



Influence of redroot pigweed (*Amaranthus retroflexus* L.) emergence time and density on yield and quality of two sugar beet cultivars

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Abstract

In order to determine the effects of emergence time and plant density of redroot pigweed (*Amaranthus retroflexus* L.) on yield and quality of two sugar beet cultivars with morphologically different growth habit (Rasoul with prostrate growth habit and BR1 with erect growth habit) field experiments were conducted in 2004 and repeated in 2005. Redroot pigweed was established at densities of 4, 8 and 12 plants per metre of sugar beet row at 0, 15, 30 and 45 days after sugar beet emergence. A weed-free control treatment was also included in the experiment. Emergence of redroot pigweed from zero to 30 days after sugar beet emergence time reduced sugar beet root, gross sugar and white sugar yield even at low density of 4 plants per metre of row. Redroot pigweed emerging 45 days after sugar beet emergence had no significant effect on sugar beet root and gross sugar and white sugar yield at all densities. The sugar beet harvest index (HI) decreased when redroot pigweed emergence time was synchronous with or 15 days after sugar beet emergence. Sugar and white sugar, potassium and sodium contents and alkalinity were not affected by weed emergence time and density. Root, gross sugar and white sugar yield of Rasoul cultivar were greater than those of BR1 when subjected to late emerging redroot pigweed competition (30 and 45 days after sugar beet emergence) and were not significantly different from the weed-free control. The results suggest that using sugar beet varieties with prostrate growth habit could reduce the redroot pigweed control costs.

Key words: Competition, emergence time, root and sugar yield, weed density.

Introduction

Weed competition is one of the major factors which limit sugar beet production in the world³. Competition between sugar beet and annual weeds can be responsible for sugar yield reductions of 25-100%¹⁸. Approximately 70% of weeds species in sugar beet fields are mainly broadleaf annuals such as redroot pigweed (*Amaranthus retroflexus* L.)^{21,24}. Redroot pigweed is one of the prevalence weeds in sugar beet, corn, sorghum, soybean and cotton plantings which spend most of their growth period in the summer^{2, 5, 11}. Weeds such as redroot pigweed and fat-hen (*Chenopodium album* L.) that become taller than the crop will cause greater yield loss than weeds that do not overtop the canopy⁸. Redroot pigweed has high competitive ability due to its great net carbon exchange, efficient use of CO₂, high photosynthetic rate and rapid increase in leaf area¹⁷.

The emergence time of weed can affect biomass and yield of crops¹⁴. Assessment of competition between snap bean (*Phaseolus vulgaris* L.) and redroot pigweed showed that the synchrony between weed and crop emergence time causes higher reduction in bean biomass and yield than late emerging redroot pigweed⁵. Abdollahian-Noghabi and Froud-Williams⁴ found that the three weeks later emergence of fat-hen and redroot pigweed in comparison to sugar beet have not any significant effect on total sugar production, sugar concentration and root impurities. Increase in weed density relative to crop density is one of the

factors causing competition for obtaining water, nutrients and light^{18, 19}. Abbassian *et al.*¹ reported that the redroot pigweed densities of 8, 10 and 12 plants per metre in soybean field decreased soybean yield 25, 31 and 38%, respectively, and therefore, it is a highly competitive weed, which causes economical losses even in low densities. An experiment for evaluating interference between sugar beet and *Suaeda glauca* indicated that increase in weed density decreased sugar beet biomass and root and sugar yield but did not have any significant effect on sugar concentration¹⁰.

Crop height and growth habit could be considered as valuable traits for breeding new varieties of sugar beet for weed suppression^{4, 18}. Lotz *et al.*¹⁶ showed that sugar beet varieties with prostrate growth habit have more horizontally leaves can stop growth of fat-hen better than erect varieties. On the other hand, Abdollahian-Noghabi and Froud-Williams³ stated that the annual broadleaf weeds such as fat-hen and redroot pigweed have an upright growth habit and may grow above the crop canopy and shade on the crop, and then cultivars with more upright growth habit would be less affected by tall growing weeds.

The objectives of this study were to determine the effects of redroot pigweed emergence time and density on yield and quality of two sugar beet cultivars (Rasoul and BR1) with morphologically different growth habit.

