Above- and Below-ground Competition between *Chenopodium album* and Sugar Beet

M. Abdollahian[1], R. J. Froud-Williams[2]

[1]Sugar Beet Seed Institute, Mardabad Road, Karaj, P O Box 4114, Iran; [2]Department of Agricultural Botany, School of Plant Sciences, The University of Reading, 2 Early Gate, Reading RG6 6AU, UK

(Received 1 November 2004; returned 15 January 2005; accepted 28 February 2005)

The effects of above and below-ground competition between *Chenopodium album* and sugar beet (*Beta Vulgaris*) on growth, yield and quality of two sugar beet cultivars of morphologically contrasting growth habit have been investigated A factorial experiment (2 × 4) under glass-house conditions in a randomised complete block design with three replications was done. *C. album* and two sugar beet cultivars 'Amethyst' and 'Celt', were subjected to one of four competition regimes as follows: two below-ground competition treatments (± root competition); two above-ground competition treatments (± shoot competition). Two seedlings of sugar beet and four of *C. album* were transplanted at cotyledon stage in plastic pots (44 cm diameter and 35 cm deep). Plants were harvested 8 (12 leaf stage) and 16 (22 leaf stage) weeks after transplanting (WAT). At each harvest, leaf chlorophyll content, plant height, leaf area and shoot and root dry matter of sugar beet and *C. album* were

---

Correspondence to: M. Abdollahian-Noghabi, E-mail: Noghabi@yahoo.com

determined. The results demonstrated that there were major differences between growth and yield of the two sugar beet cultivars which were influenced by both above and below-ground competition with *C. album*. No interactions were observed between beet cultivar and the competition regime, but shoot and root competition inter-acted negatively 8 and 16 WAT. Both sugar beet shoot and root yield were reduced by shoot and root competition with *C. album* 8 and 16 WAT. However, beet sugar content was unaffected by weed competition regimes. Root competition with *C. album* caused greater reduction of shoot and root yield of sugar beet than shoot competition 16 WAT. However, there was no significant difference between shoot and root competition 8 WAT. Yield loss of sugar beet subject to shoot and root competition with *C. album* was 47 and 82% respectively. Thus, under these conditions, the effect of *C .album* competition for above-ground resources was less than that for below-ground resources during a period up to 16 WAT.

Key words: Sugar beet, Cultivar, *Chenopodium album*, Interference, Above-ground competition, below-ground competition.

در این تحقیق، تاثیر رقابت اندام هوایی و زمینی علف‌هرز سلمه‌تره روی رشد، عملکرد و کیفیت چغندر قند در شرایط گلخانه‌ای با ۱۶ ساعت روشنایی در شبانه روز و دمای ۵ ±۲۰ درجه سانتی‌گراد، ارزیابی شد. دو رقم چغندر قند شامل آمتیست (Amethyst) و کلت (Celt) از نظر رقابت با سلمه تره تحت چهار رژیم رقابتی یعنی رقابت اندام هوایی (± اندام هوایی) و اندام زمینی (± اندام زمینی) بررسی شدند. برای این منظور، دو گیاهچه چغندقند و چهار گیاهچه سلمه‌تره در مرحله کوتیلدونی در گلدان نشاء شدند. گیاهان در ۸ و۱۶ هفته پس از انتقال نشاء برداشت شدند. در هر برداشت، میزان کلروفیل برگ چغندرقند و ارتفاع گیاه، سطح برگ، توزیع ماده خشک هر دو گیاه چغندرقند و سلمه‌تره اندازه گیری شد. نتایج نشان داد که اندام هوایی و زمینی هر دو رقم چغندر قند از نظر رشد و عملکرد محصول، بطور معنی‌داری تحت تاثیر رقابت سلمه‌تره قرار داشتند. بطوری‌که، رقابت سلمه‌تره با اندام زمینی و هوایی چغندر قند، در ۸ و ۱۶ هفته پس از انتقال نشاء، منجر به کاهش معنی‌دار عملکرد ریشه و اندام هوایی چغندرقند شد. با این حال، درصد قند در رژیم های رقابتی با سلمه‌تره تحت تاثیر قرار نگرفت. رقابت این علف‌هرز با ریشه چغندرقند، در ۱۶ هفته پس از نشا، بیش از رقابت آن با اندام هوایی باعث کاهش عملکرد ریشه و اندام هوایی و عملکرد نسبی چغندر قند شد. در حالیکه بین رقابت اندام هوایی و رقابت اندام زمینی در ۸ هفته پس از انتقال نشاء اثر متقابل معنی داری وجود نداشت. به طور کلی، کاهش عملکرد چغندرقند تحت تاثیر رقابت اندام هوایی و زمینی با علف هرز سلمه‌تره به ترتیب ۴۷٪ و ۸۲٪ بود. بنابراین تحت شرایط این پژوهش، رقابت سلمه‌تره با ارقام چغندر قند در یک دوره ۱۶ هفته ای پس از انتقال نشاها، در دریافت منابع زیر زمینی، در قیاس با منابع روی زمین، از اهمیت بیشتری برخوردار بود.

