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WEED GROWTH AND CORN YIELD AS AFFECTED BY
WEED SPECIES AND WEED EMERGENCE TIME RELATIVE
TO CORN EMERGENCE

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WEED GROWTH AND CORN YIELD AS AFFECTED BY WEED SPECIES AND WEED EMERGENCE TIME RELATIVE TO CORN EMERGENCE

By

Corey James Guza

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ABSTRACT

WEED GROWTH AND CORN YIELD AS AFFECTED BY WEED SPECIES AND WEED EMERGENCE TIME RELATIVE TO CORN EMERGENCE

By

Corey James Guza

The development of computerized weed management decision support systems, and the increased reliance on foliar-applied herbicides for weed management, requires a greater understanding of the interactions between weeds and corn to ensure the accuracy of weed management recommendations. A field study was conducted from 2001 to 2003 to examine the effect of corn on barnyardgrass (*Echinochloa crus-galli*), common lambsquarters(*Chenopodium album*), common ragweed (*Ambrosia artemisiifolia*), fall panicum (*Panicum dichotomiflorum*), giant foxtail, (*Setaria faberi*), large crabgrass (*Digitaria sanguinalis*), redroot pigweed (*Amaranthus retroflexus*), and velvetleaf (*Abutilon theophrasti*). A second study was conducted during the same time period to determine the effect of common lambsquarters, velvetleaf and giant foxtail on corn yield. Weeds were established at four different times relative to corn growth; at corn planting, at corn emergence, when corn reached V1, and when corn reached V3.

Weeds had no effect on corn development or corn height. Weeds established prior to corn emergence generally grew larger, produced more seed and had a greater effect on corn yield than weeds established after corn emergence. Common lambsquarters, common ragweed and velvetleaf generally produced a larger biomass and volume relative to the other weeds. Giant foxtail volume and biomass production was similar to common

lambsquarters, common ragweed and velvetleaf and was generally equal to or greater than the other grass weed species. Redroot pigweed volume and biomass production was more variable between years than the other weed species. In one year redroot pigweed volume and biomass production was greater than the other weed species. In the other two years, redroot pigweed volume and biomass production was less relative to the other weed species. Fall panicum and large crabgrass volume and biomass production were generally less than the volume and biomass production of the other weed species when established at or before corn emergence. Weed volume was more variable when weeds were established after corn emergence. Velvetleaf, common lambsquarters and common ragweed volume and biomass production were generally equal to and greater than the other weeds when established after corn emergence.

Weeds with smaller seed sizes generally produced the most seed. Common lambsquarters, redroot pigweed and large crabgrass produced more seed than the other weed species regardless of when weeds were established relative to corn establishment. Common lambsquarters produced more seed than redroot pigweed and large crabgrass.

Weather conditions, weed species and weed establishment time affected corn yield loss due to weeds. In cooler growing seasons, common lambsquarters and velvetleaf reduced corn yield more than giant foxtail. When established at corn planting, common lambsquarters and velvetleaf reduced corn yield in 2 of 3 years where as giant foxtail reduced corn yield in 1 of 3 years. Common lambsquarters reduced corn yield when established at corn emergence 1 of 2 years. Velvetleaf reduced corn yield when established at V3 corn 1 of 3 years.

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CHAPTER 1

WEED GROWTH AS AFFECTED BY CORN AND WEED EMERGENCE TIME

Abstract. Understanding weed competition with crop plants is important when making weed management decisions. Understanding which weeds are most competitive and when competition occurs will help to decide when to implement weed management strategies. A field study was conducted for three years to examine the effect of corn on weed growth and seed production. Weeds were established with corn at planting, at emergence, at V1, and at the V3 stage of corn development. Weeds established at corn planting generally produced more biomass than weeds that were planted after corn emergence. Differences in growth among weed species declined with later weed establishment times. Velvetleaf, common lambsquarters and common ragweed produced more biomass than, redroot pigweed, giant foxtail, barnyardgrass, large crabgrass, and fall panicum. Giant foxtail and barnyardgrass produced more biomass than large crabgrass and fall panicum. Weed size within a species was highly correlated with seed yield. Common lambsquarters produced the most seed of all the weed species. Weed biomass and volume were correlated with growing degree days (GDD) for common lambsquarters, velvetleaf, common ragweed, giant foxtail, redroot pigweed and barnyardgrass. Common lambsquarters, velvetleaf, common ragweed and giant foxtail produced more biomass in warmer years, 1200 GDD or more, relative to other weeds. Redroot pigweed and barnyardgrass produced more biomass in cooler years, 1000 GDD or less, relative to other weeds.

Nomenclature: barnyardgrass, *Echinochloa crus-galli* L. Beauv. #[1] ECHCG; common lambsquarters, *Chenopodium album* L. # CHEAL; common ragweed, *Ambrosia artemisiifolia* L. # AMBEL; fall panicum, *Panicum dichotomiflorum* Michx. # PANDI; giant foxtail, *Setaria faberi* Herrm. # SETFA; large crabgrass, *Digitaria sanguinalis*, # DIGSA; redroot pigweed, *Amaranthus retroflexus* L. # AMARE; velvetleaf, *Abutilon theophrasti* Medicus. # ABUTH.

Additional index words: Weed biology, Weed ecology, *Abutilon theophrasti*, *Amaranthus retroflexus*, *Ambrosia artemisiifolia*, *Chenopodium album*, *Digitaria sanguinalis*, *Echinochloa crus-galli*, *Panicum dichotomiflorum*, *Setaria faberi*, ABUTH, AMARE, AMBEL, CHEAL, DIGSA, ECHCG, PANDI, SETFA.

Abbreviations: C1, Cohort 1 weeds established at corn planting. C2, Cohort 2 weeds established at corn emergence. C3, Cohort 3 weeds established at the V1 stage of corn development. C4, Cohort 4 weeds established at the V3 stage of corn development.

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[1] Letters following this symbol are a WSSA - approved computer code from Composite List of Weeds, Revised 1989. Available only on computer disk from WSSA, 810 East 10th Street, Lawrence, KS 66044-8897.

INTRODUCTION

Weed growth can be affected by many factors. These factors include the ability of weeds to capture light, water, nutrients and other resources from the environment. How weeds capture resources depends highly upon the physiology and morphology of the plant. Plant architecture may be the largest morphological factor in how a weed captures resources. Since weeds usually grow with other plants, plant architecture can have a strong influence on plant competitiveness. Therefore, to understand weed growth, it is important not only to study individual weeds, but also weeds growing with other plants.

Moisture and light availability and the ability of plants to capture these resources can have a large influence on competitiveness (Akey et al. 1990; Stoller and Woolley 1985). Shading of redroot pigweed (*Amaranthus retroflexus*) by corn (*Zea mays*) plants reduced redroot pigweed growth and dry matter accumulation (McLachlan et al. 1993a and b). Common cocklebur (*Xanthium strumarium*) growth was shown to be more responsive to light availability than sicklepod (*Senna obtusifolia*) (Jones and Walker 1993). Changes in interception of photosynthetically active radiation were important in modeling competition between dry bean (*Phaseolus vulgaris*) and common ragweed (*Ambrosia artemisiifolia*) (Chikoye et al. 1996).

Growth chamber studies, however, demonstrated that temperature and photoperiod did not influence common lambsquarters (*Chenopodium album*)development (Huang et al. 2001). Model simulations suggest late season weed competition is influenced more by light than early season weed competition and that early season weed competition is influenced more by nutrient and moisture limitations (Weaver et al. 1992).When comparing growth of mixtures of common cocklebur, entireleaf morningglory (*Ipomoea hederacea*), and soybean (*Glycine max*), common cocklebur growth was affected more than morningglory growth in non-irrigated situations (Mosier and Oliver 1995). However, under irrigation, morningglory growth was reduced more than cocklebur growth, demonstrating that weeds can respond differently to changing environmental conditions (Mosier and Oliver 1995).

Depending on the plant species and stand density, weeds may grow with the crop for some period before causing a yield loss (Weaver et al. 1992). Soybean growth can be reduced if Johnsongrass (*Sorghum halepense*) is not removed early in the cropping season (Sims and Oliver 1990). Sicklepod interfered with soybean growth early as well as late in the season (Sims and Oliver 1990). Common lambsquarters could remain with soybeans for 10 weeks before a 20 percent yield reduction occurred in Michigan (Crook and Renner 1990). In Ohio, reducing common lambsquarters density from 2 plants to 1 plant per meter of soybean row, increased the amount of time that soybeans and common lambsquarters could compete, from 5 to 7 weeks, before a 5 percent soybean yield loss occurred (Harrison 1990). Models have demonstrated that duration of weed and crop competition, weed stand density and time of weed removal are all critical factors when minimizing crop losses (Berti et al. 1996; Frank et al. 1992).

While yield loss can accurately describe crop and weed competition, measurements of leaf area and plant biomass can also provide an accurate measurement of plant growth and the ability of a plant to capture resources. Plant weight has been shown to be related to the soil surface area a plant occupies (White and Harper 1970). Measuring plant weight, however, requires destructive sampling. Destructive sampling does not allow for leaf area or biomass measurements throughout the life cycle of the plant. By measuring the height and width of a plant, the area a single plant occupies can be measured throughout the growing season. The area a plant occupies can then be calculated without destructive sampling and correlated to plant competitiveness (Bussler et al. 1995).

Another measure of weed competition and resource capture is weed seed production. Soybean and sicklepod interference reduced johnsongrass seed production by 73 to 95 percent (Sims and Oliver 1990). Sicklepod seed production was also reduced from soybean and johnsongrass competition (Sims and Oliver 1990). Velvetleaf seed production was reduced by 82 percent when in the presence of crop competition (Lindquist et al. 1995). Early emerging velvetleaf in corn and soybean produced more seed than later emerging velvetleaf (Cardina et al. 1995).

A number of models have been developed to describe weed and crop interactions, particularly negative interactions such as competition between weed and crop plants (Radosevich et al. 1997). Common lambsquarters growth could be properly described in Wisconsin with regression equations even though leaf area and plant height differed between growing seasons (Colquhoun et al. 2001).Variability in plant growth can be due to differences in environments (Ghersa and Holt 1995). Differences in plant growth between environments can make it difficult to predict crop yield loss from a weed or weeds with data generated outside a growing region (Knezevic et al. 1994; McGiffen et al. 1997), limiting the usefulness of common coefficients to predict crop losses between years and locations (Lindquist et al. 1999).

Information is needed on how weeds respond to different environments. This information can be used to test models that predict the outcome of crop and weed interactions. While it may be difficult to predict the outcome of weed and crop interactions in one region with data generated in another region (Lindquist et al. 1999), data generated locally can be used in models developed in other regions to accurately describe weed growth (Colquhoun et al. 2001). Data has been generated in Michigan on the affect giant foxtail and velvetleaf density has on interference relationships in corn (Fausey et al. 1997 and Lindquist et al. 1996). Little information is available on how giant foxtail and velvetleaf growth is affected by weed emergence time relative to corn emergence. More information is needed on weed and corn interactions to improve the accuracy of weed and crop models in Michigan (Swinton et al. 2002).

Field trials were conducted in Michigan to investigate the interaction of eight weed species with corn. The objectives of the trials were:(1) to characterize differences in weed growth and seed production between four broadleaf species; velvetleaf, common lambsquarters, common ragweed and redroot pigweed, and four grass species giant foxtail (*Setaria faberi*), barnyardgrass, fall panicum *(Panicum dichotomiflorum*) and large crabgrass (*Digitaria sanguinalis*) as affected by corn, and (2) to examine the effect of weed emergence time, relative to corn emergence, on weed growth and seed production.

MATERIALS AND METHODS

A field study to examine weed and corn interactions was conducted for three years at the Michigan State University Agronomy Farm, in East Lansing, MI. The soil type was a Capac sandy loam (Aubbeenaubee Fine-loamy, mixed mesic Epiaqualfs). Study design was a split plot with six replications. The main plot was weed planting time (cohort) and the subplot was weed species. Each subplot was made up of a single weed. The whole plot consisted of four broadleaf species; velvetleaf, common lambsquarters, common ragweed and redroot pigweed, and four grass species; giant foxtail, barnyardgrass, fall panicum, and large crabgrass and three rows of corn. Plot size was 1.5 by 10.7 m. Weeds were planted 10 cm from the middle corn row and the weeds were planted one meter apart. Corn was planted at 79,000 seeds per ha and the rows were spaced 75 cm apart. Weeds were planted in four cohort timings relative to corn growth stage; cohort one at corn planting (C1), cohort two at corn emergence (C2), cohort three at the V1 stage of corn growth (C3) and cohort four at the V3 stage of corn growth (C4).

A glyphosate-resistant corn hybrid was planted each year. In 2001, DK 35-50 RR, an 88 - day relative maturity hybrid, was planted. In 2002 and 2003, a 99 - day relative maturity hybrid was planted, DK 493 RR and DK 44 46 RR, respectively. In-furrow starter fertilizer was not applied in any year. Nitrogen was applied broadcast at a rate of 140 kg/ha and shallowly incorporated into the soil with a field cultivator prior to planting. The seedbed was prepared by cultivating twice with a field cultivator. The soil was moldboard plowed in the fall each year prior to initiating the experiment.

Planting dates for corn and weeds are shown in Table 1. Planting dates were delayed in 2001 due to rainfall at the site. Cohort 2 was not planted in 2002 due to rapid corn emergence and wet field conditions. Weeds were establish by planting approximately 12 seeds per species. After weed emergence, weeds were thinned to one per each weed species. Plots were maintained weed free by covering the desired weeds with clay pots, applying glyphosate at a rate of 0.64 kg/ha, and handweeding.

Data collection and statistical analysis. After weeds were thinned to one per subplot, weekly size measurements were taken on each weed. Plant measurements included height and width. Plant height was measured from the soil surface to the top of the plant. Plant width was determined from two perpendicular measurements of the plant parallel to the soil surface. Each of the weeds were measured individually. Corn and weed leaves that overlapped the target weed were temporarily moved if the leaves interfered with weed measurement. Height and width measurements were used to calculate the area a plant occupied expressed as cylindrical volume (Bussler et al. 1995). The average of the two width measurements was divided by two to calculate the radius of the plant. The height and radius of the plant were used in Equation 1 to calculate the cylindrical volume of an individual plant.

$$\text{cylindrical volume} = \pi r^2 h \qquad [1]$$

The relationship between plant cylindrical volume and biomass was correlated between multiple plant species with different morphological characteristics (Bussler et al. 1995). Measurements of plant area expressed as a cylindrical volume can also be used to predict relationships between plant growth and seed yield (Bussler et al. 1995).