Materials and Methods

In order to determine the effects of emergence time and plant density of redroot pigweed (*Amaranthus retroflexus* L.) on yield and quality of two sugar beet cultivars with morphologically different growth habit (Rasoul with prostrate growth habit and BR1 with erect growth habit) a factorial experiment with three factors based on randomized complete block design with three replications was conducted in Mokrian Agricultural Extension Center near Mahabad, Western Azerbaijan, Iran, during 2004 and repeated in 2005. Factors included four redroot pigweed emergence times (0, 15, 30 and 45 days after sugar beet emergence), three weed densities (4, 8 and 12 plants per metre of row) and two sugar beet cultivars with contrasting growth habit (Rasoul with prostrate growth habit and BR1 with erect growth habit). Weed-free control treatment was also used in the experiment. Some climate data for 2004 and 2005 and long-term average for 1985-2005 are presented in Table 1.

Before sowing, the experimental area was plowed, fertilized with urea 200 kg ha⁻¹ (1/2 before sowing + 1/2 as top dressing) and disked in the spring prior to sowing in both years. Individual plots were 17 m² having 5 rows of 5 m length. Sugar beet seeds were sown on April 19th and 22nd in 2004 and 2005 growing seasons respectively. Plots were irrigated immediately after sowing to assure uniform germination. Later on irrigation intervals were determined on the basis of sugar beet need. Redroot pigweed was hand seeded on four different times in each year in the sugar beet rows at densities of 4, 8 and 12 plants per metre of row. Throughout the growing season, all plots were hand weeded to remove weeds other than redroot pigweed. Sugar beets in each plot were harvested from middle rows on 1st and 4th November in 2004 and 2005 respectively. After measuring the sugar beet root yield, a 30 kg sample from each plot was obtained randomly for washing and pulping. About 150 g of pulp from each plot was prepared by Venema apparatus and kept in a freezer until analysis. Frozen sugar beet pulp samples were analyzed in sugar technology laboratory in Sugar Beet Seed Preparing and Breeding Center at Karaj of Iran for purity parameters with Betalyser. Betalyser is a computer-controlled system for automated routine analysis of sugar beet on sugar content and impurities: sodium, potassium and amino-nitrogen. Sugar content (SC) was measured by polarimetry, Na and K by flame-emission photometry and amino-N by double beam filter photometry using the blue number method²². The

combined effect of Na, K and amino-N on the amount of sugar lost to molasses in the factory process was determined by the Reinfeld *et al.*²⁰ method. Molasses sugar (MS) = 0.343 * (K + Na) + 0.094 * amino-N - 0.31, where K, Na and amino-N in meq (100 g⁻¹ beet).

White sugar content (recovered sugar content) was calculated using the Reinfeld *et al.*²⁰ formula: WSC = SC - MS - SFL, where standard factory loss (SFL) = 0.6. White sugar yield (WSY) = root yield (RY) * WSC.

Molasses sugar and standard factory loss are evaluated together. The formula can be combining: WSC (%) = SC (%) - [0.343 (Na + K) + 0.094 a-amino N + 0.29]. An alkalinity coefficient (AC) was determined from the major non-sugars K, Na and amino-N, as follows²²: AC = (K + Na)/amino-N.

Gross sugar yield and white sugar yield were obtained by multiplying sugar content (SC) and white sugar content (WSC) by root yield. Furthermore, characters such as above ground biomass, harvest index and root impurities were determined for each plot in each year.

The data were subjected to the combined analysis of variance over years and the chi-square test was used to verify homogeneity of variance before combining data. LSD test was used for means separation by using the MSTATC statistical software⁶. Graphs were drawn by EXCEL 2003 software⁷.

Results and Discussion

Analysis of variance: Combined analysis of variance over years showed that redroot pigweed emergence time, redroot pigweed density and their interaction effect were statistically significant for above ground biomass, root, gross sugar and white sugar yield. Time of emergence of redroot pigweed had significant effect on harvest index and root nitrogen content. Interaction of redroot pigweed emergence time and sugar beet cultivar was significant for above ground biomass, root, gross sugar and white sugar yield. Effect of year was only significant on root yield and sodium content. None of the interactions between the experimental factors and year were statistically significant for studied variables (Table 2). Therefore, average of data from two years was used for interpretation. The sugar beet above ground biomass varied with redroot pigweed emergence time and density (Table 2). Also combined analysis of variance over years with control was shown in Table 3.

