DOES PARAQUAT CAUSE STEM SWELLINGS IN FIRST-YEAR COTTONWOOD SAPLINGS?

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Abstract-This study was prompted by the occurrence, in *1995,* of stem swellings on about 80 to 90 percent of all first-year shoots of eastern cottonwood (*Populus deltoides* J. Bartam ex Marsh.) after an application of paraquat to control weeds in a 65-hectare plantation near Fitler, MS. Paraquat was applied in spring and summer 1996, respectively, to the bases of two different sets of first-year cottonwood saplings at 0, 0.25, 0.5, 1 .0, and 2.0 times the normal rate used for weed control to determine a dose-response relationship for paraquat and the occurrence of stem swellings. The occurrence of swellings 2, 3, and 4 months after the spring treatment was positively related to paraquat dose. Swellings occurred less often, and only at the 1 .O and 2.0 rates, after the summer treatment. Sapling survival was related to paraquat dose for the spring application ranging from 97 percent in the control group to 18 percent for saplings treated with the 2.0 rate. Paraquat dose did not affect sapling survival after the summer application. Four months after the spring treatment, stem diameters of saplings treated with 1 .O and 2.0 rates were 67 and 38 percent, respectively, of those of the control saplings. Stem heights showed similar responses. Summer treatments had little effect on diameters and heights of saplings. Use of paraquat to control weeds in first-year cottonwood plantations should include provisions to reduce or eliminate contact with green stem tissues.

INTRODUCTION

In mid-June 1995, an estimated 80 to 90 percent of all first-year shoots of cottonwood (*Populus deltoides* J. Bartam ex Marsh.) in a 65-hectare (ha) plantation near Fitler, MS, exhibited IO- to 15-centimeter (cm) long swellings located 3 to 10 cm above the attachment of the shoot to the cutting. The swellings were 2 to 2.5 times the normal stem diameter and were fusiform in shape. During cultivation in mid-June, an estimated 15 to 20 percent of the shoots broke just below the swellings where the stems were brittle. Swellings first appeared in mid-May following an application of paraquat to stem bases in early May to control weeds. The spray rig used in this application was not set up to shield stem bases from being sprayed. Cottonwood clones from Fitler and Stoneville, MS, and one of Texas origin, were affected. No effort was made to determine differences in cottonwood clones in manifesting the swellings. Paraquat damage was evident as black, sunken, oval lesions measuring about 0.5 cm by 1.0 cm on portions of the shoots above the swellings. Various causes for the swellings were considered including insects, diseases, weather, and chemical drift from nearby farms, but none of these provided a satisfactory explanation. Although the evidence was circumstantial, swellings appeared related to the application of paraquat.

Subsequent discussions with other plant pathologists and herbicide specialists revealed similar injuries on branches of loblolly pines exposed to paraquat spray drift, and on cotton from an incorrect application of paraquat. Paraquat is a contact herbicide which is absorbed quickly by green plant tissue where it reacts with the photosynthetic process producing free radicals; these destroy plant cells and membranes and cause the death of tissues within hours (Rice 1992). A hypothesis emerged which held that young, green phloem and bark tissues were killed by paraquat, thereby removing the conduit for photosynthates to be transported to roots. Photosynthates accumulated in stems distal to the dead tissue, thereby causing swellings and brashness. This phenomenon is known in woody ornamental production as “wire-tag disease,” in which case a physical barrier (e.g., a wire tag) cuts into the phloem restricting the downward movement of photosynthates. Swellings occurred less frequently on first-year cottonwood saplings treated with paraquat in August 1995, presumably after bark tissue was more mature.

Paraquat was used by the grower, under the “trees and vines” section of the Federal label, to control weeds in first-year cottonwood plantations for several years before these swellings occurred. It was an important management tool because it was the only broad-spectrum herbicide that effectively controlled early-summer annual weeds, such as morning-glory (*Convolvulus* L. spp.), ragweed *(Ambrosia* L. spp.), pigweed *(Amaranths* spp. L.), cocklebur (*Xanthium* L. spp.), *Sesbania* Scop. spp., and primrose *(Primula* L. spp.) at a low cost while posing a minimal risk to cottonwood health. Paraquat was not applied to sapling bases to control weeds during 1996 because of concern over the occurrence of these stem swellings. To address the growers’ concern, this study was done to determine the concentration of paraquat at which bark and phloem were killed, thereby causing photosynthates to accrete as swellings on lower stems of first-year cottonwood saplings. A second objective was to determine whether swellings on first-year cottonwood saplings could be avoided by applying paraquat later in the season after bark tissue had become more mature.

