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Phytotoxic effects of salinity, imazethapyr, and chlorimuron on selected weed species

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Greenhouse experiments were conducted to determine the effect of salinity, imazethapyr, and chlorimuron on weed growth. Five species, barnyardgrass, common cocklebur, ivyleaf morningglory, common purslane, and yellow nutsedge, were grown in potting soil and irrigated with nonsaline (EC $\sim$ 2 dS m^{-1}) or sulfate-dominated saline (EC $\sim$ 7 dS m^{-1}) nutrient solution. Plants were treated after emergence with imazethapyr (Pursuit formulation) at 70 g ae ha^{-1} or chlorimuron ethyl (Classic formulation) at 8.8 g ai ha^{-1}. Results indicated that irrigation with saline water had no overall effect on the growth or survival of most tested weed species. Growth of yellow nutsedge (maximum height and stem diameter) was reduced for plants irrigated with saline water. Observed growth and survival trends in saline and nonsaline treatments were consistent with information on the herbicide label. Complete control of common purslane was not achieved by either chlorimuron or imazethapyr. Growth and survival of ivyleaf morningglory and yellow nutsedge were greater when plants were treated with imazethapyr than when treated with chlorimuron, whereas for barnyardgrass, growth and survival were significantly greater when plants were treated with chlorimuron. Both herbicides affected common cocklebur growth and survival in a similar way. For all tested species, most surviving plants were not vigorous and would not be highly competitive with crop plants. The results of these experiments suggest that weed control information mentioned on the labels for these herbicide formulations will not require modification for moderately saline soils.

Nomenclature: Chlorimuron; imazethapyr; yellow nutsedge, *Cyperus esculentus* L. CYPES; barnyardgrass, *Echinochloa crus-galli* (L.) Beauv. ECHCG; ivyleaf morningglory, *Ipomoea hederacea* (L.) Jacq. IPOHE; common purslane, *Portulaca oleracea* L. POROL; common cocklebur, *Xanthium strumarium* L. XANST.

Key words: Plant growth, efficacy, growth regulator, imidazolinone, sulfonylurea.

The herbicides imazethapyr and chlorimuron are often used after emergence for the control of weeds in legumes, especially soybean [*Glycine max* (L.) Merr.] and peanut (*Arachis hypogaea* L.). Imazethapyr and chlorimuron are selective herbicides that inhibit acetohydroxy acid synthase and the synthesis of branched chain amino acids. Selectivity is based on the rate or extent of metabolism (detoxification) of the active ingredient (Brown 1990; Shaner and Mallipudi 1991). Both imazethapyr and chlorimuron have been shown to decrease protein and branched-chain amino acid content of legumes (Scarponi et al. 1997).

Depending on the herbicide, plant species, and environmental conditions, stressed plants may have different susceptibility to herbicide damage than do nonstressed plants (Gerber et al. 1983; Reynolds et al. 1988). Moisture stress may affect the absorption, translocation, and phytotoxicity of postemergence herbicides. Water deficit was shown to reduce the immediate (24 h) absorption of imazamethabenz-methyl but had little effect on longer-term absorption, translocation, and plant growth (Xie et al. 1993, 1996). Some experiments have indicated that the efficacy of postemergence application of imazethapyr may be reduced in soils with insufficient or excessive soil moisture (Ackley et al. 1996; Zhang et al. 2001). Postemergence chlorimuron efficacy appears to be less affected by soil moisture (Ackley et al. 1996).

Multiple stressors affecting plant growth and metabolism have the potential to result in increased (or decreased) plant response. Limited information exists on the response of weeds to a combination of salinity and herbicide treatment. The phytotoxicity of both imazethapyr and chlorimuron is increased when applied with a nonionic surfactant and inorganic salt. Ammonium sulfate is used routinely and has been observed to increase imazethapyr uptake (Kent et al. 1991a) and efficacy (Kent et al. 1991b; Wills and McWhorter 1987).

Although field studies indicate the net response to herbicides under integrated environmental conditions, carefully controlled laboratory studies are required to isolate and investigate individual factors. In these controlled greenhouse experiments, we examined the effect of salinization, imazethapyr, and chlorimuron on the growth and survival of a variety of weed species (three broadleaved weeds, one grass, and one sedge). A large proportion of irrigated agricultural land is salt affected, and the reuse of saline drainage water to irrigate salt-tolerant crops is receiving increasing attention (Pitman and Läuchli 2002). It is likely that crops with sufficient salt tolerance will be planted on unreclaimed saline soils (Pitman and Läuchli 2002). These experiments were conducted to indicate herbicide efficacy to a variety of weed types in moderately saline soils to evaluate the need for a change in weed management in such soils.

Table 1. Average plant growth stage (mean ± standard error) at time of herbicide application.

Species	Nonsalinized		Salinized	
	Height (cm)	Growth stage	Height (cm)	Growth stage
Experiment 1				
Barnyardgrass	13.0 ± 0.4	3.20 ± 0.07[a]	12.4 ± 0.5	3.42 ± 0.08[a]
Cocklebur	1.9 ± 0.1	1.7 ± 0.1[b]	2.5 ± 0.3	2.0 ± 0.2[b]
Ivyleaf morningglory	1.16 ± 0.04	1.0 ± 0.0[b]	0.91 ± 0.09	1.0 ± 0.0[b]
Common purslane	6.8 ± 0.2	3.55 ± 0.08[b]	7.7 ± 0.3	3.5 ± 0.1[b]
Yellow nutsedge	9.1 ± 0.2	2.54 ± 0.06[c]	3.6 ± 0.3	1.54 ± 0.06[c]
Experiment 2				
Barnyardgrass	14.8 ± 0.5	3.05 ± 0.03[a]	8.8 ± 0.4	2.74 ± 0.07[a]
Cocklebur	2.08 ± 0.08	1.93 ± 0.05[b]	2.1 ± 0.3	1.8 ± 0.1[b]
Ivyleaf morningglory	1.67 ± 0.05	1.0 ± 0.0[b]	1.32 ± 0.04	1.0 ± 0.0[b]
Common purslane	8.5 ± 0.2	3.09 ± 0.06[b]	8.5 ± 0.1	3.13 ± 0.05[b]
Yellow nutsedge	20.4 ± 0.5	3.7 ± 0.1[c]	16.8 ± 0.4	3.1 ± 0.1[c]

