Comparisons of Soil and Seed Applied Systemic Insecticides to Control *Beet Curly Top Virus* in the San Joaquin Valley

S. R. Kaffka[1], W. M. Wintermantel[2], and R. T. Lewellen[2]

[1]Corresponding author. Department of Agronomy and Range Science, University of California, One Shields Avenue, Davis, CA 95616-8515; [2]USDA/ARS, U. S. Agricultural Research Station, 1636 E. Alisal St., Salinas, CA 93905

ABSTRACT

***Beet curly top virus* (BCTV), a gemini virus, remains a problem for farmers in the San Joaquin Valley (SJV) of California. It is spread by the beet leaf hopper (*Circulifer tenellus* Baker), which has become naturalized in the state. Recent dependence on sugarbeet cultivars without BCTV resistance has led to increased concern about the potential for a BCTV epidemic. Two trials were carried out in successive years in the western SJV to test the effects of alternative protective insecticides for control of BCTV on susceptible and resistant sugarbeet cultivars. Two rates of imidicloprid applied as a seed treatment (45 g and 90 g a.i. per 100,000 seeds) were compared to the current standard treatment of phorate applied to soil at 83.8 g a. i. per 1000 m of row, and an untreated control. Natural BCTV infection occurred in both years, but the second trial took place during a major beet leaf hopper population increase and infection occurred much earlier in crop development. Sugarbeet root and sugar yields declined linearly with increasing rates of infection (r^2 = 0.856). Yields declined because roots were significantly smaller with the non-tolerant cultivar. Sugar percentage was unaffected by insecticide treatments, but differed by cultivar. Imidicloprid and phorate provided similar levels of protection to plants, but were not able to prevent large yield losses among susceptible cultivars. Plant resistance provided more protection than systemic**

insecticides. Changes in land use in the San Joaquin Valley combined with recent adoption of high yielding but susceptible cultivars threaten the viability of sugar beet production in affected areas.

Additional key words: sugarbeet, *Beta vulgaris* L., beet leaf hopper, seed treatments, organo-phosphates, imidicloprid

B*eet curly top virus* (BCTV), a gemini virus, affects sugarbeets, tomatoes, melons, peppers, some ornamental plants grown in home gardens, other important crops, and a number of weed species in California. It is spread by the beet leafhopper (*Circulifer tenellus* Baker), which has become naturalized in the San Joaquin Valley (SJV) of California (Bennett 1971, Duffus 1983). One of the first successful plant breeding programs directed against a virus disease was established in the 1920s by the USDA to combat BCTV in California and elsewhere in the western United States by developing resitant cultivars. The first of these, open pollinated "US 1", was introduced in 1931 and was followed by many others (Bennett, 1971). Resistance for BCTV is a quantitatively inherited trait. Modern sugarbeet cultivars are hybrids usually derived from three parental lines: a multigerm pollen parent, and a monogerm F1 hybrid seed-bearing parent that is composed of a cytoplasmic male-sterile inbred and a type O inbred which preserves cytoplasmic male sterility in the female parent (Bosemark, 1993). The hybrids most resistant to BCTV have adequate levels of resistance in all three parental lines. Most of the cultivars planted in California during the last several decades possessed some curly top resistance, but most commercial varieties derived resistance from only one or two of the parental lines. Cultivars have undergone frequent changes in recent years to incorporate resistance to rhizomania caused by *Beet Necrotic Yellow Vein Virus* and for increased sugar yield. Consequently, curly top resistance must be assessed annually in cultivar evaluation trials in California and elsewhere in the western United States.

Recently, increasing numbers of acres in California have been planted to cultivars with no curly top resistance because of their superior yield. Yield increases with these BCTV-susceptible cultivars have been significant. Long term yield limitations that have persisted for several decades in California seem to have been overcome through cultivar improvement (Fig. 1). A world commercial yield record of 22,150 kg ha^{-1} of sugar was set in the Imperial Valley in 1999 from one field and 12,570 kg ha^{-1} for the factory district (Melin 1999), while in both 2000 and 2001, portions of some fields in the Imperial Valley have exceeded

