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An Integrated Approach to Cultivar Evaluation and Selection for Improving Sugar Beet Profitability

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A Successful Case Study for the Central High Plains

The United States is the largest global consumer of sweeteners and one of the largest importers of sugar. The U.S. sweetener market is also the largest and most diverse in the world, including the production of approximately 11 million metric tons of corn sweeteners and 8.5 million metric tons of refined sugar in 2000 (32). This ranks the United States among the top four sugar producers worldwide and makes it one of the few countries with significant production in both sugar beet and sugar cane. Sugar beet was planted on approximately 625,000 ha (1.5 million acres) in 2000, compared with 395,000 ha (0.9 million acres) planted to sugar cane, making sugar beet a major contributor to the U.S. sweetener industry (32).

Sugar beets in the United States are produced in 12 states within four diverse geographic regions. The greatest volume of production occurs in the Upper Midwest and includes Minnesota and North Dakota. This area produced 48% of the crop on 300,000 ha (758,000 acres) in 2000. The second largest production area is the Far West and includes California, Idaho, Oregon, and Washington. This region produced 22% of the crop on 138,000 ha (354,000 acres). The Great Plains region, consisting of Colorado, Montana, Nebraska, and Wyoming, produced 18% of the crop on 108,000 ha (271,000 acres). Finally, the Great Lakes region, including Michigan and Ohio, produced 12% of the sugar beet crop on 76,000 ha (190,000 acres). Nebraska leads production in the Great Plains region with 31,200 ha (78,000 acres) planted in 2000 (32). The majority of the production is in the western part of the state, known as the Panhandle.

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Background

Between the early and mid-nineties, sugar beet stands and yields in western Nebraska, southeastern Wyoming, and northeastern Colorado (hereafter referred to collectively as the Central High Plains) declined drastically. This caused major concern about the viability of the sugar beet industry in this area because the reduced yields and resulting decreased acreages were lower than what was required to sustain the industry. In 1995, Western Sugar Company beet growers commissioned a sugar beet task force composed of growers, sugar processors, bankers, agribusiness leaders, and sugar beet researchers from the Panhandle Research and Extension Center (PHREC) in Scottsbluff, NE (University of Nebraska) to address these issues.

The task force identified three primary concerns and questions. First, screening and development of cultivars specifically for use in the Central High Plains no longer occurred in this area. A question, therefore, was whether or not current cultivars used for the region had lost tolerance to local pests and adaptability to local growing conditions. Second, over 70% of the area's sugar beet production was planted-to-stand, but traditional cultivar testing used over-planting, thinning-to-stand, and avoiding fields with yield limiting factors. Thus, did the traditional testing methods adequately judge performance of new cultivars under conditions that reflect the range of problems found in grower fields? Finally, plant populations in the region were lower than those needed for

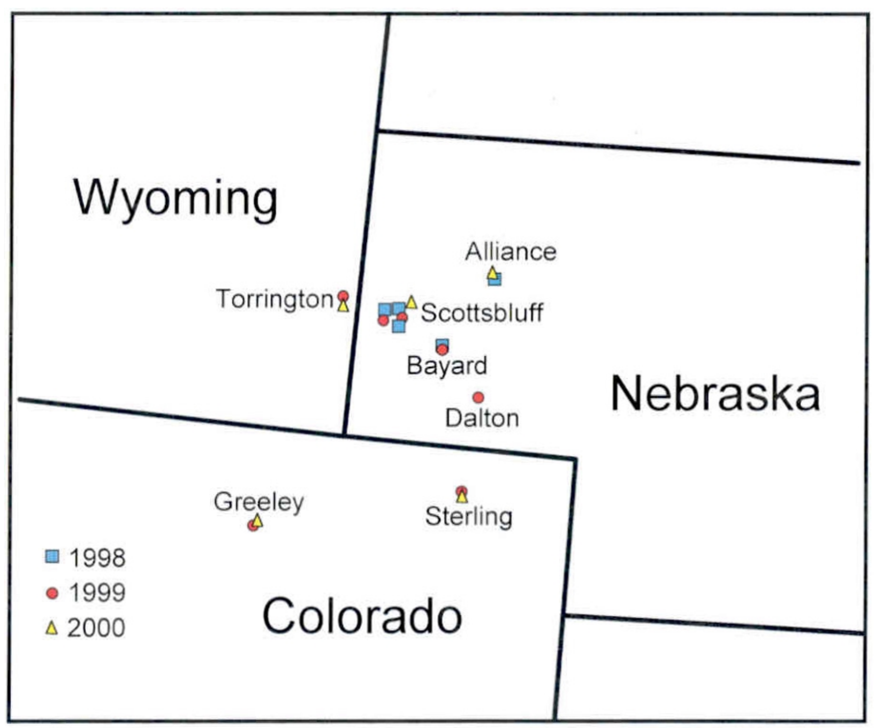


Fig. 1. Site map of University of Nebraska cultivar trials (1998 to 2000) depicting the location of the 17 sites that were harvested (excluding Alliance site in 1999). The cluster of sites around Scottsbluff also includes two in Mitchell and one in Gering.

Table 1. Cultivars included in University of Nebraska sugar beet cultivar trials (1998-2000)

Seed co.	Cultivar	Year used	Resistance
American Crystal	184	1998, 1999, 2000	*Rhizoctonia, Cercospora*
	205	1998, 2000	*Aphanomyces, Rhizoctonia, Cercospora*
	304	1999	None
	306	1998, 1999, 2000	*Rhizoctonia*
	9612	1999	None
	9720	2000	None
	9806	2000	None
	205 + Tach[a]	2000	*Aphanomyces, Cercospora, Rhizoctonia*
Beta Seed	1399	1998	None
	1775	2000	Root aphid
	2017	2000	None
	2215	1998, 1999, 2000	Root aphid
	3195	1999, 2000	None
	4006R	1999, 2000	Rhizomania
	4038R	1998, 1999, 2000	Rhizomania
	4546	1998, 1999, 2000	*Rhizoctonia*, Root aphid
	4689	1999, 2000	*Rhizoctonia*
	5823	1999	*Cercospora*
	6045	1999, 2000	Root aphid
	6863	1998, 1999, 2000	None
	8754[b]	1998	None
	Quad 4546[c]	1999	*Rhizoctonia*, root aphid
Florimond Desprez	Amalie[d]	1998	None
	Avantage[d]	1998	*Rhizoctonia,* Rhizomania
	FD0022[d]	2000	None
	FD2519[d]	1999	Rhizomania
	FD9760[d]	1999	Rhizomania
	FD9993[d]	1999, 2000	None
Holly	Phoenix	2000	Rhizomania
	Rival	1998	Rhizomania
	Rizor	1998, 1999, 2000	Rhizomania
	SS289R	1999	Rhizomania
	HH32	1998	*Rhizoctonia*
	HH50[b]	1998	None
	HH110	1998, 1999, 2000	None
	HH120[e]	1999	None
	HH125	2000	None
	98HX829	1999	None
Novartis	Oberon[f]	1998	none
	RH3	1998, 1999, 2000	*Rhizoctonia, Cercospora*
	RH5	1999, 2000	*Rhizoctonia, Cercospora*
	1605	1998, 1999, 2000	Root aphid
	1620	1998, 1999, 2000	*Cercospora*
	1639	1999, 2000	Rhizomania, Root aphid
	1640	1999, 2000	*Rhizoctonia*
	1642	2000	*Cercospora*
	9155	1998, 1999, 2000	Root aphid
Maribo	9372	1998	Rhizomania
Seedex	Alliance	2000	Root aphid
	Bison	2000	*Cercospora*
	Charger	1999, 2000	Root aphid
	Excel	1998, 1999, 2000	Root aphid
	Halt	1998, 1999, 2000	*Rhizoctonia*, Root aphid, *Cercospora*
	Kojak	1998, 1999, 2000	Rhizomania, Root aphid
	Laser	1998, 1999, 2000	*Cercospora*
	Laser + Tach[a]	2000	*Cercospora*
	Monohikari	1998, 1999, 2000	Root aphid
	Ranger	1999, 2000	Root aphid
	Turbo	1998	Root aphid
	Spartan	2000	*Cercospora*
	SX2	2000	Root aphid
	SX70293	1999	Root aphid
	Quad Monohikari[c]	1999	Root aphid

[a] Tachigaren incorporated into seed pellet at a rate of 45 g/unit (100,000 seeds).
[b] Planted in Wyoming and Montana.
[c] Quadris applied at four-leaf stage (1.25 kg/ha).
[d] French cultivar; Tachigaren incorporated into seed pellet at a rate of 20 g/unit (100,000 seeds).
[e] Experimental seed.
[f] Planted in England.

profitable yields and sugar percentages. Were lower yields due to poor seed quality, cultivars with reduced genetic capability for high emergence, or some other unknown factor?