Table 1. Some meteorological data for the growing seasons of 2004 and 2005 in Mahabad, Iran.

Month	Rainfall (mm)			Average temperature (°C)		
	2004	2005	long term average ^a	2004	2005	long term average ^a
April	17	13	54	9.5	10.8	9.9
May	137	96	49	13.7	16.2	15.7
June	8	4	3	18.9	19.1	23.2
July	12	2	2	23.6	24.9	23.2
August	0	0	1	25.3	26.6	23.0
September	0	0	1	22.5	23.0	21.7
October	17	16	27	18.7	19.3	16.2
November	85	20	48	10.7	9.7	8.2

^aLong-term average from 1985 to 2005

Biomass and root yield: Sugar beet above ground biomass varied from 28.67 t ha⁻¹ for weed-free sugar beet (control) to 18.22 t ha⁻¹ for synchronous emergence time at the density of 12 plants per metre of row. The difference between control and weed emergence time at 45 days after sugar beet emergence was not significant in all densities for above ground biomass (Fig. 1). The main reason for decreasing biomass due to the increase of weed interference period and density is attributed to the intense competition between crop and weed because of limited resources such as water, light and nutrients¹³.

Fayed *et al.*⁹ also reported that sugar beet biomass decreases due to weed competition. Fig. 2 shows the interaction of redroot pigweed

Table 2. Combined analysis of variance over years (2004 and 2005) for two sugar beet cultivars yield and quality characters at four emergence times and three densities of redroot pigweed.

Source of variation	DF	Mean squares											
		Above ground biomass	Root yield	Harvest index	Gross sugar yield	White sugar yield	Sugar content	White sugar content	Potassium	Sodium	Amino-Nitrogen	Alkalinity	Sugar content of molasses
Year	1	66.47	556.03*	7.97	3.80	0.05	18.69	31.23	4.73	5.62*	2.48	13.09	1.60
R/Year	4	32.71	67.17	4.36	5.56	5.64	10.59	13.34	7.14	0.39	1.48	2.83	0.87
Emergence time or redroot pigweed (E)	3	345.16**	2368.84**	17.69**	9.04**	8.09**	1.50	3.53	1.02	0.35	1.88**	0.17	0.30
E*Y	3	6.17	3.10	0.66	1.72	1.03	0.05	0.31	1.16	0.19	0.46	1.40	0.13
Density of redroot pigweed (D)	2	64.40**	238.10**	10.49	9.04**	8.09**	1.50	3.53	1.02	0.35	0.57	0.17	0.30
D*Y	2	6.98	29.39	0.76	1.25	1.06	0.04	0.19	0.38	0.05	0.36	1.00	0.07
E*D	6	14.44*	60.01**	0.43	2.24*	1.89*	0.98	1.21	0.41	0.12	0.07	0.86	0.08
E*D*Y	6	1.85	4.37	1.38	0.24	0.25	0.08	0.14	0.54	0.04	0.23	1.73	0.06
Cultivar of sugar beet (C)	1	8.36	28.55	0.004	0.2	0.007	1.78	3.22	2.21	0.13	0.09	0.01	0.18
C*Y	1	3.34	14.36	0.0001	0.94	1.18	0.26	0.71	0.02	0.07	0.04	1.16	0.11
E*C	3	64.74**	188.88**	2.56	4.99**	3.52**	1.65	2.09	0.29	0.06	0.01	0.23	0.05
E*C*Y	3	0.92	4.59	0.39	0.18	0.07	0.05	0.11	0.22	0.01	0.14	1.19	0.06
D*C	2	4.49	42.85	3.00	1.81	1.59	0.4	0.78	0.38	0.01	0.11	1.24	0.06
D*C*Y	2	10.34	22.48	0.66	0.63	0.48	0.04	0.02	0.33	0.05	0.01	0.14	0.1
E*D*C	6	0.94	0.94	0.13	0.56	0.65	1.6	2.09	0.05	0.03	0.06	0.96	0.05
ED*C*Y	6	0.58	1.26	0.19	0.11	0.11	0.11	0.17	0.07	0.09	0.34	2.49	0.06
Error	92	5.41	18.54	1.38	0.92	0.81	1.22	1.40	0.61	0.14	0.23	1.35	0.11
CV (%)		9.37	8.15	1.71	9.94	11.44	5.94	7.70	11.26	19.75	25.13	23.33	10.65

* and ** significant at 1% and 5% probability levels, respectively

Table 3. Combined analysis of variance over years with control for two sugar beet cultivars yield and quality characters at four emergence times and three densities of redroot pigweed.