This research also addresses an area of wider concern within the forestry community, that of having useful chemicals to control annual and perennial weeds in hardwood plantations. Commercial hardwood interests are more and more considering plantations as one key to meeting increased demands for hardwood fiber, and are looking to researchers to address questions of feasibility

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(Anonymous 1996). It is likely that more studies like this will need to be done to meet the needs of hardwood plantation growers in the private, as well as public, sectors.

METHODS

Experimental Design and Approach

The cottonwood saplings used in this study were planted as cuttings in December 1995. In February 1996, a tank mix of oxyfluorfen [80 ounce per acre] and paraquat [I quart per acre] was sprayed in 6-foot bands down the rows and over the top of the dormant cuttings. Weeds growing between rows were controlled using a disc harrow before paraquat was applied to the bases of saplings. Two times during the growing season after treatments were installed, a disc harrow was used for weed control. The disc harrow was driven between rows in one direction and then again between rows at a 90-degree angle to the first pass. These conditions replicated, as nearly as possible, the cultural conditions to which the 1995 saplings were exposed.

Treatments were set up as a two-way factorial in a randomized complete block design with 10 (two applications x five dose levels) factor-level combinations in each of three blocks. Applications of 0, 0.25, 0.5, 1, and 2 times the grower's normal operational rate of paraquat (24 ounces per acre as 37 percent paraquat dichloride a.i.) were made to the bases of first-year cottonwood saplings on June 17 (spring) and August 19 (summer) 1996. The control (0) treatment contained only the nonionic surfactant in water that was used to apply the paraquat. Paraquat was applied using a modified, conventional, farm spray rig outfitted with two 8004 flat-fan nozzles on both sides of each row of saplings. Two rows were sprayed simultaneously using a tractor speed of 4.8 miles per hour (mph) and a tank pressure of 10.5 pounds per square inch (psi) adjusted to produce relatively large droplets and avoid drift.

Each treatment was applied to 50 saplings, in 2 adjacent rows of 25 saplings each, planted in a 12 foot by 12 foot spacing. There was a total of 1,500 saplings on 5 acres. The study occupied about 12 acres, including buffers around treated areas, within a 100-acre plantation of first-year cottonwood saplings. Saplings were half-sib, first generation, improved clonal material that originated from Mississippi or Texas. It was not possible to determine clonal responses to paraquat because no record was kept of which clones were planted in the study area. The soil of the study area was of the Sharkey series.

Biological Measurements

Initial heights of saplings in the spring treatments were measured 8 days after spraying. The presence or absence of swellings was recorded on the dominant shoot of each sapling. Stem diameters were measured 10 cm above the ground. The widest diameter of each recorded swelling was measured. Weed control around each sapling was measured by estimating the percentage of area covered by weeds in a 0.5 square meter (m^2) plot centered around the sapling base. Sapling heights from the ground to the tip of the dominant leader were recorded, as were the occurrence of swellings, swelling diameters, stem diameters, percentage of weed cover, and survival for each sapling at l-month intervals following spring and summer applications. Data were taken until October 17, 2 months after the summer treatments. Biological measurement data were analyzed using a three-way analysis of variance procedure.

RESULTS AND DISCUSSION

Swelling Occurrence and Paraquat Dose

One month (July) after the spring application of paraquat, swellings occurred on 27 (or 7 percent) of the surviving saplings (fig. 1). Swellings occurred on saplings in all four paraquat treatments; no swellings were recorded on control saplings. At 2, 3, and 4 months after the spring application of paraquat, there was a clear response to dose expressed as percentages of swellings on paraquat-treated saplings. The total number of swellings on surviving saplings was about the same in July and August, but decreased in September and October. These decreases were due to diameter growth over time which tended to obscure swellings measured previously on some saplings. The percentages of saplings with swellings recorded after the spring treatment (2 to 27 percent) were less than the estimated 80 to 90 percent of saplings with swellings in 1995. One month (September) after the summer application of paraquat, there were swellings on six (or 1 percent) of the surviving saplings treated at the 1.0 (n=2) and 2.0 (n=4) rates. No swellings were recorded on saplings in 0, 0.25, or 0.5 treatments. In October, one sapling exposed to the 1 .O rate and nine saplings exposed to the 2.0 rate were the only saplings with swellings resulting from the summer treatments. These data address

