Weed Science, 48:728–733. 2000

Spatial and temporal expansion patterns of *Apocynum cannabinum* patches

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There is little information published on patch expansion of perennial weeds and none for *Apocynum cannabinum.* Studies were conducted to measure the between-season and in-season expansion patterns of natural *A. cannabinum* patches over three growing seasons. Regression analysis indicated strong relations between patch area in consecutive years 1996 to 1997 ($r^2 = 0.81$) and 1997 to 1998 ($r^2 = 0.76$). Patches less than 20 m^2 in 1996 increased in area by more than 100% in 1997 during a fallow season. However, patches decreased in size 6 to 51% between 1997 and 1998 when *Glycine max* was grown. Evidence suggested that a late-season mowing of the *A. cannabinum* patches in 1997 contributed more to the decline in patch area than competition from *G. max* during the 1998 season. The relations between patch area and growing degree units ($r^2 = 0.97$) indicated that greater than 89% of the terminal patch expansion occurred prior to the accumulation of 435 growing degree units (GDU) (June 19, 1997; May 31, 1998; June 9, 30-yr average), with minimal patch expansion between 435 and 1,000 GDU. Patches were at 50% of their final area on May 27, 1997, and May 14, 1998, a time when only 22% of the *A. cannabinum* population had emerged ($r^2 = 0.99$). Knowledge of patch size and expansion could help growers time weed scouting, to account for the later emergence patterns of this species, as well as assist in timing appropriate weed management efforts. This information could also be used in conjunction with aerial photographs to project potential patch size for site-specific management of this weed.

Nomenclature: *Apocynum cannabinum* L. APCCA, hemp dogbane; *Glycine max* (L.) Merr., soybean.

Key words: GDU, growing degree units, patch expansion, perennial weed, spatial dynamics.

Understanding spatial dynamics of weed populations and the rate of spread within fields is increasingly important as methods are being developed for site-specific management of weeds (Cousens and Mortimer 1995). This is especially true for perennial weeds in reduced tillage systems, where plowing and cultivation are no longer management options and where growers want to make informed decisions on the judicious use of herbicides.

Reduced- and no-tillage production has increased steadily in the United States in the last 10 yr and now accounts for 32% of the U.S. *Glycine max* crop (Conservation Tillage Information Center 2000). As many fields in Ohio have been converted to reduced tillage, perennial weeds like *Apocynum cannabinum* have become more troublesome (Loux and Berry 1991).

Apocynum cannabinum produces few viable seeds when growing in competition with agronomic crops and reproduces primarily vegetatively by underground rootstocks (Gerhards et al. 1997; Schultz and Burnside 1979). Adventitious shoots arising from a network of rootstocks form relatively distinct patches that reduce crop yields and interfere with harvest. *Glycine max* yield losses have exceeded 55% where *A. cannabinum* density was 28 shoots m^{-2} (Webster et al. 2000).

Several perennial plants spread in a circular pattern (Horowitz 1972, 1973; Werner et al. 1980). Densities of *Sorghum halepense* (L.) Pers. (johnsongrass) and *Cynodon dactylon* (L.) Pers. (bermudagrass) were fairly consistent throughout the circular patch (Horowitz 1972, 1973). In other species, shoot densities were unequal within a patch. As the outer border expanded, the inner and older shoots of *Cirsium arvense* (L.) Scop. (Canada thistle) and *Solidago canadensis* L. (Canada goldenrod) patches have been observed to die, resulting in a ring-like patch with low shoot densities in the center (Armor and Harris 1975; Werner et al. 1980). In a study of patch stability in a conventionally tilled field, Gerhards et al. (1997) found that patches of *A. cannabinum* occurred at about the same location over 4 yr. There are no studies of *A. cannabinum* patch stability, shoot distribution, or expansion rates in reduced-tillage systems where this weed is most common.