[a] Number of leaves (measured as in Haun 1973).
[b] Number of nodes.
[c] Diameter measured at base (mm).

Materials and Methods

Weed seeds that were purchased for use in these experiments were[1]: barnyardgrass, common cocklebur, ivyleaf morningglory, common purslane, and yellow nutsedge (nutlets). The common purslane used in this study was a fully erect variety, which has a large leaf area compared with the prostrate form (Grieve and Suarez 1997). Seeds were planted in potting mix[2] in 5-cm pots. Potting mix consisted of 50% (by volume) plaster sand, 25% peat moss, and 25% bark with limestone flour and micronutrients added. Pots were seated in a sand bed in tanks (59 cm long by 43 cm wide by 15 cm deep) so that 17 to 18 replicate pots of two or three weed species (34 to 54 pots) were included in each tank. Pots were positioned randomly, and plants were germinated and grown under controlled greenhouse conditions.

Experiment 1 was conducted from May to July 2000. During the entire experiment (planting to harvest), the mean daytime temperature was 30 C with a range of 18 to 41 C. Nighttime temperatures ranged from 18 to 29 C with a mean of 23 C. Relative humidity ranged from 42 to 48% (mean 45%) both day and night. The entire experiment was replicated the following year, from July to September 2001. During Experiment 2, the mean daytime temperature was 29 C with a range of 19 to 38 C, and nighttime temperatures ranged from 19 to 29 C with a mean of 22 C. The mean relative humidity during the experiment was 45% and ranged from 41 to 48%.

Pots were irrigated with half-strength Hoagland's solution (nonsaline water treatment, EC ~ 2 dS m^{-1}) or half-strength Hoagland's solution plus (in meq L^{-1}) $MgSO_4 \cdot 7H_2O$, 6.6; Na_2SO_4, 23.3; $CaCl_2$, 7.6; NaCl, 6.1; and KNO_3, 4.0 (salinized treatment, EC ~ 7 dS m^{-1}). This solution was designed to simulate saline drainage water commonly present in the San Joaquin Valley of California and also may represent the salt composition in prairie soils in the United States and Canada, where the salts include chlorides and sulfates. Irrigation water was contained in 60-L reservoirs, and two sand tanks were placed on top of each reservoir. A total of six reservoirs was used, three containing 2 dS m^{-1} water and three containing 7 dS m^{-1} water. Two or three weed species were assigned to each sand tank, and sand tanks were placed on reservoirs randomly within salinity treatments.

Irrigation was accomplished by bubbling air into delivery tubes inside the reservoir to drive water up to the surface and into the sand tank. Each sand tank had a small drainage hole in the bottom so that leachate drained back into the reservoirs. The maximum water level was maintained by a second drain several millimeters above the rim of the pots. Each irrigation was for 30 min, allowing for re-equilibration between the soil water and irrigation water so that salinity in the pots was relatively constant. Plants were maintained under nonsalinized or salinized conditions from planting to harvest. Tanks were irrigated as necessary, generally twice per week during germination and early growth and every day later in the experiment. The salinity of the irrigation water was maintained throughout the experiment by addition of tap water, and the pH was maintained at ~ 7 by addition of sulfuric acid.

Formulated herbicide was donated by the manufacturers. Chlorimuron (Classic)[3] was applied at 8.8 g ai ha^{-1}, and at this application rate, it is labeled for control of *Xanthium* spp. $<$ 15 cm tall, ivyleaf morningglory $<$ 5 cm in length, and yellow nutsedge $<$ 7.6 cm tall. The ammonium salt of imazethapyr (Pursuit)[4] was applied at 70 g ae ha^{-1}. At this application rate, it is labeled for use in soybean for postemergence control of *Xanthium* spp. (2 to 20 cm tall) and common purslane with no size restriction and for reduced competition from barnyardgrass and yellow nutsedge (2 to 8 cm tall) and from ivyleaf morningglory (2 to 5 cm long). According to the directions on the herbicide label, formulated herbicides were applied with 2.8 kg ha^{-1} ammonium sulfate and 2.3 L ha^{-1} nonionic surfactant.[5] A low-volume sprayer was used to apply 470 L ha^{-1} herbicide solution uniformly to the treated area, with much of the solution intercepted by the leaf surfaces. Controls consisted of a solution of 2.8 kg ha^{-1} ammonium sulfate and 2.3 L ha^{-1} nonionic surfactant (tank mix without the herbicide) applied at 470 L ha^{-1}. The plant growth stages at the time of herbicide application are given in Table 1. A single herbicide was applied to the entire tank (containing 34 to 54 plants and two or three species) to eliminate potential exposure of nontreated plants to herbicides in the leachate. Herbicide treatments were randomly assigned to the tanks. Tanks were shielded during treatment to prevent drift. Plants were irrigated ~ 4 h before herbicide application and were not irrigated again until > 40 h (Experiment 1) or > 24 h (Experiment 2) after herbicide application.