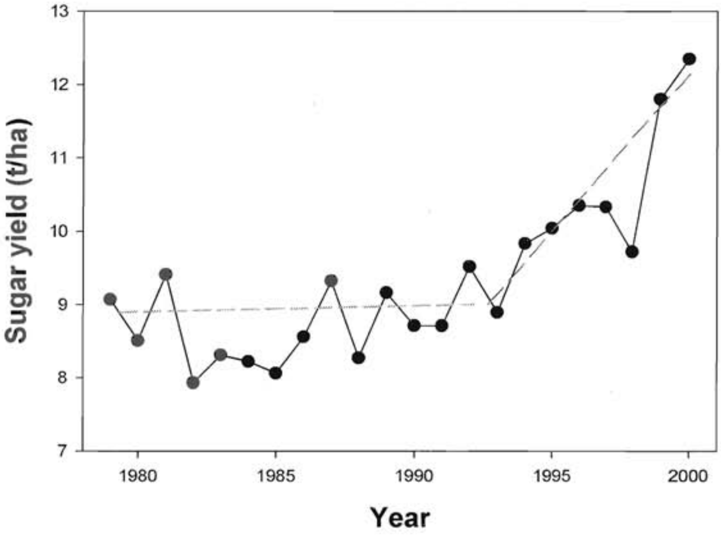

Fig. 1. Long term yield trends in California. State average sugar yields (kg/ha). California Beet Growers Association data. Stockton, California.

that record. Similarly, in the SJV yields have risen based on the use of the same non-resistant varieties. BCTV had not been observed at damaging levels in these varieties in either the Imperial or SJV until the 2000-2001 cropping season.

Older sugarbeet plants are more resistant to infection and yield loss than seedlings (Duffus and Skoyen 1977). Traditional control practices have relied on avoiding planting of beets in spring near the coastal foothills where the insects over-winter, and using insecticides, particularly phorate (Thimet®, an organo-phosphate insecticide) at planting, and several weeks later as perceived necessary (Summers et al., 2001). Because California has a Mediterranean climate, sugarbeets can be grown through the winter. Growers in the northern SJV who planted in spring and over-wintered their crop relied on insecticide and hoped for low numbers and a late arrival of the leaf hopper. In 2001, leafhopper numbers were large and arrival occurred early.

The beet leaf hopper has a migratory life cycle (Severin, 1933; Cook, 1967; Bennet, 1971). The insect, an introduction from Mediterranean regions, resides in the foothills of the western SJV during the winter months, feeding and ovipositing on winter annual weeds (Creamer et al., 1996; Duffus, 1983). In late March and April, adults and newly winged nymphs begin a migration out of the foothills, feeding on several crops. Once leafhoppers acquire the virus, they retain it for life, and are effective vectors of the disease (Duffus, 1983). Beet leaf hoppers are capable of spreading over distances of 80 to160 km in a matter of days (Severin, 1933; Bennett, 1971; Cook, 1967). Transmission is favored by larger numbers of insects and longer periods of feeding, but can occur in as little as 1 to 5 minutes of feeding by a single insect (Bennett, 1971). In late summer, they begin a return migration which is accelerated by the arrival of winter rains in late October and November.

Not all of the leaf hoppers migrate, however, and small numbers have been found in the SJV during the winter period. These small numbers have not presented a significant threat to sugarbeet producers and growers of other crops in the past, but conditions may have changed. To help manage selenium and avoid farming in areas where shallow, saline groundwater is accumulating, some farmland in the lower elevations of the western SJV is being retired from production. Land retirement is being paid for by the federal government, and is being carried out by the Westlands Water District in Fresno County, the largest irrigation district in the SJV. When these lands are retired, they are fallowed. Fallowing does not always eliminate the growth of weeds, particularly Russian thistle (*Salsola* sp.) and winter annuals which may provide very suitable over wintering habitat for the beet leaf hoppers in the center of the crop production region. The effect these fallow lands will have on the insect or on its ability to create BCTV epidemics in future years is unclear. Some control of the beet leaf hopper is provided by a California Department of Food and Agriculture program that controls the insect during the winter by spraying its natural winter nurseries in the Coast Range and Sierra Nevada foothills. The state's control program does not have the resources to manage all newly fallowed or refuge areas. Given these uncertainties, significant economic loss from BCTV remains a threat to the well-being of the state's sugarbeet industry as well as a number of other important crops.

BCTV management has become more difficult by the widespread adoption of high yielding but susceptible sugarbeet cultivars. These have been adopted to improve profits in the face of declining sugar prices. Until 2001 few recent problems with BCTV had been observed. With widespread infection present in 2001, growers are likely to increase their use of insecticides, particularly the registered organo-phosphates.