The PHREC sugar beet researchers were urged by growers and several seed companies to conduct cultivar performance evaluations on a field scale that would attempt to address some of these concerns and to provide more information to the industry than simply ranking for highest yields. The group consisted of scientists from multiple disciplines including entomology, weed science, plant pathology, irrigation engineering, and machinery systems engineering. The purpose of this project was to develop thorough, detailed information on sugar beet cultivar performance that would assist growers in making the best cultivar selections. It was not meant to replace the traditional cultivar approval trials conducted by Western Sugar, but to complement them. Therefore, the trials were begun on a limited basis in 1997 using 12 commercially approved cultivars at three sites in the Nebraska Panhandle.

The primary objectives in that first year (1997) were to measure field emergence of different cultivars and to compare results with the packed sand test (2) and laboratory germination tests conducted by an independent seed-testing lab. Yield and plant performance were evaluated under the field conditions and stresses that grow-

Table 2. Brief descriptions of planted University of Nebraska sugar beet cultivar trial sites (1998-2000)

Year	Site	Pest pressure	Comments
1998	Alliance, NE	High *Rhizoctonia*, moderate *Cercospora*, low root aphid	Pivot irrigated, irrigated for emergence
	Bayard, NE	Low *Rhizoctonia*, moderate root aphid, low *Cercospora*	Furrow irrigated, irrigated for emergence
	Gering Valley, NE	Moderate *Rhizoctonia*, moderate *Cercospora*, moderate root aphid	Furrow irrigated, not irrigated for emergence
	Mitchell, NE	Moderate *Rhizoctonia*, moderate *Cercospora*, high root aphid	Furrow irrigated for emergence, pivot irrigated through season
	Scottsbluff, NE	Low *Rhizoctonia*, low *Cercospora*, moderate root aphid	Furrow irrigated, irrigated for emergence
1999	Alliance, NE	Moderate *Rhizoctonia*, moderate *Aphanomyces*, moderate *Fusarium*, low root aphid	Pivot irrigated, injury from Stinger, irrigated for emergence, replanted 14 June
	Bayard, NE	Moderate *Rhizoctonia*, low *Aphanomyces*, moderate *Fusarium*, low root aphid, low sugarbeet root maggot	Furrow irrigated, not irrigated for emergence, light Nortron injury, 1 *Cercospora* control application
	Dalton, NE	High *Aphanomyces*, low root aphid	Pivot irrigated, irrigated for emergence, moderate late season hail damage
	Greeley, CO	Low *Rhizoctonia*, moderate *Cercospora*, low root aphid	Furrow irrigated, irrigated several times for emergence, heavy rain and snow after planting, 3 *Cercospora* control applications
	Mitchell, NE	Moderate root aphid, low *Cercospora*, low *Rhizoctonia*, low *Aphanomyces*, low sugarbeet root maggot	Furrow irrigated, not irrigated for emergence, moderate midseason hail, light Nortron injury, 1 *Cercospora* control application
	Scottsbluff, NE	High *Rhizoctonia*, low *Cercospora*, moderate *Aphanomyces*, low root aphid, low sugar beet root maggot	Furrow irrigated, irrigated for emergence, 2 *Cercospora* control applications
	Sterling, CO	High root aphid	Pivot irrigated, irrigated several times for emergence, moderate midseason hail, 1 *Cercospora* control application
	Torrington, WY	Low *Rhizoctonia*, moderate *Cercospora*, moderate root aphid, moderate cyst nematode	Furrow irrigated, not irrigated for emergence, moderate midseason hail, moderate Nortron injury
2000	Alliance, NE	Moderate *Rhizoctonia*, moderate *Aphanomyces*	Replanted 11 May, pivot irrigated, irrigated for emergence, moderate hail early and midseason
	Dalton, NE	Moderate *Aphanomyces*	Pivot irrigated, irrigated for emergence, frost 25 April, replanted 5 May, severe hail 25 May, crop destroyed 1 June
	Gering, NE		Furrow irrigated, not irrigated for emergence, heavy rain and crusting 18 April, crop destroyed 15 May
	Greeley, CO	Low curly top, low powdery mildew, moderate *Cercospora*, high root aphid	Furrow irrigated, irrigated for emergence, moderate hail 17 May, 1 *Cercospora* control application, 1 powdery mildew control application
	Scottsbluff, NE	High *Rhizoctonia*, moderate *Aphanomyces*, low root aphid, low sugarbeet root maggot, low *Cercospora*	Furrow irrigated, irrigated for emergence, 2 *Cercospora* control applications
	Sterling, CO	High root aphid	Pivot irrigated, irrigated for emergence, moderate hail 12 July
	Torrington, WY	Moderate root aphid, low cyst nematode	Pivot irrigated, not irrigated for emergence, heavy rains mid and late April, replanted 9 May and irrigated for emergence, moderate hail 28 June

ers typically experience and were compared among sites. Results from the first year suggested that final field emergence from a given site could not be predicted accurately from the packed sand test or a standard 10-day germination test. When data were averaged over the three sites, however, statistical differences in yield and plant performance were observed among the 12 cultivars. The seven cultivars that were common to both the University of Nebraska trials and the Western Sugar Grower-Joint Research Committee trials showed similar rankings with percent sugar and Cercospora leaf spot ratings, but were very different in terms of root yields. This observation suggested that the methodology and objectives of these trials should be investigated further, and resulted in expansion of the trials using more cultivar entries and sites. The evaluations by the PHREC continued to increase in scope over the next 3 years to ultimately include 17 harvested locations from three states within the Central High Plains (Fig. 1), excluding the Alliance site in 1999. The overall goal was to utilize grower assistance and practices as often as possible to experience those same conditions encountered by growers in their own fields. Emphasis was placed on obtaining high economic returns and improving profitability through achieving good stands and minimizing yield constraints such as diseases, weeds, and insects.

Methodology and Design

All sites were planted on beds utilizing 56-cm (22-in) row spacing, and each plot consisted of three 15-m-long rows. If cooperating growers used 76-cm (30-in) row width equipment, then the PHREC conducted all field operations including seedbed preparation, cultivating, planting, ditching (in furrow-irrigated fields), chemical spraying (herbicides and fungicides), and harvesting. Otherwise, the PHREC was involved with planting and harvesting operations only.

All sites were planted to stand with a Hege pneumatic plot planter using pelleted seed. Seed spacing was selected to provide a population of 75,000 to 90,000 plants per hectare at the four-leaf stage, based on an anticipated cultivar emergence of 70 to 80%. Plots at all locations were harvested mechanically with a plot harvester converted from a Hesston field-scale harvester, and two root samples were collected from each plot for sucrose analysis. Samples from Colorado and Nebraska were tested at the Western Sugar tare lab in Gering, NE, and samples from the two Torrington, WY, sites were processed at the Holly Sugar tare lab in Torrington.

Cultivar Descriptions and Site Locations

Each of the five companies selling seed in the Nebraska-Colorado-Wyoming growing region (American Crystal, Beta Seed, Holly, Novartis, and Seedex) was consulted to determine the most popular cultivars and those with local disease and insect resistances. Cultivars recommended by the seed companies were included in the trials along with a number of cultivars used in Europe or other regions of the United States for comparison. The entire project concluded in November 2000 with a cumulative total of 20 sites planted, 18 sites harvested, and inclusion of 63 entries utilizing 59 cultivars over the 3-year period 1998 to 2000 (Tables 1 and 2). Although the Alliance site in 1999 was harvested and analyzed, data were excluded from the final presentation. This site was replanted very late (14 June) after a severe windstorm killed an estimated 70% of the first stand, and as a result the data do not accurately reflect an entire growing season. Twenty-seven cultivars were common to 1999 and 2000, and 17 were evaluated in all three seasons (Table 1). Many of the recommended cultivars possessed genetic resistance to various insects and diseases including sugar beet root aphid (*Pemphigus betae*), Cercospora leaf spot (*Cercospora beticola*), Rhizoctonia root and crown rot (*Rhizoctonia solani*), and rhizomania (*Beet necrotic yellow vein virus*) (Table 1).

Cultivars from the same seed lot were planted at all sites within a given season, but the number of cultivars and sites employed were variable across years. The 1998 study utilized 28 cultivars at five separate sites in Nebraska, including farms near Alliance, Bayard, Gering, Mitchell, and Scottsbluff. The numbers of entries and locations were increased to 38 and 8, respectively, in 1999. In addition to five in Nebraska (Alliance, Bayard, Dalton, Mitchell, and Scottsbluff), the 1999 evaluation was also expanded to include two sites in Colorado (Sterling and Greeley) and one in Torrington, WY. In 2000, the number of entries was increased to 42, and cultivars were planted on seven new sites. Two of these sites in Nebraska (Dalton and Gering) were destroyed before harvest due to weather-related problems. The remaining five locations taken to harvest consisted of two in Nebraska (Alliance and Scottsbluff), two in Colorado (Greeley and Sterling), and another near Torrington, WY. (Fig. 1, Table 2).

The data collected from each site were analyzed with analysis of variance as a randomized complete block with six replications per site. As one would expect, most variables evaluated (yield parameters, emergence, herbicide injury, disease and insect response) were found to differ significantly among cultivars at each site. After a combined analysis was performed, significant interactions were also observed between cultivars and sites, limiting the value of the combined analysis in most cases.