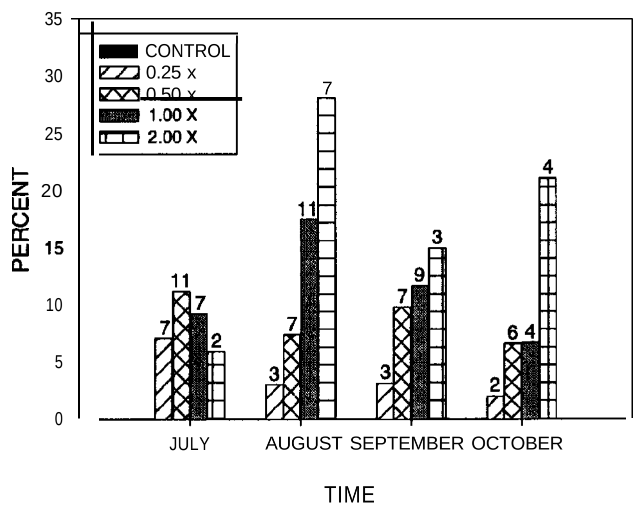

Figure I-Percentages of first-year cottonwood saplings with stem swellings caused by damage to bark tissue following the applications of various doses of paraquat on June 17. Swelling occurrences were assessed at l-month intervals. The number above each percentage bar is the actual number of swellings counted for that treatment. Doses are based on a 1 .0 rate of 24 ounces per acre.

the first objective of the study by showing that paraquat, even at the 0.25 rate, caused swellings on first-year cottonwood saplings. Further, they show a relationship between paraquat dose and the occurrence of swellings. These data also address the second objective of the study since the occurrences of swellings were less when paraquat was applied 2 months later in the summer (August) after bark tissues were more mature than during the spring application (June).

While the occurrence of swellings was related to dosage, the diameters of swellings generally were not related to dosage in either season, with the exception of saplings treated with the 2.0 rate. In 12 of 14 cases, swelling diameters at the 2.0 rate were less than those at other rates. It appeared that tissue damage was so severe at the 2.0 rate that overall sapling growth, including swelling size, was affected.

Sapling Survival and Paraquat Dose

Sapling survival following the spring application was affected by paraquat dose and ranged from 97 percent for control saplings to 18 percent for saplings treated with the 2.0 rate (fig. 2). This dosage response was inversely related to sapling heights measured 8 days after application (fig. 3). The 2.0 rate of paraquat killed all saplings less than or equal to 0.4 meters (m) tall, whereas the 0.25 rate killed saplings 0.15 m or less. Those differences were statistically significant. Paraquat dose had little effect on sapling survival after the summer application with near 100 percent survival for saplings in control and paraquat treatments (fig. 2). Factors that probably were important in the dose response and height inverse relationship following the spring treatments included spray application height, spray drift height, and the relative response of bark tissues to various paraquat doses. The near total survival following the summer application indicated the difference in bark tissue maturity, and thus relative susceptibility to paraquat damage, between the groups of saplings treated in spring and summer.

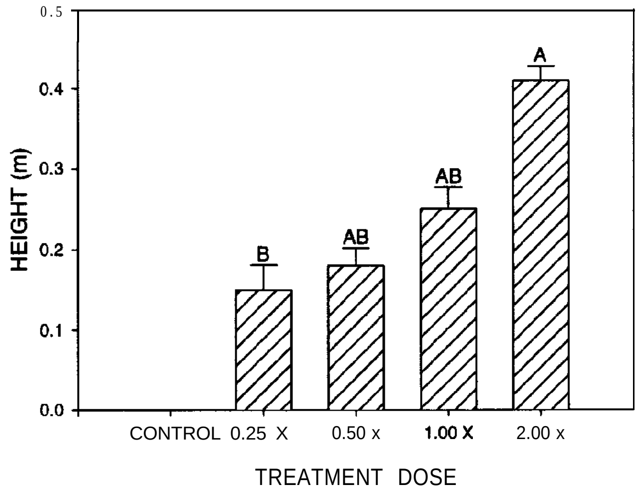

Figure 3-Average heights and standard errors of first-year cottonwood saplings killed by paraquat of various doses. Doses are based on a 1 .O rate of 24 ounces per acre. Different letters above bars indicate different heights, at P=0.5, tested by Tukey's W Procedure.