Recently, Wang et al. (1999) reported results from a greenhouse trial comparing insecticides, seedling age, and inoculation intensity on the amount of BCTV infection occurring in sugarbeet and other crops. They compared dimethoate, imidicloprid used as a seed treatment (Gaucho®), and an untreated control. Seedlings were inoculated at emergence and at 1 and 2 week intervals after the first inoculation. Inoculation intensities (numbers of leaf hoppers) were also evaluated. They found that infection was reduced most by the use of imidicloprid, and that delaying inoculation 2 or more weeks resulted in significantly lower infection rates. Organophosphate insecticides such as phorate that have been proven effective in the past for delaying or preventing curly top infection (Hills et al., 1968) may be restricted in the future as they are reevaluated under the Food Quality Protection Act. Current BCTV levels in the SJV likely will increase the use of phorate at a time when public policy objectives seek to reduce organo-phosphate use. The effectiveness of alternative insecticides at reducing infection among currently favored but susceptible cultivars under field conditions where BCTV is likely to be present needs to be evaluated. The objective of this research was to compare the effects of soil and seed applied insecticides used to control the beet leafhopper on the occurrence and severity of BCTV infection in cultivars with different levels of reaction, and on sugarbeet yield in the presence of natural levels of BCTV infection.

MATERIALS AND METHODS

One susceptible (cv. SS-Rifle) and one moderately resistant (cv. SS781R) cultivar were planted on March 31, 2000 at a site located at West Hills College (WHC) in Coalinga, California, and on April 24, 2001 at the U. C. Westide Research and Extension Center (WSREC) in the western San Joaquin Valley. The WHC site is located in the foothill overwintering areas of the BCTV vector, the beet leaf hopper, and previous curly top trials at this location have been successful (Hills et al., 1968). The WSREC site lies directly in the path of early spring leaf hopper migration from the surrounding foothills (Severin, 1933). Each cultivar was treated either with imidicloprid as a seed treatment at two rates (45 and 90 g per unit of seed—100,000 seeds) or with phorate at the labeled rate (83.8 g a.i. per 1000 m of row) applied at planting to the soil, placed directly beneath the seed line. Astec Inc. (Sheridan, WY) applied the imidicloprid with a polymer coating. A control without any seed or soil treatment was also included for each cultivar. Treatments were replicated five times in a randomized complete block design. Plots included four rows 75 cm (30 inches) wide and 9.1 m (30 feet) long and were separated by a bare row or border on all sides. To insure adequate curly top inoculum at each site, a number of curly top infected plants were produced at the USDA/ARS facility in Salinas and then transplanted at both research sites throughout the plot area.

In 2000, seedlings and growing plants were inspected throughout the growing season for curly top symptoms but scored for curly top infection only once at harvest using a scale modified from the one developed by the Beet Sugar Development Foundation in its curly top nursery in Idaho (Table 1). In 2001, plots were scored four times during

Table 1. Curly top disease severity rating system.

Rating	Description
1	Vein clearing of the heart leaves, slight pimpling of veins on the underside of leaves
3	Center few whorls of leaves with curling edges
5	Slight stunting, severe leaf curling-less than half of the upper leaf surface visible due to curling, most of the larger leaves still erect
7	Severe stunting, yellowing, leaves prostrate and some leaves dead
9	Plant dead

Modified from the BSDF scale. Images for each rating can be viewed at www.ars-grin.gov

the growing season. Plots were given an overall rating and the ratings were averaged by treatment. The center two rows of the four-row plots were harvested by hand on August 29, 2000 at WHC and on August 26, 2001 at the WSREC site. Roots were weighed and analyzed for sugar percent and impurities by the lab at the Spreckels Sugar Company near Mendota. Treatment means were compared using single degree of freedom contrasts for the treatment comparisons of interest (SAS, Inc. v 7.0, Cary, North Carolina, 2000). For comparison in 2001, yields of US H11, the industry standard for BCTV resistance, were collected from an adjacent cultivar evaluation trial with planting dates and management similar to the WSREC trial. At WHC, water application was uneven among some of the plots. For this reason, data were analyzed by year and greater emphasis was placed on results from 2001 in this report due to the greater severity of BCTV in that year.