The objectives of this study were to measure the rate of expansion of natural *A. cannabinum* patches over three growing seasons in a *G. max*–fallow–*G. max* rotation and to describe spatial changes in *A. cannabinum* patches within a season.

Materials and Methods

Field studies were conducted from 1996 to 1998 in Wooster, OH. The soil type was a well-drained Wooster silt loam (Typic fragiudalf). The field was planted to *G. max* in 1996 and 1998 and left fallow in 1997. *Glycine max* was no-till drilled in 18-cm rows on May 28, 1996, following an application of 0.42 kg ae ha^{-1} glyphosate. *Apocynum cannabinum* shoots had not emerged at the time of glyphosate application. Metolachlor was applied preemergence at 2.6 kg ai ha^{-1} and 2,4-DB was applied postemergence at 0.25 kg ae ha^{-1} for control of annual weed seedlings. Metolachlor and 2,4-DB at those rates have no significant activity on perennial shoots of *A. cannabinum* (Loux et al. 1998). Herbicides were not used during the fallow in 1997, but the field was mowed to a height of 5 cm in the middle of August. *Glycine max* was no-till planted on May 5, 1998, (which coincided with first emergence of *A. cannabinum*), following a preplant burndown application of glyphosate (0.42 kg ha^{-1}). A mixture of flumetsulam at 0.07 kg ai ha^{-1} and metolachlor at 2.6 kg ha^{-1} was applied preemergence to control annual grass and broadleaf weeds. These herbicides have minimal activity against perennial *A. cannabinum* shoots; however, they may have minimized the number of *A. cannabinum* seedlings present in this test. Clethodim was applied postemergence at 0.14 kg ai ha^{-1} for grass control.

Interseason Expansion Patterns

The borders of natural populations of *A. cannabinum* were evaluated each year using a Trimble Pro-XL[1] global positioning system (GPS) with real-time differential correction from a Racal Landstar receiver.[2] The area of each patch was integrated by the GPS. Estimates of patch area from this system have an error of 3 to 15% when patches are between 50 and 500 m^2 (Webster and Cardina 1997). *Apocynum cannabinum* patches were selected in 1996 based on their distinct boundaries and distances from other patches. The GPS operator walked around the patch perimeter, pausing 5 s at a minimum of eight points, which coincided with critical directional changes of the patch boundary. The borders of 10 *A. cannabinum* patches were measured in late June 1996, whereas 30 patches were measured in late June 1997 and 1998. Of the 30 patches, 25 were in a fallow–*G. max* rotation, and the remaining five patches were fallow in both 1997 and 1998.

Intraseason Expansion Patterns

A study was conducted to measure patterns of shoot emergence and patch expansion within a growing season. Six *A. cannabinum* patches in 1997 and 12 patches in 1998 were monitored weekly for newly emerged shoots. These patches ranged in size from 22 to 350 m^2 in 1997. To monitor shoot emergence time, surveyor's tape was tied loosely around the base of newly emerged *A. cannabinum* shoots (all shoots $>$ 0.5 cm); a different color tape was used each week. At the conclusion of the *A. cannabinum* emergence period (July 15 in 1997 and 1998), each patch was divided into regular 1-m^2 grids, and the number of shoots for each tape color was recorded.

Growing degree units (GDU) were calculated using the daily mean soil temperature[3] at a depth of 2.5 cm, from which a base temperature of 6 C was subtracted (Webster and Cardina 1999). Relations among patch size, GDU, and *A. cannabinum* emergence were evaluated through regression analysis. Previous studies showed a good relation (r^2 = 0.96) between shoot emergence and GDU with these parameters (Webster and Cardina 1999).

