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CLIMATIC VARIATION AND GROWTH OF HOLY THISTLE (*SILYBUM MARIANUM* GAERTN.)

KHAN BAHADAR MARWAT AND MUHAMMAD AZIM KHAN

Department of Weed Science,
NWFP Agricultural University Peshawar, 25130, Pakistan
E-mail: ahmadzaipk@yahoo.com

Abstract

There is an increasing interest in weed suppression through manipulation of crop density. To test this hypothesis as to how growth of Holy thistle (*Silybum marianum*) is affected by environmental conditions, experiment was conducted in RCBD with split plot arrangements by sowing four seed rates of wheat (100, 120, 140 and 160 kg ha^{-1}) in main plots and seven *S. marianum* densities (0, 3, 6, 9, 12, 15 and 18 m^{-2}) in sub-plots. Increasing seed rate of wheat greatly suppressed the growth of *S. marianum* during year 1 and had no effect on *S. marianum* growth in year 2 due to higher rainfall and low temperature which favoured the growth of *S. marianum*. With the increasing density of either species, the seed production $plant^{-1}$ of *S. marianum* decreased but the magnitude of seed reduction was dependent on seed rate, *S. marianum* density and year effect. Thus seed rate and weed density did not give accurate prediction to estimate the yield losses and competitiveness of weed. Hence other factors like rainfall and temperature should also be considered while developing a model for crop/weed competition. Optimum seed rate (120 kg ha^{-1}) of wheat could contribute to a strategy to reduce yield losses and to prevent this weed from seed production in long-term weed management. However, this approach can be used as a part of integrated weed management.

Introduction

Climate plays an important role in manipulating the crop-weed competition. Usually the crop and its associated weeds require similar environmental conditions for growth and development. However, when the environmental conditions are altered it may favour few weed species. Thus the crop yield losses shall increases due to interspecific competition in a changing climate. Although increased seed rate of crop plays an important role in suppressing weeds and thus weed seed production is reduced greatly, however, this approach can prove successful if consistent cultural practices are adopted in a particular area for long term weed management. Increased competitive ability of crops has been also associated with early emergence, rapid leaf expansion forming a dense canopy, increased plant height, early vigorous root growth, and increased root size. However, the importance of climatic conditions can not be ignored in studying crop-weed competition studies. Bailey *et al.*, (2003) hypothesized that environmental variation caused differences in measured responses between 1997 and 1998. Higher rainfall enabled *Galium aparine* to escape suppression by wheat (Seavers & Wright, 1999). Large seasonal differences in wheat yield loss from densities of *Avena* spp. across 2 years due to a function of seasonal factors such as rainfall has been reported by Murphy *et al., (*2002). Although increased seed rate is considered as a tool of weed management technique but it needs thorough study as higher seed rate alone cannot suppress weeds.

Spring wheat cultivars that were taller and tillered more profusely caused the greatest reductions in seed production of the simulated weeds, like, wild oat and wild mustard (Hucl, 1998). The establishment of a crop with a more uniform and dense plant distribution can increase its ability to suppress weeds. This is due to more rapid canopy closure that better shades weeds and help better root distribution improving access to soil nutrients and water. Increase in spring wheat seed rate from 50 to 300 kg ha^{-1} reduced *Erodium cicutarium* L., biomass by 53 to 95% and increased wheat yield by 56 to 498%. Additionally, *E. cicutarium* in the soil seedbank for future weed infestations was reduced by 79%. The greatest weed suppression may occur when higher seed rates were combined with planting of large wheat seed (Anon., 2005). Although most studies do show decreased weed biomass at higher crop densities (Doll, 1997; Hakansson, 1997), the prediction of ever increasing weed suppression at increasing crop density is not usually observed in some of the crop density studies (Teich *et al.*, 1993; Khan *et al.*, 2005). Climatic conditions can change the plant growth in a variety of ways. Temperature determines the potential length of the growing and grazing seasons, and generally has a strong effect on the timing of developmental processes and on rates of expansion of plant leaves. The latter, in turn affects the time at which a crop canopy can begin to intercept solar radiation and thus the efficiency with which solar radiation is used to make plant biomass (Monteith, 1981).