Emergence and Stand Establishment

Profitable sugar beet production in the Central High Plains is often limited by poor seedling emergence and stand establishment (5,18,33). Uniform spacing of plants, plant populations, and early plant growth have long been recognized as factors that influence yield potential and weed control later in the season (5,18). These factors have traditionally been accomplished by over-planting and later thinning to stand (5,30). Planting-to-stand as an

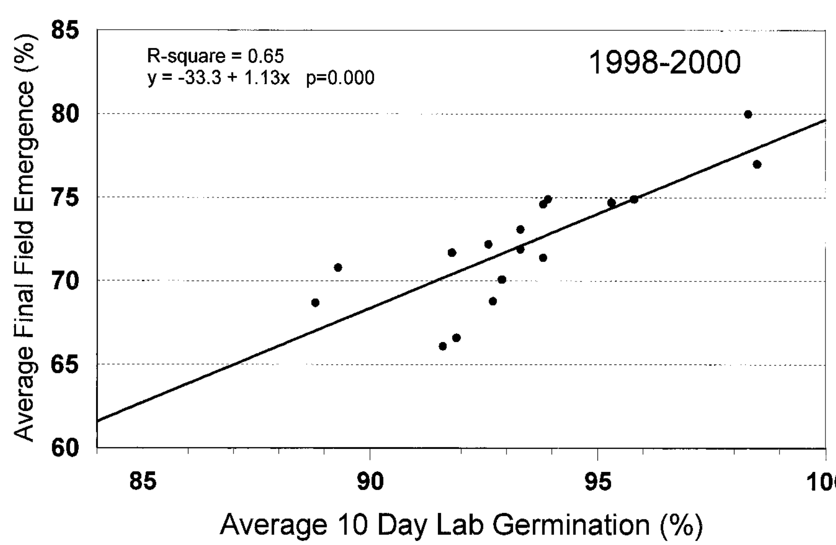


Fig. 2. Relationship of field emergence with 10-day laboratory germination of seed cultivars common to all years of the University of Nebraska cultivar trials (1998 to 2000). Each point is the average of those cultivars common to each site taken to harvest over the 3 years (excluding the Alliance site in 1999). Field emergence is averaged over all sites and six replications, and laboratory germination is averaged over four replications for respective cultivars.

alternative production technique was suggested over 20 years ago (5). It has now become more the norm than the exception for producers in this area (>70%) due to rising costs of labor and the need to cut costs and increase efficiency. However, crops planted to stand must attain a final establishment of 70% in order to realize maximum yields (4). Achieving this goal is often a challenging procedure and requires high quality seeds with predictable emergence and vigor.

Final field emergence (established stand) in the trials was recorded at the four to six true-leaf stages by counting all emerged plants in all three rows for the full 15-m length of plots at each site. Values in 1999 ranged from a low of 58% in Dalton to a high of 90% in Greeley (data not shown) and illustrated the variability and serious nature of emergence issues in the region.

All seed lots are tested in the laboratory (most being advertised on boxes as 90% germination), but this usually does not correlate well with emergence in the field. It was quickly recognized that producers and the sugar industry in this region would benefit if certain cultivars could be identified before planting that consistently resulted in adequate stands in the field. However, previous reports have concluded that predicting field emergence from laboratory germination tests was a difficult and inconsistent procedure (18).

Sugar beet seedling emergence and stand establishment problems can be caused by a wide range of factors, including diseases, insects, pesticides, freezing temperatures, improper soil preparation, and cultivar genetics (30,41). The occurrence of many of these factors is based on environmental conditions that cannot be accurately predicted. Because of the absence of any predictable pattern within a given season, years are often considered as random variables (6).

Therefore, for demonstration purposes, we chose to combine the results of those cultivars used from 1998 to 2000 with the objective of identifying those factors whose average effects remain stable over several years (6). Using this premise, our results demonstrated that a high correlation between field emergence and laboratory germination existed among that group of cultivars (Fig. 2). Although we acknowledge that interactions among parameters did exist in this case, we also feel that the significant relationship obtained after combining results over 17 site-years under highly variable environmental conditions provides more biologically meaningful results than those collected from each site independently.

This does not suggest that testing cultivars for emergence in the field is no longer necessary, but it does provide some useful information. Growers in this region must buy their seed by the end of January for the coming season, which does not allow much time for serious deliberation. The results we obtained over the 3-year study can help producers in their decision process by at least identifying and eliminating from consideration those cultivars that would most likely emerge poorly in the field.

Seedling Herbicide Injury Response

Weed competition in sugar beets has been estimated to reduce yield in the United States by 10% annually (3,26,27). The critical period for weed control in sugar beets is during the first 8 weeks after

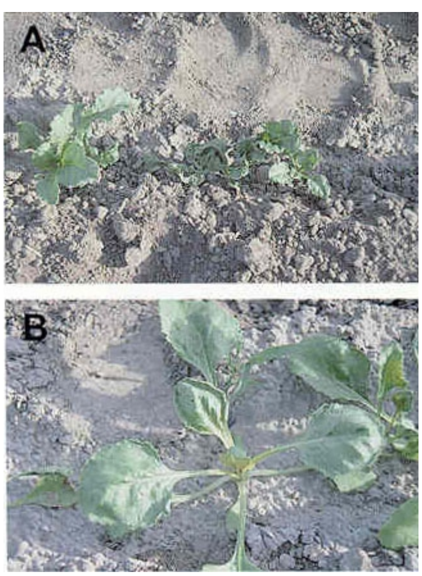


Fig. 3. Herbicide injury symptoms. A, Damage due to Nortron (ethofumesate), resulting in shoot inhibition, leaf fusing and thickening. B, Herbicide injury symptoms from Stinger (clopyralid) consisting of twisting and elongation of petioles.

Fig. 4. Sugar beet root aphids. A, Root aphid colonies on taproots and in surrounding adhering soil. The colonies consist of both aphids and a white waxy material that is associated with root aphid presence. B, Close-up view of apterous root aphids.

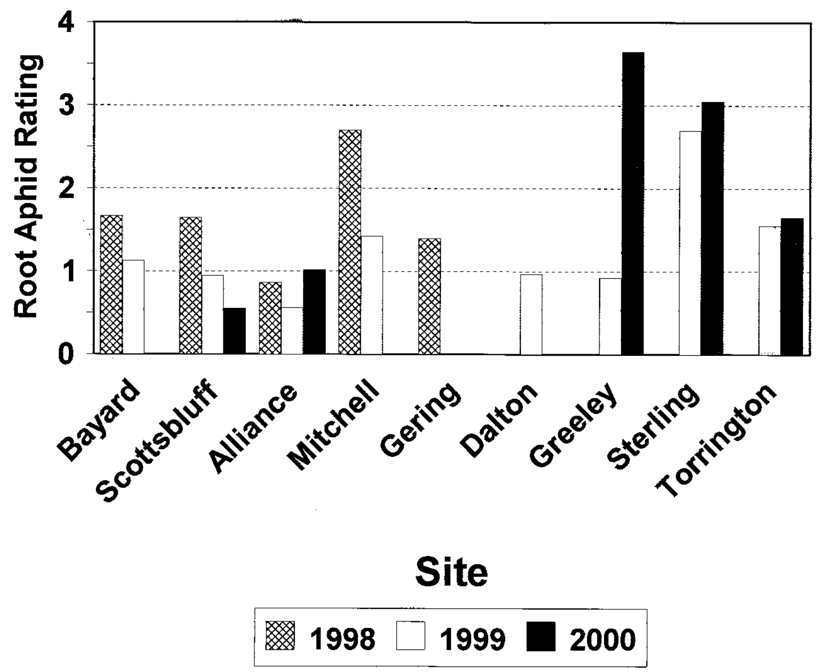


Fig. 5. Root aphid occurrence in susceptible cultivars from all cultivar trial sites (1998 to 2000). Ratings were based on a 0 to 5 scale, with 0 = no sign of aphids, 1 = colonies less than 2.5 cm in diameter, 2 = colonies greater than 2.5 cm, 3 = two or more colonies greater than 2.5 cm, 4 = greater than 50% of root surface covered, 5 = colonies covering greater than 75% of root surface.

planting (35). During this period, the sugar beet seedling has a small leaf area, is not competitive with weeds, and is generally more susceptible to injury from early-season applications of herbicides (36). Weeds that emerge later in the season are not as competitive with the crop. Later in the growing season as the sugar beet becomes larger, the plant is more tolerant of herbicides, but weeds will also increase in size and become less susceptible to herbicides. To achieve satisfactory weed control, the grower must strive to apply herbicides early in the growing season when both weeds and beets are small. Herbicide tolerance is not usually a consideration when testing sugar beet cultivars, but several experiments have shown that sugar beet cultivars can vary in herbicide susceptibility (36,37).