Spatial data for *A. cannabinum* shoot density were analyzed using geostatistical procedures described by Cardina et al. (1995). Kriged maps of *A. cannabinum* shoot densities

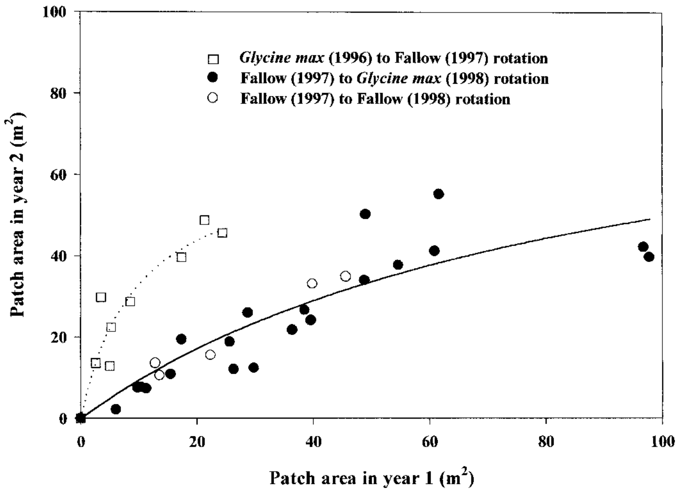

FIGURE 1. The relation between *Apocynum cannabinum* patch area in year 1 and year 2. The regression describing the relation between patch area in 1996 and 1997 was {$y = (65x)/(9.6 + x)$, $r^2 = 0.81$}. The relation between patch area in 1997 and 1998 was described by {$y = (94x)/(90 + x)$, $r^2 = 0.76$}.

were created for each patch. From these maps, the growth rate was calculated in each grid area as the change in density from the period beginning at 250 cumulative GDU (June 4, 1997, and May 19, 1998) until the conclusion of *A. cannabinum* emergence (July 15) in both border and interior grid areas. A border grid area was defined as a grid that contained the edge of the patch at the end of the growing season, and interior grids were those that did not contain this edge.

Results and Discussion

Interseason Expansion Patterns

Apocynum cannabinum patches expanded rapidly between 1996 and 1997 (Figure 1). The relation between 1996 patch size and 1997 patch size was described by a hyperbolic function (r^2 = 0.81). Patches of 5 and 25 m^2 in 1996 increased 4.5- and 1.9-fold, resulting in patches of 22 and 47 m^2 in 1997, respectively. Patches with areas 23 m^2 or less in 1996 more than doubled in area during 1997. *Apocynum cannabinum* grew in competition with *G. max* in 1996, but the field was left fallow in 1997 with a late-season mowing. The mowing occurred about 4 wk after the cessation of *A. cannabinum* emergence, so mowing did not affect patch expansion in the 1997 season.

In contrast to the large increase in *A. cannabinum* patch size from 1996 to 1997, patch area decreased from 1997 to 1998. The decrease ranged from 6% (e.g., patch size of 10 m^2 in 1997 was reduced to 9.4 m^2 in 1998) to 51% (e.g., patch size of 100 m^2 in 1997 was reduced to 49 m^2 in 1998) (Figure 1). A hyperbolic curve described the relation between 1997 and 1998 patch sizes (r^2 = 0.76). One factor that may have contributed to a reduction in patch size in 1998 was mowing the patches during the late flower to early fruit stage of *A. cannabinum* growth in the previous fallow season (1997). Carbohydrate levels in the crown roots of *A. cannabinum* are at their lowest levels during the middle- to full-flower stage (Becker and Fawcett 1998). We suspect that the underground patch borders of *A. cannabinum* normally