Thus ecological studies of every weed species is necessary to develop weed management program for infested area. If the type of weed which is likely to cause problem is known in advance, this can greatly assist in the choice of the appropriate control method. The sensitivity of marginal farmers of marginal lands to climatic change may be especially great as temperature or moisture required to avoid crop failure or a critical crop shortfall tends to increase not linearly but quasi-exponentially. Marginal areas are thus commonly characterized by a very steep "risk surface", with the result that any changes in average warmth or aridity, or in their variability, would have a marked effect on the level of risk in agriculture.

In order to address the importance of *S. marianum* as a potential major weed of wheat in NWFP and elsewhere, these experiments were designed to decipher the impact of climatic variation (mainly temperature and rainfall) on *S. marianum* and its competitiveness with wheat.

Materials and Methods

Field site description: Field experiments were conducted at Agricultural Research Farm, NWFP Agricultural University Peshawar, Pakistan for two crop seasons i.e. 2003-04 and 2004-05 on the same site. Peshawar lies between $71^0 - 27^/$ and $72^0 - 47^/$ east longitude and $33^0 - 40^/$ and $34^0 - 31^/$ north latitude. It is located at 317 m height above sea level. The experimental site has mean soil pH of 7.47 with 22.79, 55.69 and 21.52 % clay, silt and sand, respectively. Soil is silty clay loam in texture, calcareous in nature and alkaline in reaction. Meteorological data (Table 1) was recorded during both the crop seasons that varied greatly between the years. The organic matter content of soil was low with poor supply of available phosphorus and total nitrogen.

Table 1. Weather data (temperature and precipitation) of experimental site.

Year	Month		Max. (mean)	Min. (mean)		Precipitation (mm)
2003-04	December		21.2	6.0		9.5
	January		18.0	4.2		55.1
	February		23.1	6.3		39.4
	March		28.6	10.7		00.0
	April		31.0	16.5		36.7
		Mean	**24.8**	**8.74**	**Total**	**140.7**
2004-05	December		20.7	6.3		25.8
	January		16.9	3.3		75.9
	February		16.4	5.1		97.4
	March		22.1	10.8		108.5
	April		29.3	12.54		9.3
		Mean	**21.1**	**7.6**	**Total**	**316.9**

Source: Weather Station, NWFP Agricultural University Peshawar, Pakistan.

Field operation: Before sowing of wheat and *S. marianum*, seedbed was prepared by ploughing the field twice followed by harrowing. All other cultural practices were kept uniform for all the treatments. Nitrogen and phosphorus fertilizers in the form of urea and diammonium phosphate (DAP) were applied @ 135:50 NP. Half N and full dose of P was applied at sowing and remaining N was applied with second irrigation. The experiments were conducted using a Randomized Complete Block (RCB) design with split-plot arrangements, having four replications. The main plots consisted of four seed rates of wheat i.e. 100, 120, 140 and 160 kg ha^{-1}, while sub-plots had seven densities of *S. marianum* i.e., 0, 3, 6, 9, 12, 15 and 18 plants m^{-2}. The size of a main plot was 52.5 m^2 while the size of each sub-plot was 5 x 1.5 m^2 having 5 wheat rows, spaced 0.30 m apart. Wheat was sown with the help of hand hoe whereas seeds of *S. marianum* were planted using dibbler the same day. To avoid the risk of germination failure, three seeds of *S. marianum* were seeded instead of a single seed and then the population adjusted through thinning and or transplantation accordingly. All other weeds were removed manually throughout the crop season on weekly basis.

