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Solaria Help Predict In-Crop Weed Densities[1]

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Abstract: At locations in Argentina and the United States, solaria (miniature, portable, plastic greenhouses or a plastic sheet approximately 1 m^2) were placed on field soils in autumn or late winter in an attempt to predict summer annual weed densities. Initial emergence of summer annual weeds covered by solaria commenced weeks before that of weeds in exposed seedbeds. Cumulative emergence of many species in solaria reached asymptotes before crops were sown. At asymptotic cumulative emergence, densities of dominant weeds in solaria (common lambsquarters, green foxtail, and large crabgrass) were correlated with weed densities occurring 4 wk after sowing, the typical time for making postemergence weed control decisions. These results indicate that solaria may supplement seedbank-sampling techniques for predicting weed densities in crops.

Nomenclature: Common lambsquarters, *Chenopodium album* L. #[3] CHEAL; green foxtail, *Setaria viridis* (L.) Beauv. # SETVI; large crabgrass, *Digitaria sanguinalis* (L.) Scop. # DIGSA.

Additional index words: Decision making, emergence, postemergence control, seedlings, solarization.

Abbreviations: CWD, in-crop weed density; OM, organic matter; PPI, preplant incorporated; PRE, preemergence; SWD, weeds inside solaria; TWD; threshold weed density.

INTRODUCTION

Knowledge of weed species and densities that will interfere with crops during the forthcoming growing season is useful information for integrated weed management strategies, especially in attempts to make more efficient use of herbicides. This information is particularly important when weed control decisions are based on bioeconomic models because an important input in these models is weed seedling densities (Lybecker et al. 1991; Wiles et al. 1996b). Methods used to predict weed seedlings in crops include counting seeds after direct extraction from soil samples (Wiles et al. 1996a) and counting emerged seedlings from incubated soil samples (Cardina and Sparrow 1996; Forcella 1992). Both methods are labor-intensive, time-consuming, and often suffer from low accuracies for predicting in-crop weed densities. Consequently, new methods for predicting in-crop weed densities may be helpful. The value of predicting weed seedling densities originates with the need to decide before planting if weed control measures should be performed as well as with the consideration of the types of methods of control. Threshold densities of weed seedlings at which crop yields were lowered significantly have been documented (Beckett et al. 1988; McGiffen et al. 1997; Robinson et al. 1984; Shurtleff and Coble 1985). Although threshold weed densities probably vary with cultivar, soil type, environment, etc. (Lindquist et al. 1999), they can be used to illustrate the possible use of solaria for forecasting in-crop weed infestation. When the decision to implement weed control is based on a threshold, then a method to predict whether the amount of weeds in the crop will be higher or lower than the proposed threshold is needed. This may be more important than a method to predict the exact number of weed seedlings.

The objective of this article is to evaluate solaria (small portable greenhouses) as a new method to predict whether weed thresholds will be exceeded in summer crops.

MATERIALS AND METHODS

Experiments to evaluate the use of solaria were conducted at three locations: farms located in the counties

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[3] 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.

of Balcarce (36°S, 57°W) and Tandil (38°S, 59°W) in southeast Buenos Aires Province, Argentina; and Stevens County (45°N, 96°W) in west-central Minnesota. Soils in the experimental areas were Balcarce clay loams (Typic Argiudoll) in Balcarce and Tandil counties (Cabria and Culot 1994), containing 5.4 to 6.6% of organic matter (OM) and pH 5.8 to 6.3, and Barnes loam (Udic Haploboroll) in Stevens County (Lewis et al. 1971), with 6% OM and a pH of 6.8.

Experiments in Argentina. In 1998 through 2000, a total of 100 solaria (1- by 1-m and 100-μm-thick clear plastic tarps) was placed in 15 fields on seven farms in which corn (*Zea mays* L.) or soybean [*Glycine max* (L.) Merr.] was to be planted. In early September each year (approximately 30 d before corn planting), 72 solaria (12 in 1998, 30 in 1999, and 30 in 2000) were placed and fixed with wires to the soil surface in 13 no-till fields on seven farms. Solaria were distributed in a ''Z'' pattern within each field in an area between 0.75 and 1.5 ha, and the first solarium was located at 30 m from the field perimeter to avoid edge effects. In five fields in which solaria were to be placed, no weed control was attempted after wheat (*Triticum aestivum* L.) harvest, which allowed summer weeds to grow freely before chemical fallow in June, before corn planting. Remaining fields were sprayed with glyphosate at 1 kg ai/ha in February (approximately 30 d after wheat harvest) to minimize seed production of summer weeds.