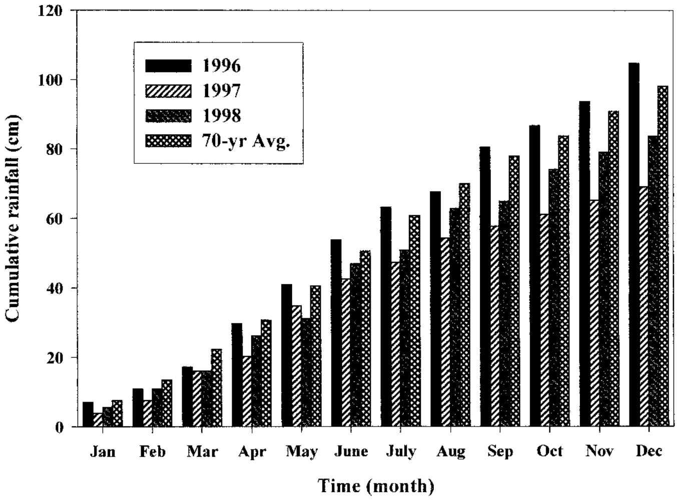

FIGURE 2. Cumulative rainfall at the Ohio Agricultural Research and Development Center in 1996, 1997, and 1998 and the 70-yr average.

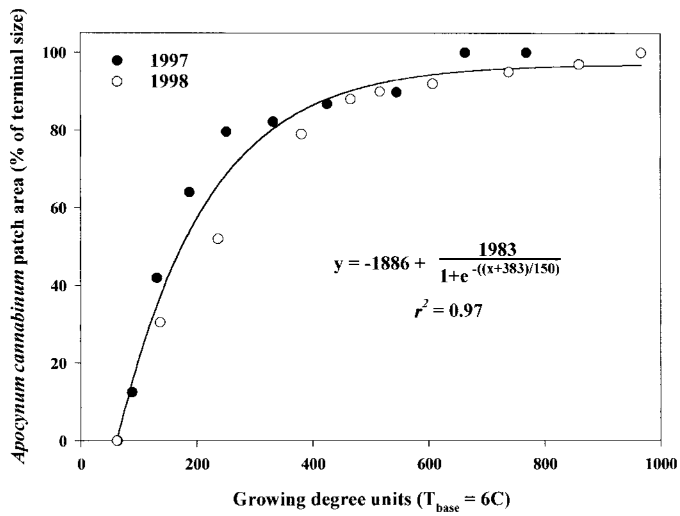

FIGURE 3. The relation between terminal area of *Apocynum cannabinum* patches and growing degree units (T_{base} = 6 C).

expand during the late growing season, during the replenishment of the underground root reserves. The late-season mowing may have prevented this expansion and may have caused some mortality of the root systems or root bud bank at the periphery of the current season's growth. Also, most of the *A. cannabinum* patches competed with *Glycine max* during 1998, whereas the fields were fallow in 1997. Crop competition may have also contributed to the reduction in *A. cannabinum* patch size. However, of the 30 patches that were measured in both 1997 and 1998, five of them were fallow in both years, whereas the other 25 were fallow in 1997 and planted to *G. max* in 1998. The relation between 1997 and 1998 patch sizes appeared to be independent of crop rotation (Figure 1). A potential third factor could be the above average rainfall in 1996 (6.4 cm greater than the 70-yr average), which may have contributed to expansion in 1997, whereas below average rainfall in 1997 (29.2 cm less than the 70-yr average) and 1998 (14.6 cm less than the 70-yr average) may have contributed to the lack of patch expansion (Figure 2).

Intraseason Expansion Patterns

The relation between patch size and growing degree units during the course of the growing season was described by a hyperbolic function (r^2 = 0.97) (Figure 3). The linearized slope of the regression between 90 GDU (May 15, 1997; May 7, 1998; and May 10 for the 30-yr average) and 330 GDU (June 11, 1997; May 31, 1998; and June 9, 30-yr average) was 0.27% per GDU. During this time period, patches expanded 2.4 and 3.5% per day in 1997 and 1998, respectively. As patch size approached 90% of its final size (at 435 GDU), the slope of the regression between this point and the terminal size of the patch (945 GDU) leveled out (0.016% per GDU) (Figure 3). During the interval between 435 GDU (June 19, 1997; May 31, 1998; and June 9, 30-yr average) and 945 GDU (July 19, 1997; July 6, 1998; and July 12, 30-yr average) patch size increased 8%, which averaged 0.27% and 0.23% each day for 1997 and 1998, respectively. Median patch area, defined as the time at which the patch was 50% of its terminal size, occurred at 175 GDU, which corresponded to May 27, 1997; May 14, 1998; and May 18, 30-yr average.