RESULTS

BCTV infection occurred in both trials. Infection was much more severe at WSREC in 2001, than at WHC in 2000, despite the proximity of WHC to overwintering areas of the beet leaf hopper (Severin, 1933; Bennet, 1971). Curly top infection levels in 2001 in the San Joaquin Valley were considered the most severe since 1973. Infection was observed on seedlings in all plots within 5 to 6 weeks of emergence at WSREC, while widespread infection was not observed at WHC until the middle of the summer, approximately 90 to 95 days post-emergence. Damage level ratings were closely correlated ($r^2 = 0.856$) with root yield loss (Fig. 2). Increasing severity of infection with time was quantified

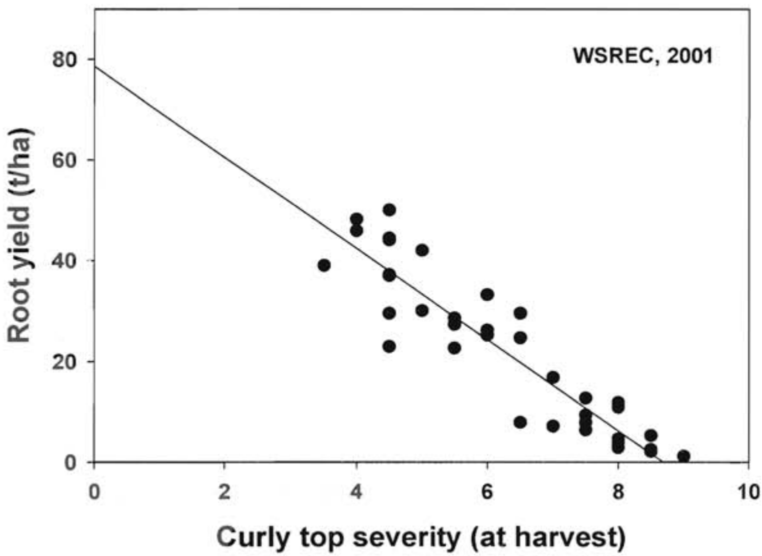

Fig. 2. Root yield and curly top disease ratings in 2001 at the UC WSREC. Yield (t/ha) = 78.6 t - 9.1 t per disease unit ($r^2 = 0.856$). The equivalent equation for gross sugar yields is: sugar yield (kg/ha) = 11410 kg -1310 kg per disease unit, ($r^2 = 0.85$).

for both cultivars in 2001 (Fig. 3). Infection and damage were more severe on the susceptible cultivar and progressed approximately twice as fast, based on regression analysis of mean infection levels (Fig. 3). For both cultivars, infection developed most rapidly during the first 70 days after emergence, and then increased slowly afterwards (Fig. 3). Rated infection levels at harvest were similar in both years (Fig. 3).

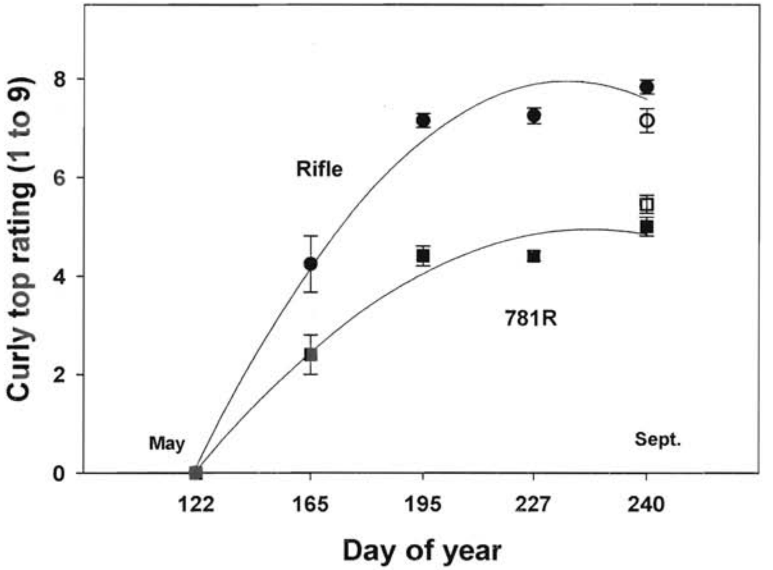

Fig. 3. Increasing severity of BCTV infection during the growing season in 2001. Open symbols are final curly top ratings in 2000 at the WHC site. Ratings were made only at harvest that year. Rifle (susceptible), 781R (tolerant). The regression equations for the two culitvars are for 781R: $y = 0.04 + 2.8\ x - 0.4\ x^2$ ($R^2 = 0.979$); or Rifle: $y = 0.1 + 4.76\ x - 0.7\ x^2$ ($R^2 = 0.985$). Vertical lines are standard errors.