An additional 28 solaria (19 in 1999 and nine in 2000) were placed on two farms before planting soybean. The size and distribution of solaria for soybean were identical to those of solaria for corn. In one of the fields, the previous crop was wheat (19 solaria) and weed control in February was performed as described above. In the latter field, the previous crop was corn (nine solaria) and no weed control occurred during the previous 3 yr when crops were grown. Weed control in this field was performed only in fallows and as needed to plant the crops.

The soil surface under each solarium was irrigated with 20 L of water when conditions were extremely dry for seed germination. Weeds present before placement of solaria were controlled with nonresidual herbicides. Soil cover by residues of previous crops was estimated by the line-intercept technique (Morrison et al. 1993).

Weeds were counted under solaria only once in 1998, 30 d after solarium placement. However, in 1999 and 2000, counts were made weekly once, beginning 7 d after solarium placement. All weed seedlings were identified, counted, and removed, after which the solarium was affixed to the soil until the next counting. If any seedling was too small to be identified, it was preserved until the next week.

At Tandil, soil temperature at 1.5-cm depth was measured in the center of the solarium and outside of it, about 40 cm from its edge, between September 9 and October 5, 1999. At Balcarce, soil temperatures were recorded between October 4 and November 4, 1999. In this case, sensors were located in the center of the solarium, 25 cm from the center, 49 cm from the center, and outside, approximately 40 cm from the edge of the solarium.

Corn was planted in Tandil in all plots and for all years between October 6 and 12, at 71,500 seeds/ha in 0.7-m rows. Soybean was planted on November 11, 1999, in Tandil, and on November 15, 1999, and November 21, 2000, in Balcarce, at 500,000 seeds/ha in rows spaced at 40 cm. No weed control occurred in the experimental areas between the times of placement of the solaria and counting weed seedlings before postemergence herbicide application.

Densities of weeds competing with the crops were estimated by counting seedlings in 1-m^2 quadrats outside of but adjacent to solaria between 25 and 35 d after crop planting. At these times, corn had five visible leaves and soybean was at V2 to V3 growth stages (Fehr and Caviness 1977). Postemergence herbicides typically are applied at these crop growth stages.

Experiments in the United States. In Minnesota, analogous experiments were conducted in 1996 and 1997 at the Swan Lake Research Farm near Morris. Solaria were constructed from commercially available ''basement window covers,'' which are made of clear acrylic plastic. Two of the window covers were bolted together to form oval dome-like solaria that were approximately 90 cm long, 70 cm wide, and 40 cm high. A 2-kg weight was suspended from the apex of each solarium for stabilization during windstorms.

Solaria were placed in the field after autumn plowing, which preceded each experimental year. One solarium was placed in the center of each of 16 plots, which were arranged in four blocks, each composed of four contiguous plots. Each plot was 6.1 m wide and 15.3 m long. A single permanently marked 0.1-m^2 quadrat was established under the center of each solarium for subsequent weekly enumeration, identification, and removal of weed seedlings from early spring until the time of crop planting. Weed seedlings also were counted in each plot in a single 0.1-m^2 quadrat located about 1 m from the solarium. One or two solaria were fitted with soil temperature

probes buried 5 cm deep. Other probes were located approximately 1 m from the nearest solarium.

On May 17, 1996, solaria were removed, seedbeds were prepared using a field cultivator, and corn was planted at 70,000 seeds/ha in 76-cm row-spacings in the 16 plots. Fertilizer was broadcast and incorporated by a field cultivator at rates equivalent to 110, 20, and 20 kg/ha for N, P, and K, respectively, before planting. On May 28, 1997, solaria were removed, seedbeds were prepared using a field cultivator, and soybean was planted at 300,000 seeds/ha in 76-cm rows in the 16 plots. No fertilizer was applied.