When the earliest planted weeds matured, all of the weeds were harvested on the same day regardless of weed planting date. Weeds were then dried and weighed. Weed seed was separated from the dried plants and then counted. Weed seed was separated from the dried plants by first removing the seed from the stems. Next the seeds and leaf material were ground by hand using a wood block wrapped in cloth and a pan. The seed and chaff were then sifted using screens appropriate for the size of the seed. Finally, the number of seeds per plant was determined by either counting all the seed or by calculating the number of seeds. If the total number of seeds was less than 100, all of the seeds were counted. If the total number was greater than 100, 100 seeds were counted and the weight of the 100 seeds was determined. The total amount of seed was then weighed. The weight of the seed was divided by the weight of 100 seeds and then multiplied by 100 to determine the number of seeds.

Daily weather data was obtained from a weather station close to the site. The rainfall pattern for each year is shown in Figure 1. Growing degree days for each planting time were calculated from a base of 10°C (Table 1).

Data was analyzed by ANOVA using PROC MIXED in SAS. Means were separated using population marginal means (least square means) LSD at the P=0.05 level of significance. Population marginal means LSD separation was used due to the large number of comparisons and unequal sample sizes. Some weeds did not emerge or died early. This lead to more observations of one weed species compared with another. Population marginal means LSD weights blocks, in this case replications, equally despite the unequal sample sizes, allowing for a more accurate reflection of treatment effects. Correlations were computed in SAS to examine the relationship between weed growth and environmental parameters.

RESULTS AND DISCUSSION

Plant growth was affected each year by periods of limited moisture. In 2001 and 2002, rainfall occurred during weed emergence and then little rainfall occurred until a month later. Adequate moisture was available through the remainder of the growing season. In 2003, moisture conditions were above average early in the growing season, however little rainfall occurred from mid-July to mid-August (Figure 1).

More growing degree days accumulated in 2002 than 2001 and 2003 (Table 1).

Within each year, growing degree days were correlated positively with weed size and biomass (Table 2). Seed yield was positively correlated with growing degree days in 2001 and 2003.

When grown with corn, each weed species had different patterns of growth and growth patterns were quite similar between years. Some weeds, such as giant foxtail and common lambsquarters, continued to increase in volume until the end of the growing season, while other weeds, such as barnyardgrass and velvetleaf reached a maximum volume and then declined near the end of the growing season (Figure 2).

When weeds were established at corn emergence, weed size and seed production were generally greater than when weeds were established after corn emergence. Changes in weed volume and biomass can be used to predict the outcome of crop and weed interactions (Bussler et al. 1995 and Ngouajio et al. 1999). Weed volume and weed biomass were highly correlated (Table 3). As weed volume increased, biomass increased, indicating that both measurements could accurately estimate weed size. Common lambsquarters and common ragweed volume and biomass were highly correlated. Redroot pigweed and fall panicum volume and biomass were not highly correlated (Table 3). Weed seed production is also a good indicator of weed competitiveness (Sims and Oliver 1990 and Lindquist et al. 1995). Weed size was positively correlated to seed production (Table 3). As weed size increased, seed production increased. Weed biomass was a better indication of weed seed production than weed volume for all weeds except large crabgrass (Table 2). Therefore, weed biomass may be a better indicator of weed and crop interactions than weed volume. Maximum weed volume, however, is important for determining how large a weed can grow at any point in the growing season. For example, velvetleaf was greater in size early in the growing season when planted at corn planting compared to the later planting times (Figure 2). However, at the end of the growing season, velvetleaf size in the first planting, was similar to velvetleaf size at the later plantings (Figure 2). If plant size is only measured at the end of the growing season, differences in weed growth patterns as shown in Figure 2 would be difficult to examine. Biomass measurements also require destructive sampling and will not allow for measurement of the same weed throughout the growing season.

Weed Biomass as affected by Weed Species

Each year common lambsquarters, velvetleaf and common lambsquarters consistently produced a large biomass, however one weed was not consistently larger each year. When weeds were planted at the time of corn planting, common ragweed produced over 70 percent more biomass than the smaller weeds, redroot pigweed, fall panicum and large crabgrass in 2001 (Table 4). In 2002, common lambsquarters produced over 50 percent more biomass than the second largest weed, common ragweed. In 2003, redroot pigweed biomass was similar to common lambsquarters and greater than all other weed species. The grass weeds generally had a smaller biomass than the larger broadleaf weeds. Fall panicum produced the least amount of biomass of all the weeds.

When weeds were planted at the time of corn emergence, common ragweed had over 60 percent more biomass than the next largest weeds, common lambsquarters and velvetleaf, in 2001 (Table 4). In 2003, redroot pigweed produced over twice as much biomass as large crabgrass, fall panicum and barnyardgrass. All other weeds produced a similar biomass. When weeds were planted at the V1 stage of corn growth, velvetleaf produced over 4 times more biomass than all weeds except fall panicum in 2001(Table

4). In 2003, redroot pigweed produced nearly 4 times more biomass than barnyardgrass, large crabgrass, and fall panicum. There were no differences in biomass between the other weeds. In 2002, all weeds produced a similar biomass. When weeds were planted at the V3 stage of corn development, there were no differences in biomass among the weed species (Table 4).

Common lambsquarters and common ragweed generally produced the greatest biomass of all the weeds when grown with corn (Table 4). Common lambsquarters was able to use the additional growing degree days available in 2002, to grow larger relative to the other weeds. Redroot pigweed responded opposite to common lambsquarters in relation to temperature during the growing season. In the two years with the greatest amount of growing degree days, redroot pigweed biomass was among the lowest of all the weeds. In the year with the least amount of growing degree days, redroot pigweed biomass was among the greatest for all the weeds. Velvetleaf produced a large biomass in the two years with more growing degree day accumulation regardless of when it emerged relative to corn. However, in the year with the lowest amount of growing degree days, velvetleaf biomass was among the lowest of the weeds.

Barnyardgrass and giant foxtail generally produced the greatest biomass of the grass weeds (Table 4). However, biomass production from these weeds was generally lower than the larger broadleaf weeds. Large crabgrass and fall panicum consistently produced a smaller biomass than other weeds when weeds were established close to corn emergence. However, at the later planting times biomass production from these two weeds was equal to the other weed species. Generally more differences in biomass were observed between weeds that were established closer to corn emergence compared to weeds established after corn emergence.

Weed Biomass as affected by Cohort Timing

Weeds established at or before corn emergence were generally larger than weeds established after corn emergence (Table 4). Large crabgrass, fall panicum and giant foxtail biomass production was not statistically different among cohort timings even though giant foxtail biomass was as much as 94 percent greater when planted at corn emergence compared to when planted at V3 stage corn, indicating that plants within the same species could be morphologically diverse. In 2001, barnyardgrass biomass was 75 percent greater when planted at corn emergence than compared to when planted at V1 and V3 stage corn. In 2003, barnyardgrass planted at corn planting produced 96 percent more biomass than barnyardgrass planted at V3 stage corn. In 2002, barnyardgrass biomass was similar between each of the planting times. There were no biomass differences between any of the planting times for the other grass weeds, large crabgrass, fall panicum and giant foxtail. The greater number of growing degree days in 2002 resulted in increased corn growth relative to barnyardgrass growth compared to 2001 and 2003. The increase in corn growth reduced barnyardgrass growth when planted at corn planting more in 2002 than in 2001 and 2003, resulting in similar barnyardgrass biomass production between the cohorts.

Common lambsquarters, common ragweed and velvetleaf growth were all impacted by time of establishment relative to corn planting. Redroot pigweed biomass was impacted less by weed planting time than the other three broadleaf weeds. Fewer growing degree days may have reduced corn growth relative to the other growing seasons resulting in increased redroot pigweed growth when established at corn planting in 2003

(Table 4). In 2002 and 2003, common lambsquarters biomass was at least 90 percent greater when planted at corn planting than common lambsquarters planted at V1 and V3 stage corn. Common ragweed biomass was at least 90 percent greater when planted at corn planting compared to common ragweed planted at V3 stage corn. There were no differences in biomass between any of the planting times for the two weeds in 2001.

In 2003, velvetleaf biomass was 87 percent greater when planted with corn than when planted at V3 stage corn (Table 4). When planted at corn planting and at the V1 stage of corn growth, velvetleaf biomass in 2001 was 75 percent greater than velvetleaf planted at the V3 stage of corn growth. Due to increased growing degree days, which resulted in increased corn growth relative to velvetleaf growth in 2002, planting time had no effect on velvetleaf biomass.

In 2003, redroot pigweed planted at corn planting produced at least 50 percent more biomass than redroot pigweed planted at the V1 and V3 stages of corn growth. Redroot pigweed, biomass was not affected by planting time in 2001 and 2002.

Maximum Weed Volume as affected by Weed Species

Weed volume can provide a good indication of the physical size of a weed. Generally larger weeds will have a larger biomass and seed yield, indicating that the weeds were able to capture more resources. When weeds were planted at corn planting velvetleaf, common ragweed and giant foxtail were the largest weeds. Common lambsquarters grew larger relative to other weeds in years with increased growing degree days. Barnyardgrass grew larger relative to other weeds in years with fewer growing degree days due to decreased competition with corn. Large crabgrass and fall panicum were generally smaller than the other weeds each year. In 2001, giant foxtail was 28 percent larger than common lambsquarters and 97 percent larger than redroot pigweed (Table 5). All other weeds were equal in size. In 2002, common lambsquarters, common ragweed and velvetleaf were larger than all other weeds except giant foxtail. Large crabgrass and fall panicum were the smallest weeds. Barnyardgrass and redroot pigweed were nearly 9 times smaller than the largest weeds and 90 percent larger than the smallest weeds. In 2003, velvetleaf , common ragweed and redroot pigweed were the largest weeds. Common lambsquarters, giant foxtail, and barnyardgrass were two-thirds to one-half the size of largest weeds. Large crabgrass and fall panicum were one-fifth to one-tenth the size of the largest weeds. Common lambsquarters responded positively to increases in growing degree days. Redroot pigweed grows well relative to other weeds in cooler years. Corn growth may not be as rapid in cooler years which results in less competition between redroot pigweed and corn.

When weeds were planted at corn emergence, growth patterns were similar to weeds planted at corn planting. When planted at corn emergence, common ragweed was greater in size than all weeds except velvetleaf in 2001 (Table 5). Velvetleaf was the second largest weed and was 82 percent larger than the other weeds. In 2003, a similar pattern of growth was measured with weeds planted at corn planting as with weeds planted at corn emergence. However, when weeds were planted at corn emergence, velvetleaf and giant foxtail instead of velvetleaf and common ragweed produced the greatest size. In 2001, redroot pigweed was the smallest of all the weeds. In 2003, fall panicum and large crabgrass were the smallest weeds.

Differences in weed growth began to decline when weeds were planted at the V1 stage of corn growth (Table 5). Corn was larger in size when the weeds were established.

The larger corn could shade the weeds quicker, resulting in more competition for light, which reduced the growth potential of all the weeds. Velvetleaf was larger than all species except fall panicum in 2001. In 2002, velvetleaf again was the largest weed. In 2003, a similar pattern of growth was measured with weeds planted at the V1 stage of corn growth as with weeds planted at corn planting and corn emergence. Velvetleaf, redroot pigweed, common ragweed and giant foxtail produced the greatest size and fall panicum and large crabgrass were the smallest weeds.

Weeds planted at the V3 stage of corn growth resulted in fewer differences in growth between the weeds (Table 5). There were no differences in weed volume in 2001 and 2003. In 2002, velvetleaf was larger than large crabgrass. All other weeds were similar in size.

When comparing weed size expressed as maximum weed volume, velvetleaf was equal to and greater than the other weed species regardless of year and emergence time relative to corn emergence. Of the other broadleaf weeds, common ragweed size was consistently among the greatest. Common lambsquarters and redroot pigweed were more variable between years. Common lambsquarters was similar in size to common ragweed but generally was smaller than velvetleaf. In 1 of 3 years common lambsquarters was among the smallest of the weeds. In 2 of 3 years redroot pigweed was among the smallest of the weeds. However, in 2003, redroot pigweed was one of the largest weeds.

Both common lambsquarters and corn appear to respond positively to increases in the number of growing degree days, while redroot pigweed responds positively to cooler growing conditions relative to the other weeds and corn. In the year with the fewest number of growing degree days, common lambsquarters was among the smallest weeds while redroot pigweed was among the largest. The cooler weather resulted in a reduction in corn growth which decreased competition between redroot pigweed and corn. Common lambsquarters was not able to respond to the reduction in corn growth since the cool conditions reduced common lambsquarters growth as well. Velvetleaf and common ragweed growth was not impacted by temperature changes as much as common lambsquarters and redroot pigweed.

Of the grass weeds, giant foxtail produced volumes equal to and greater than other weeds. Giant foxtail and common ragweed volumes were quite similar in that they were sometimes among the greatest but usually at or below the size of velvetleaf. Barnyardgrass volume was similar to or less than the volume of the largest weeds. In 2 of 3 years, large crabgrass and fall panicum consistently produced smaller volumes than other weed species.

Maximum Weed Volume as affected by Cohort Timing

Weeds grew larger in 2002 compared to 2001 and 2003 due to the warmer growing season (Table 5). Weed size generally declined with later planting time. Common ragweed however, planted at corn emergence in 2001, was larger than common ragweed planted at corn planting.

Barnyardgrass in 2001 and 2002 was 90 percent larger when planted at corn planting than when planted after the corn reached the V1 stage of growth (Table 5). In 2003, barnyardgrass was also larger when established at corn planting compared to planting at the V3 stage of corn growth. Large crabgrass volume was 70 to 90 percent greater when planted at corn planting than the other planting times each year. There were no differences in large crabgrass size between the other planting times. Fall panicum size was similar between each of the planting times each year. In 2001 and 2002, giant foxtail was largest when established at corn planting. In 2003, giant foxtail was similar in size between planting times when established as late as V1 stage corn. Giant foxtail was 90 percent smaller when planted at V3 stage corn compared to the other planting times.

While there were no differences in common lambsquarters size between planting times in 2 of 3 years, common lambsquarters was generally larger when planted at corn planting compared to when established after corn emergence (Table 5). In 2001 and 2002, redroot pigweed size was similar between the planting times. However in 2002, redroot pigweed was over 90 percent larger when planted at corn planting than when planted at V3 stage corn. In 2003, redroot pigweed when established at V3 stage corn, was twenty times less than the other establishment timings. In 2001, velvetleaf was ten times smaller when established at V3 stage corn than the earlier timings. In 2002, velvetleaf size was similar at the early planting times. Velvetleaf at the early planting times was as much as 83 percent greater than velvetleaf planted at V3 stage corn.