Apocynum cannabinum shoot densities within patches were monitored over the course of the season, and the cumulative *A. cannabinum* density frequency distribution from six of the sample dates are shown in Figure 4. On the first sample date (May 11), the distribution of *A. cannabinum* shoot densities within patches was highly skewed toward low densities and was described by a sigmoidal function (r^2 = 0.99) (Figure 4A). Densities ranged from 1 to 6 shoots m^{-2}, with 65% of the patch area at a density of 1 shoot m^{-2}. This sample date accounted for the emergence of 12% of the *A. cannabinum* shoots (Webster and Cardina 1999). One week later, *A. cannabinum* densities ranged from 1 to 10 shoots m^{-2}, with a density of 1 shoot m^{-2} accounting for 42% of the patch area (Figure 4B). The distribution was still skewed on May 28; however, it had begun to flatten out as the range extended to include densities of 1 to 14 shoots m^{-2}, and the most common density (1 shoot m^{-2}) accounted for only 15% of the patch area (Figure 4C). The distribution of *A. cannabinum* shoots remained consistent over the final month of emergence, as densities ranged from 1 to 17 shoots m^{-2} at each of the dates, and 1 shoot m^{-2} accounted for 12, 11, and 10% of the patch area on June 8, June 23, and July 7, respectively (Figures 4D–F). This was to be expected because patches were at 94% of their terminal size (Figure 3), and 92% of the shoots that would eventually emerge were accounted for by June 8 (Webster and Cardina 1999).

The change in shoot density during the interval from 250 GDU to the end of the season was not uniform at all locations within a patch. The relation between the relative increase in shoot density at the interior of patches and the increase in shoot density at patch borders was described by a linear function (r^2 = 0.77) with a slope of 1.46 (Figure 5). Patches with low relative increases in shoot density over this interval had significant *A. cannabinum* emergence prior to 250 GDU (data not shown). Therefore, the linear relation between relative increases in shoot density in the interior and exterior quadrats suggest that patches with early shoot emergence at the patch center had early emergence in