Postemergence weed densities were estimated by counting all weed seedlings in each of six 0.1-m^2 quadrats that were arranged in a diagonal line across the central 4- by 10-m section of each plot. These counts were made 24 and 27 d after planting in 1996 and 1997, respectively. These dates are typical for field scouting for weeds before postemergence herbicide applications. Standard herbicides were applied after weeds were counted.

Statistical Comparisons and Analyses. *t* Tests were used to compare levels of cumulative emergence of the dominant weed species inside and outside the solaria at weekly intervals. When data were allowed, regression was used to relate densities of dominant weed species inside solaria (SWD) at differing dates, with the single estimation of in-crop weed density (CWD) recorded before postemergence herbicide application.

A threshold density of weed seedlings (TWD), at which crop yields were lowered significantly, was established according to previous research. To evaluate the use of the solaria, plots were classified in a two by two contingency table as follows:

	CWD		
	<TWD	>TWD	Total
SWD			
<TWD	N_{11} (Control not needed and not recommended by the solarium)	N_{12} (Control needed but not recommended by the solarium)	$N_{1\cdot}$
>TWD	N_{21} (Control not needed but recommended by the solarium)	N_{22} (Control needed and recommended by the solarium)	$N_{2\cdot}$
Total	$N_{\cdot 1}$	$N_{\cdot 2}$	$N_{\cdot\cdot}$

If solaria provide the right decision about weed control, the contingency table should show a heavy main diagonal (N_{11} and N_{22}) and a light contradiagonal (N_{12} and N_{21}). The K coefficient, defined by Cohen (1960), gives a statistical measure of this relation. This coefficient measures the agreement of two methods of decision and is less than or equal to one, where one means perfect agreement for both methods, whereas zero means independence of the two methods of decision. The estimation of this coefficient is

$$\hat{K} = \frac{N_{\cdot\cdot}(N_{11} + N_{22}) - N_{\cdot 1}N_{1\cdot} - N_{\cdot 2}N_{2\cdot}}{N_{\cdot\cdot}^2 - N_{\cdot 1}N_{1\cdot} - N_{\cdot 2}N_{2\cdot}}$$

The hypothesis of independence ($K = 0$) was tested ($\alpha = 0.05$) based on the asymptotic normal distribution of K (Bishop et al. 1975).

RESULTS AND DISCUSSION

Soil Cover and Soil Temperature. In both Argentine counties, residue cover under solaria ranged from 75 to 95% when corn was the previous crop and 85 to 98% for wheat.

Soils were consistently warmer under solaria than outside (Table 1). Soils to be sown with soybean in Balcarce were warmer than those for corn because solaria were established about 1 mo later in spring, when ambient air temperatures were higher. In Tandil and Balcarce, soil temperatures in the middle of the solaria were about 3 and 5 C higher for minimum and maximum temperatures relative to outside soil temperatures. Analogous values in Minnesota were 2 and 9 C. Soil temperatures under the solaria, especially in Balcarce and Tandil, were similar to those at which soil samples are treated in greenhouses to stimulate weed seed germination (Cardina and Sparrow 1996; Forcella 1992) and did not approach temperatures used to kill seeds by solarization (Mahrer and Katan 1981; Vizantinopoulus and Katranis 1993).

Weed Seedlings. In Minnesota, weeds emerged much earlier under solaria than in exposed seedbeds (Figures 1 and 2), presumably because of higher soil temperatures. For example, cumulative emergence of comparable numbers of seedlings often was reached 3 to 4 wk earlier under solaria than in exposed seedbeds. Differences in seedling densities inside and outside solaria were significant ($P < 0.10$) until the sampling date that immediately preceded crop planting.

Cumulative seedling emergence in solaria appeared to reach asymptotes by the final sampling date for the dominant species, suggesting that emergence had reached its full potential by this date. Few additional seedlings would have been expected to emerge had the solaria been maintained undisturbed during crop planting, mak-

Table 1. Maximum and minimum soil temperatures recorded under and outside solaria at Balcarce, Tandil, and Minnesota.

