in cotton when plant density was increasing from 0-25 plants m^{-2}.

Table 2 - Effect of varying *Parthenium hysterophorus* densities on dry weight and NPK uptake of parthenium in forage sorghum

K uptake		P uptake		N uptake		Weed dry wt.		Parthenium weed density (m^{-2})
(ton ha^{-1})						(Parthenium)		
2014	2013	2014	2013	2014	2013	2014	2013	
10.20 e	7.90 f	2.86 e	2.14 e	14.81 e	11.64 f	31.76 g	25.50 g	2
13.93 de	11.26 e	3.88 de	2.88 d	20.22 d	16.90 e	43.67 fg	37.50 f	4
16.96 cd	14.07 de	4.60 d	3.33 cd	24.80 cd	21.48 de	53.78 ef	48.50 e	6
18.65 c	16.09 cd	4.90 cd	3.38 cd	27.07 c	24.64 d	59.87 de	56.25 e	8
20.69 c	19.05 c	5.11 bcd	3.79 bc	29.89 c	29.37 c	66.87 d	68.00 d	10
26.22 b	22.32 b	6.23 abc	4.29 ab	38.72 b	34.61 b	87.78 c	81.75 c	12
29.86 ab	24.84 ab	6.33 ab	4.26 ab	44.23 a	37.97 ab	101.76 b	92.75 b	14
33.63 a	27.54 a	6.87 a	4.47 a	49.52 a	42.10 a	115.98 a	104.75 a	16
4.482	3.025	1.415	0.684	5.332	4.614	11.99	10.31	HSD
21.27A	17.89 B	5.10 A	3.57 B	31.15 A	27.34 B	70.18 A	64.37 B	Year
0.838		0.259		1.116		2.37		HSD
**	**	**	**	**	**	**	**	Linear
NS	NS	NS	NS	NS	NS	NS	NS	Quadratic
NS	NS	NS	NS	NS	NS	NS	NS	Cubic

Means sharing the same letter did not differ significantly at $p \leq 0.05$ according to the HSD test, NS and ** indicate non-significant and significant at $p \leq 0.01$, respectively.

The same trend was observed by Morales-Payan, (2000), who reported that weed dry biomass was increased linearly as parthenium plant densities were increased 1 to 13 plants m^{-2} in tomato.

Parthenium NPK uptake (kg ha^{-1})

The NPK uptake of parthenium increased linearly with increase in parthenium density (Table 2). Maximum nitrogen uptake (42.01 kg ha^{-1}, 49.52 kg ha^{-1}) was observed at parthenium density of 16 plants m^{-2}, whereas minimum nitrogen uptake (11.64 kg ha^{-1}, 14.8 kg ha^{-1}) was recorded where 2 plants m^{-2} were maintained in 2013 and 2014, respectively. Planting density of 14 plants m^{-2} did not differ statistically from 12 and 16 plants m^{-2}. Similarly, the difference among the planting densities of 4, 6 and 8 could not reach a significant level in 2013 and in 2014, the planting density of 14 plants m^{-2} remained at a par with 16 plants m^{-2}. In 2014, nitrogen uptake was significantly higher than in the year 2013. Phosphorus uptake by parthenium plant showed a linear increase as parthenium density increased during both the years (2013-2014). The highest phosphorus uptake 4.47 kg ha^{-1}, 6.34 kg ha^{-1} was shown by plant density of 16 parthenium plants m^{-2} in 2013 and 2014, respectively. There was minimum phosphorus uptake where parthenium density of 2 plants m^{-2} was maintained in both years. Phosphorus uptake was significantly higher in the year 2014. The effect of parthenium densities on potassium uptake of parthenium was almost similar in both years. In both years, planting density of 14 plants m^{-2} remained at par with 12 and 16 plants m^{-2}. Similarly, planting density of 8 plants m^{-2} also remained at par with planting density of 6 and 10 plants m^{-2}. The parthenium density of 16 plants m^{-2} showed the highest (27.54 kg ha^{-1}, 33.63 kg ha^{-1}) potassium uptake in 2013 and 2014, respectively. Lowest potassium uptake of 7.90 kg ha^{-1}, 10.20 kg ha^{-1} was recorded at parthenium density of 2 plants m^{-2} in 2013 and 2014, respectively. Potassium uptake was significantly lower in 2013 than in the year 2014. A linear trend was significant for NPK uptake while quadratic and cubic were non-significant in both years. Findings of Lehoczky and Reisinger (2003) confirmed the results, who observed that NPK uptake was increased as the population of *Cannabis sativa*, *Datua stramonium*, *Amaranthus chlorostachis*, *Chenopodium album*, *Chenopodium hybridum* increased; they also observed a linear trend between NPK uptake and weed density.

Relative Competitive Index (RCI)

The Relative Competitive Index reflects the suppression potential of weeds on a crop. The Relative Competitive Index (Figure 1) showed a linear trend and ranged between 0.61 - 24.97%

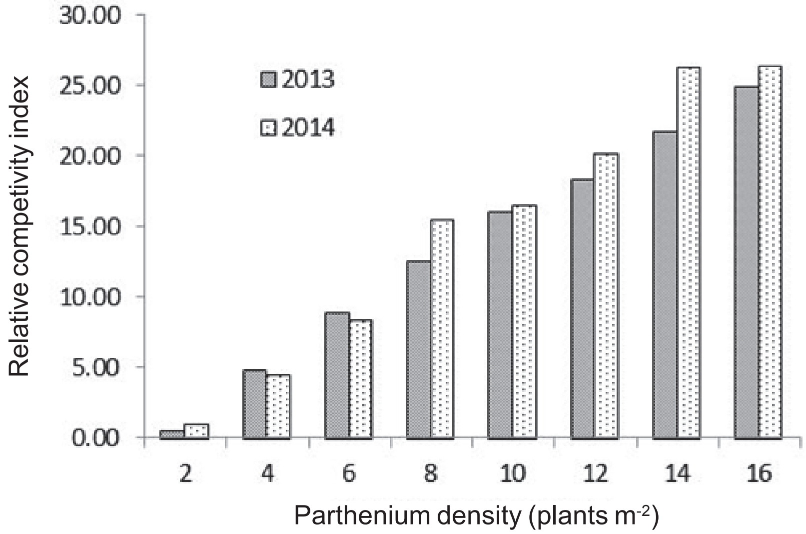

Figure 1 - Effect of varying parthenium densities (plants m^{-2}) on its Relative Competitive Index (RCI, means of 2013 and 2014).