Stem Heights and Diameters and Paraquat Dose

Average heights of saplings treated in June and measured 3 months later decreased in response to increasing paraquat dose (fig. 4). Saplings not treated with paraquat

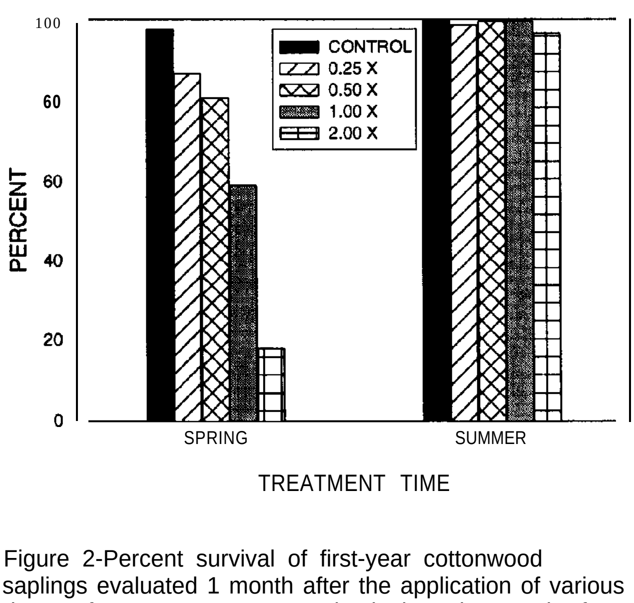

Figure 2-Percent survival of first-year cottonwood saplings evaluated 1 month after the application of various doses of paraquat on June 17 (spring), and 1 month after the application of the same doses of paraquat on August 19 (summer). Doses are based on a 1.0 rate of 24 ounces per acre.

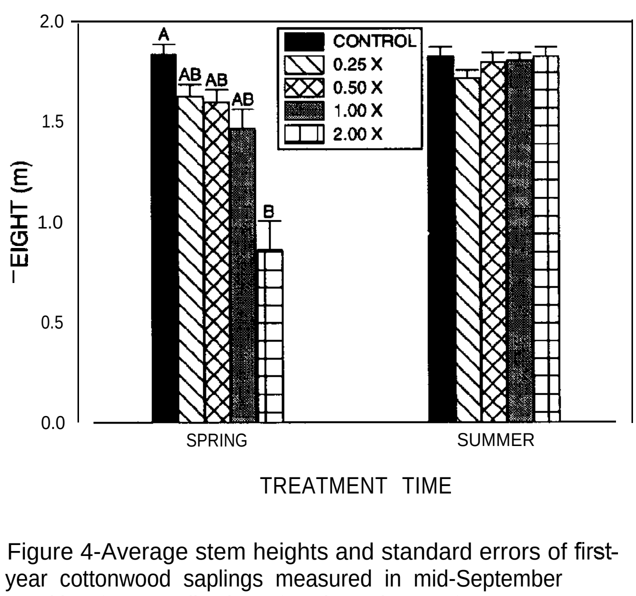

Figure 4-Average stem heights and standard errors of first-year cottonwood saplings measured in mid-September resulting from application of various doses of paraquat on June 17 (spring), or application of the same doses of paraquat on August 19 (summer). Doses are based on a 1 .O rate of 24 ounces per acre. Different letters above bars indicate different heights, at P=0.5, tested by Tukey's W Procedure.

were taller, on average, than saplings treated with the 1 .O and 2.0 rates of paraquat, but were not significantly taller than those treated with the 0.25 and 0.5 rates. There were no treatment differences among average heights of saplings treated in August and measured 1 month later (fig. 4). Average heights of all summer-treated saplings were approximately equal to average heights of spring-treated control saplings. Stem diameters of saplings treated in June and measured 3 months later also decreased as paraquat dose increased (fig. 5). Average stem diameters of control saplings were greater than those of saplings treated with the 1 .O and 2.0 rates of paraquat, but were not statistically different than diameters of saplings treated with the 0.25 and 0.5 rates. The smaller average diameter of saplings treated with the 0.25 rate compared with that of control saplings and saplings treated with the 1 .O rate, following the summer application, is explained best by experimental error. This same trend, though not statistically significant, occurred for stem heights following the summer application (fig. 4). Nonetheless, the average diameter of all summer-treated saplings was approximately equal to the average diameter of spring-treated control saplings.