Measurement and statistics: Random samples of 10 *S. marianum* plants from each sub-plot were selected before maturity to record plant height. The leaves of each plant were cut with scissors and put in plastic bags. Leaf area was measured using leaf area machine and mean of the samples determined the leaf area plant^{-1}. To record the fresh biomass, 10 plants were selected in each treatment at milk stage of wheat and weighed. The data recorded was converted into t ha^{-1}. Flowers of 10 *S. marianum* plants in each experimental unit were cut at maturity and seeds plant^{-1} were determined.

Statistics: Since years' effect was significant, thus yearly analysis was carried out accordingly. For main effects, statistical analyses were performed using ANOVA procedure and then the means were separated using LSD test (Steel & Torrie, 1980) using MSTATC software. As the treatments were spaced at equal intervals, therefore regression analyses were performed using polynomials to determine the trends and thus regression lines were fitted accordingly.

Results and Discussion

Height of *S. marianum* (cm): Height of *S. marianum* was significantly (P<0.01) decreased by increasing seed rate of wheat during year 1 (2003-04) and was not affected during year 2 (2004-05). This difference could be attributed to higher rainfall and low temperature during year 2 (Table 1). Increasing *S. marianum* density during year 1 did not affect the plant height itself due to severe intraspecific competition but during year 2, with the increasing *S. marianum* density, its height also increased probably due to competition for light (Table 2). Interaction of the wheat seed rates and *S. marianum* density showed that during year 1, the plant height of *S. marianum* was different at different seed rates and overall trend was quadratic with increasing *S. marianum* density but during year 2, the plant height was independent of seed rate and linearly increased with the increase in *S. marianum* density (Fig. 1a&b).

S. marianum is inherently taller than wheat if sown alone but in our experiments it was noted that plant height of wheat and *S. marianum* were approximately the same during year 1. While in year 2, the *S. marianum* was much taller than wheat and thus all the yield components of wheat were greatly affected. Similarly the seed rate greatly decreased the plant height of wheat during year 1 (data not given) but was not affected in year 2. These contrasting results could be attributed to the fact that higher rainfall and low temperature in year 2 favoured the growth of *S. marianum* and thus attained more plant height. Thus we can speculate that decreasing the irrigation intervals or excessive rainfall can make the *S. marianum* more competitive against wheat. Plant height of *S. marianum* during favourbale environmental conditions increased with increasing its density, irrespective of the seed rate for the obvious reason of intraspecific competition. Tessema & Tanner (1997) added that plant height appear to be the factors most closely associated with weed competitive ability with wheat.

Table 2. Means of seed rates and *S. marianum* densities during 2003-04 and 2004-05.

	Plant height (cm)		**Leaf area (cm^2) $plant^{-1}$**		**Fresh biomass ($t\ ha^{-1}$)**		**Seed production $plant^{-1}$**	
	2003-04	**2004-05**	**2003-04**	**2004-05**	**2003-04**	**2004-05**	**2003-04**	**2004-05**
Seed rate ($Kg\ ha^{-1}$)								
100	85.29 A	97.96	227.4 A	262.6 A	4.79 A	4.92 AB	245.1 A	247.9 A
120	77.43 B	97.75	205.5 B	258.8 A	4.41 AB	5.20 A	174.1 B	263.6 A
140	73.18 B	98.71	198.4 B	240.8 A	3.91 BC	5.22 A	91.61 C	185.1 B
160	64.93 C	98.18	151.4 C	189.5 B	3.40 C	4.38 B	24.79 D	146.1 B
LSD Values	6.06	NS	16.62	22.17	0.624	0.61	36.3	55.11
S.marianum Density m^{-2}								
0	0.00 B	0.00 D	0.00 D	0.00 E	0.00 B	0.00 E	0.00 C	0.00 E
3	86.81 A	110.2 C	242.0 A	301.3 A	4.59 A	5.12 D	174.7 A	281.9 A
6	85.69 A	109.0 C	242.1 A	289.9 AB	4.72 A	5.68 BC	175.8 A	270.8 AB
9	87.44 A	110.5 C	234.8 AB	279.0 BC	4.55 A	5.50 CD	168.7 A	261.1 ABC
12	86.38 A	116.5 B	224.1 BC	270.8 CD	4.82 A	5.98 AB	155.4 AB	236.3 BCD
15	89.44 A	120.1 AB	214.4 C	263.4 CD	5.10 A	6.20 A	136.4 B	221.7 CD
18	90.69 A	120.8 A	212.2 C	261.2 D	5.11 A	6.04 AB	126.3 B	203.1 D
LSD values	5.52	3.78	14.40	17.37	0.685	0.4616	29.19	40.73
Interaction SR x WD	*	NS	**	**	*	NS	**	*