INTRODUCTION

Competition from annual weeds in sugar beet (*Beta Vulgaris L.*) can result in yield reductions of 25-100% (Schweizer & Dexter, 1987); 95% sugar beet yield loss where tall-growing weeds such as *Chenopodium album* L. are involved (Scott & Wilcockson, 1976). Approximately 70% of weed species occurring in sugar beet crops are broad-leaf species (Schweizer & May, 1993) of which *C. album* is among the top ten major weeds (Holm *et al.,* 1977). In areas of low or irregular rainfall, competition for water may begin earlier in the growing season and may limit crop yield performance more than competition for light (Donald, 1963; Radosevich & Holt, 1984).

In order to understand the mechanism of competition between sugar beet cultivars and weeds, it is important to investigate the nature of weed-crop interactions and to determine for which resources any complementarily occurs. Previously, most published work on competition was on grassland species, with relatively few studies on arable crops and weeds (Wilson, 1988). Clements *et al.* (1929) concluded that competition in plant species was mainly for light, soil nutrients and water. Donald (1963) included oxygen and carbon dioxide in the list, but later considered these factors much less important. Partition techniques for plant competition study were pioneered by Donald (1958) and modified by others (e.g. Aspinall, 1960 and King, 1971). According to Wilson review (1988) root competition between species is usually more severe than shoot competition (Aspinall, 1960; King, 1971; Remison & Snaydon, 1980a,b; Martin & Field, 1984). For example, he reported that, in 19 of the 24 studies reviewed, competition for below-ground resources (water and nutrients) was more intense than competition for above-ground resources (light). However, Pozsgai (1983) found that the ‘competitive balance index’ of sugar beet subject to shoot competition with *C. album* was greater than that of root competition at the early growth stage (0.15 and 0.11, respectively). From a growth habit aspect, in weed-crop competition experiments, it has been reported that cultivars of sugar beet which are of prostrate growth habit and of early canopy closure may be more competitive (Lotz *et al.,* 1991).

In terms of interaction between shoot and root competition, Clements *et al.* (1929) suggested they interact positively, and Donald (1958) concluded this hypothesis to be correct, i.e. the combined effects of shoot and root competition were greater than the sum of their separate effects. However, King (1971) and Martin and Field (1984) found no interaction; and Tofinga *et al.*, (1993) reported a negative interaction between shoot and root competition.

The objectives of this study were to investigate the effects of above and below-ground competition of *C. album* on growth, biomass yield and quality of sugar beet, and to determine whether reduced performance of sugar beet may be attributed to shoot or root competition.

MATERIALS AND METHODS

A glass-house pot experiment was designed to investigate the effect of above and below-ground competition between *C. album* and sugar beet on growth, yield and quality of two sugar beet cultivars of morphologically contrasting growth habit. This was a factorial experiment (2 × 4) in the glass-house (20±5 ^{o}C; 16 h natural and supplementary lighting) in a randomised complete block design (pots were arranged in three blocks based on the amount of the available light) with three replications. *C. album* and two sugar beet cultivars, ‘Amethyst’ (triploid) and ‘Celt’ (diploid), were subjected to one of four competition regimes as follows: two below-ground competition treatments (± root competition); two above-ground competition treatments (± shoot competition).

Two seedlings of sugar beet (for reducing pot to pot variability, Ulrich, 1961) and four of *C. album* were transplanted at the cotyledon stage into plastic pots (44 cm diameter and 35 cm deep) equivalent to approximately 13 beet and 26 *C. album* plants m^{-2}. Each container was filled with approximately 30 litres soil, containing 80% loam and 20% peat-moss (Farahbakhsh & Murphy, 1986) with no fertiliser added. Soil moisture was kept close to field capacity for the whole growing period. Plants were harvested 8 and 16 weeks after transplanting (WAT). At each harvest, beet leaf chlorophyll content, plant height, leaf area and shoot and root dry matter of sugar beet and *C. album* were determined. Leaf area was determined using a leaf area meter[1].