Plant growth parameters were measured before herbicide application and continued at least weekly until termination of the experiment (20 to 31 d after treatment). Plant height was measured from the soil surface to the extended tip of the tallest leaf (for barnyardgrass and yellow nutsedge) or to the plant apex (for all other species). For common cocklebur, ivyleaf morningglory, and common purslane, the number of nodes on the primary stem was counted, including the cotyledonary node. For barnyardgrass, the leaf development was rated following the method of Haun (1973). Stem diameter of yellow nutsedge was measured at the base of the plant using calipers. Plant survival was monitored throughout the experiment. Plants were considered to have survived if at least one leaf was turgid and partly green and were considered dead only when all leaves were necrotic.

Statistical Analysis

The experiment was analyzed as a split-plot design with salinity and herbicide treatments serving as the main plot effects and the weed species representing the subplot effect. Two salinity levels (2 and 7 dS m^{-1}) and three herbicide treatments (chlorimuron, imazethapyr, and control or no herbicide) were randomly assigned to the main plot, and five weed species were assigned to the subplot units. The design was replicated across 2 yr. In this design, the year represents a random block effect, whereas the nested–crossed year (salt × herbicide) effect represents the appropriate main plot error term. Multiple species-specific samples (approximately 18 per species) were grown in each tank and observed over time. Measurements of the maximum height of each sample, the maximum number of nodes or leaves of each sample, and the plant survival status 20 d after herbicide application were subjected to statistical analysis. All individual species-specific samples were combined into average estimates at the end of each experiment. This resulted in a total of 60 (2 salinities × 3 herbicide treatments × 5 species × 2 yr) observations for each response measurement.

The entire set of average maximum plant height and node count data was first analyzed using the following split-plot model:

$$y_{ijkm} = \mu + T_i + S_j + H_k + SH_{jk} + T(SH)_{ijk} + P_m + SP_{jm} + HP_{km} + SHP_{jkm} + \varepsilon \quad [1]$$

where T represents the random year effect (i = 1, 2), S represents the fixed main plot salinity effect (j = 1, 2), H represents the fixed main plot herbicide effect (k = 1, 2, 3), and P represents the fixed subplot weed species effect (m = 1, 2, . . . , 5). In Equation 1, μ represents the overall mean response level, the $T(SH)_{ijk}$ effect represents the main plot error term for testing the salt and herbicide effects, and ε represents the subplot error term for testing the plant effects (Montgomery 1997). This model was estimated using the MIXED and general linear model (GLM) procedures in SAS (SAS Institute 1999) following the methodology of Littell et al. (1996). The MIXED procedure was used to generate all the F-test statistics, and the GLM procedure was used to generate some basic model summary statistics (r^2 and percentage of coefficient of variance [CV]) and also to facilitate analysis of the model residuals.

The species-specific maximum plant height and node count effects were next analyzed using a randomized complete block (RCB) model:

$$y_{ijk} = \mu + T_i + S_j + H_k + \varepsilon \quad [2]$$

where all the main effect terms are defined as before, except that the SH_{jk} interaction effect was assumed to be negligible and thus pooled into the main plot error term (ε). This model was used to quantify the specific salinity and herbicide effects on each weed species because the split-plot test statistics confirmed that the five weed species responded to these effects in dissimilar ways. This model was estimated using the GLM procedure, and Tukey's studentized range test was used to differentiate between the various salinity and herbicide effects (Dunnett 1980).

A reduced set of plant survival rate data also was analyzed using the previously defined split-plot model, with two modifications. First, because nearly all the controls (no herbicide treatment) survived to the end of the experiment, these observations were removed to compare only herbicide-treated weeds. This reduced the effective sample size from 60 to 40 observations. Second, the remaining average survival rates were logit transformed to induce approximate normality; i.e.,

$$y = \log\left[\frac{SR}{100 - SR}\right] \quad [3]$$

where SR represents the observed average survival rate. When the recorded rates were 0 (1 case) or 100% (10 cases), the SR values were redefined to be either 1 or 99%, respectively. This latter split-plot model also was estimated using the MIXED and GLM procedures in SAS (SAS Institute 1999) and used to produce predicted survival rate means and 95% confidence intervals for specific herbicide–weed species combinations.

Results and Discussion

Morphological Effects of Herbicide Application

Sublethal morphological effects of chlorimuron in broadleaved plants include reduced stem internode length, leaf burn, reduced biomass, and reduced leaf area (Halloway and Shaw 1995; Patterson et al. 1990; Wilcut et al. 1989). Symptoms of imazethapyr injury to broadleaved plants include stunted growth of shoots and roots, chlorosis, necrosis, abnormal root development, an alteration in the number and size of root nodules, and decreased specific leaf area (Dusky and Stall 1996; Fielding and Stoller 1990; Hart et al. 1997; Ivany and Reddin 2002; Royuela et al. 2000). Symptoms of imazethapyr injury to grasses include reduced plant height, reduced biomass, chlorosis, and necrosis (Johnson 1989; Wilson 1995; Zhang et al. 2001). Symptoms of injury to nutsedge caused by chlorimuron and imazethapyr include reduced biomass, reduced plant height, chlorosis, and leaf necrosis (Ackley et al. 1996; Jordan 1996; Reddy and Bendixen 1988; Richburg et al. 1993).