Values followed by different letters are significantly different at p≤ 0.01 level according to LSD test.
SR = Seed rate, WD = Weed (*S. marianum*) density, NS = Non significant,
* = Significant at p≤ 0.05, ** = Significant at p≤ 0.001

Leaf area of *S. marianum* (cm^2): In both the years (2003-04 and 2004-05), the leaf area of *S. marianum* plant^{-1} decreased with increasing the density of either species due to inter and intraspecific competition (Table 2). Medium seed rates (120 and 140 kg ha^{-1}) gave statistically similar value of leaf area during year 1 while during year 2, all seed rates gave statistically similar value of leaf area except the highest seed rate (160 kg ha^{-1}), where lowest values of leaf area plant^{-1} was recorded. During year 1, the increasing *S. marianum* density upto 9 plants m^{-2} had no effect on leaf area but increasing *S. marianum* density beyond 9 plants m^{-2} decreased the leaf area significantly. Similarly during year 2, leaf area plant^{-1} decreased with increasing *S. marianum* density. In both the years, leaf area plant^{-1} of *S. marianum* was decreased linearly in all seed rates of wheat except the highest seed rate (160 kg ha^{-1}) where the response of leaf area to *S. marianum* density was quadratic (Fig. 2a&b). With the increasing wheat seed rate, the leaf area of *S. marianum* decreased in interspecific competition. But at high seed rate of wheat the intraspecific competition among wheat plants increased and as a result *S. marianum* got advantage of it.

As the wheat seed rate increased, the *S. marianum* leaf area plant^{-1} decreased significantly. Similarly increasing *S. marianum* density also decreased its leaf area due to intra-specific competition. However, it was noted that the older leaves of *S. marianum* dried soon when its canopy shaded them. Maximum leaf area per plant^{-1} was recorded in lowest seed rate (100 kg ha^{-1}) and minimum in highest seed rate (160 kg ha^{-1}). The data showed that greater leaf area plant^{-1} was noted in year 2 as compared to year 1 (Table 3). This difference in leaf area was due to higher rainfall and low temperature during year 2 (316 mm and 21 ^{0}C) as compared to year 1 (140mm and 24^{o}C). Thus *S. marianum* with greater leaf area and plant height can be considered as more competitive with the crop plants because higher vegetative growth of a weed in a crop is inversely proportional to yield. Empirical models of crop yield loss were derived based on relative green area to different growing seasons (Storkey 2004). Damage to crop can be calculated based on the weed density or relative leaf area of the weed (Knezevic *et al.,* (1995). Few plants in the same treatment obtained surprising growth and thus they out competed the rest of the plants in the same treatment. This behaviour of the plants could be described by the statement of Wettberg & Weiner (2004) that many plants can change their locations through plastic growth, determined by the climate. These studies are supportive of the results reported here.