Common ragweed was larger when established at corn emergence rather than corn planting in 2001. Common ragweed emergence was poor in 2001. Common ragweed seed was acid scarified to induce germination in 2001. In 2002, new common ragweed seed was collected and was buried in the field over winter to release dormancy. Poor seed germination may have contributed to size differences between the planting times. In 2002 and 2003, common ragweed growth patterns were as expected with common ragweed established at the time of corn planting producing the largest size (Table 5).

Weed Size Summary

Although weed volume and weed biomass were correlated (Table 2), weed volume was more variable than weed biomass. Small changes in weed height or diameter can lead to large differences in calculated plant size. Variability in weed morphology may explain why few statistical differences were measured between planting times despite large differences in mean volume and biomass between early and later cohorts. Velvetleaf was among the largest weeds when measured by maximum weed volume. When measured by weed biomass however, it was not one of the larger weeds. Velvetleaf has large leaves that senese quickly as it matures. Leaf loss may have contributed to the lower biomass relative to other weeds. Some variability can be attributed to growing conditions. Common lambsquarters, velvetleaf, common ragweed and giant foxtail all grew larger in years when greater than 1200 growing degree days accumulated. Redroot pigweed and barnyardgrass grew larger in years which 1100 or fewer growing degree days accumulated. Large crabgrass and fall panicum were similar in size each year. Weeds that are smaller also have fewer differences between establishment timings. Large crabgrass, fall panicum and redroot pigweed were the smallest weeds and had fewer differences between establishment timings.

Weed Seed Yield as affected by Weed Species

Seed production generally declined with later planting time. Common lambsquarters, redroot pigweed and large crabgrass generally produced more seed than the other weeds when planted later in the growing season (Table 6). There were no differences in seed production among the weeds when established after the V1 stage of corn development. When established at corn planting, common lambsquarters, large crabgrass, and redroot pigweed produced a greater amount of seed per plant than barnyardgrass, fall panicum and velvetleaf in 2001. Giant foxtail and common ragweed produced less seed per plant than common lambsquarters and a similar amount of seed compared to the other weed species. In 2002 and 2003, common lambsquarters produced more seed than any of the other weed species when grown with corn.

When established at corn emergence, common lambsquarters and common ragweed produced the most seed per plant in 2001 (Table 6). However, there were no statistical differences in seed production between any of the weeds. In 2003, common lambsquarters and redroot pigweed produced the greatest amount of seed followed by large crabgrass.

When established at the V1 stage of corn development, common lambsquarters produced a greater amount of seed than all species except redroot pigweed and large crabgrass in 2003 (Table 6). In 2001 and 2002, there were no differences in seed production.

When weeds were established at the V3 stage of corn development, there were no differences in seed production among the weed species (Table 6).

Weed Seed Yield as affected by Cohort Timing

Barnyardgrass, fall panicum and giant foxtail seed production declined with later establishment time relative to corn emergence, however, there were no large differences in seed production between the planting times (Table 6). Large crabgrass seed production in 2001 was greater when planted at corn planting than the other cohort timings. In 2002 and 2003, there were no differences in seed production between the planting times.

Common lambsquarters established at corn planting produced more seed than the later timings each year (Table 6). Common lambsquarters seed production generally declined with later planting time. In 2003, common lambsquarters established at corn emergence and V1 stage corn produced more seed than common lambsquarters established at V3 stage corn. In 2002, common ragweed and velvetleaf seed production also declined with later planting time. In 2001 and 2003, common ragweed and velvetleaf seed production between establishment timings was similar. Redroot pigweed produced similar amounts of seed regardless of planting time in 2001 and 2002. In 2003, redroot pigweed seed production at the earlier planting times was six times greater than when planted at V3 stage corn.

Common lambsquarters produced the most seed of all the weeds when grown with corn each year (Table 6). When established at corn planting, common lambsquarters produced between 1300 and 20,000 seeds per plant. Large crabgrass, giant foxtail and redroot pigweed produced between 40 and 1000 seeds per plant. Velvetleaf, common ragweed and barnyardgrass seed production ranged from 10 to 350 seeds per plant. Fall panicum produced less than 100 seeds per plant each year. Some weeds produced large quantities of seed even at later emergence times. When planted at the V1 stage of corn development, common lambsquarters produced between 300 and 1,600 seed per plant. Redroot pigweed, giant foxtail and large crabgrass averaged 100 seeds per plant each year. Common ragweed also showed potential for seed production late in the season.

Seed Yield Summary

Seed yield was correlated with weed biomass and weed volume. Size of individual weeds can be a good indicator of seed production. However, weed size was not always a good indicator of seed production between weed species when grown with corn. Within years, weeds that were large in size produced relatively more seed. Redroot pigweed was among the largest weed in 2003 and produced a relatively large amount of seed. Common lambsquarters was generally one of the larger weeds and also produced the largest amount of seed. Velvetleaf and common ragweed were two of the larger weeds however, that did not produce as much seed as some of the smaller weeds, giant foxtail, large crabgrass, and redroot pigweed.

Weeds that produced the least number of seeds per plant generally produced the largest seed size. Velvetleaf and common ragweed have larger seed sizes and produced fewer seeds than common lambsquarters and redroot pigweed. Large crabgrass had a smaller seed size than the other grass weeds and generally produced a larger number of seeds.

Summary

Velvetleaf, common lambsquarters, common ragweed, giant foxtail and barnyardgrass size was greatly impacted by their emergence time relative to corn emergence. Time of emergence had little impact on growth of redroot pigweed, fall panicum and large crabgrass. To improve weed models and weed management decision tools, weed growth as impacted by time of weed establishment relative to corn growth needs to be considered.

Weed growth relative to corn growth was sensitive to environmental conditions each year. Common lambsquarters, velvetleaf, common ragweed and giant foxtail growth was reduced in a cooler growing seasons, compared other weeds especially redroot pigweed and barnyardgrass. The reduction in common lambsquarters growth resulted in a decrease in seed production. Redroot pigweed appears to be larger and produce more seed relative to other seeds in cooler growing conditions. Fall panicum and large crabgrass did not respond to environmental changes relative to the other weeds.

Environmental variability can reduce the accuracy of weed growth models and weed management decision tools through which weed growth models are applied. Weed management models would become more accurate by using growing degree day information to predict weed growth and seed production (Lindquist et al. 1999, Colquhoun et al. 2001, and Storkey 2004). If growing degree day numbers are increasing slowly, redroot pigweed may be a troublesome weed in that particular season. If growing degree days are accumulating rapidly common lambsquarters and barnyardgrass may be a greater problem relative to other weeds.

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Table 1. Planting dates of corn and weeds and growing degree days for weeds.

	2001		2002[b]		2003	
	Date	GDD[a]	Date	GDD	Date	GDD
Corn			May 21			
Cohort 1 (C1)	June 11	1053		1393	May 18	944
Cohort 2 (C2)	June 15	994	-		May 27	922
Cohort 3 (C3)	June 18	959	June 1	1334	May 30	906
Cohort 4 (C4)	June 25	889	June 10	1270	June 11	857

[a] Total of growing degree days from weed planting date. Daily growing degree days were calculated from the average high and low Celsius temperature over a 24 hour period minus a base temperature of 10 degrees.

[b] Cohort 2 was not planted in 2002 due to excessive rainfall and rapid corn emergence.

Table 2. Correlation of weed morphological properties to growing degree days.

Year	GDD & Biomass		GDD & Volume		GDD & Seed	
	Correlation[a]	P value	Correlation[a]	P value	Correlation[a]	P value
2001	0.29	0.0019	0.34	<0.0001	0.29	0.0021
2002	0.30	0.0009	0.19	0.0100	0.14	0.1386
2003	0.35	<0.0001	0.22	0.0027	0.20	0.0067

[a] Correlation Coefficient.

Table 3. Correlation of weed morphological properties.

Weed	Biomass & Volume		Biomass & Seed		Volume & Seed	
	Correlation[a]	P value	Correlation[a]	P value	Correlation[a]	P value
barnyardgrass	0.84	<0.0001	0.57	<0.0001	0.38	0.0035
large crabgrass	0.83	<0.0001	0.75	<0.0001	0.77	<0.0001
fall panicum	0.50	0.0006	0.93	<0.0001	0.47	0.0036
giant foxtail	0.71	<0.0001	0.93	<0.0001	0.47	0.0003
common lambsquarters	0.98	<0.0001	0.95	<0.0001	0.92	<0.0001
common ragweed	0.91	<0.0001	0.76	<0.0001	0.62	<0.0001
redroot pigweed	0.67	<0.0001	0.41	0.0054	0.26	0.0899
velvetleaf	0.83	<0.0001	0.92	<0.0001	0.66	<0.0001

[a] Correlation Coefficient.

Table 4. Weed biomass per plant.[a]

	Biomass 2001			
Weeds[b]	corn planting	corn emergence	V1	V3
	grams			
barnyardgrass	A 4.15 ab	AB 1.89 bc	B 0.70 b	B 1.02 a
large crabgrass	A 2.86 bc	A 0.97 c	A 0.80 b	A 1.07 a
fall panicum	A 0.50 c	A 0.19 c	A 1.98 ab	A 0.19 a
giant foxtail	A 2.94 abc	A 1.32 bc	A 0.67 b	A 0.51 a
common lambsquarters	A 3.06 abc	A 4.07 b	A 1.07 b	-
common ragweed	A 6.54 a	A 9.70 a	-	-
redroot pigweed	A 1.84 bc	A 0.21 c	A 0.78 b	A 0.55 a
velvetleaf	A 4.55 ab	AB 3.05 bc	A 4.86 a	B 1.15 a

Table 4. (Continued)

Weeds[b]	Biomass 2002			
	corn planting	corn emergence	V1	V3
	--------grams--------			
barnyardgrass	A 2.20 c	-	A 0.77 a	A 0.28 a
large crabgrass	A 1.13 c	-	A 0.71 a	A 0.85 a
fall panicum	A 0.51 c	-	A 0.45 a	A 0.54 a
giant foxtail	A 5.73 bc	-	A 1.27 a	A 0.36 a
common lambsquarters	A 32.67 a	-	B 6.03 a	B 0.45 a
common ragweed	A 15.08 b	-	AB 3.25 a	B 0.43 a
redroot pigweed	A 6.67 bc	-	A 1.98 a	A 1.35 a
velvetleaf	A 13.05 bc	-	A 4.97 a	A 1.80 a

Table 4. (Continued)

	Biomass 2003			
Weeds[b]	corn planting	corn emergence	V1	V3
	-----grams-----			
barnyardgrass	A 3.65 bcd	AB 1.08 bc	AB 0.80 b	B 0.15 a
large crabgrass	A 1.01 de	A 0.73 c	A 0.38 b	A 0.25 a
fall panicum	A 0.32 e	A 0.17 c	A 0.08 b	A 0.01 a
giant foxtail	A 1.83 cde	A 1.5 bc	A 1.63 ab	A 0.15 a
common lambsquarters	A 5.42 ab	AB 3.77 ab	B 1.67 ab	B 0.99 a
common ragweed	A 4.45 bc	AB 2.52 bc	AB 1.67 ab	B 0.95 a
redroot pigweed	A 7.35 a	AB 5.62 a	B 3.65 a	C 0.54 a
velvetleaf	A 3.65 bcd	AB 1.43 bc	AB 2.15 ab	B 0.49 a

[a] Means within a column (weed planting time) with the same lower case letter were not different according to an LSD test (P=0.05).

[b] Means within a row (weed species) with the same upper case letter were not different according to an LSD test (P=0.05).

Table 5. Maximum weed volume per plant.[a]

Weeds[b]	Maximum Volume 2001			
	corn planting	corn emergence	V1	V3
	---------- cm^3 ----------			
barnyardgrass	A 59903 ab	AB 32899 bc	B 9700 b	B 5856 a
large crabgrass	A 72162 ab	B 18123 cd	B 17694 b	B 11160 a
fall panicum	A 34596 ab	A 13440 cd	A 26830 ab	A 3319 a
giant foxtail	A 85428 a	B 25087 bc	B 17503 b	B 7842 a
common lambsquarters	A 24633 bc	A 28227 bc	A 3930 b	-
common ragweed	B 41775 ab	A 154653 a	-	-
redroot pigweed	A 2914 c	A 462 d	A 296 b	A 186 a
velvetleaf	A 73701 ab	A 84268 ab	A 61489 a	B 6279 a

Table 5. (Continued)

Weeds[b]	Maximum Volume 2002			
	corn planting	corn emergence	V1	V3
	------cm^3------			
barnyardgrass	A 29732 bc	-	B 4030 b	B 4148 ab
large crabgrass	A 4057 c	-	A 476 b	A 131 b
fall panicum	A 6829 c	-	A 4489 b	A 393 ab
giant foxtail	A 110304 ab	-	B 13463 b b	B 3871 ab
common lambsquarters	A 230813 a	-	B 18827 b	B 3602 ab
common ragweed	A 254863 a	-	B 27397 b	B 1246 ab
redroot pigweed	A 39657 bc	-	A 6337 b	A 3044 ab
velvetleaf	A 279545 a	-	AB 131863 a	B 46955 a

Table 5. (Continued)

Weeds[b]	Maximum Volume 2003 corn planting	corn emergence	V1	V3
	-------------------	------------------- cm^3 -------------------	-------------------	-------------------
barnyardgrass	A 66998 ab	AB 20418 ab	AB 30706 ab	B 2922 a
large crabgrass	A 22587 bc	A 7581 bc	A 4653 bc	A 5425 a
fall panicum	A 9142 c	A 682 c	A 1090 c	A 958 a
giant foxtail	AB 51117 ab	A 70156 a	A 61544 a	B 5869 a
common lambsquarters	A 71717 ab	A 21156 ab	A 15851 ab	A 13722 a
common ragweed	A 91724 ab	AB 36841 ab	AB 45886 a	B 8550 a
redroot pigweed	A 96690 a	A 53629 ab	A 89365 a	B 5031 a
velvetleaf	A 102246 a	AB 70114 a	A 77240 a	B 13005 a

[a] Means within a column (weed plant time) with the same lower case letter were not different according to an LSD test (P=0.05).

[b] Means within a row (weed species) with the same upper case letter were not different according to an LSD test (P=0.05).