A unique opportunity arose in 1999 to evaluate sugar beet seedling damage from herbicides at several sites. Plants at three sites, (Torrington, Bayard, and Mitchell) exhibited early-season damage from preplant applications of Nortron (ethofumesate). Nortron was applied before planting and incorporated into the soil to control weeds as they emerged with the crop (19). Nortron injury to the sugar beets consisted of stunting, shoot inhibition, and leaf thickening and fusion of leaves (Fig. 3A). The injury was most severe at Torrington, ranging from 3 to 27% among cultivars. Nortron damage observed at the Torrington, Bayard, and Mitchell sites was shown to influence sugar beet root yields. Each 10% increase in crop injury from Nortron resulted in a 5.5 to 6.5 metric ton reduction in root yield (data not shown).

Soils at the Torrington, Bayard, and Mitchell sites were classified as sandy loams with approximately 1% organic matter. Past research has shown that Nortron does have the potential to injure sugar beets, and injury is more common when sugar beets are grown on coarse-textured soils (29). Nortron was also utilized for weed control at the Dalton site; however, crop injury was not observed at this site. Soil at the Dalton site was classified as a silt loam with 2% organic matter. The heavier texture at Dalton probably lessened the crop response from Nortron by absorbing some of the herbicide.

Fig. 6. Powdery mildew symptoms. Note white, dusty substance on leaves, consisting of masses of conidia.

Sugar beet seedlings were also injured by herbicides at Alliance. Stinger (clopyralid) had been applied postemergence to the first planting of sugar beets. The crop was subsequently lost because of severe weather and had to be replanted. Sugar beets from the second planting emerged, and plant injury symptoms consisting of stem twisting and elongation were observed (Fig. 3B). Sugar beet cultivars differed in their response to Stinger, and it was also noted that the cultivars sensitive to Stinger at Alliance were different than those cultivars sensitive to Nortron at Torrington. Those plants injured by Stinger quickly recovered, and by harvest no measurable root yield loss was attributable to postemergence herbicide injury.

In most situations, herbicides utilized for sugar beet weed control are selective to the crop. But there are situations where herbicides can damage the crop (36). Crop injury was observed in one out of three years in these studies, and in the year when it did occur, it was the result of an interaction involving herbicide, soil type, and cultivar.

Response to Sugar Beet Root Aphids

Sugar beet root aphids occur throughout the major sugar beet–growing areas of North America (15,21). These aphids are associated with various cottonwood trees (*Populus* spp.) as their primary host (21). Additionally, they have a number of secondary hosts, of which the most economically important is sugar beet (15,31). Two synonyms are also known for the sugar beet root aphid, *Pemphigus populivenae* and *P. balsamiferae* (7). There is considerable confusion, however, as to the correct taxonomic status of sugar beet root aphids, as it needs to be determined if there is a single species found throughout North America, or if multiple species are present. The aphid is considered to be a potential problem throughout the intermountain region because of the proximity to many sources of the narrowleaf cottonwood (*Populus angustifolia*) that are commonly found above elevations of 1,200 to 1,500 meters in the foothills of the Rocky Mountains.

From mid-June through mid-July in the Central High Plains, winged aphids produced in galls formed on narrowleaf cottonwood leaves fly to sugar beet fields and initiate colonies on sugar beet roots (Fig. 4A and B). The root aphid increased substantially across the region during 1997 compared with previous years, and it has been very common since. Root ratings were performed utilizing a 0 to 5 scale modified from that of Hutchison and Campbell (15), with 0 being no evidence of aphids and 5 being 75% or more of roots covered with aphid colonies. The variable degree of root aphid pressure found among sites over the course of the study (1998 to 2000) is based on ratings performed on susceptible cultivars (Fig. 5). Root aphids have traditionally been difficult to control chemically. They are similar in this respect to many root rotting pathogens in that they are often not noticed until major damage has already occurred. Their habit of colonizing and attacking roots under the soil surface during the latter portion of the season means that insecticides cannot be effectively delivered without either being drenched into the soil, or through systemic action in the plants (40).

Fig. 7. Curly top symptoms. Note stunting and upwardly cupping leaves.

It has also been difficult to predict or estimate the true magnitude of yield reductions due to root aphids. One of the primary reasons for this is the aphid's sporadic and nonuniform incidence among and within fields. The few reported studies attempting to address this question have either evaluated affected plants restricted to obvious infested loci within fields (15,31) or measured yield reduction via gradients from top to bottom of furrow-irrigated fields (40). Yield losses have been determined to range from 30 to 60% in heavily infested areas compared with adjacent uninfested portions of the field

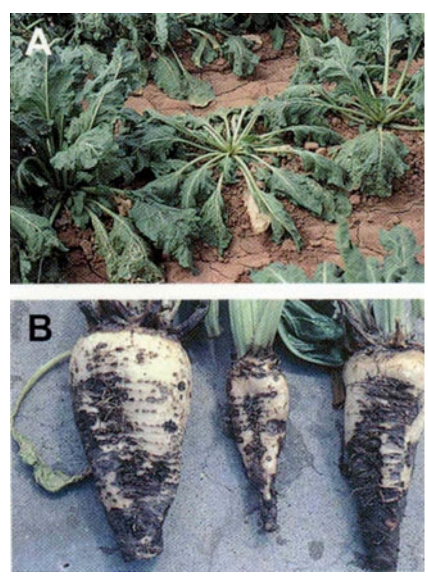


Fig. 8. Rhizoctonia root and crown rot symptoms. A, Foliar symptoms initially exhibiting sudden, permanent wilting and collapse of leaves and petioles. B, Root symptoms showing small, discrete lesions coalescing to form larger rotted areas on taproot.

(15,31), but no significant differences were obtained in the furrow irrigation gradient study, presumably because of late onset of infestation (40). Most studies, however, have observed greater levels of infestation and damage under dry soil conditions (15,31,40).

Another reason for the difficulty with estimating yield losses due to root aphids is distinguishing their effects from the confounding ones associated with rhizomania, Cercospora leaf spot, or other disease problems. The results of this study have been able to consistently document the potential yield reductions associated with root aphids from several sites that also lacked other conflicting disease, pest, or weather-related problems.

Response to Diseases

Diseases have long been recognized as significant and important constraints to optimal sugar beet production. Thus, a great deal of work and effort has been undertaken in the task of breeding new cultivars for resistance to various diseases. Once resistant cultivars are developed, their use becomes one of the more practical and economical disease management tools and can be adapted into most production systems.

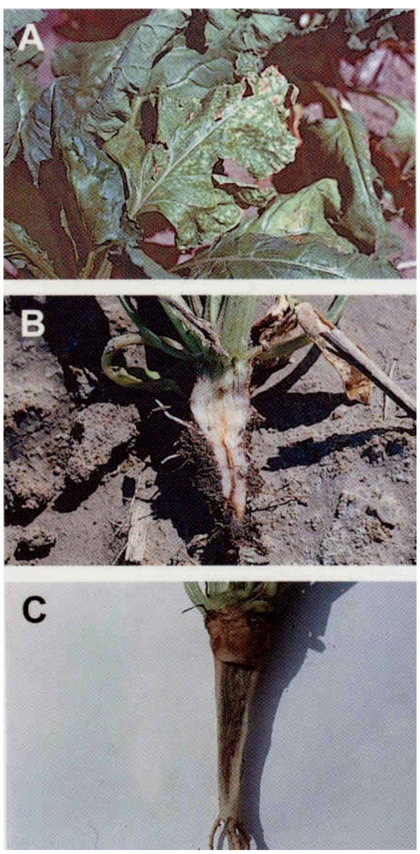


Fig. 9. Fusarium yellows symptoms. A, Foliar symptoms characterized by interveinal yellowing of younger leaves. B, Limited necrosis and discoloration of vascular elements in young root from early infection. C, Advanced infection showing greater extent of vascular necrosis and discoloration.

The most important diseases that routinely affect sugar beets in this region are Cercospora leaf spot and a complex of different root diseases including rhizomania, Rhizoctonia root rot, Aphanomyces root rot (*Aphanomyces cochlioides*), Fusarium yellows (*Fusarium oxysporum*), and cyst nematode (*Heterodera schachtii*). Thus, 15 of the 27 cultivars common to the trials in both 1999 and 2000 (55%) had resistance to one or more of these diseases (Table 1).

Two other foliar diseases are found sporadically in the region, but are generally not considered to be significant problems to growers. These include powdery mildew, caused by *Erysiphe polygoni* (Fig. 6), and beet curly top, caused by *Beet curly top virus* (BCTV) (Fig. 7). Powdery mildew is not generally yield limiting if it occurs after the first of September, and fungicidal sprays can effectively manage the disease if it occurs before this time. The incidence of curly top is dependent upon transmission of the virus by its leafhopper vector (*Circulifer tenellus*), and the optimal environmental conditions and habitat necessary for the insect are generally not favorable in this area.