Shoot and root competition between the weed and sugar beet were separated using the technique of Donald (1958) considering the conclusions of Ulrich (1959 and 1961) in which he suggests that, in order to reduce pot to pot variability, the minimum number of plants per pot for sugar beet experiments is two or three plants. Different arrangements of shoot and soil partitions produced four competition regimes: no competition between species (species isolated both above and below-ground i.e. monoculture), shoot competition only (species separated below-ground), root competition only (species separated above-ground), and full competition (species not separated either above or below-ground). No root competition from the weed was achieved by installing PVC cylinders of 9 cm diameter and 32 cm length into the soil container and growing one plant of *C. album* inside each cylinder. A plastic net was used as an aerial partition. Mesh size of netting was sufficiently small to exclude *C. album* leaves. The height of netting was raised as *C. album* grew.

Plants were harvested 8 (early growing period) and 16 (mature stage) WAT. Before each harvest leaf lamina samples were taken from the fifth sugar beet leaf, using a cork borer, and dipped into liquid nitrogen. The frozen samples were homogenised with a pestle and mortar following addition of 10 ml acetone (80% v/v in water) and then kept in the dark. The homogenate was centrifuged at 3000 RPM for 5 minutes to remove leaf debris. Absorbency of the extract was taken at 647 and 664 nm, using a spectrophotometer[2] to

[1] Delta-T Devices Ltd., Cambridge, UK

[2] SP, 8-400 UV/VIS, Pye Unicam, Ltd., England

determine chlorophyll a, b and total chlorophyll contents, the extinction coefficients of Graan & Ort (1984) were used.

Sugar content of individual beet storage root was measured by a manual refractometer[3] at final harvest only (16 WAT). The effect of competition regimes on total dry matter of sugar beet were calculated as the relative yield (de Wit, 1960), i.e. Yij/Yii, where Yij is the biomass yield per unit area of sugar beet in mixture with *C. album*, and Yii is the biomass yield per unit area of sugar beet in monoculture

RESULTS AND DISCUSSION

In general, there were major differences between growth, development and yield of the two sugar beet cultivars and they were influenced by both above and below-ground competition with *C. album*. However, there were no interactions between cultivar and competition regimes for any of the sugar beet variables, except for leaf chlorophyll content measured 16 weeks after transplanting (WAT).

Growth and Dry Matter Production

Leaf area index (LAI) of cultivar Amethyst was significantly greater than that of Celt at both 8 and 16 WAT ($P<0.001$). Total dry weight (TDW) of Amethyst was also greater than Celt 8 and 16 WAT ($P<0.001$) (Table1). Greater LAI and TDW of Amethyst may be due to ploidy level-Amethyst a triploid cultivar-compared with Celt which is a diploid.

Fraction of total dry matter allocated to the shoot or the root was different for both cultivars 8 and 16 WAT (Table 2). At final harvest, shoot and root dry weight of Celt were 25 and 35% less than that of Amethyst respectively ($P<0.001$).

---

[3] Bellingham & Stanley Ltd., England

Table 1. Main effect of cultivar on leaf area index (LAI) and total dry weight (TDW) of sugar beet 8 and 16 weeks after transplanting (*mean of four competition regimes).

Cultivar	Weeks after transplanting			
	8		16	
	LAI	TDW (g m^{-2})	LAI	TDW(g m^{-2})
*Amethyst	2.40	246.0	2.30	809.0
*Celt	1.50	171.0	1.50	555.0
Mean	2.00	209.0	1.90	682.0
SED (14df)	0.19	22.9	0.17	62.2

Table 2. Main effect of cultivar on shoot and root dry weight (SDW and RDW) of sugar beet 8 and 16 weeks after transplanting (*mean of four competition regimes).