Table 6. Weed seed yield per plant.[a]

Weeds[b]	Seed Yield 2001			
	corn planting	corn emergence	V1	V3
	Number of Seeds per Plant			
barnyardgrass	A 120 c	A 125 a	A 30 a	A 41 a
large crabgrass	A 1013 ab	B 168 a	B 136 a	B 22 a
fall panicum	A 72 c	A 68 a	-	-
giant foxtail	A 305 bc	A 184 a	A 118 a	A 37 a
common lambsquarters	A 1460 a	B 637 a	B 300 a	-
common ragweed	A 330 bc	A 601 a	-	-
redroot pigweed	A 893 ab	A 157 a	A 51 a	A 15 a
velvetleaf	A 103 c	A 94 a	A 106 a	-

Table 6. (Continued)

Weeds[b]	Seed Yield 2002 corn planting	corn emergence	V1	V3
	---Number of Seeds per Plant---			
barnyardgrass	A 12 b	-	A 5 a	A 7 a
large crabgrass	A 47 b	-	A 8 a	A 0 a
fall panicum	A 0 b	-	A 0 a	A 0 a
giant foxtail	A 929 b	-	A 93 a	A 1 a
common lambsquarters	A 19389 a	-	B 1602 a	B 33 a
common ragweed	A 347 b	-	A 136 a	A 9 a
redroot pigweed	A 294 b	-	A 103 a	A 6 a
velvetleaf	A 222 b	-	A 22 a	A 0 a

Table 6. (Continued)

	Seed Yield 2003			
Weeds[b]	corn planting	corn emergence	V1	V3
	Number of Seeds per Plant			
barnyardgrass	A 102 b	A 0 c	A 2 b	A 0 a
large crabgrass	A 201 b	A 247 b	A 223 ab	A 16 a
fall panicum	A 28 b	A 0 c	A 0 b	A 7 a
giant foxtail	A 56 b	A 73 c	A 86 b	A 3 a
common lambsquarters	A 1393 a	B 691 a	B 492 a	C 42 a
common ragweed	A 14 b	A 17 c	A 0 b	A 1 a
redroot pigweed	AB 168 b	A 491 ab	AB 215 ab	B 28 a
velvetleaf	A 12 b	A 0 c	A 0 b	A 0 a

[a] Means within a column (weed planting time) with the same lower case letter were not different according to an LSD test (P=0.05).

[b] Means within a row (weed species) with the same upper case letter were not different according to an LSD test (P=0.05).

Figure 1. Rainfall in relation to corn and weed planting (2001-2003).

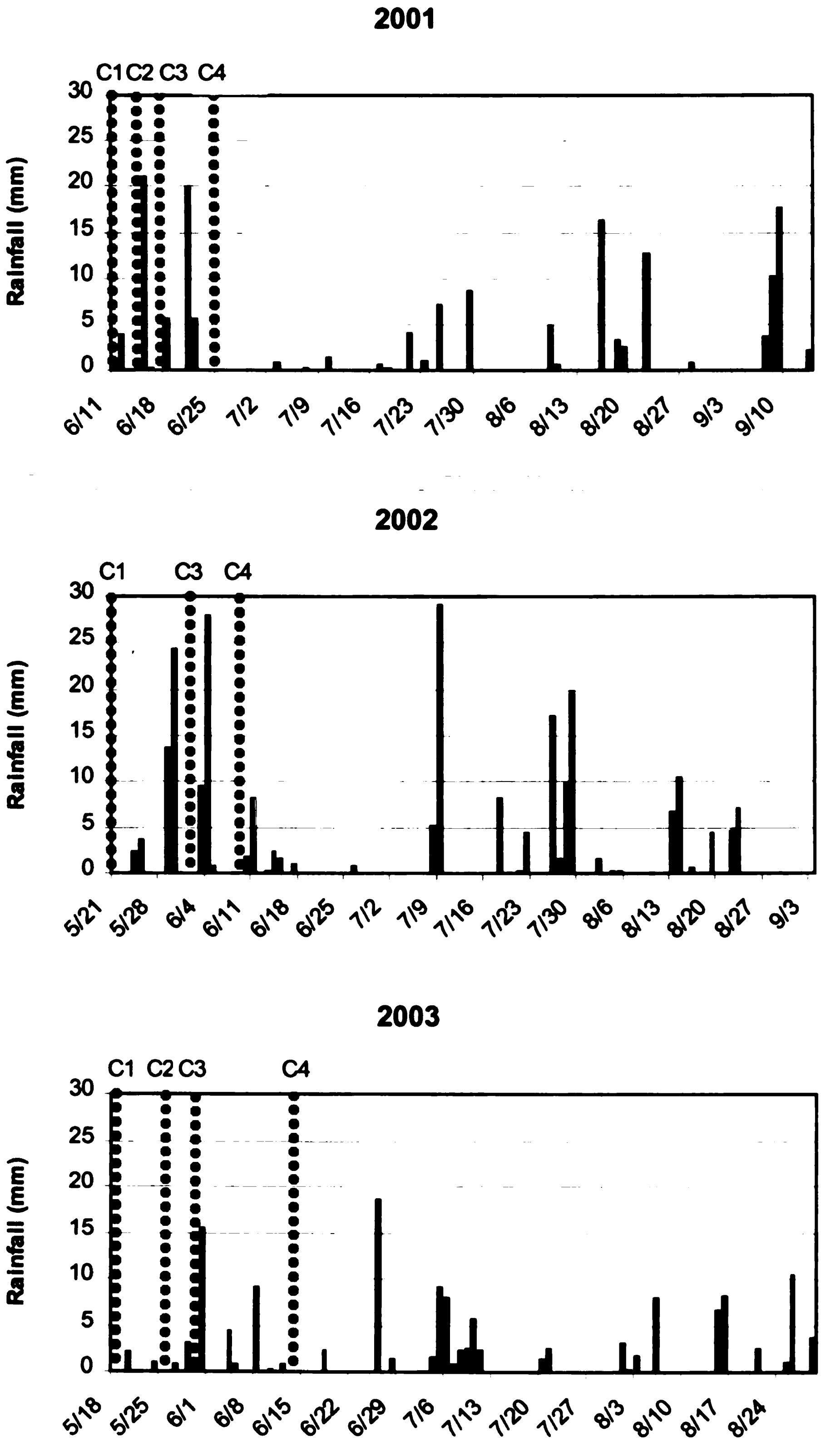
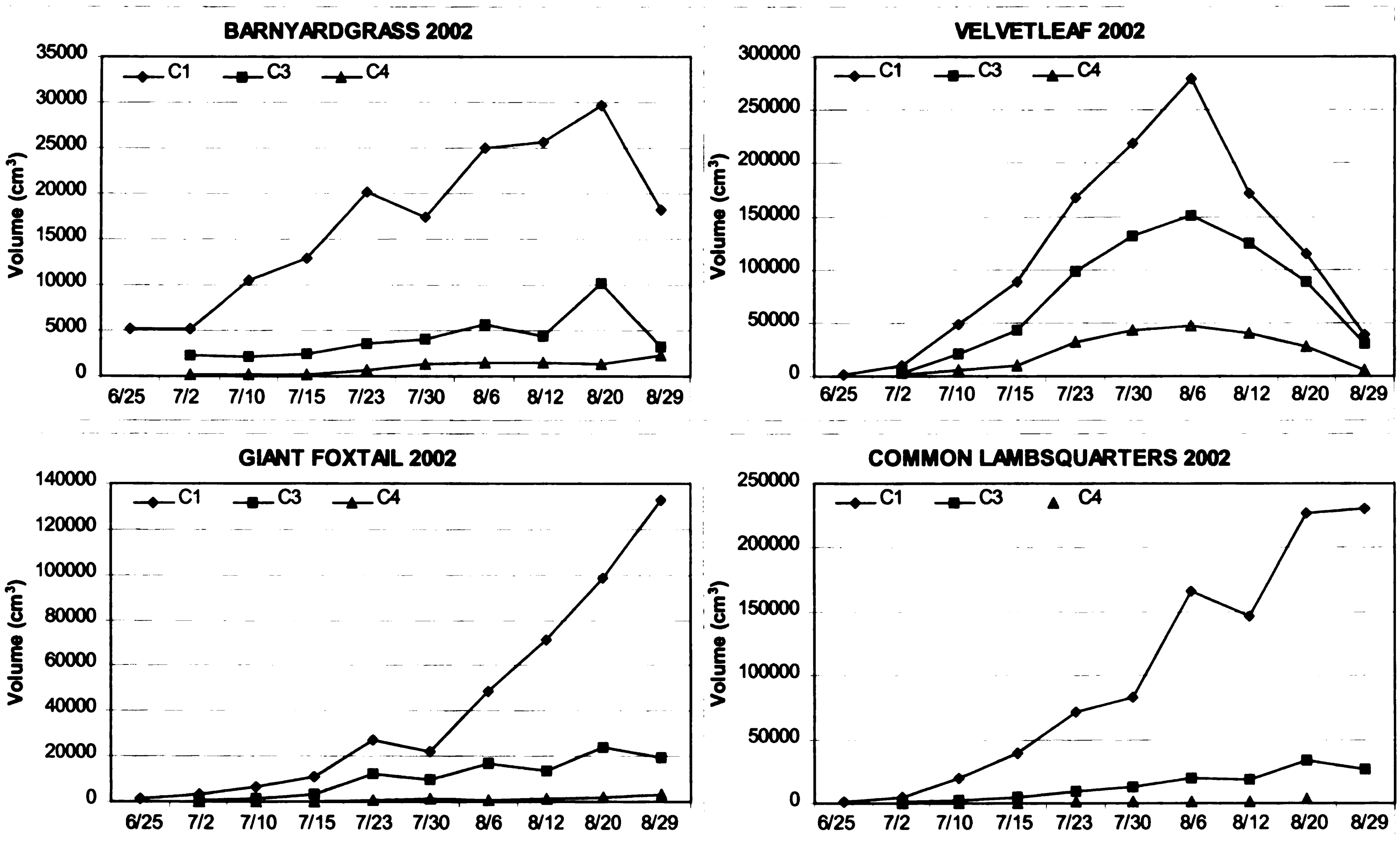


Figure 2. Barnyardgrass, velvetleaf, giant foxtail and common lambsquarters volume for each cohort timing, 2002.



CHAPTER 2

CORN GROWTH AND YIELD AS AFFECTED BY WEED SPECIES AND WEED EMERGENCE TIME

Abstract. Increasing emphasis is being placed on the management of weeds after emergence using only foliar-applied herbicides and the development of weed management decision support systems. To avoid corn yield loss, more information is needed to accurately predict the competitiveness of individual weed species with corn. A study was conducted in the field at the Michigan State University Agronomy Farm for 3 years examining the effect of giant foxtail, common lambsquarters, and velvetleaf emerging at different times on corn growth and yield. Weeds were established at corn planting, at corn emergence, when corn reached V1 and when corn reached V3. Weeds did not affect corn development or corn height. When established at corn planting, common lambsquarters and velvetleaf reduced corn yield 2 of 3 years and giant foxtail reduced corn yield 1 of 3 years. Common lambsquarters reduced corn yield in 1 of 3 years when established at corn planting. Velvetleaf reduced corn yield in 1 of 3 years when established at V1 stage corn. When weeds were established at V3 corn, no yield loss occurred. Weeds were generally larger when established at corn planting compared to establishment at corn emergence or later. Common lambsquarters produced more seed per plant than velvetleaf or giant foxtail.

Nomenclature: common lambsquarters, *Chenopodium album* L. #[1] CHEAL; giant foxtail, *Setaria faberi* Herrm. # SETFA; velvetleaf, *Abutilon theophrasti* Medicus. # ABUTH.

Additional index words: Weed biology, Weed ecology, *Abutilon theophrasti*, *Chenopodium album*, *Setaria faberi*, ABUTH, CHEAL, SETFA.

Abbreviations: At plant, weeds established at corn planting. VE, weeds established at corn emergence. V1, weeds established at the V1 stage of corn development. V3, weeds established at the V3 stage of corn development.

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[1] Letters following this symbol are a WSSA - approved computer code from Composite List of Weeds, Revised 1989. Available from WSSA.

INTRODUCTION

Weeds compete with crop plants for nutrients, water and light. The nature and extent of this competitive interaction is highly dependent upon the environment and plant species involved. Research has focused on the effect of weed stand density and multiple weed species on crop yield. Less information is available on how time of weed emergence affects crop yield. Researchers are developing weed management decision support systems that consider weed species, size, density, seed production and competitiveness with the crop when recommending weed management strategies. Weed competitiveness in these decision tools is often based on years of empirical data on weed and crop interactions. Information is needed on the competitiveness of individual weed species, with corn, at different establishment times during the growing season to ensure weed management recommendations will be accurate.

The response of a weed to moisture, light, and temperature is dependent on weed species. In mixtures of common cocklebur, entireleaf morningglory, and soybean, common cocklebur growth was reduced more than morningglory growth from competition with soybean in non-irrigated situations (Mosier and Oliver 1995). However, under irrigation, morningglory was not as competitive as cocklebur (Mosier and Oliver 1995). Common cocklebur growth was more responsive to light and water availability than sicklepod (Jones and Walker 1993). Redroot pigweed growth rate increased with increasing temperature (McLachlan et al. 1993).

The cropping system along with growing conditions will influence weed and crop interactions. Corn yield loss was greater from velvetleaf in a warm, wet year than in a dry or cold, wet year (Cardina et al. 1995). Velvetleaf caused greater yield loss in corn planted no-till compared to conventional tillage (Cardina et al. 1995). Some weeds are quite competitive with a particular crop regardless of growing conditions. Common cocklebur and entireleaf morningglory, with or without irrigation, reduced soybean yield by as much as 60 percent (Klingaman and Oliver 1994).

Weed stand density has a large impact on crop yield. Ghosheh et al. (1996) showed that johnsongrass stand densities greater than three plants per 9.8 m of row reduced corn yield. Corn yield was reduced by as much as 14 percent from giant foxtail populations of 10 per meter of corn row (Fausey et al. 1997). Densities of Palmer amaranth as low as 0.5 plant per meter of corn row, reduced corn yield by as much as 11 percent. Common cocklebur populations as low as 0.5 per meter reduced soybean yield (Mortensen and Coble 1989). As few as one barnyardgrass or redroot pigweed plant per meter of row in potato, reduced marketable tuber yield by as much as 33 percent (Vangessel and Renner 1990).

Weed emergence time can have as large of an impact on crop growth as weed stand density. Generally weeds that emerge after crop emergence are not as competitive. Corn yield loss was affected more by Palmer amaranth time of emergence than stand density (Massinga et al. 2001). Corn yield loss from barnyardgrass declined with later barnyardgrass emergence date (Bosnic and Swanton 1997). Early emerging velvetleaf resulted in greater corn yield loss compared to late emerging velvetleaf (Cardina et al. 1995). Date of crop planting, however, showed mixed results on the effect of weed competition on crop yield. Early planting dates resulted in greater soybean yields in competition with entireleaf morningglory and sicklepod than later planting dates (Klingaman and Oliver 1994). However, another study reported no effects of soybean planting date on yield loss from entireleaf morningglory or common cocklebur (Mosier and Oliver 1995). Planting date also had little effect on the competitiveness of cotton with entireleaf morningglory and sicklepod (Klingaman and Oliver 1994).