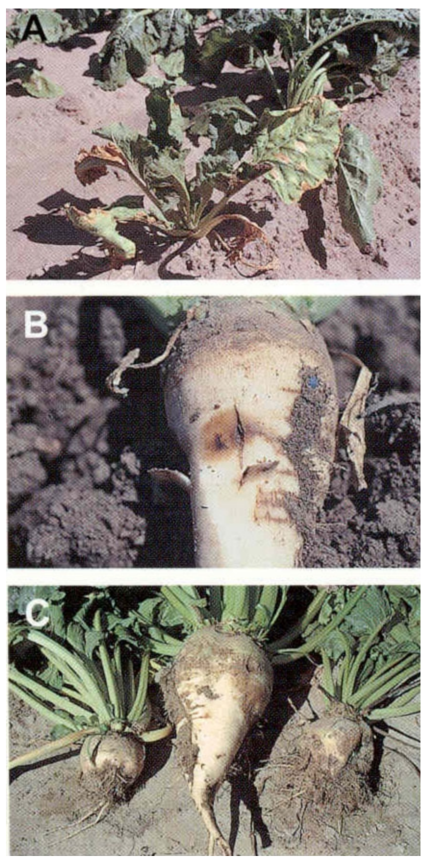


Fig. 10. Aphanomyces root rot symptoms. A, Foliar symptoms consisting of stunting, wilting, and yellowing. B, Young root infection showing localized lesion, with a yellowish-brown internal discoloration. C, Older root infections depicting severity and extent of taproot size reductions of two infected plants compared with the unaffected plant in center.

Rhizoctonia root and crown rot, caused by *R. solani*, anastomosis group (Ag) 2-2, is consistently the most destructive and widespread of the pathogens occurring in the root disease complex in this area. It is characterized by a permanent and sudden wilting (Fig. 8A), and small discrete lesions on roots that often coalesce, causing large areas of taproots to become rotted (Fig. 8B) (23,39). *R. solani* can also cause serious stand problems in very warm soils, although a different group (Ag 4) has been associated with the seedling disease (23).

In the United States, sugar beet diseases caused by *Fusarium* spp. are poorly understood, and there is considerable confusion regarding the various species associated with root disease and their variation. The classical symptoms associated with Fusarium yellows include slight to moderate foliar wilting, interveinal chlorosis (Fig. 9A), scorching, yellowing, and necrosis of vascular elements in taproots (Fig. 9B and C) (22,25). A number of species of *Fusarium* have been reported to be pathogenic to sugar beets, including *F. solani*, *F. acuminatum*, *F. avenaceum*, and *F. oxysporum* f. sp. *betae*; however, only *F. oxysporum* and one isolate of *F. avenaceum* have induced typical yellows symptoms (22).

Another *Fusarium* disease of sugar beets has been studied in Texas, and the pathogen was shown to be distinct from that causing Fusarium yellows by causing an external rot of the taproot (10–12). Although still identified as *F. oxysporum*, the isolates causing the root rot were different genetically from Fusarium yellows isolates collected from other sugar beet growing regions in the western United States (11), and were designated with a distinct form species (*radicis-betae*) to reflect the genetic and symptom expression differences exhibited among isolates (12).

Aphanomyces root rot has recently been reported from Nebraska and Wyoming (8), but has likely been present as an undiagnosed participant in the disease complex with Rhizoctonia root rot for some time. It is caused by *A. cochlioides* and can attack plants both as a seedling pathogen and as the cause of a chronic root rot anytime during the season, depending on environmental conditions (20). Foliar symptoms are characterized by stunting, yellowing, and nonvigorous growth (Fig. 10A). Root symptoms of the chronic phase can vary from dark external lesions with a yellowish-brown interior (Fig. 10B) to completely rotted taproots with little root tissue remaining except crowns (Fig. 10C). One of the surprising aspects of this disease is that late in the season if conditions have become more favorable for the host and not the pathogen, plants may appear deceptively healthy based on foliage appearance, yet still produce poor root yields (Fig. 10C) (9).

Rhizomania (Fig. 11A and B) is an unusual root disease because it is caused by the soilborne virus, *Beet necrotic yellow vein virus* (BNYVV), and is transmitted by the zoosporic, plasmodiophorid, *Polymyxa betae* (24). The vector can remain viable for long periods in soil as resistant cystosori, retaining the ability to both protect and disseminate the viral pathogen. It is a much-feared disease that has now been identified from nearly every sugar beet–growing area in the world (24). However, the pathogen was not found in levels high enough to induce symptoms or cause measurable damage from any of the sites during these trials.

The Dalton site was unusual in that it was infested with *A. cochlioides* exclusively without the confounding effects of other diseases or pests. The Dalton site was also able to provide important information on cultivar response to Aphanomyces root rot late in the season. If soil conditions dry out and become less favorable for the pathogen, chronic infections can often stop, minimizing effects on yields (9). At harvest, plants in many of the plots had roots that were severely scarred and distorted (characteristic of earlier infection by *A. cochlioides*) and protruded 6 to 8 inches above the soil line (Fig. 12A). Root yield was not always substantially altered from these plots; however, the inconsistency of crown heights caused many roots to break off and fall into furrows during the defoliation procedure (Fig. 12B). In commercial farming, this would have resulted in an unacceptable level of field loss, as many broken roots would never have been retrieved by the harvester.

Cercospora leaf spot is the most destructive foliar disease in the region and is characterized by tan to light-gray, circular lesions with a dark border (Fig. 13A). Disease incidence and severity are dependent upon extended periods of high temperatures (>21°C) and greater than 11 hours of leaf wetness (16,38). The use of resistance alone is not adequate to prevent yield problems; however, resistant cultivars do slow disease progress and may help to prevent severe symptoms under ideal conditions.

The lack of complete resistance is likely due to the complex nature of resistance in sugar beet to *C. beticola*, which is thought to be quantitative and controlled by four to five pairs of genes (28). Conditions favoring disease in the Central High Plains often occur in July and August, but generally damage and severity are limited compared with the Red River Valley of North Dakota and Minnesota (38). Nevertheless, Cercospora leaf spot can still be a serious problem that may reduce both sucrose and root tonnage (Fig. 13B). Management of the disease is most effectively accomplished by utilizing disease resistance in combination with the rotation of fungicides with differing modes of action.

Cercospora leaf spot severity was evaluated in six locations over the course of the study. However, the pathogen did not significantly affect sugar yield at any of the sites. Even though differences were readily seen in cultivar response, infection and disease development must have occurred late enough in the season to avoid severe yield reductions. The same is true for the moderate levels of powdery mildew and curly top that appeared at the Greeley site in 2000. Significant differences were observed among entries in response to both diseases from ratings made in early September, but no yield differences at harvest could be attributable to either disease.

Conversely, effects of the root diseases could be documented as having a significant impact upon yield from several sites. Over the course of these trials, the highest levels of root pathogens occurred from the Scottsbluff and Dalton sites in 1999, and the Alliance and Scottsbluff sites in 2000. This group of pathogens consisted primarily of *R. solani* and *A. cochlioides*. A highly significant negative relationship was observed between root disease and sugar yield from three of the four severely infested sites (Fig. 14).

Developing cultivars with high levels of rhizomania resistance has been a relatively successful process. The inheritance of resistance to BNYVV is controlled by a single dominant gene (17,34), which has more easily resulted in a number of excellent resistant cultivars. Successfully developing highly resistant cultivars for the fungal root rot has been much more difficult and complex (1,13,14). Resistance to Fusarium yellows and to Rhizoctonia and Aphanomyces root rots is multigenic, and the heritabilities are lower than those observed for rhizomania (1,13). The presence of several minor genes increases the difficulty in identifying or isolating those genes that are responsible for inducing resistance (14). Therefore, fewer cultivars with high levels of resistance to fungal root diseases are available to area producers compared with rhizomania, and these diseases continue to cause some degree of yield reductions.

Examples of Utilizing Data for Cultivar Selection

The way the information obtained from this study can be effectively used in mak-

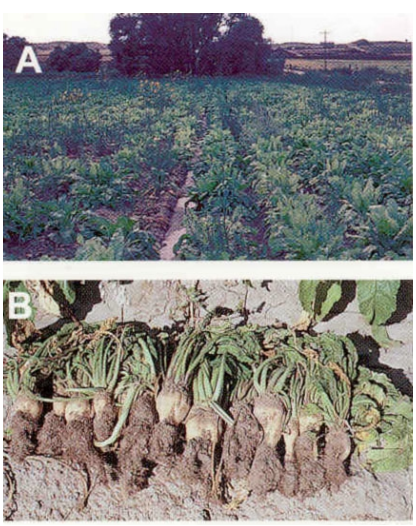


Fig. 11. Rhizomania symptoms. A, Foliar symptoms of infected plants at the lower end of a furrow-irrigated field, consisting of chlorotic leaves with an erect posture. B, Root symptoms of severely affected plants showing stunted taproots with masses of secondary root formation.