Cultivar	Dry weight (g m^{-2}), after transplanting			
	8 Weeks		16 Weeks	
	SDW	RDW	SDW	RDW
*Amethyst	176.0	70.0	348	461.0
*Celt	121.0	51.0	258	297.0
Mean	149.0	60.0	303	379.0
SED (14df)	16.4	8.6	13	54.4

Sugar beet LAI subjected to weed competition 8 and 16 WAT was reduced ($P<0.001$) compared to no competition treatment (Table 3). Sugar beet LAI was not differentially affected by above and below-ground competition with *C. album* 8 WAT. However, sugar beet LAI subjected to root competition was significantly less than that of shoot competition 16 WAT ($P<0.05$).

Specific leaf weight of sugar beet subjected to below-ground competition was greater ($P<0.05$) than that subjected to above-ground competition, at 8 WAT only (Table 3). However, competition treatments had no effect on SLW of sugar beet 16 WAT. It is a typical response of plants to reduce their SLW under low light (Scott & Wilcockson, 1976).

Table 3. Overall effect of competition regimes on sugar beet leaf area index (LAI) and specific leaf weight (SLW) 8 and 16 weeks after transplanting (*mean of two beet *cvs*).

Competition	Weeks after transplanting			
	8		16	
	LAI	SLW (g m^{-2})	LAI	SLW (g m^{-2})
*None	3.10	0.450	2.80	0.55
*Shoot	1.70	0.370	1.90	0.53
*Root	1.60	0.420	1.40	0.58
*Full	1.50	0.330	1.40	0.58
Mean	2.00	0.390	1.90	0.56
SED (14df)	0.27	0.023	0.24	0.048

Shoot and root dry weight of sugar beet subjected to above or below-ground competition with *C. album* were reduced 8 and 16 WAT ($P<0.001$) compared to no competition treatments (Table 4). The differences between sugar beet shoot dry weight subjected to above and below-ground competition was not significant 8 WAT. However, shoot dry weight of sugar beet subject to root competition 16 WAT was 30% less than that subjected to above-ground competition ($P<0.05$).

Sugar beet root dry weight under shoot competition 8 WAT was 29% less than that subjected to root competition, though the difference was not significant (Table 4). Furthermore, sugar beet root dry weight for below-ground competition treatment 16 WAT was 62% less than that subjected to shoot competition treatment ($P<0.05$). The relative importance of shoot and root competition varied during the growing period and supports work by Aspinall (1960) and Martin & Field (1984). The results of the current experiment demonstrate that the effects of below-ground competition in terms of both sugar beet shoot and root dry weight are greater than above-ground competition 16 WAT.

Sugar beet root yield was reduced ($P<0.001$) by both above and below-ground competition with *C. album* 16 WAT (Table 5). However, sugar content was unaffected by weed competition. Similar studies with weed competition in sugar beet (Farahbakhsh & Murphy, 1986; Froud-Williams, 1992; Houghton, 1996) have shown that although root yield of sugar beet was reduced, the sugar content was unaffected by weed competition.

Yield loss of sugar beet subject to shoot and root competition with *C. album* was 47 and 82% respectively ($P<0.01$) showing that competition for above-ground resources between sugar beet cultivars and *C. album* had less effect than competition for below-ground resources during a period of 16 WAT.

Table 4. Main effect of competition regimes on shoot and root dry weight (SDW and RDW) of sugar beet 8 and 16 weeks after transplanting (*mean of two sugar beet *cvs*).

Competition	Dry weight (g m^{-2}), after transplanting			
	8 Weeks		16 Weeks	
	SDW	RDW	SDW	RDW
*None	275	173	470	866
*Shoot	111	20	318	361
*Root	116	28	224	136
*Full	93	21	200	152
Mean	149	60	303	379
SED (14df)	23.1	12.2	18.4	77.0

Table 5. Overall effect of competition regimes on root yield and sugar content of sugar beet 16 weeks after transplanting (*mean of two beet *cvs*).

Competition	Root yield (g m^{-2})	Sugar content (%)
*None	4213	16.5
*Shoot	2230	14.8
*Root	780	15.8
*Full	953	14.9
Mean	2044	15.5
SED (14df)	392.1	0.74

Leaf Chlorophyll Content

Leaf chlorophyll contents (chlorophyll a, b and total) of sugar beet subjected to weed competition 8 WAT were reduced ($P<0.01$), (Table 6). Values of leaf chlorophyll content 16 WAT failed to show any significant difference for competition regimes. Shoot competition between sugar beet and *C. album* caused a 14% reduction in chlorophyll a, chlorophyll b and total chlorophyll content of sugar beet leaf 8 WAT ($P<0.05$).