Depending on the plant species, weeds may grow with the crop for some period before causing a yield loss. Soybean growth may be reduced if johnsongrass is not removed early in the growing season (Sims and Oliver 1990). Sicklepod can interfere with soybean early and late in the growing season (Sims and Oliver 1990). Common lambsquarters could remain with soybeans for 10 weeks before a 20 percent yield reduction occurred in Michigan (Crook and Renner 1990). In Ohio, reducing common lambsquarters density from 2 plants to 1 plant per meter of soybean row, increased the amount of time that soybeans and common lambsquarters could compete, from 5 to 7 weeks, before a 5 percent soybean yield loss occurred (Harrison 1990).

Along with growing conditions and plant populations, the size and shape of a weed can be a good indicator of the effect a weed can have on a crop. Size and canopy architecture will influence the amount of light a plant can capture. Size and canopy architecture of a particular plant may also influence the amount of light available to other plants. This can have a large influence on competitiveness of a particular plant or types of plants (Akey et al. 1990; Stoller and Woolley 1985). Shading of dry bean by common ragweed reduced dry bean yield by as much as 50 to 70 percent (Chikoye et al. 1996). When common cocklebur, jimsonweed and velvetleaf were grown with soybean, jimsonweed and velvetleaf overtopped the soybean canopy, however common cocklebur produced some leaves above and below the soybean canopy (Regnier and Stoller 1989). Studies have also demonstrated that grass weed species reduced soybean yield more than small-seeded broadleaf weeds (Bussan et al. 1997).

The relative leaf area of weeds is a good predictor of the outcome of crop and weed interactions (Ngouajio et al. 1999). Soybean leaf area was reduced in the presence of weeds compared to soybeans grown without weeds (Legere and Schreiber 1989). Leaf area index within the soybean canopy was reduced more by common cocklebur than entireleaf morningglory. In this case morningglory leaf area was not large enough to affect the size of the soybean canopy (Mosier and Oliver 1995). Soybean yield was reduced by shoot interference with common cocklebur (Regnier et al. 1989).

Along with leaf area, plant biomass can be used to measure the effect of weed competition on crops. Each kg/ha increase in common lambsquarters biomass was shown to reduce soybean yield by 0.26 kg/ha (Harrison 1990). Measurements of leaf area and plant biomass by destructive sampling can provide an accurate measurement of plant growth at a particular point in time, but does not allow for leaf area or biomass measurements throughout the life cycle of the plant.

Plant height and cylindrical volume are two measurements that have been used to develop simple models of plant interference. Plant height is simple to measure and farmers are familiar with using plant height as an estimate of weed size. Plant height can be measured throughout the growing season without destructive sampling and correlated to plant competitiveness. (Bussler et al. 1995).

The ability of a weed to capture resources can be measured by weed seed yield. Soybean and sicklepod interference reduced johnsongrass seed production 73 to 95 percent. Sicklepod seed production was also reduced from soybean and johnsongrass competition (Sims and Oliver 1990). Velvetleaf seed production was reduced by 82 percent when in the presence of crop competition (Lindquist et al. 1995). Soybeans and entireleaf morningglory competition reduced common cocklebur seed production by as much as 47 percent (Cardina et al. 1995; Lindquist et al. 1995).

Strong correlations were found between plant size, emergence time and seed yield (Lindquist et al. 1995). Taller velvetleaf plants produced more seed than shorter plants (Cardina et al. 1995). As common lambsquarters size increased seed yield increased (Crook and Renner 1990; Harrison 1990). In years with increased pigweed growth, more seed production per plant occurred (Knezevic et al. 1994). In most cases weed size and seed yield was greater with weeds that emerged earlier relative to crop emergence. When a single pigweed plant emerged prior to corn reaching the four leaf stage, it produced 3,500 to 32,000 seeds per meter of row compared to 1,500 to 5,400 seeds per meter of row when emergence occurred between four and seven leaf corn (Knezevic et al. 1994). When Palmer amaranth emerged with corn, seed production was over five times greater than when it emerged after corn emergence (Massinga et al. 2001) Early emerging velvetleaf is likely to produce more seed than later emerging velvetleaf, however velvetleaf seed production is not consistent from year to year (Cardina et al. 1995; Lindquist et al. 1995).

A number of models have been developed to describe weed and crop interactions, particularly negative interactions such as competition between weed and crop plants (Radosevich et al. 1997). These models are accurate in describing plant growth in the regions which they are tested (Knezevic et al. 1994; McGiffen et al. 1997). For example, leaf area and plant height differed between growing seasons in Wisconsin, however common lambsquarters growth could be properly described with regression equations

(Colquhoun et al. 2001). The accuracy of a model can be reduced when a model developed in one region is applied to other geographic regions such as midwestern states compared to western states (Knezevic et al. 1994; McGiffen et al. 1997). Differences in plant growth between environments can make it difficult to predict crop yield loss with data generated outside a growing region (Lindquist et al. 1999). Variability in plant growth may be due to differences in the environment in which the plants are grown (Ghersa and Holt 1995). Crop yield can also be variable across years and locations (Lindquist 2001). Environmental stress, such as drought, can also reduce the accuracy of simulating reductions in crop yield from weeds (Kropff et al. 1992). The usefulness of common coefficients to predict crop losses between years and locations is limited (Lindquist et al. 1999).

Understanding crop and weed growth is important in increasing the accuracy of weed management models. Growth chamber studies have been conducted to understand the influence of temperature and photoperiod on common lambsquarters development (Huang et al. 2001). Changes in interception of photosynthetically active radiation were important in modeling competition between dry bean and common ragweed (Chikoye et al. 1996). Duration of weed and crop competition, weed stand density and time of weed removal could be modeled to determine timing of weed control to minimize crop losses (Berti et al. 1996; Frank et al. 1992). Model simulations in tomato and sugarbeet suggest that at greater weed stand densities crops could tolerate weed competition for shorter periods of time than at lower weed densities. Early season weed competition may also be influenced greater by nutrient and moisture limitations than light limitations (Weaver et al. 1992).

There is an increased interest in using models to predict yield loss from weeds and generate weed management recommendations in Michigan. While models have been accurate in predicting weed and crop growth in the regions in which they were developed, accuracy is lost when the models are applied to other regions (Colquhoun et al. 2001; Knezevic et al. 1994; McGiffen et al. 1997; Lindquist et al. 1999). One of the challenges of adapting predictive models to a region, is obtaining the information needed to understand biological interactions between crops and weeds in a particular environment (Swinton et al. 1994). Information has been generated on the effect of giant foxtail and velvetleaf density on corn yield in Michigan (Fausey et al. 1997; Lindquist 2001; Lindquist et al. 1999). More information is needed on the affect giant foxtail, common lambsquarters and velvetleaf time of emergence, relative to corn emergence, has on weed growth, weed seed production and corn yield (Renner et al. 1999; Swinton et al. 2002).

Field trials were conducted in Michigan to investigate the interaction of three weed species with corn. The objectives of the trials were: (1) To examine the effect of weed growth on corn growth and yield. (2) To determine the effect of weed emergence time on the effect weeds have on corn growth and yield. (3) To characterize differences in weed growth and seed production between giant foxtail, common lambsquarters and velvetleaf when growth with corn. (4) To examine the effect of weed emergence time on weed growth and seed production.

MATERIALS AND METHODS

A field trial was conducted in 2001, 2002 and 2003 at the Michigan State University Agronomy farm East Lansing, MI. The soil type was a Capac sandy loam (Aubbeenaubee Fine-loamy, mixed mesic Epiaqualfs). Study design was a split plot with six replications. The main plot was weed planting time and the subplot was weed species. Main plot size was 3 by 10.7 m. Subplot size was 0.75 by 4 m. Weeds were spaced 20 cm apart, 10 cm from a single corn row. Weeds were staggered on either side of the treatment corn row to achieve a target plant population of 10 weeds per meter. Two corn rows bordered the treatment corn row. Corn was planted at 79,000 seeds per ha. Corn row spacing was 75 cm. Weeds studied were two broadleaf species velvetleaf and common lambsquarters, and one grass species, giant foxtail. Weeds were planted at four timings relative to corn growth stage; at corn planting (At plant), at corn emergence (VE), at the V1 stage of corn growth (V1) and at the V3 stage of corn growth (V3).

A Dekalb[2] glyphosate-resistant corn hybrid was planted each year. In 2001, DK 35-50 RR an 88 - day relative maturity hybrid, was planted. In 2002 and 2003, 99 - day relative maturity hybrids were planted, DK 493 RR and DK 44 46 RR, respectively. In-furrow starter fertilizer was not applied in each year. Nitrogen was applied broadcast at a rate of 140 kg/ha and shallowly incorporated into the soil with a field cultivator prior to planting. The seed bed was prepared by tilling twice with a field cultivator. The soil was moldboard plowed in the fall prior to each study.

Planting dates for corn and weeds are shown in Table 1. Planting dates were delayed in 2001 due to rainfall at the site. The at emergence timing was not planted in 2002 due to rapid corn emergence and wet field conditions that prevented weed seed planting. Weeds were establish by planting approximately 12 seeds every 20 cm on either side of the corn row. After weed emergence, weeds were thinned to a target population of

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[2] Dekalb Genetics Corporation, 3100 Sycamore Rd, Dekalb, IL 60115-9600 USA

10 plants per meter. Weed counts were taken in July to determine actual populations (Table 2). Plots were maintained free of additional weeds by selectively applying glyphosate at a rate of 0.64 kg/ha and hand weeding. Desired weeds were covered with rain troughs and glyphosate was applied over the weeds and corn.

Data collection and statistical analysis. After weeds were thinned to 10 per meter, weekly measurements were taken on both corn and weeds. Three corn plants and 5 weed plants were selected randomly and measured throughout the growing season. Plant measurements included height and biomass. Plant height was measured from the soil surface to the highest point on the plant. Upon maturity of the earliest planted weeds, weeds were harvested, dried and weighed. Weed seed was separated from the dried plants then counted. Weed seed was separated from the dried plants by first removing the seed from the stems. Then the seeds and leaf material were ground by hand using a wood block wrapped in cloth and a pan. The seed and chaff were then sifted using screens appropriate for the size of the seed. Finally, the number of seeds was determined either by counting all the seed or by estimating the number of seeds based on weight. If the total number of seeds were less than 100, all of the seeds were counted. If the total number was greater than 100, 100 seeds were counted and the weight of the 100 seeds was determined. The total amount of seed was then weighed. The weight of the seed was divided by the weight of 100 seeds and then multiplied by 100. Weed seed yield was then calculated based on the number of seeds produced per plant.

Corn was hand harvested from the center row of the 4 m subplot and weights were adjusted to 15.0% moisture. Daily weather data was obtained from a weather station close to the site. Growing degree days (GDD) were calculated from the average of the high and the low temperature for a 24 hour period and subtracted from the base of 10 °C (Table 1). The rainfall pattern for each year is shown in Figure 1.

Data was analyzed by ANOVA using PROC MIXED in SAS. Means were separated using population marginal means (least square means) LSD. Corn yield and weed biomass was separated at the P=0.05 level of significance. Weed seed yield was separated at the P=0.10 level of significance and square root transformed prior to analysis due to variability in weed seed production per plant. Population marginal means LSD separation was used due to the large number of comparisons and unequal sample sizes. Some weeds did not emerge or died early. This lead to more observations of one weed species than another. Population marginal means LSD weights blocks, in this case replications, equally despite the unequal sample sizes, allowing for a more accurate reflection of treatment effects. Correlations and simple linear regressions were computed in SAS to examine the relationship between weed growth parameters. Weed growth parameters were correlated to corn yield. Weed and crop growth were regressed against growing degree days. Variability within plant species height and year was characterized using regression coefficients of determination (r^2).

RESULTS AND DISCUSSION

Giant foxtail, common lambsquarters and velvetleaf biomass were negatively correlated to corn yield (Table 3). Velvetleaf and giant foxtail height and seed yield were also negatively correlated to corn yield ($P < 0.10$). Common lambsquarters height and seed production were not as strongly correlated to corn yield as weed biomass. The negative correlation between velvetleaf morphology and corn yield was stronger than the negative correlation between giant foxtail and common lambsquarters morphology and corn yield. Biomass and seed production from giant foxtail had a stronger negative correlation to corn yield than common lambsquarters biomass and seed production. Maximum weed height, biomass and seed yield were all strongly positively correlated.

Weeds did not affect corn height. Corn height was similar when grown with or without weeds (Figures 2, 3, and 4). As growing degree days increased, corn height increased steadily until reaching a maximum height at tasseling (Figures 2, 3, and 4). Corn tassels emerged between 600 and 750 growing degree days each year. Corn height and growing degree day relationships were well described by regression equations in most cases, with r^2 values greater than 0.69 (Table 4). In 2001, however the relationship was not as strong when weeds were established at the V3 stage of corn growth, r^2 less than 0.57, due to fewer height measurements early in the season (Table 4).

Weed biomass was a better indicator of corn yield loss than maximum weed height for all three species (Table 3). Maximum weed height, however, is an important indicator of the size of a weed at any point in the growing season. Velvetleaf was generally taller than common lambsquarters and giant foxtail (Figures 5, 6, and 7). Giant foxtail and common lambsquarters were generally similar in height, however giant foxtail was taller than common lambsquarters in 2001 and common lambsquarters was taller than giant foxtail in 2002 (Figures 5 and 6). The relationship between weed height and growing degree days was generally well described by regression equations in 2001 and 2002 (Table 5). However in 2003, weed growth was influenced by a dry period from mid-July to mid-August (Figure 1). Variation in weed growth patterns between years have been observed in numerous studies. Differences in growth patterns between years was attributed to changes in weather conditions which lead to shifts in the resource that was the most limiting (Colquhoun et al. 2001; Lindquist et al. 1999; Lindquist et al. 1996; Cardina et al. 1995). Rainfall may have influenced weed growth more than temperature in 2003, leading to the differences in weed growth patterns which may have caused the correlation to be weaker between weed height and growing degree days.

Despite the impact of environmental conditions on weed height, weed height is an important measurement for determining differences in weed growth between species (Colquhoun et al. 2001). Biomass measurements require destructive sampling and will not allow for measurement of the same weed throughout the growing season. If plant size is only measured at the end of the growing season, differences in weed growth patterns as shown in Figures 5, 6, and 7 would be difficult to examine.