In these experiments, multiple shoots formed at the apex,

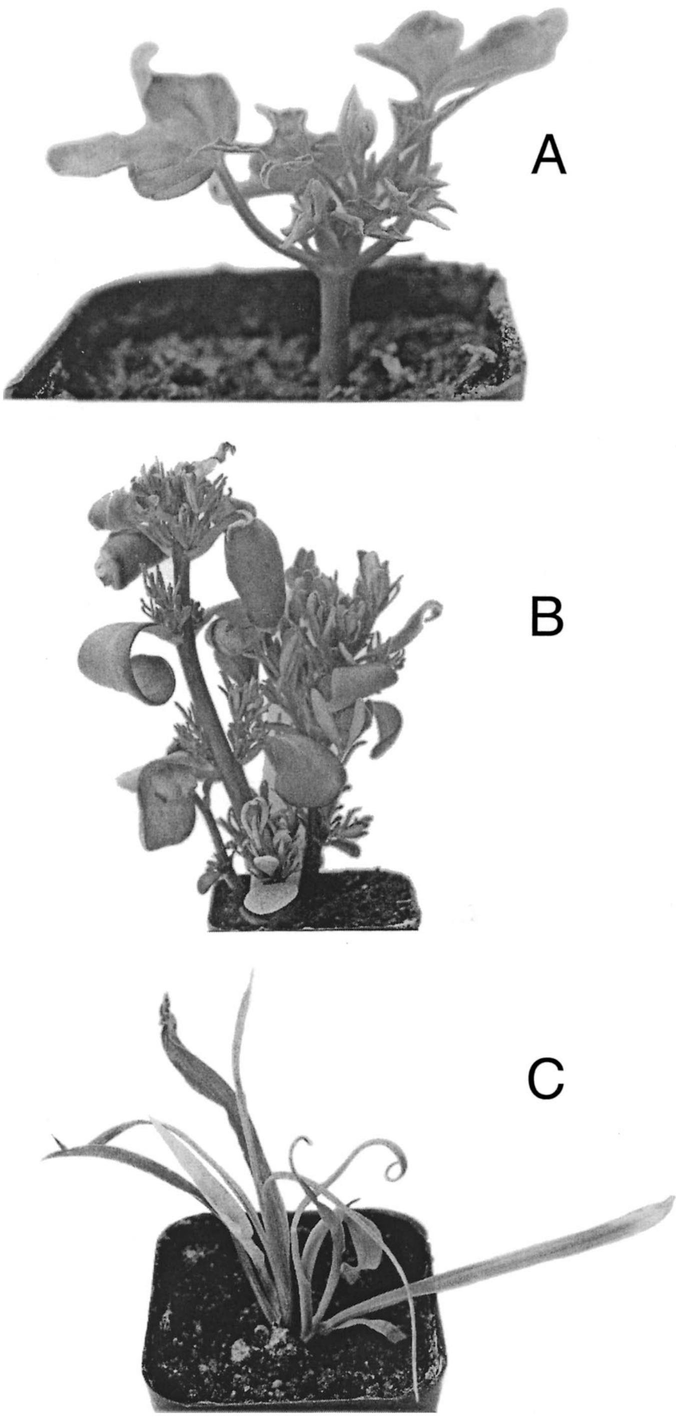

FIGURE 1. Plant development 20 d after herbicide application demonstrating (1) increase in the number of nodes or leaves with no increase in plant height and (2) small and misshapen leaves resulting from herbicide treatment. (A) Ivyleaf morningglory treated with imazethapyr; (B) common purslane treated with imazethapyr; (C) barnyardgrass treated with chlorimuron. Common purslane treated with chlorimuron showed similar effects. The larger leaves on ivyleaf morningglory and common purslane were formed before herbicide application.

and leaves formed subsequent to herbicide application were small and misshapen (Figures 1A–C). These effects occurred in both nonsalinized and salinized treatments. In both experiments, a large proportion (up to 80%) of the ivyleaf morningglory treated with imazethapyr and chlorimuron formed multiple (~ 10) shoots at the growing point (Figure 1A). This formation of adventitious buds occurred beginning at ~ 14 d after treatment and was not observed in ivyleaf morningglory not treated with herbicide.

For common purslane, ~ 26% of the imazethapyr-treated plants and 38% of the chlorimuron-treated plants formed at least two shoots of approximately equal height after herbicide application in both experiments (Figure 1B). These effects were observed within 10 d after herbicide application. No control plants demonstrated the development of multiple shoots.

Symptoms of chlorimuron injury in barnyardgrass included an increase in the number of shoots at the growing point and misshapen leaves (Figure 1C). Plants treated with chlorimuron in the first experiment showed an increase in the mean number of leaves per centimeter of height from an initial value of 0.3 to 0.4 at 20 d and 0.6 at 31 d because additional leaves were formed with little or no accompanying increase in plant height. The number of leaves per centimeter of height for control plants decreased from 0.3 to 0.1 in 20 d because plant height increased at a greater rate than did leaf number. Similar effects were observed in the second experiment. Barnyardgrass treated with imazethapyr did not demonstrate a significant increase in height or leaf number after herbicide application.

Salinity and Herbicide Effects on Plant Growth Variables

Fitting the split-plot model to the average maximum height data (as calculated by the MIXED procedure) produced an r^2 value of 0.91 and a CV of 44.1% (when estimated using the GLM procedure). For the maximum number of nodes or leaves and the maximum stem diameter, the split-plot model produced an r^2 value of 0.85 and a CV of 28.4%. For both response variables, an analysis of the model residuals revealed no outliers, and the residuals appeared to be normally distributed, thus suggesting that the split-plot modeling assumptions were appropriate. For both response variables, the main plot herbicide effect was found to be highly statistically significant, as were the subplot weed species and herbicide × species interaction effects. The main plot salinity effect was significant at the 0.05 level, but not at the 0.01 level for maximum height. For the maximum number of nodes/leaves/diameter, the main plot salinity effect was not significant. All remaining *F*-tests were nonsignificant at the 0.05 level. These results imply that the average maximum plant height changed across both herbicide treatment and weed species and that the herbicides affected the five species in dissimilar ways.