in 2013 and 1.04 - 26.44% in 2014 with increasing parthenium density from 2-16 plants m^{-2}, and the highest RCI was recorded at the highest parthenium density. The increase in yield reduction with increasing parthenium density may be described by increase in inter-species competition for the same resources throughout the season of crops. Our findings are parallel with the results of Morales-Payan (2000), who reported up to 63% reduction in tomato yield with increasing 0-12 parthenium plants m^{-2}. Bridges et al. (1992) also reported 4 to 54% reduction in peanut yield as density of *Euphorbia heterophylla* increased from 1-32 plants in 5 m long row.

Estimation of economic threshold of *P. hysterophorus* in sorghum fodder

The non-linear regression model (Figure 2) showed that observed and predicted fresh fodder yield of sorghum reduced when parthenium density increased during both the year. Weed competitivity (β), whose reciprocal (1/β) is the parthenium density that reduced sorghum yield by 50%, was 0.0191 and 0.0251 in 2013 and 2014, respectively (Figure 2). The economic threshold level (ETL) of Parthenium was calculated by estimating the herbicide cost of 13.09 US$ and

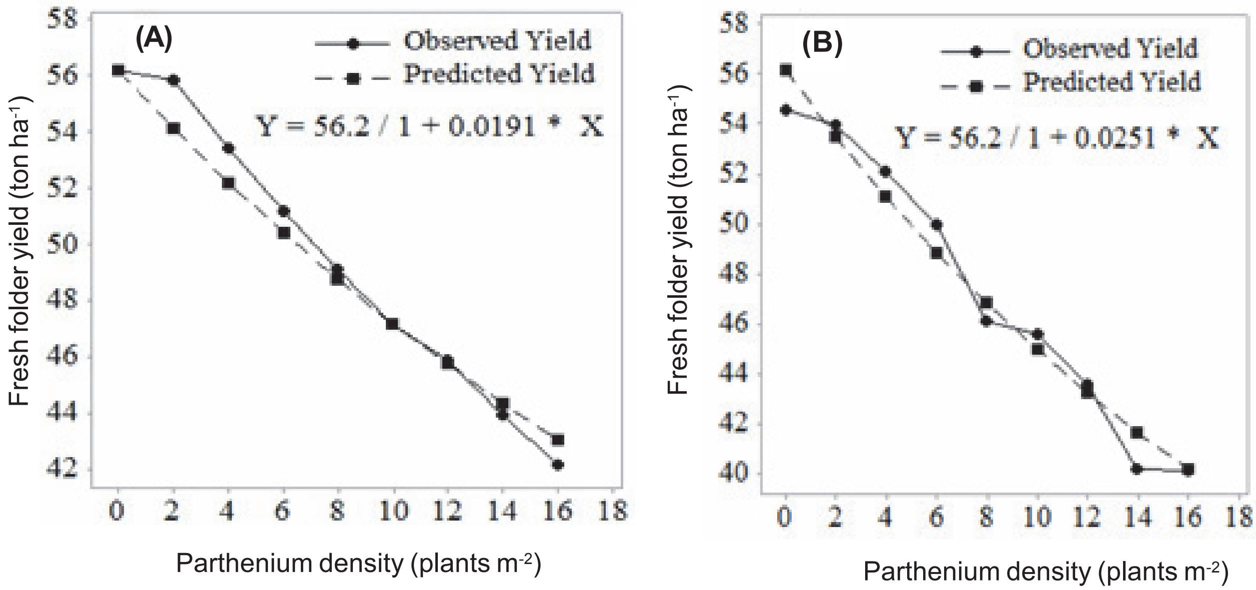

Figure 2 - Non-Linear regression between maize grain yield and varying *P. hysterophorus* densities during (A) 2013 and (B) 2014.

14.28 US$, application cost 7.15 US$ and 7.75 US$, value per unit of crop US$ 9.15 and 10 in 2013 and 2014, respectively. Herbicide efficiency was supposed to be 0.95 irrespective of the year. The economic threshold level (ETL) (Table 3) was estimated to be 2.2 and 1.6 plants m^{-2} in the years 2013 and 2014, respectively.

Table 3 - Parameter estimates and economic threshold (ET) of *P. hysterophorus* in forage sorghum

ET (plants m^{-2})	H	L	P (US$ ton^{-1})	Y_o (t ha^{-1})	C_h+C_a (US$)	Year
2.2	0.95	0.0191	9.15	56.2	13.09 + 7.15	2013
1.6	0.95	0.0251	10	56.2	14.28 + 7.75	2014

C_h = herbicide cost, Ca = application cost, Y_o = weed free corn yield, P = value per unit of sorghum fodder, L = proportional loss per unit weed density, and H = herbicide efficacy.

The results of the present study will be helpful for the growers of fodder sorghum for economic control of *Parthenium.hysterophorus Parthenium hysterophorus* causes different losses at different densities. To prevent economic loss, *Parthenium hysterophorus* must be controlled when density exceeds 1.6 plants m^{-2}.

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