In both years, cultivars influenced overall crop performance significantly more than seed or soil treatments (Tables 2 and 3). The susceptible variety, Rifle, exhibited more severe symptoms than 781R, resulting in significantly smaller roots (Tables 2 and 3) and lower sugar yields (Fig. 4a and b). Sugar percent in roots was not affected by curly top infection (Fig. 5), and reflected inherent differences between the cultivars (Tables 2 and 3). Compared to untreated controls, phorate and imidicloprid treatments resulted in significantly greater yields (Tables 2 and 3), but in the case of the susceptible cultivar, yields were much below average values for the state (Fig. 4, Fig. 1). In both years, imidicloprid treatments were at least as effective as phorate (Fig. 4).

Root yields of cultivar 781R were approximately 70 % of US H11, the industry standard for BCTV resistance (Fig. 6). This is the reverse of normal performance under disease free conditions (Fig. 6 insert).

Table 2. Single degree of freedom contrasts between treatments, WHS, 2000.

Variable	Contrast	Mean Square	F	Pr > F
Weight per root	1. Rifle vs 781R	1.003	41.86	<0.0001
(kg/root)	2. Control vs phorate	0.0222	0.93	0.3446
	3. Control vs imidicloprid	0.046	2.24	0.1478
	4. Imidicloprid rates	0.0535	1.92	0.1785
Sugar %	5. Rifle vs 781R	9.02	9.41	0.0053
	6. Control vs phorate	1.50	1.57	0.2227
	7. Control vs imidicloprid	0.79	0.83	0.3725
	8. Imidicloprid rates	0.212	0.22	0.6124
Gross sugar	9. Rifle vs 781R	12.556	15.42	0.0006
(kg/ha)	10. Control vs phorate	2.502	3.07	0.0924
	11. Control vs imidicloprid	12.103	14.87	0.0008
	12. Imidicloprid rates	2.766	3.40	0.077

Table 3. Single degree of freedom contrasts (WSREC site, 2001)

Variable	Contrast	Mean Square	F	Pr > F
Weight per root	1. Rifle vs 781R	1.87	194.3	<0.0001
(kg/root)	2. Control vs phorate	0.0470	4.85	0.0374
	3. Control vs imidicloprid	0.1168	12.12	0.0019
	4. Imidicloprid rates	0.00005	0.01	0.9429
Sugar %	5. Rifle vs 781R	12.81	29.08	<0.0001
	6. Control vs phorate	0.034	0.08	0.7847
	7. Control vs imidicloprid	0.122	0.28	0.6043
	8. Imidicloprid rates	0.00008	0.00	0.9894
Gross sugar	9. Rifle vs 781R	158.17	178.57	<0.0001
(kg/ha)	10. Control vs phorate	7.78	8.79	0.0068
	11. Control vs imidicloprid	15.1	17.05	0.0004
	12. Imidicloprid rates	0.13	0.15	0.7050