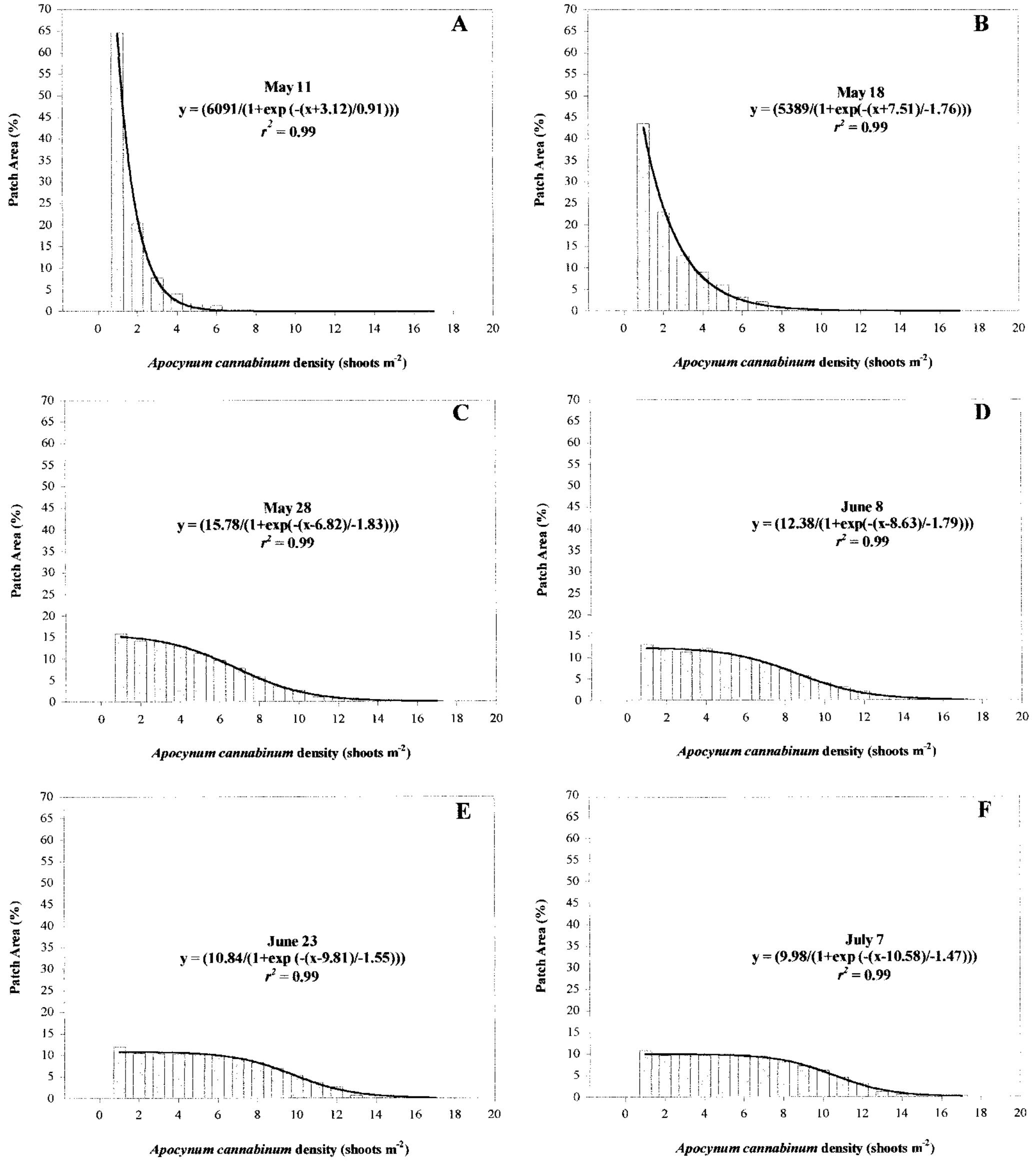

FIGURE 4. Frequency distribution of cumulative *Apocynum cannabinum* densities within patches over the course of the season in 1998. Densities were determined using the contours from the kriged maps (e.g., Figure 6).

the patch exterior (Figure 5). Similarly, interior grid cells with large increases in shoot density between 250 GDU and the end of the growing season also had large increases in shoot density at exterior grid cells. The difference in relative increases in shoot density among patches could be due to microclimate differences. It appears that *A. cannabinum* emergence within a patch may be relatively synchronous. However, differences in the timing of emergence between patches that were found in this study could have significant implications for the success of *A. cannabinum* management.

In spite of the differences in the relative increase in shoot density within patches, the patch borders were established relatively early in the growing season. Later shoot emergence was concentrated within the interior of the patch. Grid cells at the interior of patches had increases in shoot density that were 1.5 to 2.4 times those at the patch borders. Kriged maps of a representative patch over time illustrates the shoot emergence pattern at 132 GDU (May 21, 1997), 250 GDU (June 4, 1997), and 869 GDU (July 15, 1997) (Figures 6A–C, respectively). This figure indicates that the shape of the patch could be detected early in the growing season and that patch shape remained relatively stable throughout the growing season.