Fresh biomass of *S. marianum* (t ha^{-1}): Fresh biomass of *S. marianum* decreased ($P<0.01$) with increasing seed rate during year 1 while during year 2 the seed rate at 100, 120 and 140 kg ha^{-1} gave statistically similar values and significantly decreased at highest seed rate (160 kg ha^{-1}). With the increase in *S. marianum* density there was no significant effect of density on fresh biomass during year 1 and significantly increased with the increase in *S. marianum* density during year 2 (Table 2). However, this increase in fresh biomass was upto 12 *S. marianum* plants m^{-2} and beyond this density there was no significant increase due to intraspecific competition. Regression analysis showed that increasing seed rate of wheat suppressed the growth of *S. marianum* in both the years. However there was linear increase in fresh biomass of *S. marianum* at lowest seed rate during year 1 and at seed rate of 100 and 140 kg ha^{-1} during year 2 (Fig. 3a&b). In all other seed rates, the response of fresh biomass was quadratic due to impact of intraspecific competition.

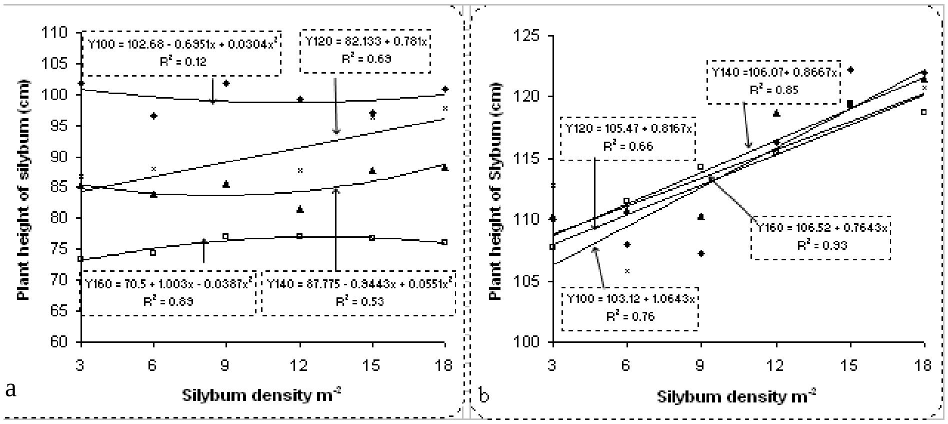

Fig. 1. Plant height of *S. marianum* at various seed rates (◆ =100, × = 120, ▲=140, □ = 160 kg ha^{-1}) during a) 2003-04 and b) 2004-05.

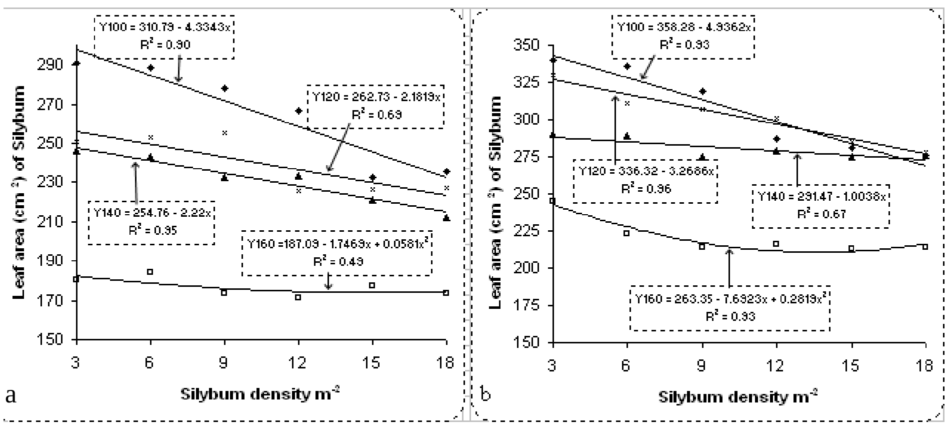

Fig. 2. Leaf area plant-1 of *S. marianum* at various seed rates (◆=100, × = 120, ▲=140, □=160 kg ha^{-1}) during a) 2003-04 and b) 2004-05.