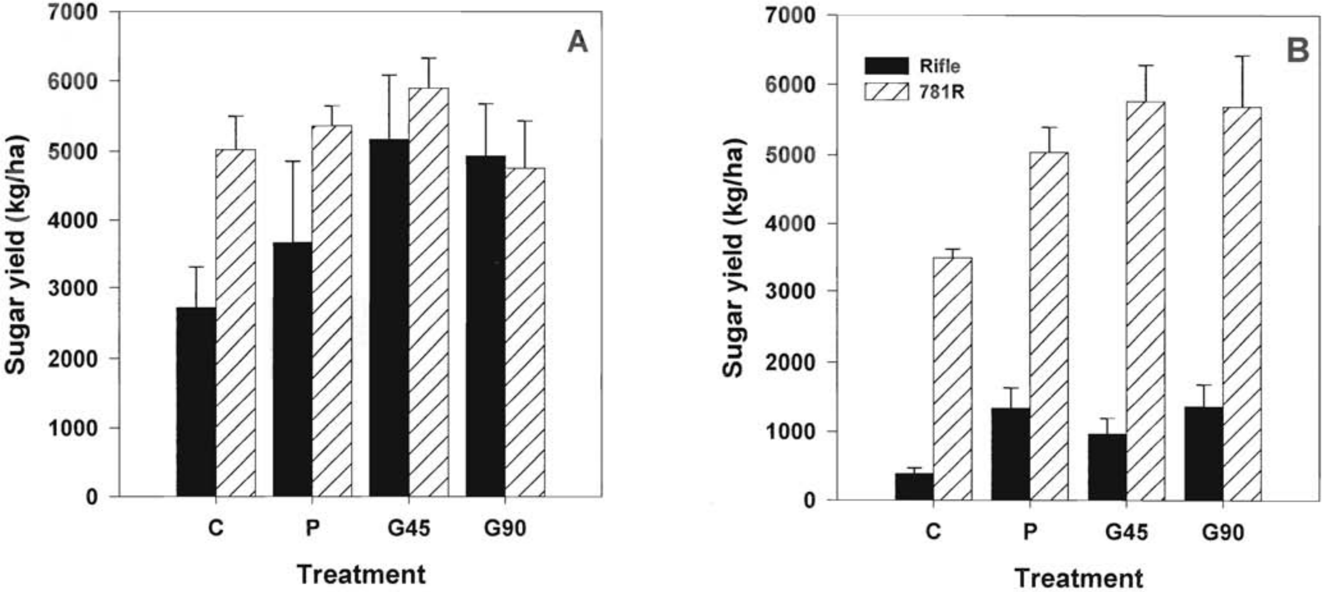

Fig. 4A. Average gross sugar yields (kg/ha) compared by treatments at the WHC site (2000). **B.** at the WSREC site (2001). C = control, P = Phorate, G45 = imidicloprid at 45 g a.i. per 100,000 seeds, G90 = imidicloprid at 90 g a.i. per 100,000 seeds. Vertical lines are standard errors.

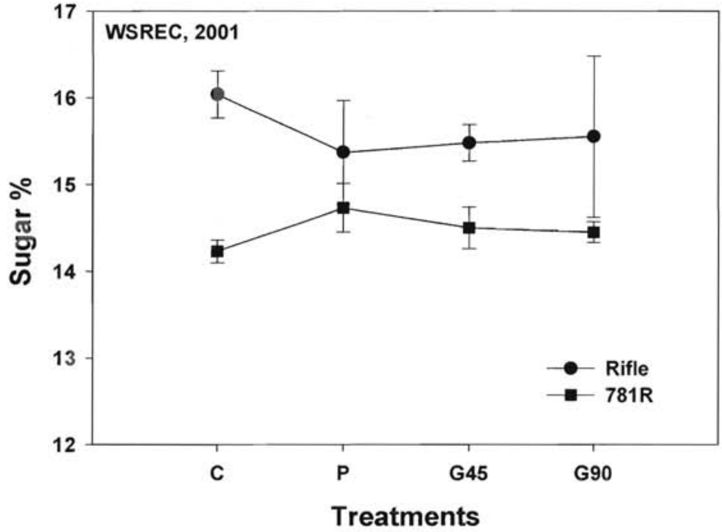

Fig. 5. Sugar % by cultivar at the WSREC site (2001). Similar results occurred in 2000 (not shown). See Figure 4 for symbols.