The losses of growth apparent in stem height and diameter data indicate that there is some risk in applying paraquat for weed control before cottonwood sapling bark tissues have matured enough to not be damaged by the herbicide. In this study, the degree of maturation of bark tissues that protected saplings from paraquat damage occurred in the 2 months between the spring (June 17) and summer (August 19) applications. This time period is likely to vary depending on phenology and genetics. For example, the onset of spring was late in 1996 in comparison to the previous year when the first application of paraquat occurred in mid-May. In general, it would be inadvisable to use paraquat around the bases of first-year cottonwood saplings during spring and early summer. Applications made in mid- to late summer are less likely to cause damage to bark tissues. Stem height and diameter data of spring-treated saplings also suggested a threshold of damage starting with the 1.0 rate. Certainly at the 2.0 rate, paraquat damage was severe enough to reduce even the diameters of swellings. September measurements of stem heights (fig. 6) and diameters (fig. 7) of saplings treated in spring were less, at all four paraquat dosage levels, than their counterparts treated in summer; there were no differences between untreated controls. These spring-summer comparisons suggest that a damage threshold occurred at the 0.25 rate.

Weed Control and Paraquat Dose

Higher doses of paraquat tended to decrease the percentage of weed cover around sapling bases (fig. 8). Although paraquat was sprayed once for the spring treatment, the same dose-related trends in weed cover occurred at 1, 2, 3, and 4 months after spraying. The same trend occurred for percentage of weed cover after summer treatments. Although not specifically documented, it was apparent that different species of weeds were present around sapling bases during the various measurement times. This is evidenced somewhat by the increased weed cover measured in September and October compared to that measured for July and August following the spring treatments. The initial removal of weeds by paraquat may have given saplings time to occupy sites and maintain dominance over annual weeds well after the applications.

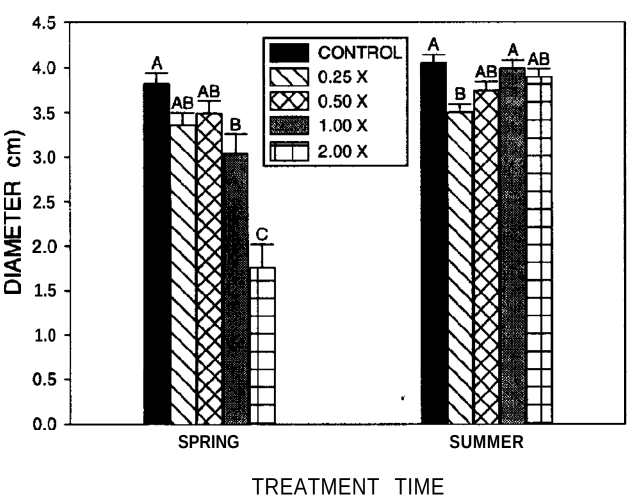

Figure 5—Average stem diameters and standard errors of first-year cottonwood saplings measured in mid-September resulting from application of various doses of paraquat on June 17 (spring), or application of the same doses of paraquat on August 19 (summer). Doses are based on a 1 .O rate of 24 ounces per acre. Different letters above bars indicate different diameters, at P=0.5, tested by Tukey's W Procedure.

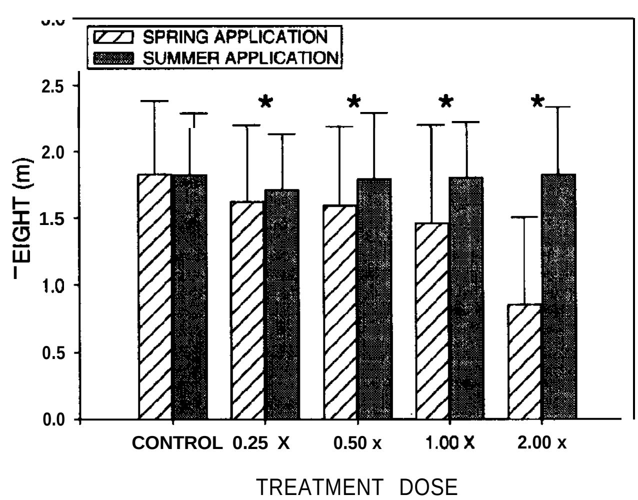

Figure 6-Comparisons between average stem heights, with standard errors, of first-year cottonwood saplings measured in mid-September following either spring or summer applications of various doses of paraquat. Doses are based on a 1.0 rate of 24 ounces per acre. Asterisks indicate different heights between application times, at P=0.5, tested by Tukey's W Procedure.