Corn Yield. In 2001, velvetleaf reduced corn yield only when established at corn planting while common lambsquarters reduced corn yield when established as late as V1 stage corn. Corn yield was not reduced by giant foxtail in 2001 (Table 6). In 2002, velvetleaf reduced corn yield when established as late as V1 stage corn. Common lambsquarters only reduced corn yield when established at corn planting. Giant foxtail did not reduce corn yield at any of the establishment timings (Table 6). In 2003, weeds did not reduce corn yield.

When established at corn planting, velvetleaf and common lambsquarters reduced corn yield compared to the weed free control in 2001 and 2002 (Table 6). Velvetleaf reduced corn yield over 30 percent while common lambsquarters reduced corn yield by 15 percent in 2001 and 25 percent in 2002. In 2002, giant foxtail established at corn planting reduced corn yield by 17 percent compared to the weed free control (Table 6). In 2001, common lambsquarters established at corn emergence, reduced corn yield by 20 percent. In 2002, velvetleaf established at the V1 stage of corn growth, reduced corn yield by 19 percent. In 2003, weeds did not affect corn yield regardless of species or cohort timing (Table 6).

Corn yield loss from weeds decreased with later weed emergence time, and was impacted more by late emerging velvetleaf than later emerging common lambsquarters (Table 6). Giant foxtail that was established after corn emergence had no impact on corn yield in any year. Weeds did not impact corn yield when established at V3 stage corn. Velvetleaf established at V1 stage corn reduced corn yield in 1 of 3 years (Table 6). Common lambsquarters reduced corn yield in 1 of 2 years when established at corn emergence (Table 6). Common lambsquarters and velvetleaf established at corn planting reduced corn yield each year except 2003. Giant foxtail reduced corn yield only one year (Table 6). Yield loss from velvetleaf and common lambsquarters is similar to previous research in Michigan and other states which found each weed generally reduced corn yield at populations of 10 plants per meter when established at corn planting (Lindquist 2001; Lindquist et al. 1996; Cardina et al. 1995). Corn yield loss from velvetleaf is less in cool dry conditions compared to warm wet conditions (Cardina et al. 1995). Less rainfall late in the year (Figure 1) and cooler growing conditions (Table 1) in 2003 may explain the reason why weeds did not reduce corn yield in 2003. Yield loss from giant foxtail in 2002 is consistent with previous research in Michigan. Fausey et al. (1997) reported yield losses of 14 percent from giant foxtail at a population of 10 plants per meter of row when established at corn planting. Giant foxtail may reduce corn yield more in warmer growing seasons compared to cooler growing seasons (Fausey et al. 1997). Cooler weather conditions in 2001 and 2003 (Table 1) may have reduced competition between giant foxtail and corn resulting in less corn yield loss (Table 6).

Weed Biomass. Weed biomass was generally smaller at the later planting times compared to the early planting times. In 2001 and 2003, giant foxtail and velvetleaf produced a greater biomass when established at corn planting than the later establishment timings (Table 7). In 2001, biomass from giant foxtail established at corn planting was five times greater than the biomass from the at emergence establishment time. Velvetleaf biomass was twice as large at the at plant timing compared to the at emergence timing each year. In 2002 and 2003, common lambsquarters also produced twice as much biomass at the at plant timing compared to the later timings. Velvetleaf biomass when established at the V3 stage of corn growth was five to twenty-five times less than when established at V1 stage corn (Table 7).

Common lambsquarters produced the greatest biomass of all the weeds in 2 of 3 years and the least biomass in 1 of 3 years (Table 7). When established at corn planting, common lambsquarters biomass was 70 percent greater than giant foxtail and 30 percent larger than velvetleaf in 2002. In 2003, common lambsquarters was twice as large as either weed. Velvetleaf biomass was nearly twice as large as giant foxtail in 2 of 3 years, and four times larger than common lambsquarters in 2001. Giant foxtail biomass was generally less than or equal to the biomass of the other two weeds (Table 7). These results demonstrate how environmental conditions can impact biomass accumulation. Weed biomass accumulation will depend on temperature and moisture availability as well as weed species.

When established at corn emergence, velvetleaf produced a greater biomass than giant foxtail each year (Table 7). Common lambsquarters produced a greater biomass than velvetleaf and giant foxtail in 1 of 2 years. When established at V1 stage corn, common lambsquarters and velvetleaf biomass was seven times greater than giant foxtail in 2002. Biomass was similar between each of the weeds in the other two years. Each of the weeds produced relatively less biomass when established after V1 stage corn compared to the other timings (Table 7).

Weed size was influenced by environmental conditions each year. Environmental conditions that maximize common lambsquarters growth appear to be less favorable for velvetleaf growth. Giant foxtail growth was relatively consistent each year. Biomass was generally the greatest from weeds established at corn planting and least when established at the V3 stage of corn growth (Table 7). In 1 of 3 years, giant foxtail and common lambsquarters were not impacted by later establishment time. In each case giant foxtail and common lambsquarters were the smallest of the three weeds. Common lambsquarters produced more biomass than the other weeds in 2 of 3 years. In the other year velvetleaf produced more biomass than common lambsquarters or giant foxtail (Table 7). Common lambsquarters biomass when grown with soybeans appeared to be positively influenced by temperature and negatively influenced by increased moisture availability (Harrison 1990). Foxtail, however, appeared to be positively influenced by increased moisture availability when grown with corn (Fausey et al. 1997 and McGiffen et al. 1997). Common lambsquarters appears to be more tolerant than velvetleaf or giant foxtail to fluctuations in environmental conditions. Warm temperatures in 2002 and cool dry conditions in 2003 may have been the reasons for increased biomass production from common lambsquarters relative to velvetleaf and giant foxtail.

Weed Seed Yield. When established at corn planting, common lambsquarters produced the most seed of the three weeds in 2 of 3 years (Table 8). Weed seed production was similar between each of the weed species in 1 of 3 years. Common lambsquarters seed production was over 7 times greater than giant foxtail or velvetleaf in 2002 and 2003. Seed production from common lambsquarters was between 3,000 and 35,000 seeds per plant. This was lower than a previous study in which common lambsquarters produced 30,000 to 176,000 seeds per plant when grown with soybeans (Harrison 1990). Corn may shade weeds more than soybean at the time of weed seed production. Increased shading from corn, compared to soybean, may have reduced the amount of light intercepted by common lambsquarters leading to the reduction in common lambsquarters seed production. Giant foxtail produced over 2,500 seeds per plant in 2 of 3 years which was consistent with previous studies in Michigan (Fausey et al. 1997). Velvetleaf produced between 80 to 1,700 seeds per plant. When established at corn planting, common lambsquarters and giant foxtail generally produced more seed than velvetleaf, and common lambsquarters generally produced more seed than giant foxtail. Giant foxtail, common lambsquarters and velvetleaf seed production declined with later establishment time (Table 8). This is consistent with research in other regions which has shown a decline in seed production from multiple weed species as they are established later relative to corn emergence. Palmer amaranth, redroot pigweed, and barnyardgrass seed production declined when established after corn planting compared to establishing weeds at corn planting (Massinga et al. 2001, Bosnic and Swanton 1997 and Knezevic et al. 2001). Cardina et al. (1995) reported a decline in velvetleaf seed production with later emergence date relative to corn emergence and Lindquist et al. (1995) reported a similar relationship between velvetleaf and soybean.

Success of weed management strategies and the ability to predict the outcome of interactions between weeds and crops will depend upon a better understanding of weed growth (Ghersa and Holt 1995). This information will be used to fine tune weed management recommendations, particularly computerized weed management decision support systems in Michigan. The data can also be used to compare bioeconomic weed management models across regions. Further research is needed, however, to understand how changes in environmental conditions will impact weed growth and crop yield.

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Table 1. Planting dates of corn and weeds and growing degree days for weeds.

	2001		2002[c]		2003	
	Date	GDD[b]	Date	GDD	Date	GDD
At plant[a]	June 11	1053	May 21	1393	May 18	944
VE	June 15	994	-		May 27	922
V1	June 18	959	June 1	1334	May 30	906
V3	June 25	889	June 10	1270	June 11	857

[a] Stage of corn growth at which weeds were established (At plant, weeds established at corn planting, VE, weeds established at corn emergence, V1, weeds established when corn developed one collar, V3, weeds established when corn developed 3 collars).

[b] Total of growing degree days from weed planting date. Daily growing degree days were calculated from the average high and low Celsius temperature over a 24 hour period minus a base temperature of 10 degrees.

[c] The VE (at corn emergence) timing was not planted in 2002 due to excessive rainfall and rapid corn emergence.

Table 2. Weed population.

	2001			2002			2003		
	SETFA	CHEAL	ABUTH	SETFA	CHEAL	ABUTH	SETFA	CHEAL	ABUTH
	-----Number of plants per meter of row-----								
At plant [a]	10	7	8	9	9	8	10	10	9
VE	9	8	7	-	-	-	10	10	8
V1	9	7	10	9	7	7	10	10	9
V3	7	5	7	8	8	7	9	9	7

[a] Stage of corn growth at which weeds were established (At plant, weeds established at corn planting, VE, weeds established at corn emergence, V1, weeds established when corn developed one collar, V3, weeds established when corn developed 3 collars).

Table 3. Correlation of weed morphological characteristics to corn yield.

	Giant foxtail		Common lambsquarters		Velvetleaf	
	Correlation[a]	P value	Correlation[a]	P value	Correlation[a]	P value
Weed Height & Corn Yield	-0.25	0.0721	-0.24	0.0960	-0.45	0.0007
Weed Biomass & Corn Yield	-0.34	0.0166	-0.29	0.0553	-0.63	<.0001
Weed Seed & Corn Yield	-0.27	0.0657	-0.17	0.2642	-0.58	<.0001
Weed Biomass & Height	0.77	<.0001	0.84	<.0001	0.82	<.0001
Weed Biomass & Seed Yield	0.75	<.0001	0.75	<.0001	0.89	<.0001
Weed Height & Seed Yield	0.68	<.0001	0.51	<.0001	0.71	<.0001

[a] Correlation Coefficient.

Table 4. Regression equations and coefficients of determination (r^2) for corn height when grown alone or with giant foxtail, common lambsquarters or velvetleaf based on growing degree days.

	Corn Height					
	Regression Equation [a]			r^2		
Weeds	2001	2002	2003	2001	2002	2003
	Weed Establishment Time - At corn planting					
giant foxtail	0.2057x + 8.0126	0.4153x - 86.036	0.4131x - 25.459	0.78	0.95	0.86
common lambsquarters	0.1735x +17.325	0.4099x - 82.590	0.4004x - 20.970	0.80	0.96	0.85
velvetleaf	0.1806x + 20.523	0.3948x - 77.413	0.3955x - 19.484	0.77	0.95	0.84
weed free	0.1782x + 21.730	0.4111x - 75.137	0.4126x - 28.892	0.80	0.95	0.85
	Weed Establishment Time - At corn emergence					
giant foxtail	0.2050x + 12.466	-	0.4320x -31.468	0.80	-	0.85
common lambsquarters	0.1671x + 20.142	-	0.3985x - 24.055	0.77	-	0.86
velvetleaf	0.2104x + 10.561	-	0.4014x - 22.949	0.80	-	0.84
weed free	0.2050x + 11.650	-	0.3783x - 12.415	0.79	-	0.75

Table 4. (Continued)

	Corn Height					
	Regression Equation[a]			r^2		
Weeds	2001	2002	2003	2001	2002	2003
	Weed Establishment Time - At V1 stage corn					
giant foxtail	0.1608x + 40.161	0.4298x - 94.324	0.4097x - 27.304	0.69	0.94	0.84
common lambsquarters	0.1441x + 37.136	0.4281x - 95.869	0.4067x - 19.492	0.72	0.94	0.86
velvetleaf	0.1480x + 45.952	0.4347x - 103.16	0.4139x - 30.549	0.74	0.96	0.86
weed free	0.1570x + 46.700	0.4589x - 110.33	0.4181x - 26.116	0.72	0.95	0.87
	Weed Establishment Time - At V3 stage corn					
giant foxtail	0.0852x + 100.62	0.4054x - 82.379	0.4123x - 23.390	0.46	0.92	0.87
common lambsquarters	0.1203x + 112.59	0.4262x - 91.233	0.3951x - 17.802	0.56	0.94	0.85
velvetleaf	0.0953x + 97.256	0.4195x - 98.157	0.4270x - 36.231	0.39	0.94	0.86
weed free	0.1048x + 94.057	0.4243x - 89.128	0.4271x - 30.800	0.52	0.93	0.88

[a] x, growing degree days calculated with a base of 10° C.

Table 5. Regression equations and coefficients of determination (r^2) for weed height when grown with corn based on growing degree days.

	Weed Height					
	Regression Equation [a]			r^2		
Weeds	2001	2002	2003	2001	2002	2003
			Weed Establishment Time - At corn planting			
giant foxtail	0.1414x - 18.170	0.1350x - 23.708	0.0869x + 21.918	0.84	0.84	0.46
common lambsquarters	0.0856x - 25.012	0.2240x - 63.348	0.1055x + 6.2041	0.95	0.80	0.52
velvetleaf	0.2160x - 42.503	0.2651x - 71.432	0.0850x + 24.845	0.91	0.93	0.26
			Weed Establishment Time - At corn emergence			
giant foxtail	0.0818x - 15.791	-	0.0378x + 20.224	0.63	-	0.19
common lambsquarters	0.0746x - 23.321	-	0.0718x + 11.086	0.62	-	0.39
velvetleaf	0.1770x - 45.323	-	0.0642x + 23.530	0.89	-	0.21

Table 5. (Continued)

	Weed Height					
	Regression Equation [a]			r^2		
Weeds	2001	2002	2003	2001	2002	2003
	Weed Establishment Time - At V1 stage corn					
giant foxtail	0.0623x - 12.623	0.0661x - 20.064	0.0321x + 17.359	0.76	0.73	0.20
common lambsquarters	0.0859x - 32.238	0.1519x - 51.952	0.0425x + 8.5318	0.73	0.77	0.36
velvetleaf	0.1023x - 27.803	0.2594x - 88.063	0.0497x + 21.631	0.85	0.88	0.19
	Weed Establishment Time - At V3 stage corn					
giant foxtail	0.0440x - 12.039	0.0346x- 9.8485	0.0166x + 9.3272	0.74	0.74	0.15
common lambsquarters	0.0206x - 2.0896	0.0341x -11.220	0.0309x + 4.2420	0.65	0.47	0.28
velvetleaf	0.0427x - 9.3970	0.0585x - 14.872	0.0253x + 15.735	0.65	0.54	0.30

[a] x, growing degree days calculated with a base of 10° C.

Table 6. Corn yield.