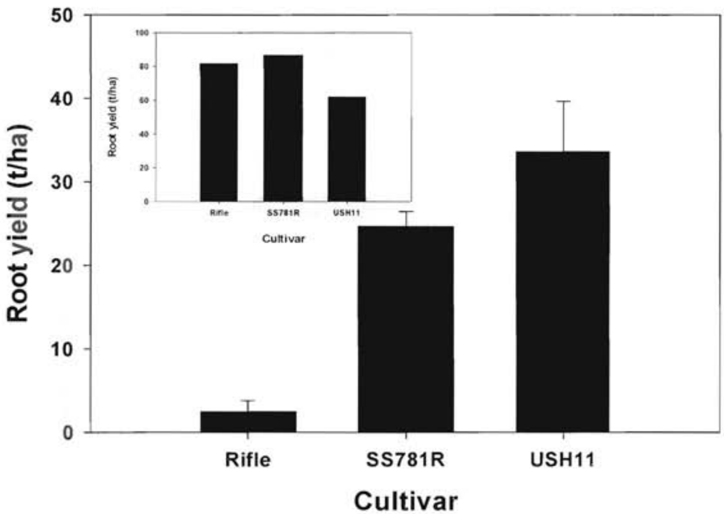

Fig. 6. Root yields of untreated test cultivars and US H11, which was grown adjacent to the WSREC site under similar conditions (2001). The smaller figure (insert) compares the root yields of the same three cultivars under disease free conditions in 1999, the last year all three cultivars were tested in coded variety trials. Data are from the Imperial Valley, where curly top symptoms were not observed. (R. Lewellen unpublished data).

DISCUSSION

In these trials, imidicloprid provided some protection for the susceptible line at the WHC site, where infection occurred at a later crop growth stage. In both years, imidicloprid at 45 g was as effective as 90 grams and appears to be an adequate substitute for phorate. Plant protection materials are much less effective at preventing loss to curly top, however, than varietal resistance in the presence of substantial infection pressure, especially early in crop development. Yield differences were larger between cultivars than between treatments (Tables 2 and 3, Fig. 4). A cultivar with high levels of resistance (USH 11), that yields poorly under disease free conditions, yielded more than a newer, high-yielding cultivar with less resistance in the presence of early infection (Fig. 6). Varietal resistance remains the most effective defense against loss to this chronic virus disease. This is supported by the strength of the contrasts between cultivars and the high levels of significance observed (Tables 2 and 3). In the face of severe, early infection, effective defense against significant yield loss is not available for the non-resistant cultivars currently favored by growers.

Despite differences in disease pressure in 2000 and 2001, results were largely similar. Most of the contrasts were similar between years. Because infection occurred later in crop development, and because irrigation was somewhat uneven, mean differences were less pronounced in 2000 than in 2001 resulting in lower significance values. Three of the contrasts, however, differed with respect to significance between years. These are contrasts 2, 3, and 12 (Tables 2 and 3). Root weights were smaller in control plots without insecticides in 2000, however differences were not significant. These differences were significant in 2001. This is likely due to the later infection in 2000 (Duffus and Skoyen, 1977). Reasons for the significant differences between imidicloprid rates in 2000 with respect to gross sugar yield (Table 2, contrast 12) are not apparent and may have resulted from non-uniform irrigation in 2000.

Seedling emergence occurred during a severe leaf hopper migration and BCTV infection in 2001. In addition, 2001 was an exceptionally severe BCTV year. These conditions foreshadow possible problems in future years in the spring plant-spring harvest areas of the northern SJV. Chronic infection pressure may exist in the valley now that more beet leaf hopper refugia have been created inadvertently in the center of the SJV. Crops are planted in fall in the western San Joaquin Valley when leaf hopper populations typically are smaller. Fall planting in the western San Joaquin Valley has been an effective defense against early infection until 2001 and may be effective in the future. Results from this trial indicate what can be expected under the most severe conditions likely to be experienced and they provide a benchmark for the effectiveness of available control measures and the performance of current sugarbeet cultivars.

Imidicloprid provides some protection for resistant cultivars and for susceptible cultivars if infection does not occur too early in plant development, and if infection is not uniform. In these field trials, imidicloprid performed as well or better than phorate, the long term industry standard. Imidicloprid is used at much lower rates than phorate and when applied as a seed treatment, reduces farmer exposure. It appears to be an adequate substitute for phorate under field conditions in the SJV. Farmers need cultivars with both high yielding characteristics and some BCTV resistance. These are not likely to appear for several years, however, so the use of imidicloprid as a seed treatment is an effective alternative to phorate.

This research showed a strong correlation between disease rating and yield (Fig. 2). This scale (Table 1) is used in trials throughout the western United States to evaluate new cultivars proposed for commercial production. Often, however, seed committees and submitting seed companies question whether the scale is biologically and agronomically valid. These findings suggest that cultivar performance under disease conditions is closely related to reaction to BCTV as measured by this scale. Our results agreed with those reported by Gallian and Stanger (1993) from the Oregon-Idaho region. They reported a decline of 12.9 t per disease unit under conditions of natural infection, compared to the 9.1 t observed here.

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