Source of variation	DF	Mean squares											
		Above ground biomass	Root yield	Harvest index	Gross sugar yield	White sugar yield	Sugar content	White sugar content	Potassium	Sodium	Amino-nitrogen	Alkalinity	Sugar content of molasses
Year (T)	1	61.37	474.03*	7.01	3.37	0.08	16.83	28.49	4.42	5.40*	3.07	12.89	1.43
R/Year	4	31.25	63.15	4.12	5.18	4.83	10.79	13.32	6.73	0.37	1.47	3.09	0.80
Treatment (T)	25	65.72**	368.49**	8.48**	5.44**	4.59**	1.38	2.07	0.84	0.17	0.68**	1.92	0.15
Control vs others	1	105.65**	811.96**	37.51**	47.17**	62.63**	1.39	2.47	0.60	0.34	4.23**	1.66	0.11
T*Y	25	4.45	11.83	0.67	0.74	0.56	0.09	0.18	0.54	0.05	0.22	1.47	0.08
Error	100	5.48	18.07	1.26	0.88	0.74	1.15	1.33	0.59	0.13	0.23	1.32	0.11
CV (%)		8.22	9.01	1.80	9.72	11.15	5.95	7.74	10.89	19.65	24.68	23.33	10.26

* And ** significant at 1% and 5% probability levels, respectively

emergence time with its density. Root yield varied from 61.78 t ha⁻¹ for the control to 36.36 t ha⁻¹ for synchronous emergence time of redroot pigweed at the density of 12 plants per metre of row. Sugar beet root yield in redroot pigweed emergence time of 45 days after the crop emergence had no significant difference with the control in all densities. As a general rule, sugar beet is a poor competitor with weed from emergence until the sugar beet leaves shade the ground, so weeds can compete easily in the early stages of growth⁸. Weeds that emerge with or just before the crop, cause greater yield losses than weeds of the same species emerging later²³. Abdollahian-Noghabi and Froud-Williams³ have reported that late establishment of weed caused little reduction in sugar beet yield even at high weed densities but when weeds emerged synchronously with the crop, then root yield was reduced by 26-65%, depending on the weed density. 'Rasoul' produced more above ground biomass and root yield than 'BR1' when subjected to late emergence time of redroot pigweed (30 and 45 days after sugar beet emergence). However, yield performance of 'BR1' in early emergence time of redroot pigweed was better than that of 'Rasoul'. The above ground biomass and root yield of 'Rasoul' in redroot pigweed emergence times of 30 and 45 days after crop emergence had no significant difference with control (Figs 3 and 4). Longden¹⁵ and Lotz *et al.*¹⁶ observed that sugar beet varieties having prostrate growth habit suppress better the late emerging weeds through shading. If the emergence time of annual broad-leaf weeds, such as fat-hen, are close to sugar beet emergence time, these weeds, because of erect growth habit, may reach above the crop canopy and shade the crop. Thus cultivars with erect growth habit will be less affected by tall growing weeds³. The effect of year was significant on the sugar beet root yield (Table 2). Root yield in 2005 was greater than 2004 (data not shown).

Sugar content and yield: Sugar yield and white gross sugar yield varied from 11.08 and 9.21 t/ha for weed free condition (control) to 6.55 and 5.06 t ha⁻¹ for synchronous emergence time and density of 12 plants per metre of row, respectively (Figs 5 and 6). Decreasing of gross sugar yield and white sugar yield due to weed competition was the result of effects on the sugar beet root yield (Fig. 2), because sugar content and white sugar content were not affected by redroot pigweed emergence time and density (Table 2). Redroot pigweeds that emerged 45 days after sugar beet emergence, had no significant effect on gross sugar yield and white sugar yield at all densities (Figs 5 and 6). In an experiment, at equivalent densities of redroot pigweed and sugar beet, when emergence times of both species were similar, 66% of light was intercepted by the weed growing above the sugar beet canopy and caused a 64% reduction in gross sugar yield². Sugar yield and white sugar yield of Rasoul cultivar in weed emergence times of 30 and 45 days after sugar beet emergence were higher than in BR1 and not significantly different from the control (Figs 7 and 8). However, in early emergence time of redroot pigweed no significant difference was observed between the cultivars, although the gross sugar yield and white sugar yield of 'BR1' were greater than those of 'Rasoul'.