To further examine the effects of herbicide and salinity on each weed species, the maximum height and maximum number of nodes or leaves and the maximum stem diameter data for each species were reanalyzed individually using the RCB model (Equation 2). Salinity was significant at the 0.05 level only for yellow nutsedge, for which plants irrigated with 7 dS m^{-1} water had significantly lower maximum height or stem diameter than did plants irrigated with fresh water (Figure 2). The average maximum height of yellow nutsedge decreased from 31.1 to 17.2 cm when the salinity of the irrigation water was increased from 2 to 7 dS m^{-1}. Likewise, the increase in salinity decreased the average maximum stem diameter from 4.6 to 3.2 mm. The maximum

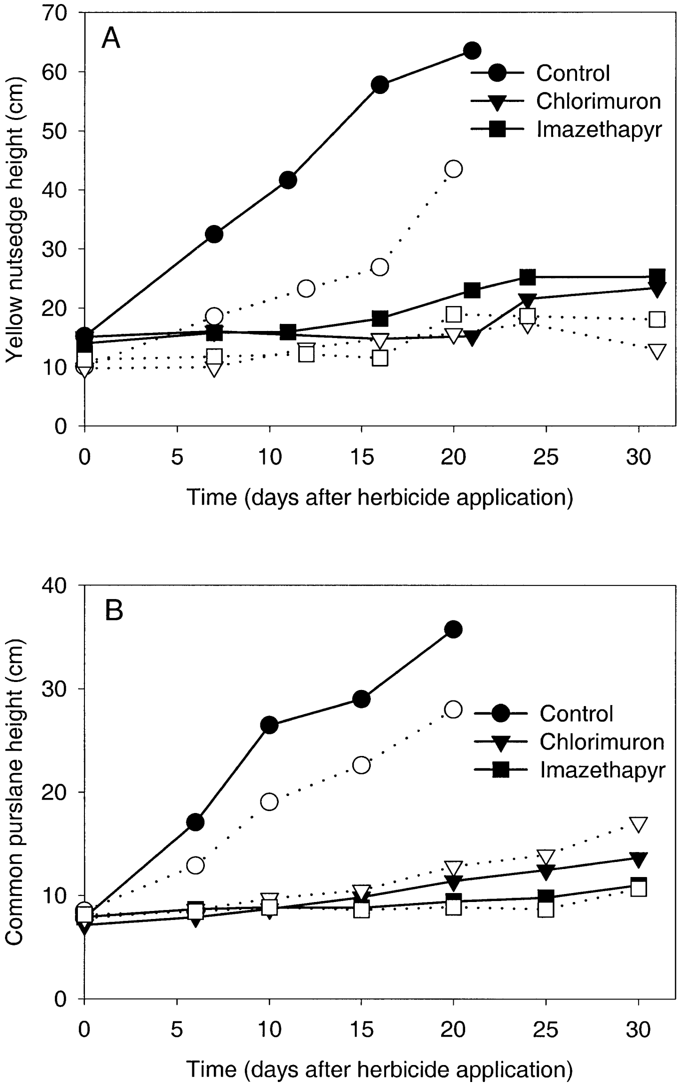

FIGURE 2. Height of surviving (A) yellow nutsedge and (B) common purslane measured just before (time 0) and after herbicide application. Values indicate the mean of all subsamples in both experiments (≤ 36 subsamples per data point). Closed symbols and solid lines indicate plants irrigated with nonsaline (EC = 2.5 dS m^{-1}) water; open symbols and dotted lines indicate plants irrigated with saline (EC = 7 dS m^{-1}) water.

height and maximum number of nodes or leaves of barnyardgrass, ivyleaf morningglory, common purslane, and common cocklebur were not affected by salinity. Previous research has demonstrated that at salinity similar to or greater than those used in these experiments, some reduction in growth is observed for barnyardgrass (Aslam et al. 1987; Rahman and Ungar 1990), common purslane (Grieve and Suarez 1997), and purple nutsedge (*Cyperus rotundus* L.) (Shamsi and Ahmad 1986). Although the reduction in the maximum height or maximum number of nodes or leaves caused by irrigation with saline water was not statistically significant in these experiments, plants irrigated with saline water were consistently smaller at each measurement time than were their nonsalinized counterparts (Figure 2). In these experiments, all plants received adequate water, and plants were not affected by light exclusion.

Herbicide application severely arrested the growth of all tested species (Figures 1–3). Beginning with the first measurement time after herbicide application (5 to 7 d), all herbicide-treated plants had markedly lower height than did the controls. The effect of each herbicide on the maximum height and number of nodes or leaves and the maximum stem diameter varied with the weed species (Table 2). In general, plant height was a more sensitive measure of sublethal herbicide injury than was the number of nodes on the main stem, number of leaves (for barnyardgrass), or stem diameter (for yellow nutsedge).

TABLE 2. Average maximum height and average maximum number of nodes/leaves/stem diameter averaged over salinity and year.[a]

Species	Control	Imazethapyr	Chlorimuron
Barnyardgrass			
Height	54.61 a	13.44 b	17.67 b
Leaves	6.54 a	3.51 b	6.09 a
Cocklebur			
Height	19.11 a	3.17 b	3.52 b
Nodes	7.22 a	2.57 b	3.20 b
Ivyleaf morningglory			
Height	62.63 a	6.39 b	3.59 b
Nodes	7.98 a	3.68 b	2.28 b
Common purslane			
Height	28.81 a	11.26 b	15.78 b
Nodes	7.12 ab	5.44 b	8.54 a
Yellow nutsedge			
Height	40.33 a	18.22 b	13.83 b
Diameter	4.55 a	3.86 ab	3.35 b

[a] Values for each growth variable followed by a different lower-case letter indicate a significant difference classified by Tukey's studentized range test ($\alpha = 0.05$).