	Soil temperature							
	Maximum temperatures				Minimum temperatures			
	Under solarium				Under solarium			
Location	Center	25 cm from edge	Edge	Outside	Center	25 cm from edge	Edge	Outside
	C							
Balcarce[a]								
Average	25.4	23	21.3	17.4	16.8	15.8	14.9	13
Extremes	34.2	30.2	27.2	22.9	21.4	19.5	18.9	17.3
	16.3	15.2	14.7	13.5	13.7	13.1	11.7	8.1
Tandil[b]								
Average	17.3	—	—	12.4	9	—	—	7.6
Extremes	29.7	—	—	19.8	15.9	—	—	13.1
	11.7	—	—	7.4	4.3	—	—	2.8
Minnesota[c]								
Average	18.7	—	—	9.6	2	—	—	− 0.3
Extremes	27.9	—	—	19.6	9.6	—	—	7.1
	3.4	—	—	0	− 3.1	—	—	− 5.1

[a] Recorded between October 4 to November 4, 1999.
[b] Recorded between September 9 to October 5, 1999.
[c] Recorded between March 30 to May 12, 1996.

ing the final SWD possible predictors of subsequent CWDs.

SWDs before crop planting were related to densities of weeds that subsequently interfered with crops, especially for the most common species at each location: large crabgrass in Argentina in 1998 to 2000 (Figure 3) and common lambsquarters and green foxtail in Minnesota in 1996 and 1997, respectively (Figures 4 and 3). SWDs recorded for green foxtail at the very earliest times were not correlated with CWDs as well as later estimates. To illustrate this result, Table 2 lists correlation coefficients for relationships of CWD (dependent variable) with time sequences of SWDs (independent variable). The best correlations for foxtail tended to occur with the latest solarium sampling dates, i.e., after apparent maximum cumulative emergence had been reached in the solaria.

Researchers have documented for several species threshold densities of weed seedlings at which crop yields are lowered significantly. For soybean, this threshold seems to be about 2 plants/m^2 of crabgrass when associated with other species, totaling 82 individuals for each 3 m^2 (Robinson et al. 1984). In other studies large crabgrass diminished soybean yield significantly when

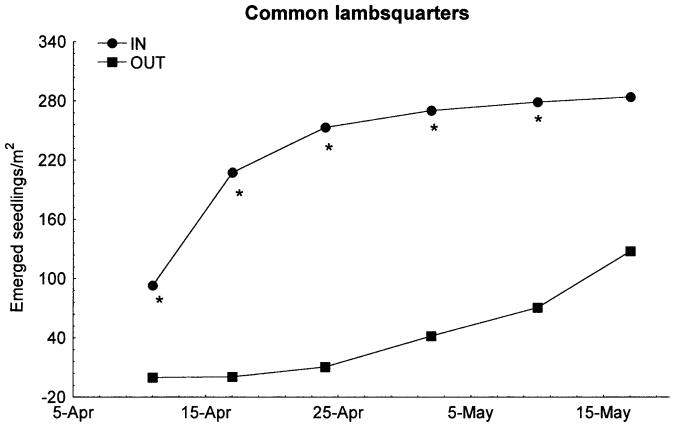

Figure 1. Cumulative emergence of common lambsquarters seedlings occurring inside (IN) and outside (OUT) solaria during 1996 in Stevens County, MN. Asterisks indicate significant differences of seedling densities inside and outside solaria at specific dates according to paired *t* tests ($P < 0.05$).

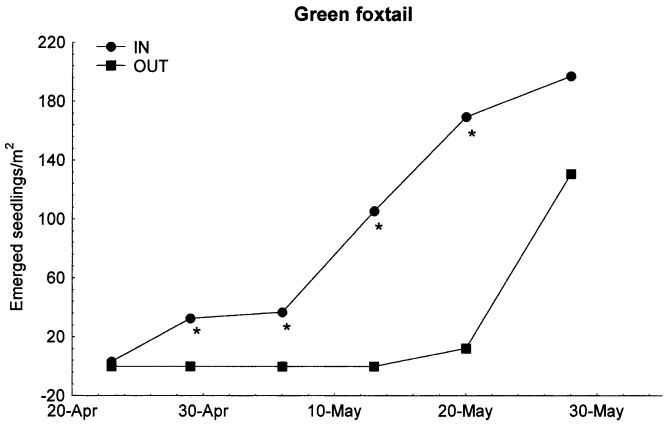

Figure 2. Cumulative emergence of green foxtail seedlings occurring inside (IN) and outside (OUT) solaria during 1997 in Stevens County, MN. Asterisks indicate significant differences of seedling densities inside and outside solaria at specific dates according to paired *t* tests ($P < 0.10$).