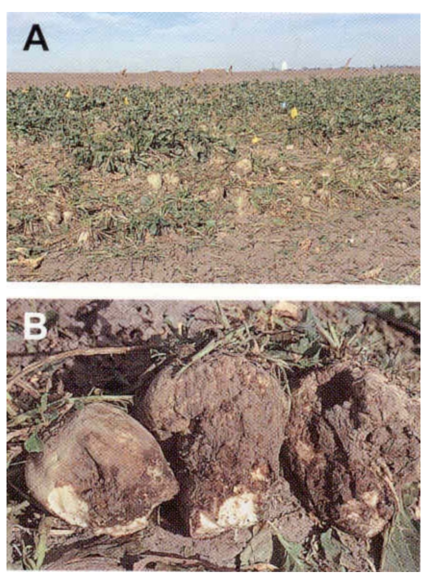


Fig. 12. Cultivar trials at Dalton site, heavily infested with *Aphanomyces cochlioides*, 1999. A, Plot depicting the inconsistency of heights of sugar beet crowns at harvest. B, Severely scarred and distorted roots broken off at ground level after defoliation.

Fig. 13. Cercospora leaf spot symptoms. A, Circular, ash-gray lesions surrounded by a dark brown-purple border. B, Severe field infection resulting in extensive necrosis and death of foliage.

ing cultivar selections is demonstrated with several examples from three sites during the 1999 trials, including Sterling, Dalton, and Scottsbluff. These particular sites are highlighted because of specific production problems that were documented that season. The Sterling site suffered from a high root aphid infestation without the presence of other conflicting factors (Table 2, Fig. 5). The Dalton site was unique by being heavily infested with *A. cochlioides* only, whereas the Scottsbluff site contained high concentrations of *R. solani* and moderate levels of *A. cochlioides* (Table 2).

The overall incidence of root aphids from the Sterling site was judged to be high based on a rating from susceptible cultivars (Fig. 5). When evaluating entries individually from this site, significant differences were observed (Fig. 15A). Note that a number of cultivars, including Kojak, Excel, 9155, and Ranger, resulted in low aphid colonization ratings, while 9612 and 98HX829 produced high ratings (Fig. 15A). This relationship also corresponds with significantly reduced sugar yields for 9612 and 98HX829 (Fig. 16A). The yields from 9612 and 98HX829 were approximately 7,000 kg/ha, whereas the yields from those previously mentioned cultivars producing a low aphid rating all exceeded 10,000 kg/ha. When these cultivars were compared at Scottsbluff (with low root aphid pressure), however, the yield performance of Kojak and Excel were dramatically lowered, below 8,000 kg/ha, while that of 9612 and 98HX829 reached nearly 10,000 (Fig. 16C). This reinforces the efficacy of root aphid resistance in Kojak and Excel, but also suggests a susceptibility to root diseases, particularly Rhizoctonia root rot, by these cultivars.

The root disease rating at Dalton was performed during harvest using a scale of 0 to 4 as previously described for Aphanomyces root rot (10). The comparison of FD9993 with the two 4546 entries (4546 and 4546 + Quadris) shows a dramatic difference in cultivar response to *A. cochlioides*. The two 4546 entries were affected to the greatest extent of any entries in the test producing severity ratings ranging between 2.5 and 3 (Fig. 15B). The rating of FD9993 was significantly better and was actually below the average of all entries with a 1.6 (Fig. 15B). The more severe disease ratings at Dalton for the 4546 entries likewise resulted in lowered yields ranging between 9,000 and 9,500 kg/ha, while that of FD9993 exceeded 11,000 kg/ha (Fig. 16B). When the response of the same cultivars was compared at the Scottsbluff site, the opposite results were obtained. Both 4546 entries yielded approximately 2,000 kg/ha more sucrose than did FD9993 (Fig. 16C). This is presumably due to several factors at Scottsbluff, including high levels of *R. solani*, the resis-

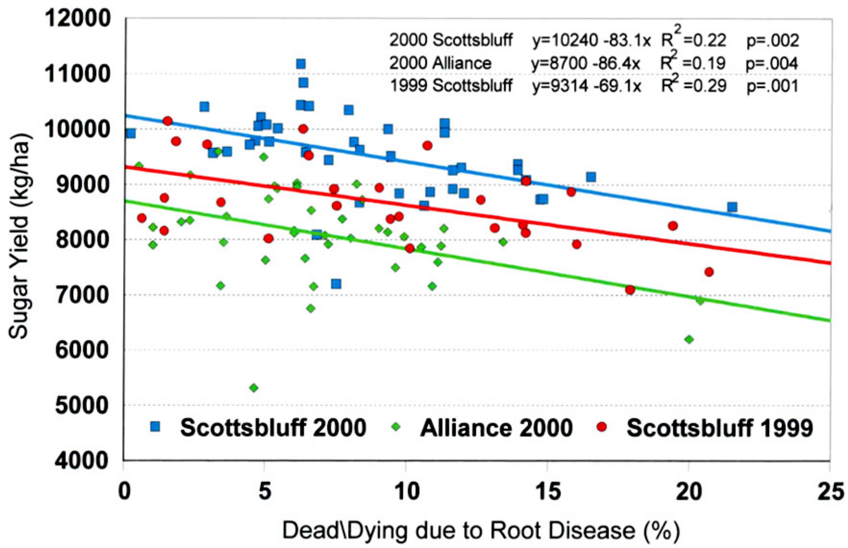


Fig. 14. Relationship of root disease counts with sugar yield from University of Nebraska cultivar trials at Scottsbluff in 1999, and Alliance and Scottsbluff in 2000. Each point is the average of six replications of each entry at each of the three sites.

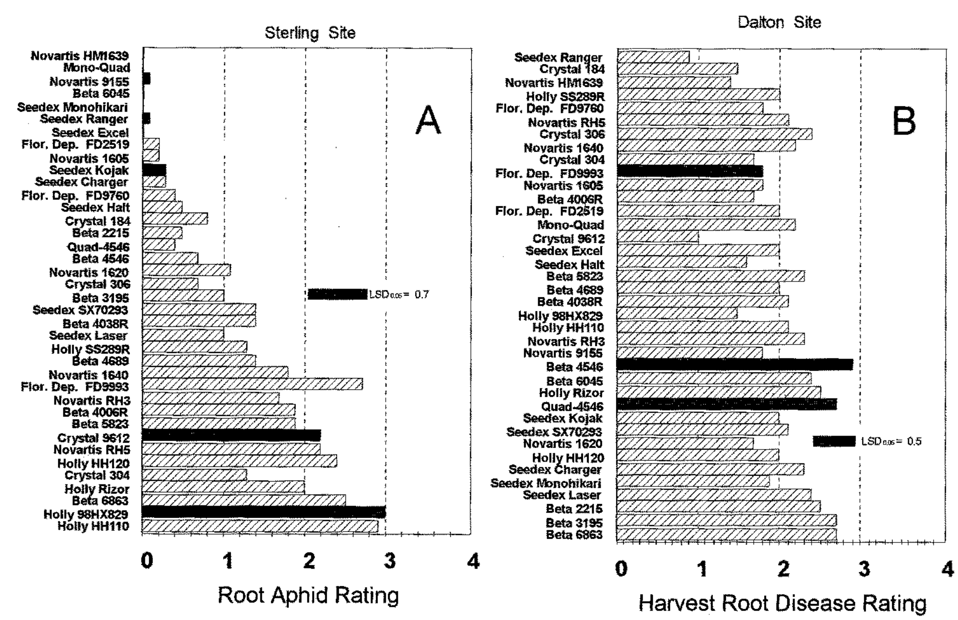


Fig. 15. Root aphid and root disease ratings made at the Sterling and Dalton sites in 1999. A, Sterling site, root aphid ratings (0 to 5): 0 = no sign of aphids, 1 = colonies less than 2.5 cm in diameter, 2 = colonies greater than 2.5 cm, 3 = two or more colonies greater than 2.5 cm, 4 = more than 50% of root surface covered, 5 = colonies covering more than 75% of root surface. B, Dalton site, root disease ratings for Aphanomyces root rot made at harvest (0 to 4): 0 = no disease, 1 = small, localized lesions, 2 = distal tip of beet rotted, but less than 10% of entire taproot rotted, 3 = 10 to 25% of taproot rotted, 4 = more than 25% of taproot rotted. Each value is the average of six replications per entry.

tance to this pathogen possessed by 4546, and the lack of resistance to this pathogen in FD9993.

These examples strongly illustrate the importance, not only of observing and maintaining records of pest or disease production problems, but also of recognizing and correctly identifying symptoms of pest or disease problems. Had someone confused Rhizoctonia and Aphanomyces root rots, and selected 4546 for use at the Dalton site because of its resistance to *R. solani*, this would have resulted in yield reductions approaching 2,000 kg/ha compared with those of higher performing entries (Fig. 16B).