Weeds [b]	Corn Yield [a] 2001			
	At plant [c]	VE	V1	V3
	----------kg/ha----------			
giant foxtail	A 6320 a	A 6577 a	A 6577 a	A 6255 a
common lambsquarters	B 5396 b	B 5424 b	B 5604 a	A 6955 a
velvetleaf	B 4307 b	A 6270 ab	A 5667 a	A 6453 a
weed free	A 6365 a	A 6840 a	A 6647 a	A 6329 a

Table 6. (Continued)

	Corn Yield [a] 2002			
Weeds [b]	At plant [c]	VE	V1	V3
	--kg/ha--			
giant foxtail	A 8230 b	-	A 9025 a	A 8945 a
common lambsquarters	B 7368 bc	-	AB 8590 a	A 8669 a
velvetleaf	B 6367 c	-	B 7360 b	A 8871 a
weed free	A 9906 a	-	A 9074 a	A 9860 a

Table 6. (Continued)

	Corn Yield [a] 2003			
Weeds[b]	At plant[c]	VE	V1	V3
	kg/ha			
giant foxtail	A 9862 a	A 9877 a	A 10995 a	A 8914 a
common lambsquarters	A 8869 a	A 8975 a	A 10163 a	A 10332 a
velvetleaf	A 9347 a	A 9011 a	A 10845 a	A 10153 a
weed free	A 9882 a	A 9718 a	A 10640 a	A 10333 a

[a] Means within a column (cohort timing) with the same lower case letter were not different according to an LSD test (P=0.05).

[b] Means within a row (weed species) with the same upper case letter were not different according to an LSD test (P=0.05).

[c] Stage of corn growth at which weeds were established (At plant, weeds established at corn planting, VE, weeds established at corn emergence, V1, weeds established when corn developed one collar, V3, weeds established when corn developed 3 collars).

Table 7. Weed biomass.

	Biomass [a] 2001			
Weeds [b]	At plant [c]	VE	V1	V3
	----------grams----------			
giant foxtail	A 10.23 b	B 2.07 b	B 1.78 a	B 0.31 a
common lambsquarters	A 4.66 c	A 4.99 ab	A 4.41 a	A 0.53 a
velvetleaf	A 16.32 a	B 6.92 a	B 5.19 a	C 0.69 a

Table 7. (Continued)

	Biomass [a] 2002			
Weeds [b]	At plant [c]	VE	V1	V3
	---grams---			
giant foxtail	A 5.11 c	-	A 1.31 b	A 0.21 a
common lambsquarters	A 18.71 a	-	B 9.88 a	C 1.19 a
velvetleaf	A 12.41 b	-	A 8.97 a	B 0.35 a

Table 7. (Continued)

Weeds [b]	Biomass [a] 2003			
	At plant [c]	VE	V1	V3
	-----------	grams	-----------	
giant foxtail	A	B	BC	C
	3.74 b	1.22 c	0.68 a	0.16 a
common lambsquarters	A	B	C	C
	8.32 a	3.64 a	1.34 a	0.60 a
velvetleaf	A	B	B	C
	4.02 b	2.14 b	1.46 a	0.36 a

[a] Means within a column (cohort timing) with the same lower case letter were not different according to an LSD test (P=0.05).

[b] Means within a row (weed species) with the same upper case letter were not different according to an LSD test (P=0.05).

[c] Stage of corn growth at which weeds were established (At plant, weeds established at corn planting, VE, weeds established at corn emergence, V1, weeds established when corn developed one collar, V3, weeds established when corn developed 3 collars).

Table 8. Weed seed yield.

	Seed Yield [a] 2001			
Weeds [b]	At plant [c]	VE	V1	V3
	----------Number of Seeds per Plant----------			
giant foxtail	A	B	B	C
	2933 a	1271 b	922 b	178 a
common lambsquarters	AB	A	B	C
	3147 a	4417 a	2239 a	292 a
velvetleaf	A	B	B	C
	1694 a	403 c	134 c	0 b

Table 8. (Continued)

Weeds [b]	Seed Yield [a] 2002			
	At plant [c]	VE	V1	V3
	----Number of Seeds per Plant----			
	A		B	C
giant foxtail	4229 b	-	1158 b	108 a
	A		B	C
common lambsquarters	32432 a	-	4484 a	155 a
	A		B	C
velvetleaf	1139 c	-	197 c	0 b

Table 8. (Continued)

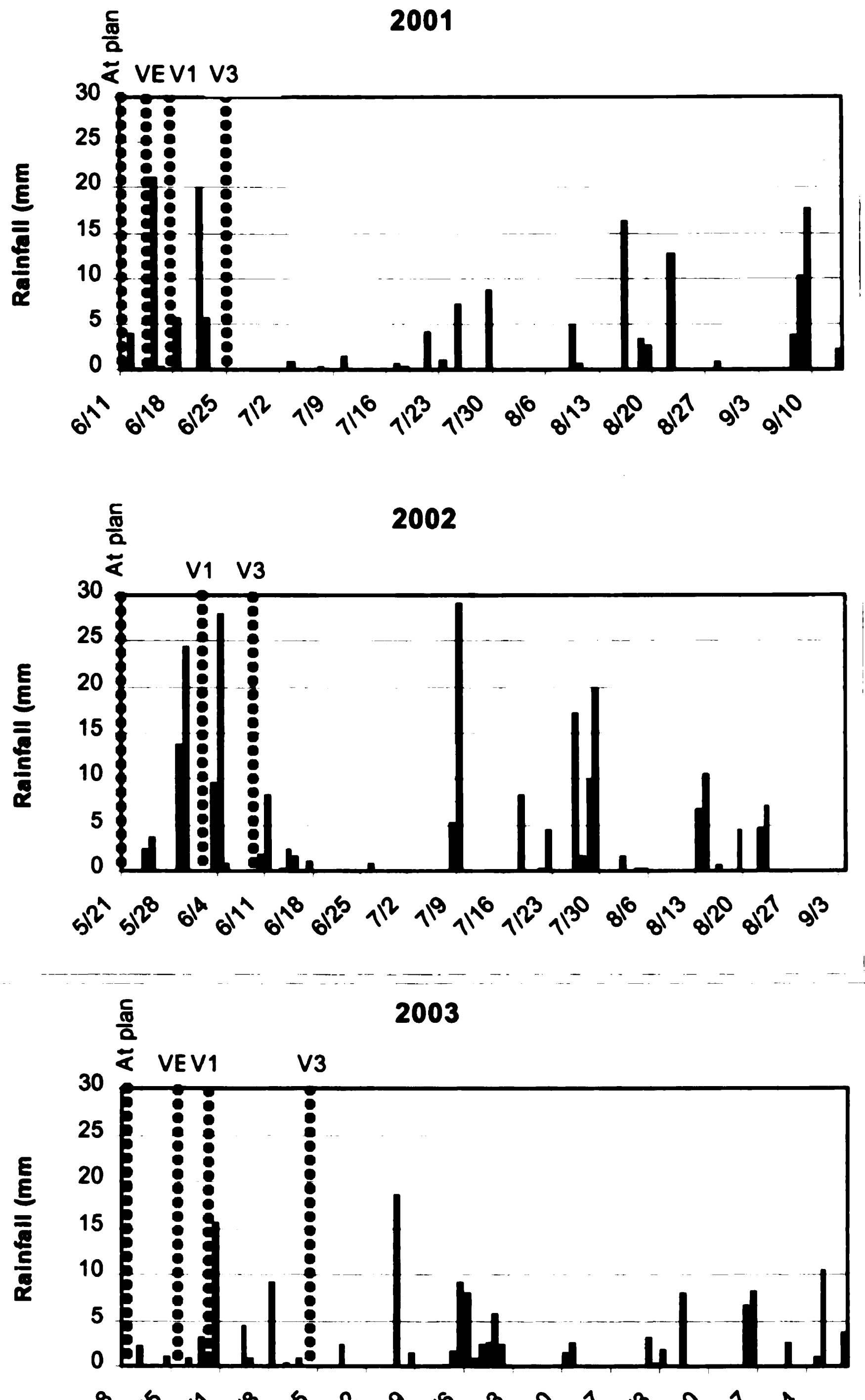
Weeds [b]	Seed Yield [a] 2003			
	At plant [c]	VE	V1	V3
	---Number of Seeds per Plant---			
giant foxtail	A 851 b	A 427 b	B 229 b	C 34 b
common lambsquarters	A 11814 a	B 4694 a	C 1877 a	D 702 a
velvetleaf	A 80 c	B 6 c	B 0 c	B 0 b

[a] Means within a column (cohort timing) with the same lower case letter were not different according to an LSD test (P=0.10).

[b] Means within a row (weed species) with the same upper case letter were not different according to an LSD test (P=0.10).

[c] Stage of corn growth at which weeds were established (At plant, weeds established at corn planting, VE, weeds established at corn emergence, V1, weeds established when corn developed one collar, V3, weeds established when corn developed 3 collars).

Figure 1. Rainfall in relation to corn and weed planting (2001-2003)[a].



[a] Stage of corn growth at which weeds were established (At plant, weeds established at corn planting, VE, weeds established at corn emergence, V1, weeds established when corn developed one collar, V3, weeds established when corn developed 3 collars).

Figure 2. Corn height when grown alone (x) or with giant foxtail (◇), common lambsquarters (□), or velvetleaf (○) based on growing degree days (GDD; 10° C) in 2001. Equations listed in table 4.

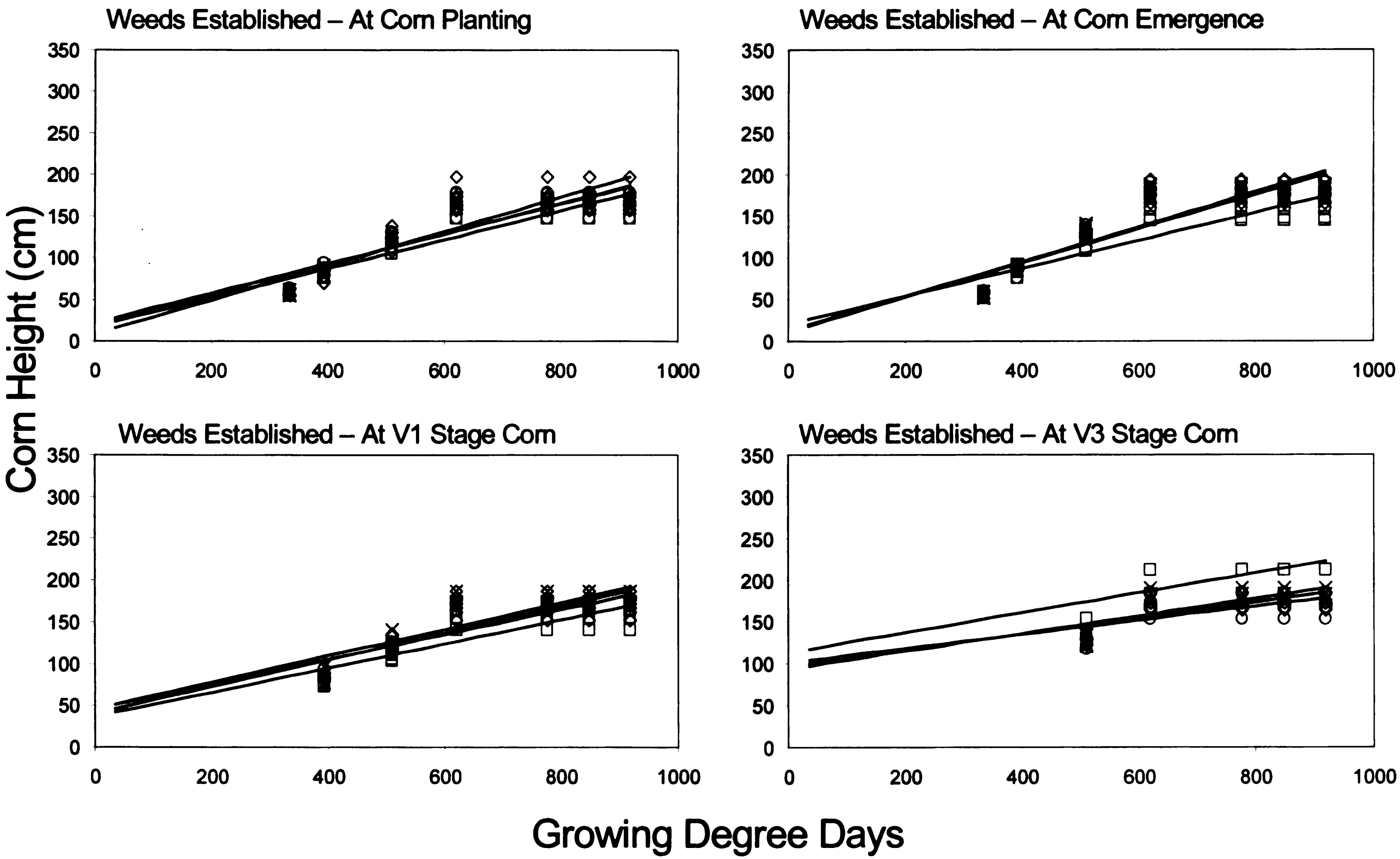


Figure 3. Corn height when grown alone (x) or with giant foxtail (◇), common lambsquarters (□), or velvetleaf (○) based on growing degree days (GDD; 10° C) in 2002. Equations listed in table 4.