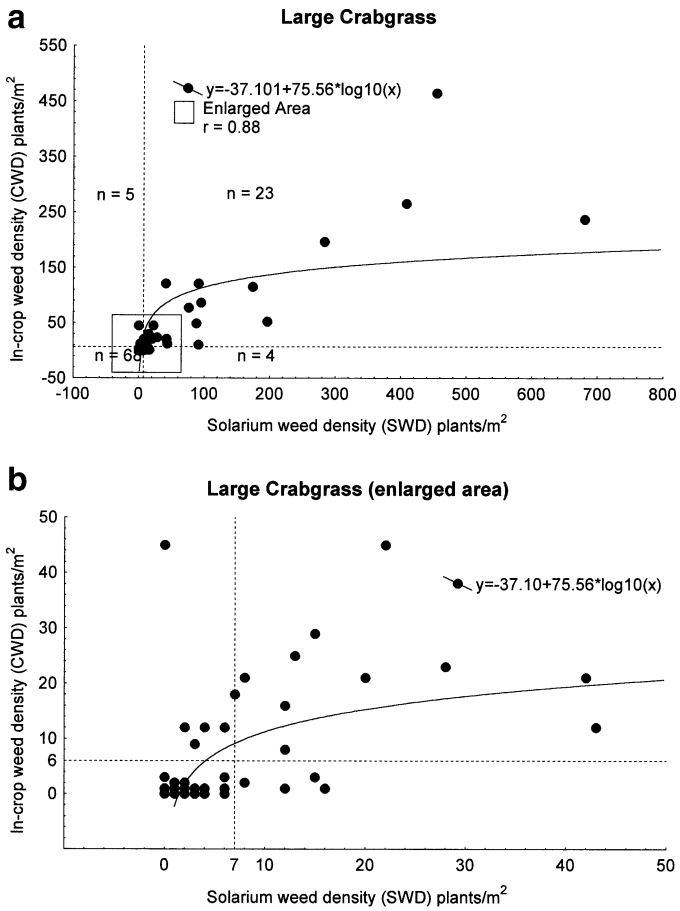

Figure 3. (a) Relationships of seedling densities emerging under solaria before crop planting and subsequent weed densities affecting the crop at the time when decisions are made for postemergence control for large crabgrass in 1998, 1999, and 2000 in Balcarce, Argentina. Dotted lines in the graph indicate threshold densities to exert control according to weeds observed under solaria (vertical lines) or in-crop (horizontal lines); *n* indicates number of observations in each quadrant. (b) Enlarged area of Figure 3a.

partially controlled; 97 plants/m^2 remained after control (Eyherabide 1993). Large crabgrass is a highly competitive species, for example, more than *Setaria* spp. (Elmore et al. 1983; Walker and Williams 1989). For green foxtail, the threshold for 10% yield loss in soybean is 15 to 19 plants/m^2 in dry years and 92 plants/m^2 in wet years, whereas in corn this threshold was 56 ($\pm$ 35) plants/m^2, calculated as average of 14 thresholds (McGiffen et al. 1997). The threshold for common lambsquarters in soybean is 1.2 plants/m^2 (Shurtleff and Coble 1985), whereas in corn it is 4 plants/m^2 (Beckett et al. 1988). Although threshold weed densities probably vary with cultivar, soil type, environment, etc. (Lindquist et al. 1999), they can be used to illustrate the possible use of solaria for forecasting in-crop weed densities. Examples are described below.