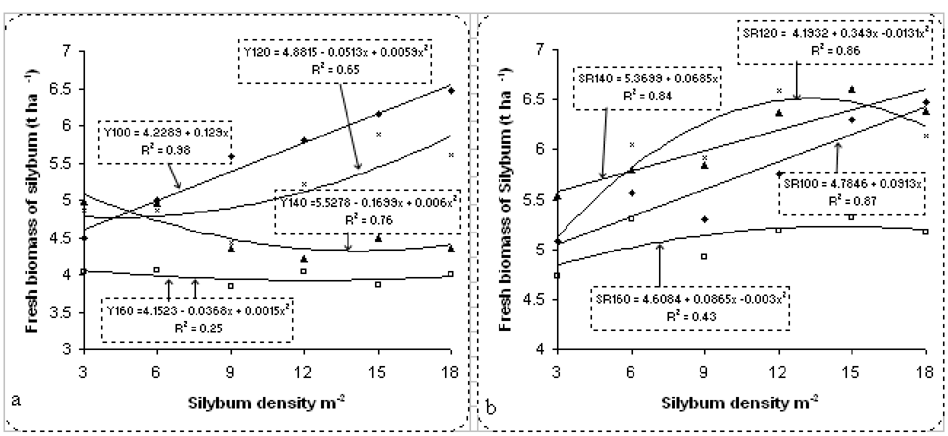

Fig. 3. Fresh biomass of *S. marianum* at various seed rates (◆ =100, × = 120, ▲=140, □ = 160 kg ha^{-1}) during a) 2003-04 and b) 2004-05.

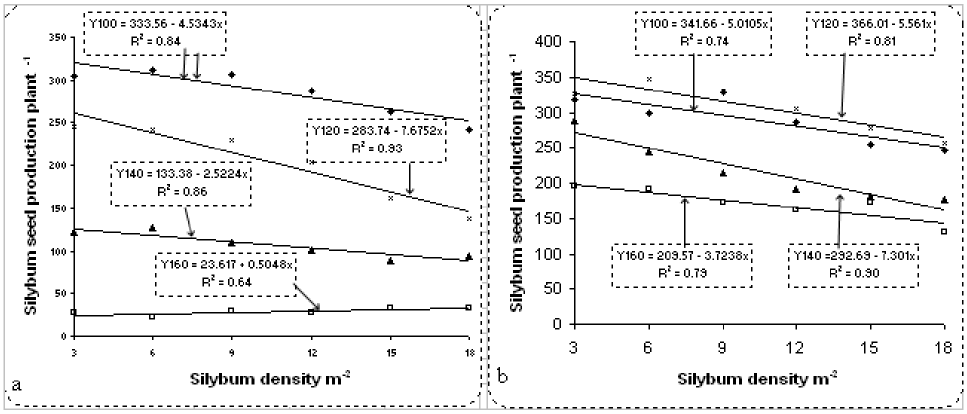

Fig. 4. Seed production of *S. marianum* at various seed rates (◆ =100, × = 120, ▲=140, □ = 160 kg ha^{-1}) during a) 2003-04 and b) 2004-05.