For barnyardgrass, both imazethapyr and chlorimuron significantly reduced the average maximum plant height (Table 2). The mean height 20 d after treatment showed the same trend, where the height of barnyardgrass treated with imazethapyr or chlorimuron was only ~ 25 to 30% of the controls (Figure 3A). Similar reductions in barnyardgrass height were observed with postemergence application of imazethapyr in greenhouse studies (Zhang et al. 2001). Smaller decreases in height were observed for other grasses treated with imazethapyr in field studies (Wilson 1995). Treatment with imazethapyr significantly decreased the average maximum number of leaves (Table 2). Treatment with chlorimuron resulted in the continued formation of leaves with no increase in plant height (Figure 1C) and treatment with chlorimuron did not result in a significantly different maximum number of leaves compared with the controls, which were not treated with herbicide (Table 2). These trends also were reflected in the mean leaf number 20 d after treatment (Figure 3B).

Yellow nutsedge plants treated with imazethapyr and chlorimuron had significantly lower maximum heights than nontreated controls (Figure 2, Table 2). Both herbicides reduced maximum stem diameter, but only chlorimuron was statistically significant at the 0.05 level (Table 2). Similar results were observed for the mean plant height and stem diameter 20 d after treatment (Figure 3), which indicated that treatment with imazethapyr or chlorimuron reduced the mean yellow nutsedge height by ~ 60% but had a less significant effect on stem diameter. Similar decreases in yellow nutsedge height after application of imazethapyr and chlor-

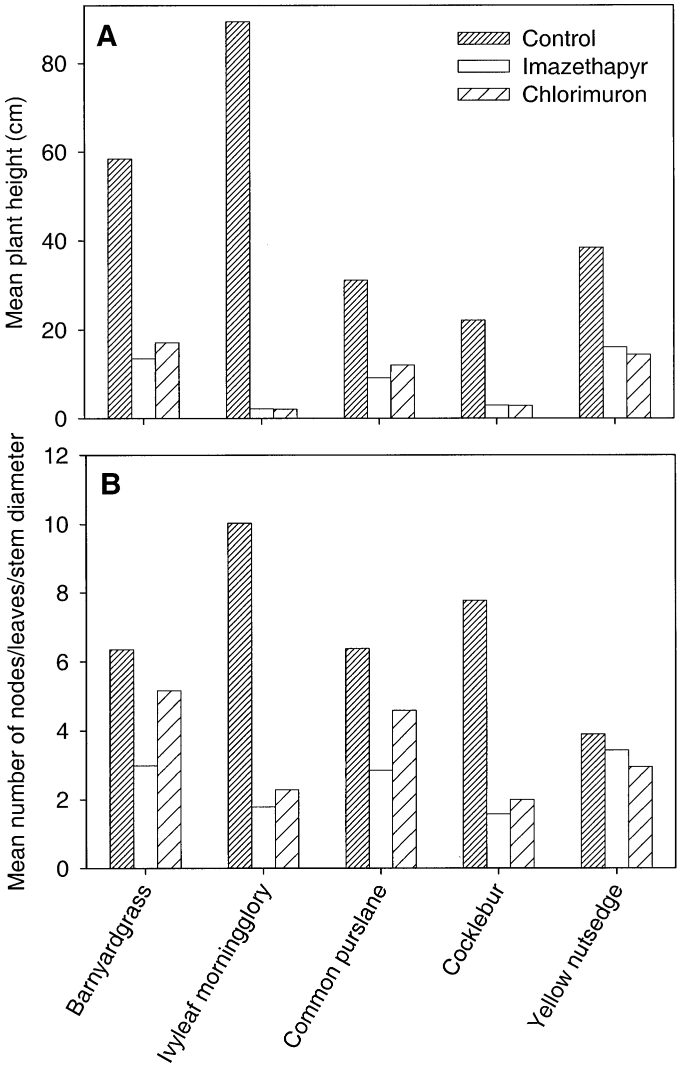

FIGURE 3. (A) Mean height and (B) number of nodes/leaves/stem diameter of surviving plants measured 17 to 20 d after herbicide application. Values indicate the mean of all subsamples in both experiments at both salinities.

imuron were observed in greenhouse and field studies (Ackley et al. 1996). These authors reported that imazethapyr was more effective against yellow nutsedge in the greenhouse because of the lack of moisture stress. In these experiments, all plants received adequate water and were not subject to light exclusion.

For ivyleaf morningglory, both herbicides significantly reduced the maximum plant height achieved in 31 d (Table 2). Although it appeared that both herbicides also reduced the maximum number of nodes (Table 2), because of the formation of multiple shoots after herbicide application (Figure 1A), only the chlorimuron effect was statistically significant. Ivyleaf morningglory growth was slowed after herbicide application, but for some subsamples, one of the multiple shoots formed after herbicide application continued growing. In each experiment, several ivyleaf morningglory that had been treated with herbicides grew to a height greater than that of the respective control 10 d after application (> 40 cm for 2 dS m^{-1}). This growth occurred from ~ 20 d after treatment to the end of the experiment (31 d after treatment). Because of this late growth, the arithmetic mean of subsamples measured 20 d after application showed a more dramatic trend in growth reduction than did the mean maximum values. Twenty days after herbicide application, the mean height of herbicide-treated ivyleaf morningglory was only ~ 2% of the controls, and the mean number of nodes on herbicide-treated plants was ~ 20% of the controls (Figure 3).

