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An Emergence Model for Wild Oat (*Avena fatua*)

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Wild oat is an economically important annual weed throughout small grain producing regions of the United States and Canada. Timely and more accurate control of wild oat may be developed if there is a better understanding of its emergence patterns. The objectives of this research were to evaluate the emergence pattern of wild oat and determine if emergence could be predicted using soil growing degree days (GDD) and/or hydrothermal time (HTT). Research plots were established at Crookston, MN, and Fargo, ND, in 2002 and 2003. On a weekly basis, naturally emerging seedlings were counted and removed from six 0.37-m^2 permanent quadrats randomly distributed in a wild oat–infested area. This process was repeated until no additional emergence was observed. Wild oat emergence began between May 1 and May 15 at both locations and in both years and continued for 4 to 6 wk. Base soil temperature and soil water potential associated with wild oat emergence were determined to be 1 C and −0.6 MPa, respectively. Seedling emergence was correlated with GDD and HTT but not calendar days ($P = 0.15$). A Weibull function was fitted to cumulative wild oat emergence and GDD and HTT. The models for GDD ($n = 22$, $r^2 = 0.93$, root mean square error [RMSE] = 10.7) and HTT ($n = 22$, $r^2 = 0.92$, RMSE = 11.2) closely fit observed emergence patterns. The latter model is the first to use HTT to predict wild oat emergence under field conditions. Both models can aid in the future study of wild oat emergence and assist growers and agricultural professionals with planning timely and more accurate wild oat control.

Nomenclature: Wild oat, *Avena fatua* L. AVEFA.

Key words: Hydrothermal time, soil growing degree days, Weibull function, soil moisture, soil temperature.

Early germination is an important factor contributing to wild oat persistence and success as a weedy species (Sharma and Vanden Born 1978). Wild oat prefers a temperate, cool climate, moist soil conditions, and heavy clay and clay loam soil types (Sharma and Vanden Born 1978). All of these conditions are typical of the Red River Valley of Minnesota and North Dakota.

Approximately 79% of wheat (*Triticum aestivum* L.) and 72% of barley (*Hordeum vulgare* L.) hectares seeded in northwestern Minnesota are infested with wild oat (Dexter et al. 1981). Weed surveys conducted in North Dakota in 1978 and 1979 (Dexter et al. 1981) and in 2000 (Zollinger et al. 2003) found wild oat occurring in 66% of the surveyed fields in 1978, 60% in 1979, 32% in spring 2000, and 41% in summer 2000. Zollinger et al. (2003) also found that plant densities in fields were almost twice as high in spring 2000 as compared to past surveys, indicating high seed bank populations were present in fields. Wild oat is considered one of the most persistent weed species in the region.

A wide range of temperatures for optimum wild oat germination and emergence has been reported. Mather (1946) reported maximum wild oat germination at temperatures between 0 and 10 C. Friesen and Shebeski (1961) noted optimum temperature for wild oat emergence was between 15 and 21 C, and Banting (1974) reported that wild oat germinated well at temperatures between 10 and 27 C. Results of Sharma et al. (1976) were similar to those of Friesen and Shebeski (1961) and Banting (1974). They determined the optimum temperature for wild oat germination was between 10 and 21 C, and that temperatures above 27 C were detrimental to wild oat germination. Some researchers have attributed the wide wild oat emergence temperature range (0 to 27 C) to seed dormancy (Banting 1974). The above research was conducted primarily in Canada (Alberta and Manitoba). Imam and Allard (1965) observed genetic variability within wild oat populations in the same region as well as across regions. Such variability is another potential explanation for the range in reported temperatures.

Soil moisture also influences emergence of wild oat. Sharma et al. (1976) determined that wild oat seedlings emerged best at 50 to 75% field capacity. At field capacity, no wild oat seedlings emerged, and after 11 d, nearly all seeds had died (Sharma et al. 1976). Mickelson and Grey (2006) found that wild oat seed mortality increased linearly as soil water content increased.

Soil temperature, converted to soil thermal time or GDD, has been used to predict seedling emergence (Bewick et al. 1988; Harvey and Forcella 1993). Even though soil temperature and moisture have proven critical to weed emergence, they are not commonly used together to predict emergence. Early models for predicting weed emergence were based solely on GDD (Alan and Wiese 1985; Bewick et al. 1988; Eizenberg et al. 2004). In these models, average air or soil temperatures were accumulated daily until weed emergence. More recent weed emergence models have been based on integrating soil water potential and soil temperature into HTT (Forcella 1998; Grundy 2003; King and Oliver 1994). HTT is an approach that was originally proposed by Gummerson (1986) and has since been expanded and used by other scientists (Ekeleme et al. 2004; Roman et al. 2000). HTT has been used successfully to predict weed emergence more accurately than soil GDD or calendar days for some weed species (Forcella et al. 2000). Even though GDD and HTT models have been developed for other crop and weed species, no such model has been developed for wild oat emergence to date, except for the preliminary model developed by Gonzalez-Andujar et al. (2001).