Note also that several entries, including 9155 and Ranger, performed well at all three sites, regardless of the pest or disease problem present (Fig. 16A–C). It is no surprise that they were among the leaders at Sterling (Fig. 16A) because of root aphid resistance, yet they also yielded well in fields heavily infested with root pathogens (and little root aphid pressure) without any specific disease resistance (Fig. 16B and C). These results support prior studies in Texas suggesting that in situations where multiple pathogens were present, it was more beneficial to plant cultivars with good overall field tolerance and adaptation to local conditions rather than cultivars with specific disease resistance to a single pathogen (10; R. M. Harveson and C. M. Rush, *unpublished*). All these examples additionally highlight how important the cultivar evaluation and selection process can be. This selection procedure needs to include evaluations that identify both site-specific characteristics (soilborne diseases) and characteristics that are not likely to be site-specific, such as environment and root aphid presence. If correctly done, selecting the right cultivar can ultimately result in substantially better profitability for producers.

Recommendations and Outcome

This has been a unique approach to cultivar testing because it involved a team concept consisting of many disciplines and personnel within sugar beet production. It has also tested nearly 60 cultivars at multiple sites, all using similar production practices. Finally, it has evaluated a number of sugar beet production problems that are not normally considered in typical cultivar trials. In the testing of new cultivars, disease resistance is one of the most commonly evaluated traits; however, much less time has been spent developing or testing cultivars with characteristics such as herbicide or insect tolerance, germination, or emergence ability.

We have demonstrated that the selection process is not as simple as picking the top several entries from a ranked yield list. Therefore, we feel that producers must take into account as many traits or characteristics of the cultivars as possible, because any of these parameters can ultimately influence yields, and no single cultivar trait evaluated in these trials can be relied upon exclusively. As another example of how to utilize this data, one of the most useful methods for choosing cultivars for this region can be summarized by reviewing the yields and gross return values for those cultivars common to the 1999 to 2000 trials (Fig. 17). The top performers in these figures consistently yielded well across 12 sites, regardless of the production problem or site characteristics. Many of these better entries had no specific disease resistance but did possess root aphid resistance (Table 1, Fig. 17).

It is also encouraging to note that three of the top 10 highest yielding cultivars from this group were resistant to rhizomania, even without high levels of the pathogen being found from any of the sites (Table 1, Fig. 17). There have been several major concerns voiced over the years concerning the use of rhizomania-resistant cultivars in this region. They include a severe susceptibility to several of the fungal root rots (10), and the characteristic of yielding poorly in the absence of the disease. These trials have helped to soften some of these fears, and demonstrated the substantial advancements made by breeders in developing new rhizomania-resistant cultivars. To minimize risks, we recommend that producers select three to four diverse cultivars that meet the criteria for their particular growing conditions or field history problems.

Initially, this project was viewed as primarily an extension effort. Results each year were analyzed, collated, and presented in 75- to 80-page booklets that were distributed at meetings throughout Colorado, Montana, Nebraska, and Wyoming. Over the 3-year period (1998 to 2000), approximately 3,000 booklets were distributed, and presentations of results to growers and sugar industry personnel were made at more than 20 different meetings throughout the region.

Because of the extent and depth of knowledge obtained, this project has expanded far beyond initial expectations. A number of unexpected, but important discoveries have been made directly because of this study. Field emergence of some

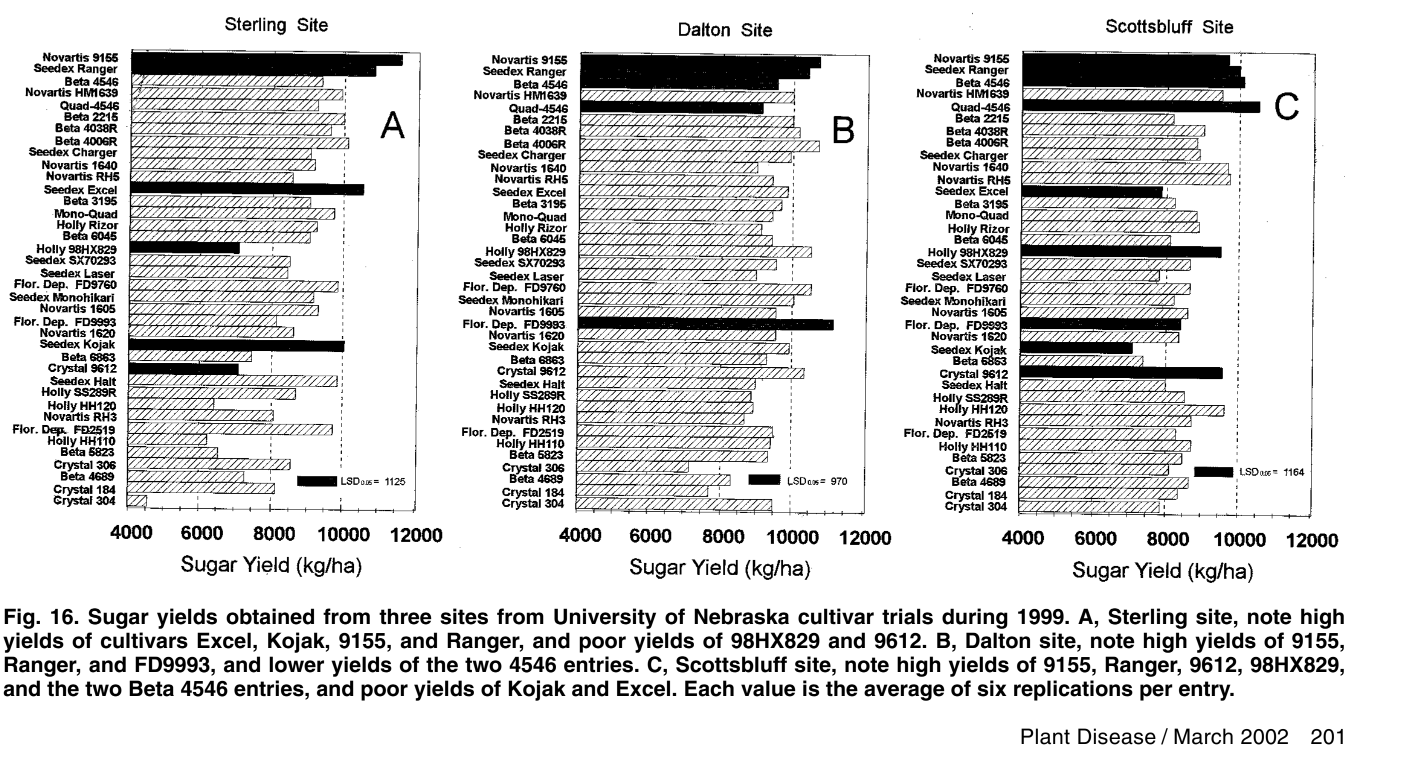


Fig. 16. Sugar yields obtained from three sites from University of Nebraska cultivar trials during 1999. A, Sterling site, note high yields of cultivars Excel, Kojak, 9155, and Ranger, and poor yields of 98HX829 and 9612. B, Dalton site, note high yields of 9155, Ranger, and FD9993, and lower yields of the two 4546 entries. C, Scottsbluff site, note high yields of 9155, Ranger, 9612, 98HX829, and the two Beta 4546 entries, and poor yields of Kojak and Excel. Each value is the average of six replications per entry.

cultivars has been shown to be reliably predictable by comparison with laboratory germination. Another surprising finding involved seedling emergence associated with irrigation type. It was observed that the average seedling emergence measured from 10 furrow-irrigated sites was 13% greater than that of nine sites using center pivot irrigation (data not shown). These furrow-irrigated sites also resulted in higher average root and sucrose yields (data not shown). Although not compared statistically, these observations are noteworthy because they refute the long held belief in this region that those fortunate enough to have access to sprinkler irrigation had a big advantage over growers restricted to furrow irrigation.

This study has additionally provided convincing evidence that the potential for yield loss in this region due to root aphids is greater than was previously believed. Prior to these trials, root aphid resistance was not a high priority in cultivar selection for growers; however, a direct result of these trials was demonstrating the impact that aphid resistance can have on sugar yields. When root aphid presence was significant, dramatic negative relationships were observed between aphid ratings and sugar yield (data not shown). As a result, the predominant cultivars currently planted in western Nebraska are resistant to root aphids. Finally, this study allowed the first identification of Aphanomyces root rot in Wyoming and Nebraska (8). This proved that another disease (likely previously confused with Rhizoctonia root rot) was widely distributed throughout the region as part of a disease complex, and could at least partially explain the occurrence of surprisingly severe losses recently from fields planted with *Rhizoctonia*-resistant cultivars.

There have also been a number of very positive and encouraging aspects derived indirectly from the trials. Since 1997, more effective cultivar selection coupled with the application of genetic traits to mediate disease and insect pressure has helped to increase root yields in the region by nearly 7 metric tons/ha and sugar content by 0.5%. Over 3,200 ha in Nebraska have now been put back into production, and the net result of this project has been to help reverse the state's sugar beet acreage decline begun in the mid-1990s.