Root competition, however, had no effect on leaf chlorophyll content of sugar beet. It is suggested that reduction in chlorophyll content is due to shading by *C. album* which was taller than sugar beet under shoot competition. Farahbakhsh & Murphy (1986) reported a significant reduction in sugar beet leaf chlorophyll content following weed competition for 12 weeks, but chlorophyll content recovered if weeds were removed at six to ten leaf stage of the crop.

The interaction between sugar beet cultivars and competition regimes was significant ($P<0.05$) only for chlorophyll *a* and total chlorophyll content of beet leaf 16 WAT (Table 7). Following below-ground competition between sugar beet with *C. album*, chlorophyll *a* and total chlorophyll content of cultivar Celt was greater than that of Amethyst ($P<0.01$). However, for the other competition regimes there were no significant differences between the leaf chlorophyll contents of the two cultivars.

Table 6. Overall effect of competition regimes on sugar beet leaf chlorophyll content fresh weight (FW) 8 weeks after transplanting (*mean of two beet *cvs*).

Competition	Cholorophyl content (mg g^{-1})		
	Chlorophyll **a**	Chlorophyll **b**	Total Chlorophyll
*None	2.22	0.70	2.92
*Shoot	1.91	0.60	2.50
*Root	2.09	0.65	2.73
*Full	1.81	0.57	2.37
Mean	2.00	0.63	2.63
SED (14df)	0.121	0.037	0.156

Relative Yield

The total dry weight of sugar beet (including root dry weight) in monocultures averaged 447 and 1335 g m^{-2}, 8 and 16 WAT respectively. All levels of competition with *C. album* (shoot only, root only and full competition) reduced the sugar beet relative yield (P<0.001). That is, the relative yields of sugar beet were significantly less than 1.0, at 8 and 16 WAT (Table 8). However, there was no significant sugar beet cultivar × competition regime interaction.

Table 7. The effect of sugar beet cultivar and competition regimes on leaf chlorophyll content, fresh weight (FW), of sugar beet 16 weeks after transplanting.

Competition	Cholorophyl content (mg g^{-1})			
	Chlorophyll **a**		Total Chlorophyll	
	Amethyst	Celt	Amethyst	Celt
None	1.80	1.88	2.37	2.50
Shoot	2.01	1.67	2.63	2.22
Root	1.82	2.42	2.37	3.17
Full	1.95	2.05	2.53	2.68
SED (14df)	0.205		0.273	

During the early growing period (up to 8 WAT), there was no significant difference between relative yield of sugar beet subjected to above and below-ground competition with *C. album* (Table 8). The interaction between shoot competition × root competition was negative and significant (P<0.001). Full competition, above and below-ground, did not reduce relative biomass yield of sugar beet more than shoot or root competition alone (Table 8). This contradicts the hypothesis that shoot and root competition interact positively (Clements *et al.*, 1929).

At final harvest 16 WAT, root competition with *C. album* reduced the relative yield of sugar beet more than shoot competition did (Table 8). Full competition did not reduce the relative yield of sugar beet more than that of root competition alone (Table 8) so that the shoot competition × root competition interaction was negative and significant (P<0.001). Similarly, Tofinga *et al.*, (1993) observed a negative interaction between shoot and root competition for peas and cereals in mixture.

Table 8. Relative yield of sugar beet, as affected by various competition regimes with *Chenopodium album*, 8 and 16 weeks after transplanting. (*mean of two sugar beet *cvs*).

Competition	Weeks after transplanting	
	8	16
*None	1.000	1.000
*Shoot	0.308	0.495
*Root	0.317	0.267

The fact that root competition with *C. album* had a greater effect on relative yield of sugar beet than shoot competition 16 WAT agrees with the conclusions of Wilson (1988) who reported that, in 19 out of 24 studies reviewed, competition for below-ground resources (water and nutrients) was more intense than competition for above-ground resources (light). However, Pozsgai (1983) found that shoot competition with *C. album* had a greater effect on relative yield of sugar beet than root competition at the early stage of growth; as the ‘competitive balance index’ of sugar beet subject to shoot competition with *C. album* was greater than that of root competition at the early stage of growth (0.15 and 0.11 respectively). Although the results for sugar beet total dry weight 8 WAT (131 and 143 g m^{-2} for shoot and root competition respectively) are similar to those observed by Pozsgai (1983) the results obtained here 16 WAT are in contradiction with his results.