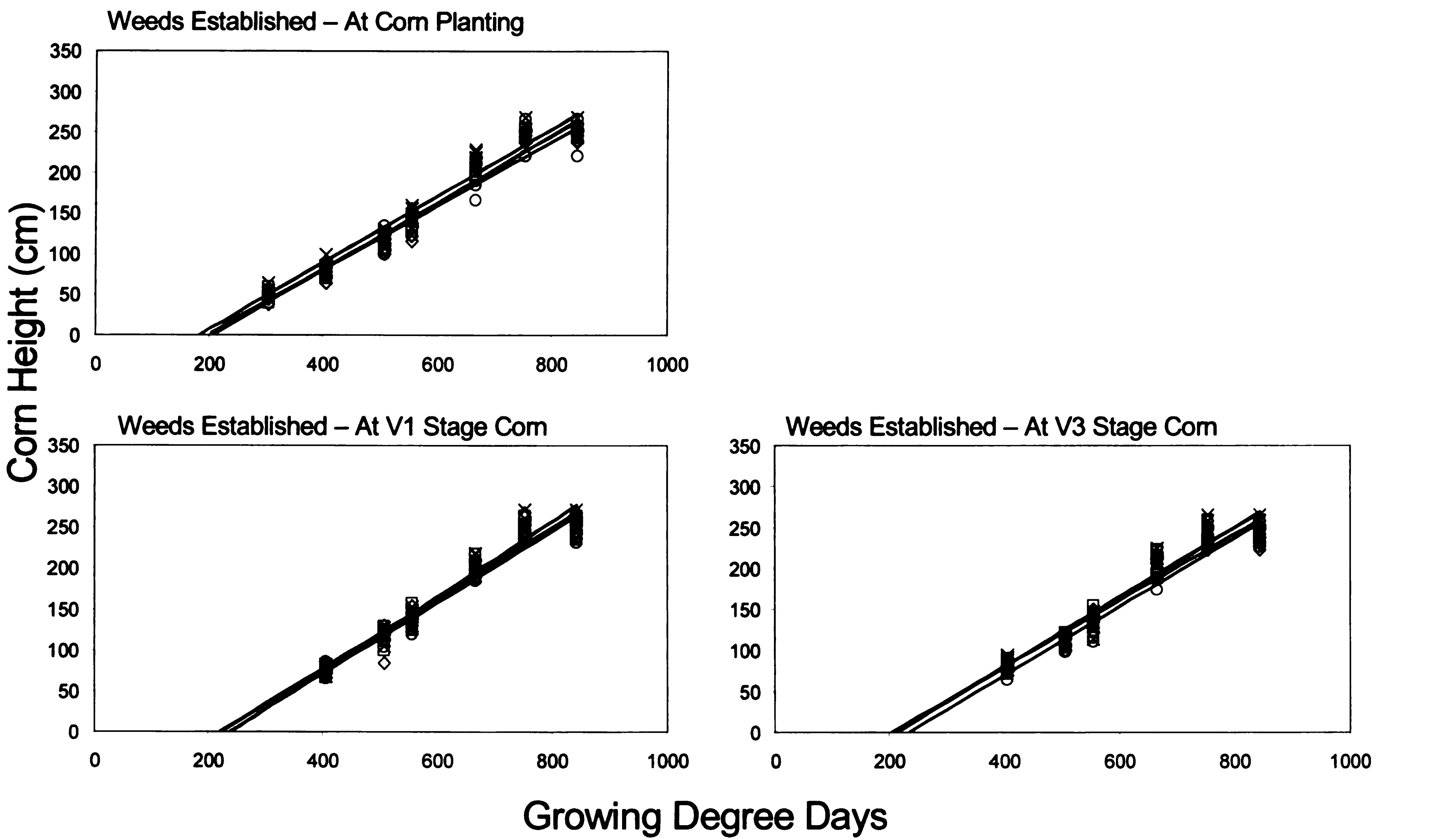


Figure 4. Corn height when grown alone (x) or with giant foxtail (◇), common lambsquarters (□), or velvetleaf (○) based on growing degree days (GDD; 10° C) in 2003. Equations listed in table 4.

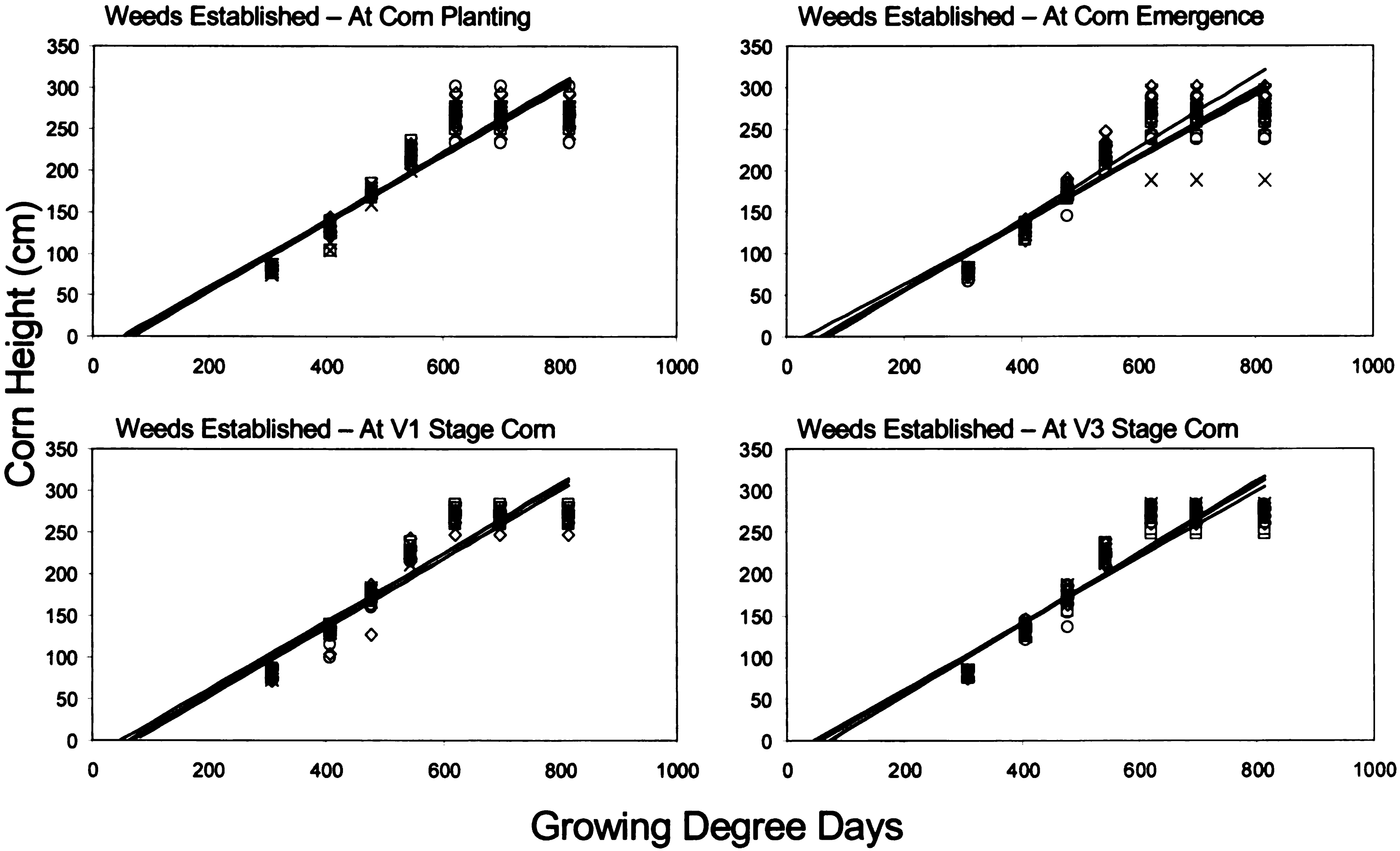


Figure 5. Giant foxtail (◇), common lambsquarters (□), and velvetleaf (○) height as impacted by corn growth and weed establishment time based on growing degree days (GDD; 10° C) in 2001. Equations listed in table 5.

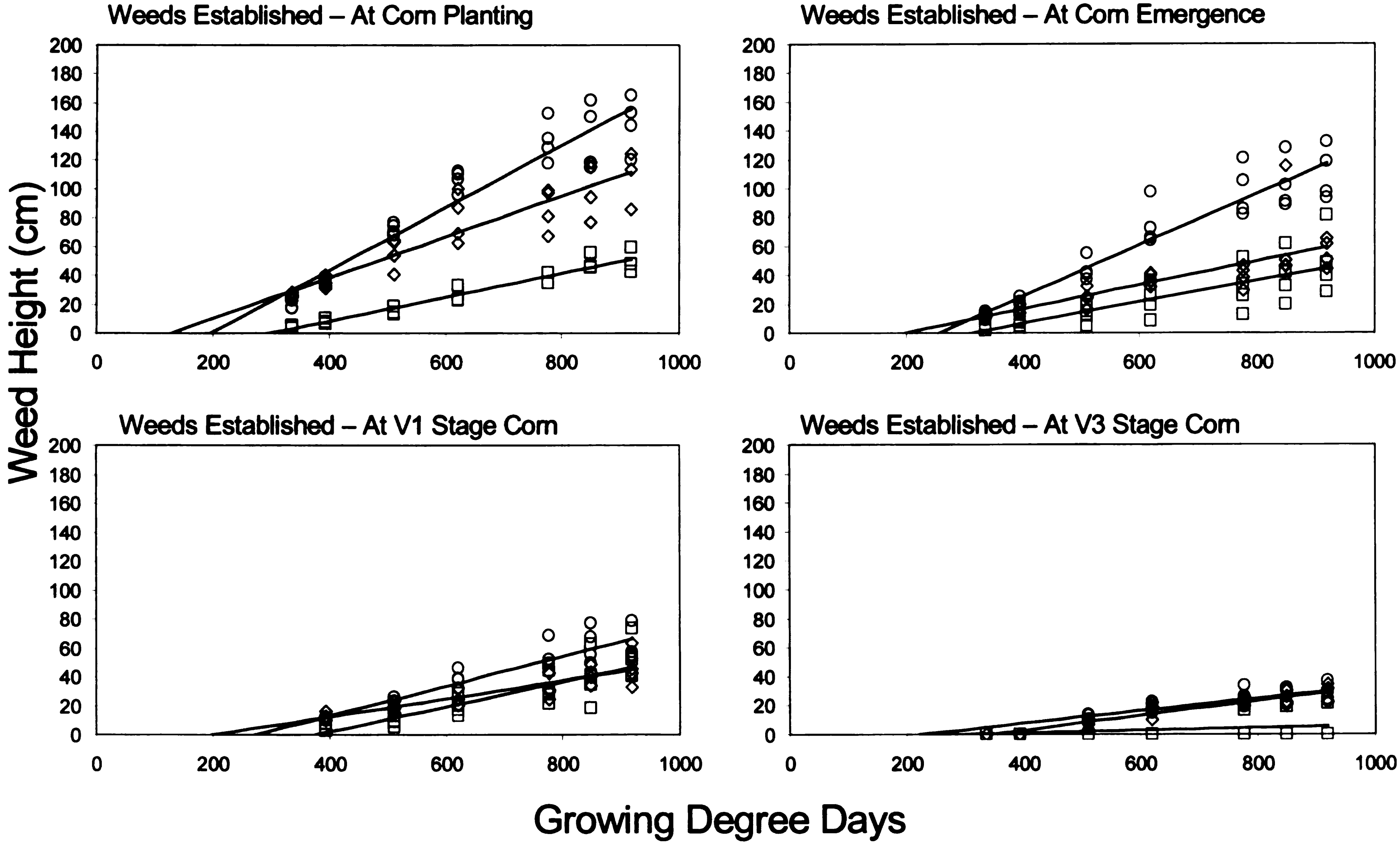


Figure 6. Giant foxtail (◇), common lambsquarters (□), and velvetleaf (○) height as impacted by corn growth and weed establishment time based on growing degree days (GDD; 10° C) in 2002. Equations listed in table 5.

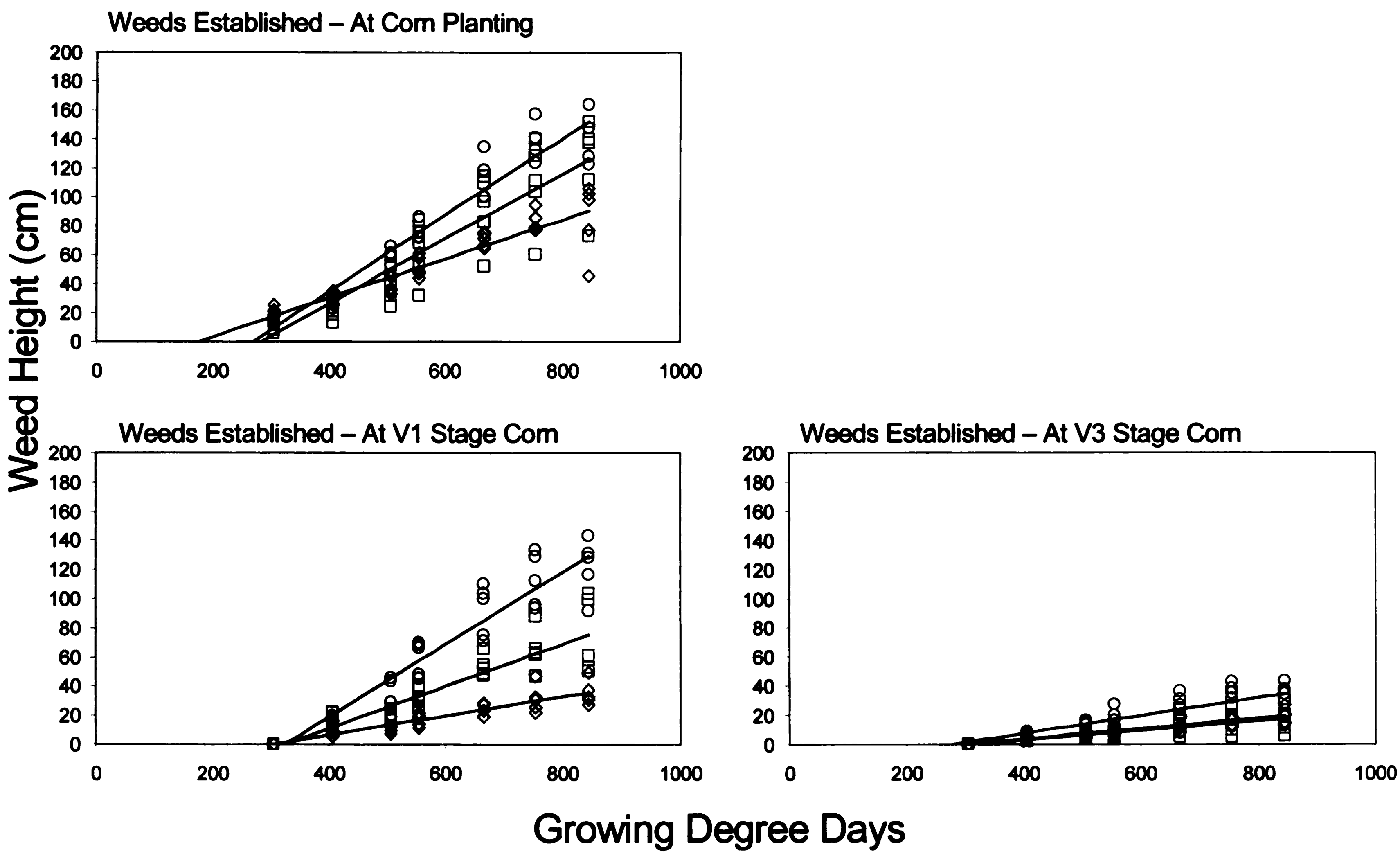


Figure 7. Giant foxtail (◇), common lambsquarters (□), and velvetleaf (○) height as impacted by corn growth and weed establishment time based on growing degree days (GDD; 10° C) in 2003. Equations listed in table 5.