Harvest index: When weed emerged at the time of crop emergence and also 15 days after it, reduction of harvest index was significant compared to the control (Fig. 9). Crops usually allocate larger portion of their assimilates to leaves to increase their growth and receive more light in order to dominate the weeds¹².

Quality: Early emergence times of redroot pigweed decreased root amino-nitrogen content whereas the emergence time of 45 days after sugar beet emergence was not significantly different from the control (Fig. 10). Fayed *et al.*⁹ also reported the decrease of root impurities concentration due to weed competition. Redroot pigweed is a nitrophilous plant with a strong positive growth response to the soil nitrogen. Therefore, this weed competes effectively with sugar beet to absorb nitrogen^{9,25}. The effect of year was significant on root sodium content (Table 2). Root sodium content in 2005 was greater than 2004 (data not shown).

Conclusions

Present study demonstrated that redroot pigweed is a highly competitive weed which decreases sugar beet root yield and gross sugar and white sugar yield in low densities, if emerges earlier than 30 days after sugar beet emergence. Therefore, in order to prevent yield loss it is recommended to control redroot pigweed before 45 days after sugar beet emergence time, because emerged redroot pigweed in this time has no significant effect on sugar beet yield. Also yield performance of cultivars with the prostrate growth habit, such as Rasoul, is better than the cultivars having erect growth habit, such as BR1, when redroot pigweed emerges later in the growing season (30 days after sugar beet emergence time). Thus in order to suppress late emerging weeds and reduce the herbicide input, the prostrate growth habit may be considered as a criterion in breeding new varieties of sugar beet.

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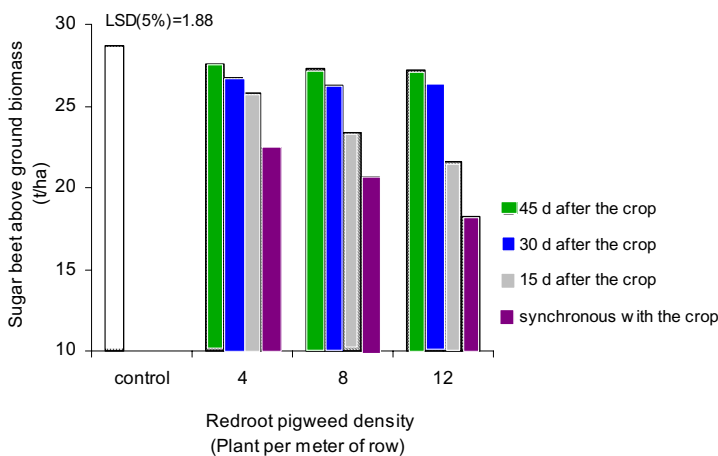


Figure 1. Sugar beet above ground biomass at different densities and emergence times of redroot pigweed. Symbols represent mean values of two years (2004 and 2005).

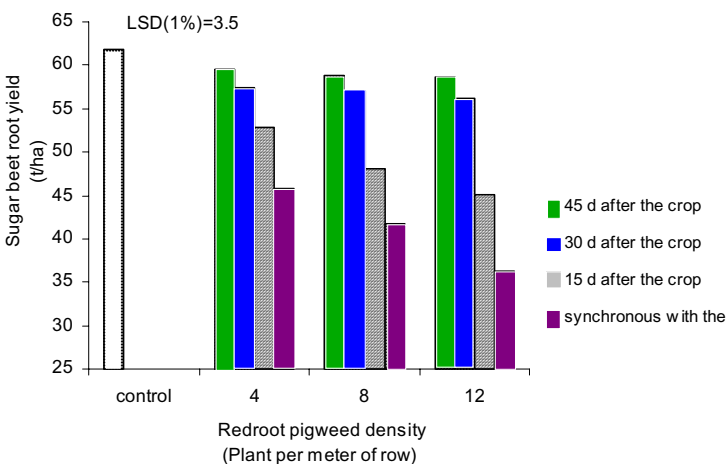


Figure 2. Sugar beet root yield at different densities and emergence times of redroot pigweed. Symbols represent mean values of two years (2004 and 2005).