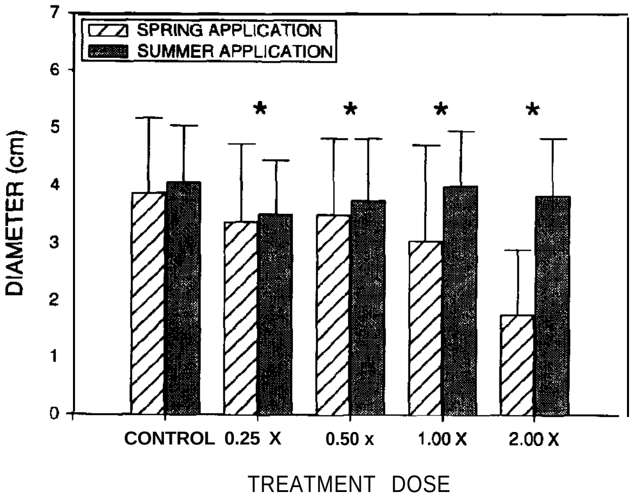

Figure 7-Comparisons between average stem diameters, with standard errors, of first-year cottonwood saplings measured in mid-September following either spring or summer application of various doses of paraquat. Doses are based on a 1.0 rate of 24 ounces per acre. Asterisks indicate different heights between application times, at P=0.5. tested by Tukey's W Procedure.

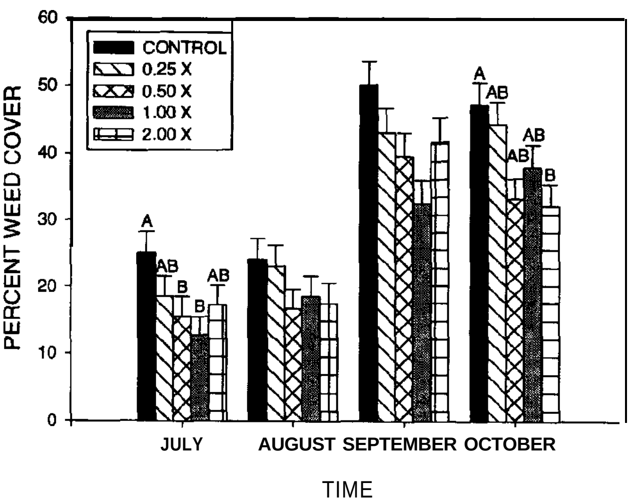

Figure 8-Weed control around the bases of first-year cottonwood saplings, measured by percentage of weed cover (with s.e.m.) within a 0.5 m2 plot, following the application of various doses of paraquat on June 17. Weed cover was assessed at l-month intervals. Doses are based on a 1 .O rate of 24 ounces per acre. Different letters above bars indicate different percentages of weed cover, at P=0.5, tested by Tukey's W Procedure on arc sine-transformed data.

CONCLUSIONS

This study showed that applications of paraquat at 6 oz/ac, the 0.25 x operational rate, caused necrosis of cottonwood bark tissue and stem swellings. Also at this dose, sapling survival was less than for untreated controls, and heights and diameters of saplings treated in June were less than those of saplings treated in August. Higher doses of paraquat increased these effects. Therefore it is inadvisable to apply paraquat around the bases of first-year cottonwood saplings to control weeds before bark tissues have matured enough to be resistant to paraquat damage-probably sometime after mid-summer. Otherwise, sapling mortality or loss of growth is likely to occur. Mechanical cultivation may be all that is needed for weed control since these data do not show any benefit to growth from paraquat applications. Further, a spray rig modified to shield stem bases from the herbicide should be used to apply paraquat. Eastern cottonwood is the fastest-growing commercially important tree species in North America (Cooper and Van Haverbeke 1990), and as such has the innate capacity to recover quickly from injury. Considering the rapid regrowth inherent to the species, cottonwood plantation managers should weigh the advantages of chemical control of annual weeds early in the growing season against the disadvantages of potential decreases in survival and growth in the first year. Additional controlled experiments and documentation of growth beyond the first year could address these issues. These findings should be useful to other commercial, private, and government growers interested in controlling annual weeds in first-year cottonwood plantations, and in reforestation efforts in which cottonwood is planted alone or intermixed with other species.

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