The maximum height of common purslane was significantly reduced by treatment with imazethapyr and chlorimuron (Table 2). The number of nodes continued to increase after herbicide application (Figure 1B) and neither imazethapyr nor chlorimuron significantly reduced the maximum number of nodes on common purslane (Table 2). Similar trends were observed in the mean height and number of nodes 20 d after herbicide application, when the mean height of common purslane was ~ 60 to 70% lower than that of the controls (Figure 3). Growth of herbicide-treated common purslane was slowed compared with the control, but a steady increase in height was observed throughout the experiment. By the end of each experiment, several common purslane plants that received herbicides had grown taller than the respective control 10 d after treatment (~ 20 cm).

Herbicide-treated common cocklebur had significantly lower maximum height and maximum number of nodes compared with plants that received no herbicide (Table 2). No consistent differences in plant height or node number were observed between the two herbicides (Table 2). These trends also were observed in the mean of the subsamples 20 d after herbicide application, when the mean height of common cocklebur treated with chlorimuron or imazethapyr was 13% of the control, and the mean number of nodes was ~ 20% of the control (Figure 3). Similar rates of chlorimuron resulted in up to a 95% reduction in common cocklebur fresh weight 10 d after treatment in greenhouse studies (Wilcut et al. 1989).

Herbicide and Salinity Effects on Plant Survival

Phytotoxic symptoms such as disrupted plant growth began immediately after herbicide application, but complete necrosis of affected plants required several weeks. Survival data were logit transformed and fitted to the split-plot model described in Equation 1 using the MIXED procedure. This model produced an r^2 value of 0.87 and a CV of 93.4% (when estimated using the GLM procedure). An analysis of the model residuals revealed no outliers, and the residuals appeared to be normally distributed, thus suggesting that the split-plot model assumptions were appropriate and that the logit transformation was effective. Statistical analysis indicated that the subplot species and herbicide × species interaction effects were highly significant, whereas all other effects including the main plot effects of salinity and herbicide were not significant (control plants had nearly 100% survival and were excluded from this statistical analysis). Salinity had no overall effect on survival 20 d after herbicide application.

Yellow nutsedge plants treated with chlorimuron had significantly higher mortality rates 20 d after application than did those treated with imazethapyr (Figure 4). Approximately 65% of the chlorimuron-treated plants survived 20 d after treatment, whereas no mortality of imazethapyr-treated plants was observed (Figure 4). Logit-transformed estimates of survival rates were 72% for chlorimuron (95% confidence interval 45.2 to 93.2%) and > 99% for ima-

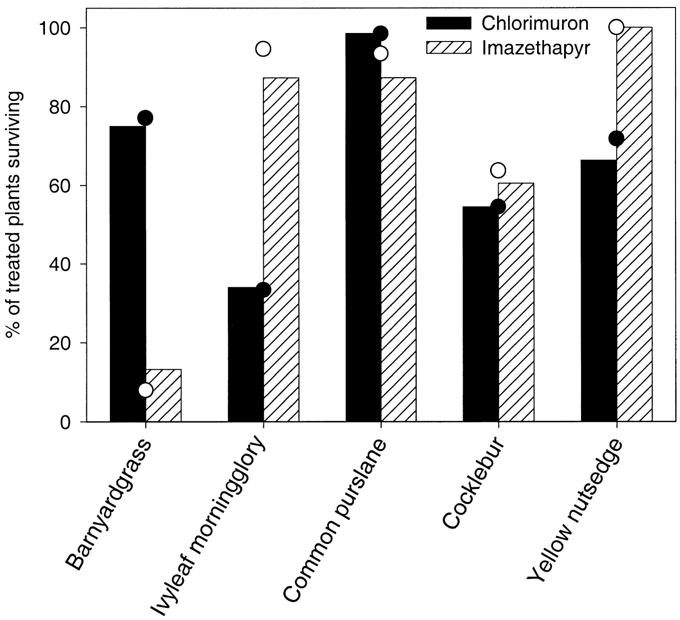

FIGURE 4. Survival of herbicide-treated weeds 20 d after herbicide application. Values indicated in the bar graph are the arithmetic mean survival rate in both experiments across both salinity treatments. Solid and open symbols indicate logit-transformed survival rates for chlorimuron and imazethapyr, respectively. Symptoms of herbicide injury appeared almost immediately after herbicide application, but complete necrosis required several weeks or more.

zethapyr (95% confidence interval 96 to 100%). Similar control (40 to 60% phytotoxicity) was observed in greenhouse experiments using similar rates of chlorimuron (Reddy and Bendixen 1988). Chlorimuron demonstrated better nutsedge control than did imazethapyr in field studies (Ackley et al. 1996; Jordan 1996), whereas in greenhouse studies the two herbicides showed similar control (Ackley et al. 1996). Uptake through the roots appears to be important for imazethapyr efficacy against nutsedges, whereas foliar uptake may be more important for chlorimuron (Jordan 1996). In these experiments, herbicides were applied to the whole sand tank with interception by the plant leaves, resulting in foliar and soil applications. Soil was moist during application, and plants were irrigated > 24 h after application. Except for the very lowest plant leaves, leaves did not get wet during irrigation, so foliar-applied herbicide was not washed off. The conditions used in these experiments (foliar and soil applications, adequate and consistent soil moisture, flood irrigation) may have favored imazethapyr and chlorimuron efficacy, whereas other factors (postemergence application to plants ≤ 20 cm tall) may have resulted in lower rates of necrosis. Similar to the results observed in these experiments, where the proportion of herbicide-treated yellow nutsedge that survived decreased with time (data not shown), visible phytotoxicity of yellow nutsedge from chlorimuron continued to increase from 7 to 28 d after treatment (Reddy and Bendixen 1988).