This project has also helped the industry by demonstrating that yield and quality improvements can be achieved, regardless of the production problem. This has resulted in a more positive and optimistic outlook from the perspectives of growers, the seed industry, and sugar processors. The industry in the region is currently undergoing a major change. The Rocky Mountain Growers Cooperative is now in place with a proposal for six grower-owned factories, to be located in Colorado, Montana, Nebraska, and Wyoming, which were formally under the control of the Western Sugar Company.

We have concluded that the selection process must involve accessing and assimilating as much information about cultivar

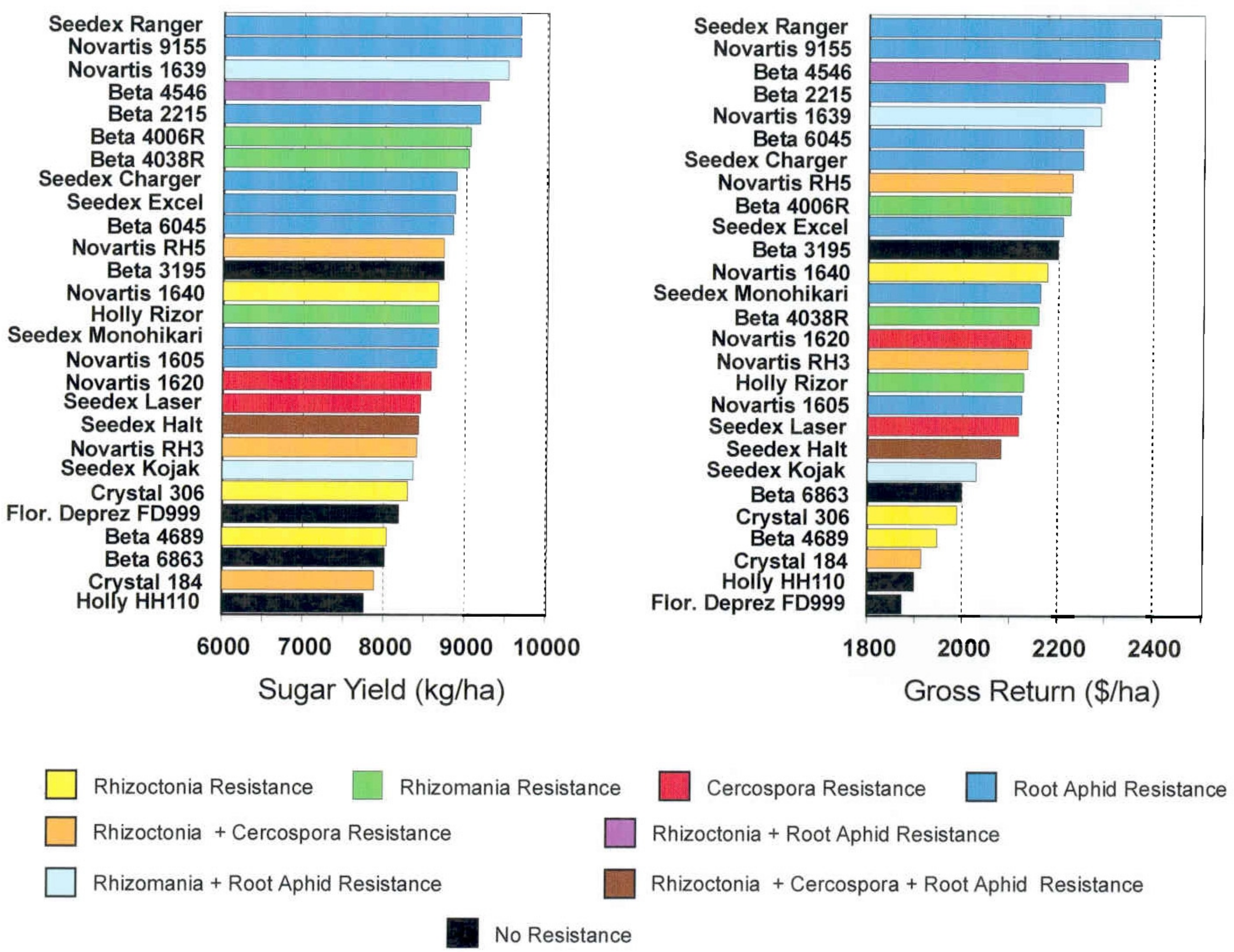
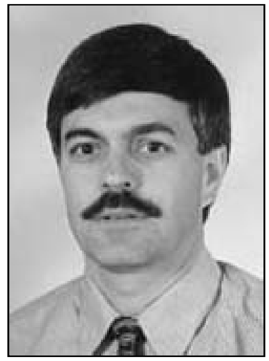
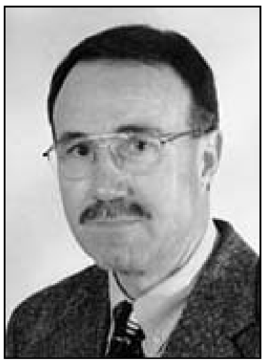


Fig. 17. Sugar yield and gross return for 27 cultivars common to 1999-2000 University of Nebraska cultivar trials. Values are averaged over 12 sites. Gross return values are based on a net selling price of $23.50/cwt of processed sugar and are calculated from the following formula: $31.77/ton of clean beet roots (plus or minus) $0.34/ton for each 0.1% sugar content above or below the base 14% sugar content, respectively.

R. M. Harveson



G. L. Hein



J. A. Smith

R. G. Wilson

C. D. Yonts

Dr. Harveson is an assistant professor in the Department of Plant Pathology at the University of Nebraska. He received his Ph.D. in 1999 from the University of Florida and began his current appointment located at the Panhandle Research and Extension Center in that same year. He received an M.S. degree in plant pathology in 1989 from Texas A&M University. He then worked for 2 years for the University of Florida as a diagnostician and manager of the plant disease diagnostic clinic at the Southwestern Florida Research and Education Center in Immokalee. From 1991 to 1995, he was employed as a research associate with the Texas Agricultural Experiment Station in Amarillo working on diseases of sugar beets and wheat. His appointment involves 50% research and 50% extension, with statewide programming responsibility for diseases of specialty crops in Nebraska, including sugar beets, dry-edible beans, potatoes, sunflowers, proso millet, chickpeas, and chicory. His research program focuses on integrated and applied methods for disease management, with an emphasis on soilborne diseases of sugar beets and dry beans.

Dr. Hein is a professor in the Department of Entomology at the University of Nebraska, and is stationed at the Panhandle Research and Extension Center in Scottsbluff. His responsibilities include a 50/50 research/extension appointment developing integrated management strategies for regional insect pests of wheat, dry beans, and sugar beets. Recent research projects have focused on sugar beet and root aphid damage relationships and virus–vector relationships of wheat streak mosaic virus and the wheat curl mite. He received a Ph.D. from Iowa State University in 1984 and joined the faculty at the University of Nebraska in 1988.

Mr. Smith is a professor in the Biological Systems Engineering Department at the University of Nebraska, and is located at the Panhandle Research and Extension Center in Scottsbluff. He received a B.S. in mechanical engineering from Tri-State College in 1970 and an M.S. in agricultural engineering from the University of Wyoming in 1978. He joined the University of Nebraska in 1981 with a research and extension appointment as a machinery systems engineer. His responsibilities include machinery management for the crops and cropping systems unique to the Nebraska Panhandle. His work has focused on management of field equipment for the tillage, planting, and harvesting of dry-edible beans and sugar beets.

Dr. Wilson is a professor in the Department of Agronomy and Horticulture at the University of Nebraska. He received his B.S. and M.S. from the University of Nebraska and his Ph.D. in 1975 from Washington State University. Since 1975, he has been located at the Panhandle Research and Extension Center in Scottsbluff, NE, working in the area of integrated weed control programs for sugar beets, dry beans, corn, alfalfa, and other important irrigated crops in western Nebraska. He is also a member of several research teams and provides input on agronomic practices and is an instructor for the Panhandle Center's annual crop management schools.

Mr. Yonts is an associate professor in the Biological Systems Engineering Department at the University of Nebraska. He is located at the Panhandle Research and Extension Center in Scottsbluff. His appointment as an irrigation engineer is 50% research and 50% extension. He received his B.S. and M.S. in agricultural engineering from the University of Wyoming in 1974 and 1978, respectively. He has been with the University of Nebraska for the past 27 years. Areas of research interest include irrigation water management with an emphasis on furrow and sprinkler irrigation. His work has included the impact of irrigation timing, both early and late in the growing season, on yield of sugar beets and dry beans. He has also worked extensively with surge irrigation as a method to improve furrow irrigation uniformity, and included the use of polyacrylamide (PAM) as a method to reduce irrigation-induced sediment erosion in furrow irrigation.

performance as possible, as almost any cultivar trait or characteristic can influence yields under certain conditions. To achieve maximum efficiency and profitability, growers must be aware of production problems in their fields, and learn to combine this knowledge with cultivar responses to factors such as field emergence, preplant herbicides, insect pests, and diseases. This project has been designed, conducted, and reported in order to make this type of information available to sugar beet growers in the Central High Plains and to assist them in making the most informed decision.

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