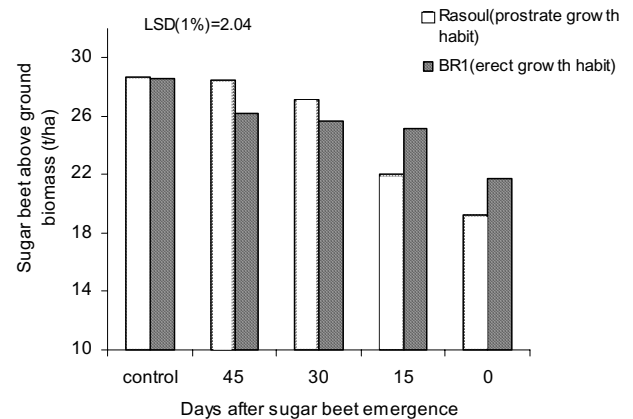


Figure 3. Above ground biomass of two sugar beet cultivars at different emergence times of redroot pigweed and weed-free control (Mean of 2004 and 2005).

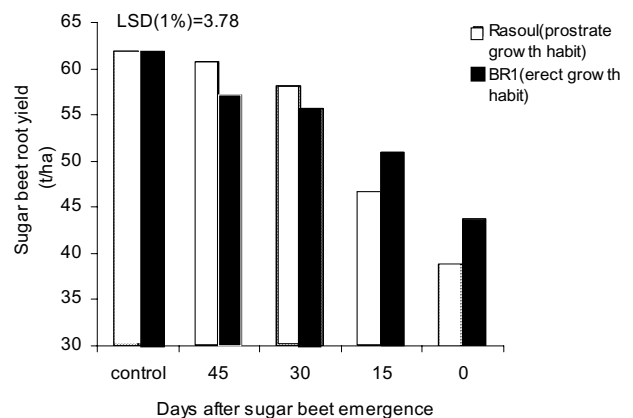


Figure 4. Root yield of two sugar beet cultivars at different emergence times of redroot pigweed and weed-free control (Mean of 2004 and 2005).

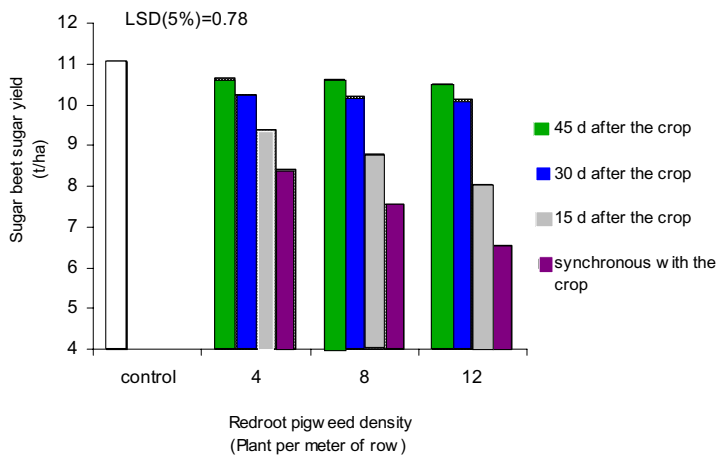


Figure 5. Sugar beet gross sugar yield at different densities and emergence times of redroot pigweed. Symbols represent mean values of two years (2004 and 2005).

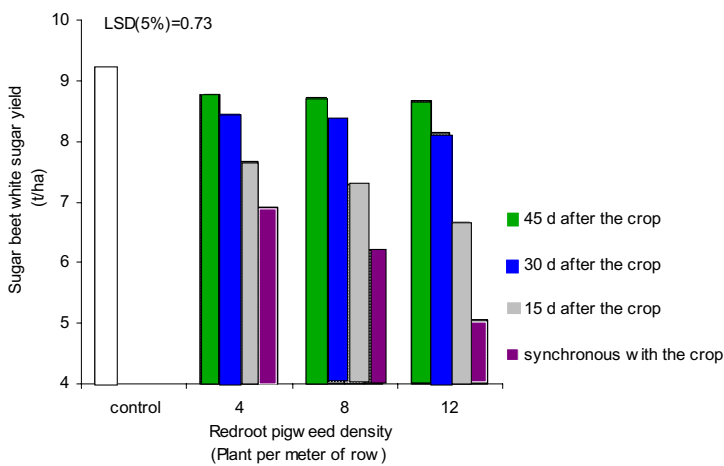


Figure 6. Sugar beet white sugar yield at different densities and emergence times of redroot pigweed. Symbols represent mean values of two years (2004 and 2005).