There is no model or tool that can be used by growers and agricultural professionals to predict wild oat emergence. Such a tool could provide timely information to plan more accurate wild oat control measures. Consequently, the objectives of this

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experiment were to evaluate the emergence of wild oat and determine if its emergence can be predicted using soil GDD and/or HTT.

Materials and Methods

Field Experiments. Research plots were established at Crookston, MN, and Fargo, ND, in 2002 and 2003. Both sites had dense, naturally occurring populations of wild oat. Soil type at Crookston was a Donaldson clay loam (course loamy over clayey, mixed over smectitic, superactive, frigid Oxyaquic Hapludoll) with 5.0% organic matter and pH 7.8. The soil type at Fargo was a Fargo clay (fine, smectitic, frigid Typic Epiaquert) with 4.5% organic matter and pH of 7.5. Research areas received no spring tillage. On a weekly basis, naturally emerging wild oat plants were counted and then removed from six randomly distributed 0.37-m^2 permanent quadrats. This process was repeated until no additional wild oat emergence was observed.

Weather Data. Soil temperature at a depth of 5 cm, air temperature, rainfall, solar radiation, wind speed, and dew point were recorded on a daily basis from a North Dakota Agriculture Weather Network (NDAWN) station located approximately 2 km from the plot area in Fargo. In Crookston soil temperature at a depth of 5 cm, air temperature, and rainfall were recorded from a University of Minnesota weather station located approximately 5 km from the plot area, and solar radiation, wind speed, and dew point were recorded by a NDAWN station located in Eldred, MN, approximately 16 km from the plot area. The 5-cm soil temperature depth was chosen based on research conducted by Sharma and colleagues (1976), which determined that wild oat emergence is greatest from soil depths ranging from 2 to 8 cm, with 5 cm being the average.

Model Development. Soil temperature was used to calculate soil GDD from the following equation (Eizenberg et al. 2004):

$$\text{Soil GDD} = \sum [(T_{\max} + T_{\min})/2 - T_{\text{base}}]_n \qquad [1]$$

where $T_{\max}$ = maximum daily temperature (C), $T_{\min}$ = minimum daily temperature (C), T_{base} = base temperature (C) below which emergence will not occur, and n = number of days.

Daily maximum and minimum air temperature, dew point, wind speed, rainfall, and solar radiation were used as climate input variables in the simultaneous heat and water (SHAW) model to estimate soil water potential (Flerchinger 2000). Soil physical input variables used in the model were 50% clay, 10% sand, 40% silt, 5% organic matter, and 1.2 g cm^{-3} bulk density. In the model, initial soil temperature and water content were set at -9 C and 0.50 cm^3 cm^{-3}, respectively, based on weather data, field observations, and/or estimations. These values were used for both the Crookston and Fargo locations because of the similarities in soil types.

Development of the emergence model was based on the HTT concept defined by Bradford (2002). HTT is defined as an integration of hydrotime (HT) and thermal time (TT). HTT, calculated daily, was described by Roman et al. (2000) as the following:

$$\text{HTT} = \sum_{d=1}^{n} \text{HT TT} \qquad [2]$$

where HT = 1 when $\psi > \psi_b$, otherwise, HT = 0; TT = $T - T_b$ when $T > T_b$, otherwise TT = 0; ψ symbolizes average daily soil water potential, ψ_b is base soil water potential, T is average daily soil temperature and T_b is base temperature. In summary, HTT was accumulated only on days when ψ was greater than ψ_b and T was greater than T_b (Ekeleme et al. 2004).

The base soil temperature and base soil water potential were determined by iterating a set of temperatures (0 to 5 C at 1 C intervals) and water potentials (0 to -5 at 0.1 MPa intervals) in Equation 2 until there was a maximum fit between cumulative HTT and percentage of cumulative wild oat emergence for each of the experimental years. Best fit was obtained when T_{base} and ψ_b were 1 C and -0.6 MPa, respectively. The temperature range used in the iterations was based on literature reports and previous field observations from Crookston and Fargo. Water potential bases for other species range from -10 to -0.1 MPa, with -10 MPa representing little sensitivity to water stress and -0.1 MPa demonstrating a high sensitivity to water stress (Forcella 1998).