Regression analysis indicated that patch size expressed as a percentage of final size was related to cumulative shoot emergence (r^2 = 0.99) (Figure 7). The curve initially had a steep slope, which reflected the fast development of patch size at low *A. cannabinum* densities. The patch was 50% of its final size when only 22% of the *A. cannabinum* shoots had emerged and was 75% of its final size with 48% of shoots emerged. These data indicate that the patch size is established earlier in the season than is final shoot density within the patch. Therefore, herbicide applications or cultivation initiated too early in the season, even when patch size is relatively well established, may miss the main period of *A. cannabinum* shoot emergence. These data also reinforce the recommendation by Becker and Fawcett (1998) that tillage, cultivation, or mowing of *A. cannabinum* should

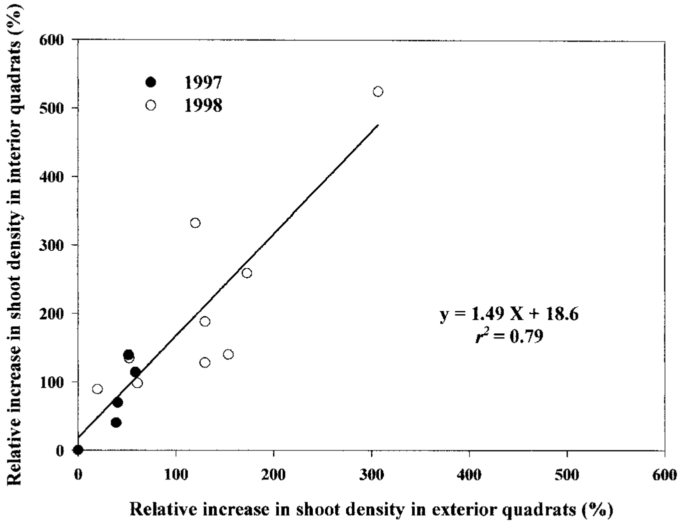

FIGURE 5. The relation between the changes in the shoot densities from 250 growing degree units until the end of the growing season in the interior and exterior quadrats of 18 *Apocynum cannabinum* patches.

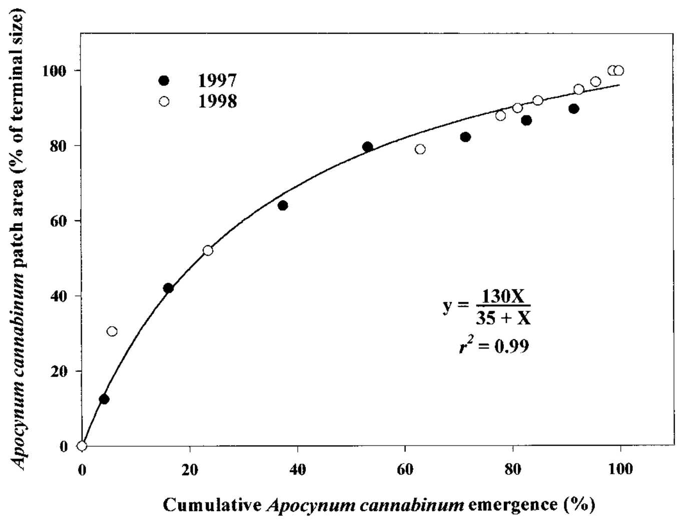

FIGURE 7. The relation between terminal area of *Apocynum cannabinum* patches and cumulative *A. cannabinum* emergence.

be targeted to the mid- to full-flower stage, before root carbohydrates begin to replenish.

When growing in competition with *G. max*, *A. cannabinum* patches that were less than 20 m^2 in 1996 more than doubled their size during the fallow in 1997. Although this cannot be extrapolated to the growth rate of *A. cannabinum* in *G. max*, this does illustrate the potential growth of this species from one season to the next. If this rate of growth is coupled with poor weed control, *A. cannabinum* has the potential to become an increasingly prevalent weed problem in Ohio. Research indicates that predicted *G. max* yield losses within an average *A. cannabinum* patch will range from 19 to 36% (Webster et al. 2000).