TWD for large crabgrass in this experiment was established as 6 plants/m^2, taking into account that it is a more competitive species than foxtail, especially in dry years (Elmore et al. 1983; McGiffen et al. 1997). The degree of agreement using this threshold was estimated as K = 0.65, which was significantly greater than zero ($P < 0.05$). In 85% of the observed plots, decisions based on solaria information agreed with decisions based on in-crop data. In 61% of the cases there was agreement that control was necessary, and in 24% there was agreement that control was not needed. However, in 11% of the cases solaria recommended control, whereas later observations of in-crop showed that control was not needed, and in 4% of the cases solaria did not recommend control, whereas later observations of in-crop indicated that control was needed (data not shown). This means that 15% of the time solaria did not make the correct decision about weed control. This could be considered a high percentage of wrong decisions. Perhaps environmental conditions under solaria promote higher numbers of weed seedlings than what actually emerged in the crop. Using the same TWD for both CWD and SWD could generate extremely high values for N_{21} (use of solaria recommends control more often than needed). Consequently, the value of TWD used for classifying SWD was increased by one individual (TWD = 7). Degree of agreement increased (K = 0.77), and the hypothesis of independence of criteria also was rejected ($P < 0.05$). With TWD = 7, 91% of observations were coincident with these two discrete decisions, with 23% associated with control and 68% linked to no control. In the remaining 9% of the cases, SWD and CWD disagree: in 4% of the cases, SWD suggested control but CWD did not, and in 5% of cases, SWD did not suggest control but CWD did (Figures 3a and 3b).

For common lambsquarters in 1996 in Minnesota, all plots had sufficiently high SWD and CWD to elicit recommendations for this species' control (Figure 4). Apparently, for lambsquarters, solaria overestimated the number of weed seedlings occurring in the crop; thus,

Table 2. Correlation coefficients (*r*) of densities of weeds occurring in solaria at different dates and the in-crop density of the same species about 4 wk after crop sowing. Correlation coefficients are based on best-fit quadratic equations, where the origin was assumed to be zero for both the dependent and independent variables.

Date	*r* (lambsquarters)	Date	*r* (foxtail)
April 11, 1996	0.57	April 23, 1997	0.00
April 17, 1996	0.66	April 29, 1997	0.41
April 24, 1996	0.55	May 6, 1997	0.35
May 2, 1996	0.57	May 13, 1997	0.62
May 10, 1996	0.57	May 20, 1997	0.71
May 17, 1996	0.57	May 28, 1997	0.70

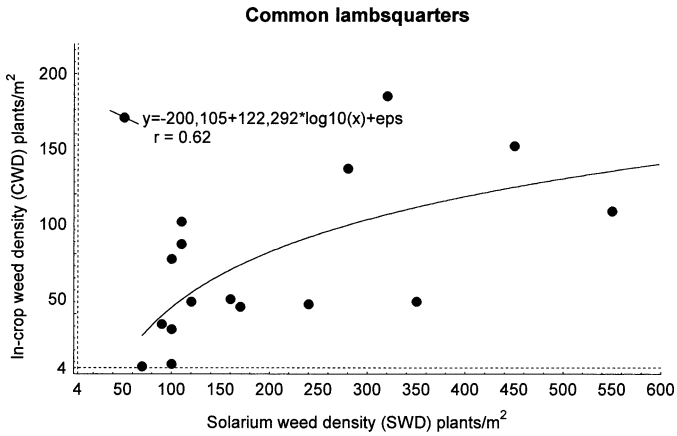

Figure 4. Relationships of seedling densities emerging under solaria before crop planting and subsequent weed densities affecting the crop at the time when decisions are made for postemergence control for common lambsquarters in 1996 in Stevens County, MN. Dotted lines in the graph indicate threshold densities to exert control according to weeds observed under solaria (vertical lines) or in-crop (horizontal lines).