HTT and GDD were accumulated daily for each experiment, beginning on April 1 of each year. This date reflects the average time at which soils in the area begin to thaw after freezing to depths of at least 50 cm each winter.

To predict the pattern of wild oat seedling emergence, the percentage of cumulative emergence values were compared to GDD and HTT using a Weibull function (Ekeleme et al. 2004):

$$Y = M[1 - \exp(-k(\text{GDD or HTT} - z)^c)] \qquad [3]$$

where Y is the cumulative percentage emergence at cumulative GDD or HTT, M is the asymptote (theoretical maximum for Y normalized to 100%), k is the rate of increase, z is the lag phase, and c is a curve-shaped parameter. For estimation purposes, k was parameterized as $k = (1/z)^c$. The parameters (k, z, and c) in the Weibull function were estimated by nonlinear regression procedure (PROC NLIN) that used the Gauss–Newton algorithm in SAS. The Weibull function was chosen because it does not assume symmetry on either side of the midpoint, and there is no obvious biological reason to assume such symmetry for weed emergence (Ekeleme et al. 2004).

An ANOVA was calculated as an initial test to evaluate the effect on cumulative wild oat emergence of calendar days, soil GDD, and HTT, with P set at 0.05 to determine significance. Nonlinear regression was used to further evaluate effects of soil GDD and HTT.

Model Validation. Research plots were established on research centers in 2004 (Crookston, MN), 2005 (Crookston and Morris, MN), and in nine production agricultural fields in 2006 for model validation. Soil type was Donaldson clay loam (as above) at Crookston. The soil type at Morris was Barnes loam (fine-loamy, mixed, superactive, frigid Calcic Hapludoll) with 6% organic matter and a pH of 6.8. Sites and soil characteristics for the production fields are reported in

Table 1. Locations, planting dates, number of observations, soil series, soils characteristics, root mean square error (RMSE), and r^2 for eight Minnesota and one North Dakota production agricultural fields in 2006.

Field locations	Planting date	n[a]	Soil series	Soil characteristics					RMSE	r^2
				Sand	Silt	Clay	Organic matter	Bulk density		
				%				g cm^{-3}		
Stephen, MN	May 6	16	Borup	50	35	15	3.7	1.2	3.50	0.99
Mallory, MN	April 27	8	Colvin	10	60	30	2.5	1.2	5.26	0.99
Warren, MN	April 26	8	Fargo	10	40	50	2.2	1.2	8.90	0.97
Warren, MN	May 6	8	Fargo	10	40	50	2.2	1.2	9.90	0.96
Sabin, MN	April 27	8	Glyndon	15	60	15	2.3	1.2	17.21	0.86
Perley, MN	May 17	8	Fargo	10	40	50	4.9	1.2	22.83	0.84
Hillsboro, ND	April 25	16	Bearden	15	55	30	5.6	1.2	21.77	0.79
Eldred, MN	May 12	8	Colvin	10	60	30	2.5	1.2	29.05	0.72
Eldred, MN	May 21	8	Colvin	10	60	30	2.5	1.2	33.10	0.65

[a] n = number of observations. Stephen and Hillsboro had two plots that were combined due to the same planting date and soil type, and similar wild oat emergence and pattern. All other sites had eight observations.

Table 1. Soil temperature at a depth of 5 cm, air temperature, rainfall, solar radiation, wind speed, and dew point were recorded on a daily basis from the U.S. Department of Agriculture–Agricultural Research Service Swan Lake Research Farm weather station located 0.5 km from the plot areas in Morris. In Crookston, meteorological data were collected as described earlier. Weather data for the nine production fields were collected from NDAWN stations located approximately 4 km from Stephen, MN; 11 km from Mallory, MN; 2 km from Warren, MN (April 26); 3 km from Warren, MN (May 6); 8 km from Sabin, MN; 3 km from Perley, MN; 2 km from Hillsboro, ND; 4 km from Eldred, MN (May 12); and 8 km from Eldred (May 21).

Soil physical variables, used in the numeric soil moisture and temperature modeling, were 40% clay, 30% sand, 30% silt, 6% organic matter, and 1.2 g cm^{-3} bulk density for Morris, and as previously reported for Crookston. Initial soil temperature and water content were set at -9 C and 0.50 cm^3 cm^{-3}, respectively, for both locations.