REFERENCES

Aspinall, D. 1960. An analysis of competition between barley and white persicaria. *Annals of Applied Biology* **48**, 637-654.

Clements, F.E., Weaver, J.E. & Hauson, H.C. 1929. Plant Competition: An Analysis of Community Functions. Washington DC: Carnegi Institute.

De Wit, C.T. 1960. On competition. *Verslagen van Landbouwkundige Onderzoekingen* **66**, 1-82.

Donald, C.M. 1958. The interaction of competition for light and nutrients. *Australian Journal of Agricultural Research* **9**, 421-435.

Donald, C.M. 1963. Competition among crop and pasture plants. *Advances in Agronomy* **15**, 1-118.

Farahbakhsh, A. & Murphy, K.J. 1986. Comparative studies of weed competition in sugar beet. *Aspects of Applied Biology* **13**, 11-16.

Froud-Williams, R.J. 1992. Weed competition in sugar beet: A practical experiment in applied plant sciences for use in schools**.** *Aspects of Applied Biology* ***32*,**125-128.

Graan, T. & Ort, D.R. 1984. Quantitation of the rapid electron donors to P 700, the functional plastoquinone pool, and the ratio of the photosystems in spinach chloroplast. *Journal of Biological Chemistry* **259**, 14003-14010.

Holm, L.G., Plucknett, D.L., Pancho, J.V. & Herberger, J.P. 1977. The World's Worst Weeds*:* Distribution and Biology. Honolulu: University Press of Hawaii.

Houghton, S.K. 1996. Effect of elevated carbon-dioxide concentration and temperature on the growth and competition between sugar beet (*Beta vulgaris*) and fat-hen (*Chenopodium album*). *Aspects of Applied Biology* **45**, 197-204.

King, J. 1971. Competition between established and newly sown grass species. *Journal of the British Grassland Society* **26**, 221-229.

Lotz, L.A.P., Groeneveld, R.M.W. & de Groot, N.A. M.A. 1991. Potential for reducing herbicide inputs in sugar beet by selecting early closing cultivars. Proceedings of Brighton Crop Protection Conference-Weeds.

Martin, M.P.L.D. & Field, R.J. 1984. The nature of competition between perennial ryegrass and white clover. *Grass and Forage Science* **39**, 247-253.

Pozsgai, J. 1983. Competition between sugar beet and its major weeds. I. Shoot-, root- and full competition. *Novenytermeles* **32**, 29-36.

Radosevich, S.R. & Holt, J.S. 1984. Weed Ecology, Implications for Vegetation Management*.* New York: John Wiley & Sons.

Remison, S.U. & Snaydon, R.W. 1980a. Effects of defoliation and fertilisers on root competition between Dactylis glomerata and Lolium perenne. *Grass and Forage Science* **35**, 81-93.

Remison, S.U. & Snaydon, R.W. 1980b. A comparison of root competition and shoot competition between Dactylis glomerata and Holcus lanatus. *Grass and Forage Science* **35**, 183-187.

Schweizer, E.E. & Dexter, A.G. 1987. Weed control in sugarbeets (*Beta vulgaris*) in north America. In: *Reviews of Weed Science* (L. F. Chester, ed), 113-133. Champaign: Weed Science Society of America.

Schweizer, E.E. & May, M.J. 1993. Weeds and weed control. In: *The Sugar Beet Crop: Science into Practice* (D. A. Cooke & R. K. Scott, eds), 485-519. London Chapman & Hall.

Scott, R.K. & Wilcockson, S.J. 1976. Weed biology and the growth of sugar beet. *Annals of Applied Biology* **83**, 331-335.

Tofinga, M.P., Paolini, R. & Snaydon, R.W. 1993. A study of root and shoot interactions between cereals and peas in mixtures. *Journal of Agricultural Science, Cambridge* **120**, 13-24.

Ulrich, A. 1959. Effect of competition on sugar beet plants in pot experiments. *Journal of the American Society of Sugar Beet Technologists* **10**, 448-458.

Ulrich, A. 1961. Variability of sugar beet plants growing in pots without competition for light, water and nutrients. *Journal of the American Society of Sugar Beet Technologists,* **XI**, 595-604.

Wilson, J.B. 1988. Shoot competition and root competition. *Journal of Applied Ecology* **25**, 279-296.