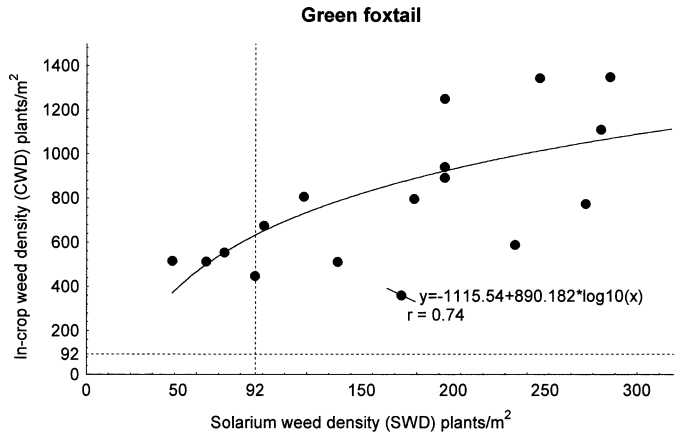

Figure 5. Relationships of seedling densities emerging under solaria before crop planting and subsequent weed densities affecting the crop at the time when decisions are made for postemergence control for green foxtail in 1997 in Stevens County, MN. Dotted lines in the graph indicate threshold densities to exert control according to weeds observed under solaria (vertical lines) or in-crop (horizontal lines).

using the same TWD for SWD and CWD will produce the same type of error as in large crabgrass (use of solaria recommends control more often than needed). TWD for SWD probably needs to be increased, but the lack of cases with low numbers of weed seedlings for SWD and CWD made this quite impossible.

For green foxtail in 1997 (Figure 5), SWD underestimated the number of weed seedlings within the crop. Using the same TWD for both SWD and CWD, three plots showed SWD to be low enough (< 92 plants/m^2) to decide that control would not be needed, whereas CWD information generated a decision for control. As opposed to what happened in common lambsquarters, TWD for SWD should be decreased but, again, the lack of information for low weed densities makes this correction impossible.

Clearly, to validate the method, more research is needed for the last two species discussed above, especially in places in which few individuals would be expected in the field. Nevertheless, most of the errors associated with solaria predictions are conservative, that is, control would be recommended even when not needed. This problem would only be important if the control decision involved soil-applied herbicides because postemergence herbicides could be withheld until predicted in-crop weed densities were confirmed by scouting.

The solarium method does not attempt to predict with high accuracy the number of weeds that will compete with the crop. Instead, its value is to determine if number of weed seedlings will be more or less than a threshold and only then to make decisions about whether control should be attempted.

At all locations higher temperatures under solaria than outside (Table 1) hastened seed germination and seedling emergence of major weed species, such as large crabgrass, green foxtail, and common lambsquarters. This emergence of weed seedlings before planting allows an anticipated decision about weed control. In consequence, the control method can be chosen from a wider range of tactics, including those of applying preplant incorporated (PPI) or preemergence (PRE) herbicides.

Although solarization may be used to control weeds in areas with hot climates (Abu-Irmailleh 1991; Al Masoom et al. 1993) or in areas that have periods of prolonged light intensity during the summer (Standifer et al. 1984), this weed control technique typically is not effective in more temperate regions. Nevertheless, soil heating of very small areas (e.g., 1 m^2) by solaria may be effective as a predictive tool when used to compliment traditional scouting and management techniques. As predictive tools, solaria may be useful for crop advisors in making recommendations for PPI, PRE, and postemergence herbicide applications in summer-growing crops. The ability to make the decision of applying a PPI or PRE herbicide under a more rationale basis may allow decreases in crop production costs and environmental problems without significant yield crop losses. The method, whether performed with miniature greenhouses or with plastic sheets spread on the soil, is fast, simple, inexpensive, and easy to perform and requires a basic knowledge of weed seedling identification. Because the time to set solaria in the field can be near the date of crop planting, many weed seeds already have lost dormancy and most overwinter seed mortality in the

seedbank already has occurred. In consequence, the information obtained by solaria may be more realistic than that obtained by soil samples with cores extracted several months before planting. Certainly, more research is needed concerning other weed species and the minimum number and distribution of solaria in the field necessary to make good decisions. However, low cost and feasibility of the method encourage further research. Indeed, the minimum number of solaria samples almost certainly would be less than the number of soil cores for seedbank samples because the area of sampling is many times larger under each solarium than within a soil core.

LITERATURE CITED

Abu-Irmailleh, B. E. 1991. Soil solarization controls broomrapes (*Orobanche* spp.) in host vegetable crops in the Jordan Valley. Weed Technol. 5:575–581.