Treatment of barnyardgrass with imazethapyr resulted in significantly higher mortality than did treatment with chlorimuron 20 d after application (Figure 4). In both experiments, all barnyardgrass plants treated with imazethapyr were completely necrotic 31 d after treatment, whereas ~ 40% of the plants treated with chlorimuron survived. Twenty days after treatment, mortality of imazethapyr-treated barnyardgrass was < 85%, whereas mortality with chlorimuron was ~ 25% (Figure 4). Logit-transformed survival estimates were 8% for imazethapyr (95% confidence interval 2 to 26%) and 77% for chlorimuron (confidence interval 45 to 93%). Similar results for barnyardgrass control (> 85%) with postemergence application of imazethyapyr were reported by Zhang et al. (2001).

Ivyleaf morningglory treated with chlorimuron had significantly higher mortality rates 20 d after application than did those treated with imazethapyr (Figure 4). Mortality of chlorimuron-treated ivyleaf morningglory was ~ 65%, whereas mortality with imazethapyr was < 15% 20 d after application (Figure 4). Logit-transformed survival estimates were 33% for chlorimuron (confidence interval 11 to 67%) and 94% for imazethapyr (confidence interval 81 to 99%). Similar control of ivyleaf morningglory with chlorimuron (56 to 72%) was observed in field studies (Fielding and Stoller 1990). Control of ivyleaf morningglory by 70 g ha^{-1} of imazethapyr was ≥ 70% 4 wk after treatment in soybeans (Mills and Witt 1989). In these experiments, imazethapyr failed to completely control growth of ivyleaf morningglory, although surviving plants would not likely be highly competitive, especially because significant growth only occurred ≥ 20 d after herbicide application.

Chlorimuron and imazethapyr affected common cocklebur survival similarly, with approximately half the herbicide-treated plants dead 20 d after application (Figure 4). Logit-transformed survival estimates were 55% for chlorimuron (confidence interval 23 to 83%) and 64% for imazethapyr (confidence interval 30 to 88%). Good control (> 80%) of common cocklebur with the same application rate of imazethapyr was observed in field studies 4 wk after treatment, with higher efficacy observed in nontillage systems, perhaps caused by an increase in soil moisture (Mills and Witt 1989). A higher rate of escape was observed in these experiments, in which common cocklebur was grown in the greenhouse with no competition.

Nearly all the common purslane plants survived for at least 30 d in both experiments, under all salinity and herbicide treatments (Figure 4). Logit-transformed survival estimates were 98% for chlorimuron (confidence interval 94 to 100%) and 93% for imazethapyr (confidence interval 77 to 98%). Postemergence application did not control common purslane in leafy vegetables but did slow the growth of common purslane in field studies (Dusky and Stall 1996). In these experiments, application of either chlorimuron or imazethapyr did not result in complete necrosis of common purslane within 30 d after treatment. Plant growth was significantly slowed by both herbicides (Figure 2B), and control of common purslane may improve in cropping systems in which a canopy is established while common purslane plants are sufficiently small.

The results of these experiments indicated that irrigation with sulfate-dominated saline water (7 dS m^{-1}) had no overall effect on the growth or survival of the tested weed species. Complete control of common purslane was not achieved by either chlorimuron or imazethapyr, and nearly all treated plants survived and continued to grow until 31 d after herbicide application, when the experiment was terminated. Only the imazethapyr formulation used in these experiments was labeled for the control of common purslane. Growth and survival of ivyleaf morningglory and yellow nutsedge was greater for plants treated with imazethapyr than for those treated with chlorimuron. The chlorimuron formulation used in these experiments was labeled for the control of these species, whereas the imazethapyr label indicated reduced competition. For barnyardgrass, growth and survival was significantly greater for chlorimuron-treated plants than for those treated with imazethapyr. The chlorimuron formulation used in these experiments was not labeled for barnyardgrass control, and the imazethapyr was labeled for reduced competition. Both herbicides are labeled for control of *Xanthium* spp., and both herbicides affected common cocklebur growth and survival similarly. For all tested species, most surviving plants were not vigorous. The surviving plants would likely pose little competition to legume crops. The results of these experiments suggest that weed control aspects of the labels for these herbicide formulations will not require modification for crops grown in moderately saline soils.

Sources of Materials

[1] Weed seeds, Valley Seed Service, P.O. Box 9335, Fresno, CA 93791.

[2] Potting mix 2, University of California Riverside, Riverside, CA 92521.

[3] Chlorimuron ethyl herbicide, Classic formulation (dispersible granules, 25% chlorimuron ethyl by weight), E. I. du Pont de Nemours, Agricultural Products, Wilmington, DE 19898.

[4] Imazethapyr herbicide, Pursuit formulation (aqueous concentrate, 22.9% ammonium salt of imazethapyr), American Cyanamid, Crop Protection Chemicals Department, One Campus Drive, Parsippany, NJ 07054.

[5] Nonionic surfactant (40% tri-methyl ether of polyethylene glycol-isopropyl alcohol), Spray-Grip, Proguard, Inc., P.O. Box 550, Suisun, CA 94585.

Use of a company or product name is for the convenience of the reader and does not imply endorsement of the product by the USDA to the exclusion of others that also may be suitable.

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