Knowledge of predicted patch size at a given point during the growing season can guide weed scouting and weed management. This information could also be a component of a precision agriculture system by recommending the appropriate time for capturing remotely sensed images; these images could be useful in quantifying the percentage of a field that is infested with this weed as well as identifying areas within the fields with high numbers of *A. cannabinum* patches. Although identification of individual plants of *A. cannabinum* in remotely sensed images would be difficult, the clonal nature of this weed may allow for identification of *A. cannabinum* patches. Information from this study (e.g., relations among GDU and patch area and phenology of shoot emergence within patches) could assist in interpreting data from remotely sensed images. These data could be useful to a grower in formulating a multiple-season weed management plan, especially since *A. cannabinum* has been shown to have relatively stable patches over time, even in conventional tillage systems (Gerhards et al. 1997).

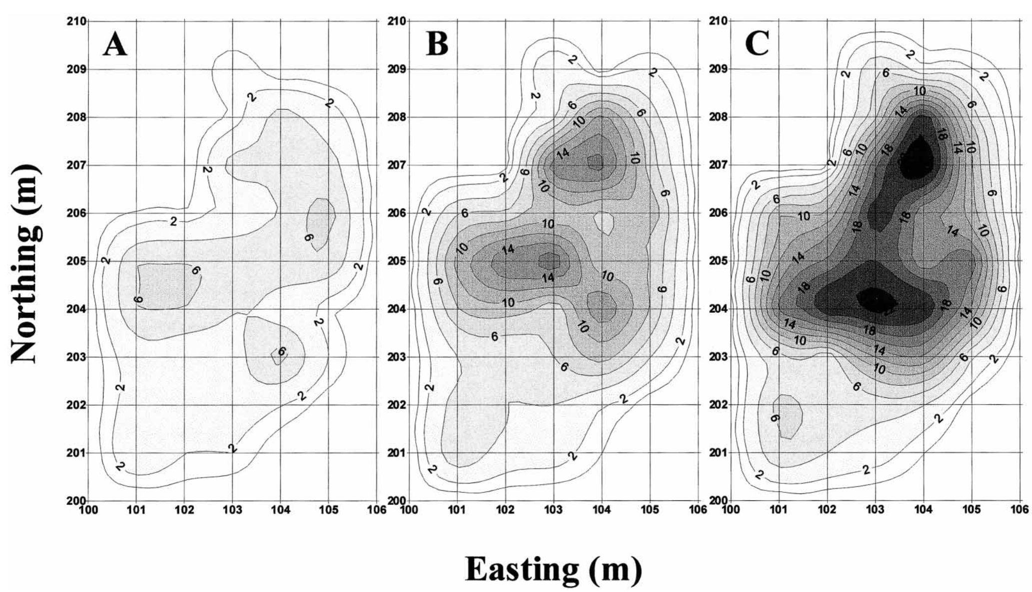

FIGURE 6. Kriged maps of estimated shoot densities (m^2) of a representative *Apocynum cannabinum* patch illustrating emergence patterns at three different times. (A) 132 growing degree units (GDU) (May 21, 1997), (B) 250 GDU (June 4, 1997), and (C) 869 GDU (July 15, 1997).

Sources of Materials

[1] Trimble Navigation, 645 N. Mary Avenue, Sunnyvale, CA 94088-3642.

[2] Racal Survey USA, Inc., 3624 Westchase Drive, Houston, TX 77042.

[3] Recording temperature probe, Onset Computers Corp., P.O. Box 3450, Pocasset, MA 02559-3450.

Acknowledgments

The authors thank Gary Coffing for the generous use of his field and Paul McMillen, Brian Sugerman, Tim Koch, Cathy Herms, and Lisa Webster for technical assistance. Salaries and research support provided by state and federal funds appropriated to the Ohio Agricultural Research and Development Center, The Ohio State University. Manuscript 99-36.

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Received December 12, 1999, and approved July 14, 2000.