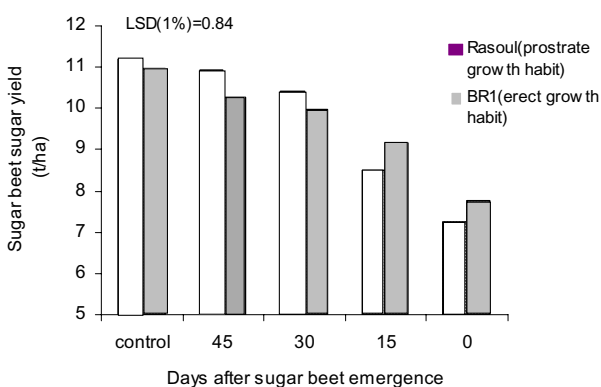


Figure 7. Gross sugar yield of two sugar beet cultivars at different emergence times of redroot pigweed and weed-free control (Mean of 2004 and 2005).

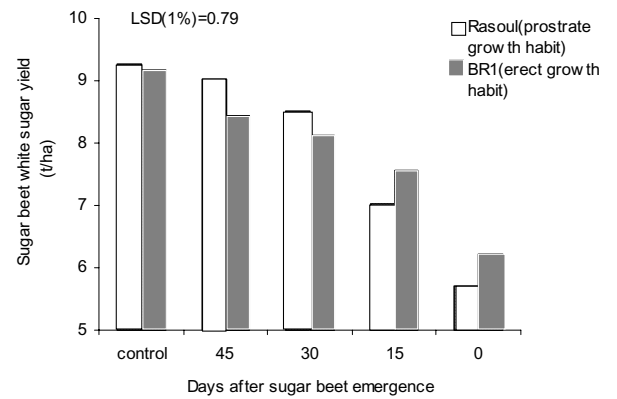


Figure 8. White sugar yield of two sugar beet cultivars at different emergence times of redroot pigweed and weed-free control (Mean of 2004 and 2005).

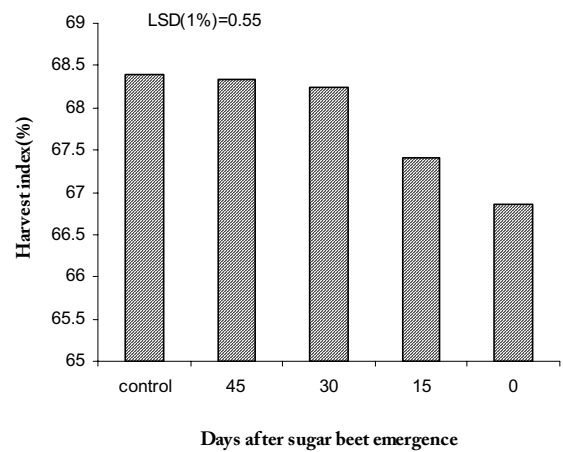


Figure 9. Effect of redroot pigweed emergence time on sugar beet harvest index (Mean of 2004 and 2005).

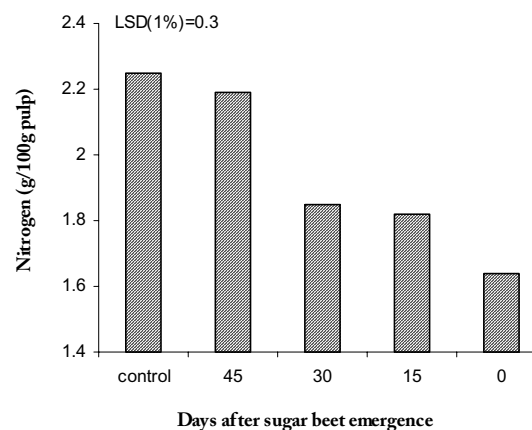


Figure 10. Effect of redroot pigweed emergence time on sugar beet root nitrogen content (Mean of 2004 and 2005).