Green area of a species can be used as an indicator of its competitiveness. Our results showed that in year 1 with the increasing seed rate of wheat, *S. marianum* was suppressed and ultimately decreased its fresh biomass whereas in year 2 this suppressing ability of wheat was noted only at highest seeding rate. Similar trend of decrease in dry weight was observed with increasing seed rate (Gaffer *et al*., (1997). Thus the higher rainfall and low temperature (Table 1) enabled *S. marianum* to escape suppression by wheat and obtained more vegetative growth and hence greater fresh biomass. In the season with high rainfall *Galium aparine* was not suppressed by wheat (Seavers & Wright, 1999). Similarly in year 1, *S. marianum* density had no significant effect on fresh biomass but in year 2, the fresh biomass increased with increasing *S. marianum* density and maximum biomass was noted at density of 12 m^{-2}. In year 1, the low density accumulated more biomass plant^{-1} and thus compensated the biomass. While in year 2 the environmental conditions were favourable and thus plenty of moisture did not restrict the growth *S. marianum*. Hence it is concluded from the results that in year 1 there was potential in *S. marianum* to achieve more growth but their growth was restricted by intraspecific competition. According to Stoimenova *et al.,* (1994) during years in favourable climatic conditions for crop, the competitive ability of soybeans increased and *Echinochloa crus-galli* accumulated less biomass and the main factors influencing the competitive relations were quantity of accumulated fresh and dry biomass of the weed and temperature. Trend lines depict that at lowest seed rate, the fresh biomass increased linearly and in quadratic fashion in all other seed rates in year 1. In year 2, fresh biomass increased linearly at seed rate of 100 and 140 kg ha^{-1} and quadratically at other seed rates. However, in both years, at highest seed rate the fresh biomass was not significantly increased with the increasing density of *S. marianum*. These results are similar to the reports of Wilson *et al.,* (1995) who indicated the suppressing ability of wheat at highest seed rate and reported that weed biomass declined, and its maximum level reached earlier, with increasing crop density. Khan & Marwat (2006) reported that tillers in wheat were differently affected across the years.

Seed production of *S. marianum* plant^{-1}: Seed production of *S. marianum* plant^{-1} was significantly ($p<0.01$) decreased with the increase in seed rate of wheat (Table 2). During year 1 (2003-04) the seed rate of wheat significantly decreased the *S. marianum* seed production. However, lower seed rate (100 and 120 kg ha^{-1}) and higher seed rates (140 and 160 kg ha^{-1}) were statistically at par with each other during year 2 (2004-05). Similarly during year 1, the seed production $plant^{-1}$ was at par either at *S. marianum* density ranging from 3-12 plants m^{-2} while increasing density beyond this, significantly decreased seed production $plant^{-1}$. While during year 2, the seed production continued to decrease up to *S. marianum* density of 18 m^{-2}. Trend lines show that the effect of seed rates and *S. marianum* density on the seed production $plant^{-1}$ of *S. marianum* was in line in both the years i.e. with the increase in *S. marianum* density, the seed production $plant^{-1}$ decreased linearly (Fig. 4a&b) at all seed rates. The regression coefficient (R^2) value ranged from 64-93 % during year 1 and 74-90% during year 2.

Increasing seed rates significantly ($p \leq 0.01$) decreased seeds $plant^{-1}$ during year 1 while during year 2 lower seed rates (100 and 120 kg ha^{-1}) and higher seed rate (140 and 160 kg ha^{-1}) gave statistically similar values for seed $plant^{-1}$. It was noted that seed production $plant^{-1}$ was much greater during year 2 as compared to year 1. This increase may be attributed to the higher rainfall and low temperature in year 2 (Table 1). These results show that seed rate of wheat can contribute significantly in decreasing the weed seeds and hence poor seed bank. Wilson *et al.,* (1995) also reported that weed seed production was related to weed biomass; the progressive lowering of crop density increased seed production. Similarly, Singh *et al*., (2000) reported that high seed rate recorded the lowest weed dry weight. In another study dry weight and seed production of *Chenopodium album* were suppressed by increasing planting density or by the presence of crop (Grundy *et al*., 2004). However the seed rate alone can not prevent the weeds from seed production and other factors like rainfall, temperature and other favourable envoronmental conditions that favour a particular weed should also be considered. Because of differences in environmental conditions, velvetleaf achieved maximum height later in 1998 than in 1997 however, velvetleaf seed production was higher in 1998 than in 1997 regardless of velvetleaf density.

Thus *S. marianum* being taller than other weeds can be considered as harmful weed as it can shade the crop plants and other pasture species and become dominant. It would suggest that higher seed rates play an important role in suppressing weeds however this approach will be weather dependent. The present studies suggests that lowering the seed production of weeds is the best long term management of *S. marianum*. Due to prolific seed production, this weed can become a hindrance in the way of higher yields of wheat. Therefore this weed needs to be studied in a range of environmental conditions.

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