Al Masoom, A. A., A. R. Saghir, and S. Itani. 1993. Soil solarization for weed management in U.A.E. Weed Technol. 7:507–510.

Beckett, T. H., E. Stoller, and L. M. Wax. 1988. Interference of four annual weeds in corn (*Zea mays*). Weed Sci. 36:764–769.

Bishop, Y. M., S. E. Feinberg, and P. W. Holland. 1975. Discrete Multivariate Analysis. Theory and Practice. Cambridge, MA: MIT. 557 p.

Cabria, F. and P. Culot. 1994. Selección y utilización de características edáficas para describir series de Argiudoles en el Sudeste Bonaerense. Ciencia del Suelo 12:41–46.

Cardina, J. and D. Sparrow. 1996. A comparison of methods to predict weed seedling populations from the soil seed bank. Weed Sci. 44:46–51.

Cohen, J. 1960. A coefficient of agreement for nominal scales. Educ. Psych. Meas. 20:37–46.

Elmore, C. D., A. Brown, and E. P. Flint. 1983. Early interference between cotton (*Gossypium hirsutum*) and four weed species. Weed Sci. 31:200–207.

Eyherabide, J. J. 1993. Evaluation of pre-emergence applications of flumioxazin alone and with imazaquin against weeds in soybeans. Tests Agrochem. Cultiv. 14:62–63.

Fehr, W. R. and J. Caviness. 1977. Stages of Soybean Development. Cooperative Extension Service, Agricultural and Home Economics Experiment Station, Iowa State University of Science and Technology, Ames, IA.

Forcella, F. 1992. Prediction of weed seedling densities from buried seed reserves. Weed Res. 12:29–38.

Lewis, R. R., D. E. De Martelaere, and E. L. Miller. 1971. Soil Survey of Stevens County, Minnesota. USDA-SCS, U.S. Government Printing Office, Washington, DC. 88 p.

Lindquist, J. L., D. A. Mortensen, P. Westra, et al. 1999. Stability of corn (*Zea mays*)-foxtail (*Setaria* spp.) interference relationships. Weed Sci. 47: 195–200.

Lybecker, D. W., E. E. Schweiser, and R. P. King. 1991. Weed management decisions in corn based on bioeconomic modelling. Weed Sci. 39:124–129.

Mahrer, Y. and J. Katan. 1981. Spatial soil temperature regime under transparent polyethylene mulch: numerical and experimental studies. Soil Sci. 131:82–87.

McGiffen, M. E., F. Forcella, M. J. Lindstrom, and D. C. Reicosky. 1997. Covariance of cropping systems and foxtail density as predictors of weed interference. Weed Sci. 45:388–396.

Morrison, J. E., Jr., C.-H. Huang, D. T. Lightle, and C.S.T. Daughtry. 1993. Residue measurement techniques. J. Soil Water Conserv. 48:478–483.

Robinson, E. L., G. W. Langdale, and J. A. Stuedemann. 1984. Effect of three weed control regimes on no-till and tilled soybeans (*Glycine max*). Weed Sci. 32:17–19.

Shurtleff, J. L. and H. D. Coble. 1985. Interference of certain broadleaf species in soybean (*Glycine max*). Weed Sci. 33:654–657.

Standifer, L. C., P. W. Wilson, and R. Porche-Sorbet. 1984. Effects of solarization on soil weed seed populations. Weed Sci. 32:569–573.

Vizantinopoulus, S. and N. Katranis. 1993. Soil solarization in Greece. Weed Res. 33:225–230.

Walker, K. L. and D. J. Williams. 1989. Annual grass interference in container-grown bush cinquefoil (*Potentilla fruticosa*). Weed Sci. 37:73–75.

Wiles, L. J., D. H. Barlin, E. E. Schweizer, H. R. Duke, and D. E. Whitt. 1996a. A new sampler and elutriator for collecting and extracting weed seeds from soil. Weed Technol. 10:35–41.

Wiles, L. J., R. P. King, E. E. Schweiser, D. W. Lybecker, and S. M. Swinton. 1996b. GWM general weed management. Agric. Syst. 50:355–376.