Soil physical input variables for the production fields are presented in Table 1. These values were input into the soil temperature and moisture model (STM^2). STM^2 is based on existing theoretical heat and moisture transport models (Campbell 1985; Flerchinger 2000; Hammel et al. 1981), but also includes additional empirical models to ease user input requirements (Rawls et al. 1982; Saxton et al. 1986; Spokas and Forcella 2006). This new model is being designed to have a graphical, user-friendly interface for soil moisture and temperature modeling, while reducing input data requirements. Required user inputs for STM^2 are simpler than for SHAW, and include daily maximum and minimum air temperatures, daily precipitation, geographical location (latitude, longitude, and elevation), and soil texture information (sand, silt, clay, and organic matter). Once STM^2 estimates the soil heat and moisture transport parameters, the model solves for heat, liquid water, and water vapor transport by an iterative finite-difference calculation that is identical to other soil temperature and moisture models. The switch from using SHAW to STM^2 occurred because the former model is DOS-based and did not easily run on newer computers. Both models provided comparable results for soil temperature and soil water potential.

Spring tillage occurred on April 26 at Crookston in 2004, on May 2 at Crookston in 2005, and on April 17 at Morris in 2005. Planting dates (the only spring tillage received) for the 2006 production fields are reported in Table 1. After spring tillage occurred, naturally emerging wild oat plants were counted and then removed by hand on a weekly basis from six randomly distributed 0.37-m^2 plots in Crookston; 12 randomly distributed 0.1-m^2 plots in Morris; and six randomly distributed 0.37-m^2 plots in each of the production fields. This process was repeated until no additional wild oat emergence was observed. Soil GDD and HTT began accumulating for each location and year on the day following spring tillage.

The cumulative emergence values from Crookston 2004 and 2005, Morris 2005, and the 2006 production fields were regressed against the predicted values from the wild oat emergence model. The attributed variability of the regression coefficient (r^2) and RMSE were used to determine how well the predicted values fit observed field emergence (Ekeleme et al. 2004).

Results and Discussion

Wild Oat Emergence at Crookston and Fargo 2002 and 2003. Wild oat emergence began between May 1 and 15 at both locations and years. Emergence continued for 4 wk at all locations and years except Crookston 2002, where emergence lasted 6 wk (Figure 1). Sharma et al. (1976) found

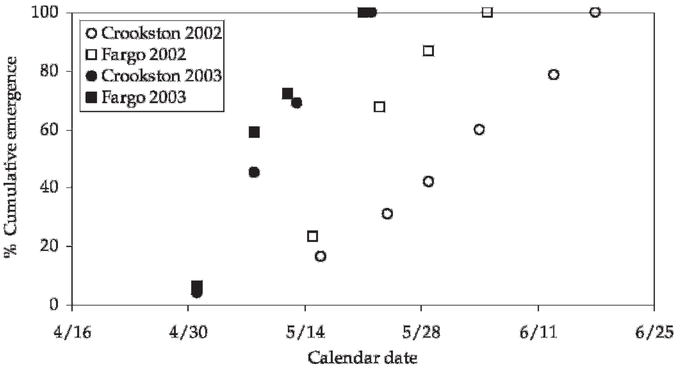

Figure 1. Percentage of wild oat cumulative emergence based on calendar days at Crookston, MN, and Fargo, ND, in 2002 and 2003. Each symbol represents the mean of six observations.

that maximum emergence of wild oat was reached 17 d after seeding and no further emergence occurred 30 d after seeding. In our study, 100% emergence was reached 28 to 42 d after initial emergence. At Crookston 2002, dry conditions prior to emergence could have triggered secondary dormancy, leading to an extended emergence period once moisture levels reached more favorable germination conditions. The differences in reported time to maximum emergence are most likely because of weather conditions and possibly dormancy.

Cumulative wild oat emergence was correlated with soil GDD ($P < 0.01$) and HTT ($P < 0.01$); however, wild oat emergence was not correlated with calendar date ($P = 0.15$). Other researchers also have found that GDD and HTT are better predictors of weed seedling emergence than is calendar date (Forcella et al. 2000).

GDD and HTT Models. Wild oat emergence was well described by the wild oat emergence model. Predicted wild oat emergence values and field emergence observations were related significantly with both the GDD ($n = 22$, $r^2 = 0.93$, RMSE = 10.7) (Figure 2) and HTT ($n = 22$, $r^2 = 0.92$, RMSE = 11.2) (Figure 3) models. The GDD and HTT models had similar fits because of the fact that soil moisture was rarely limiting at either location or year. Even though the GDD model has a slightly better fit, the HTT model may be of greater value during dry years or periods of low rainfall, where it should more accurately predict wild oat emergence compared to the GDD model. Because soil moisture was rarely limiting in either location or year, estimates of the base soil water potential are considered approximations and probably need further scrutiny.

In both GDD and HTT models (Figures 2 and 3), data for Crookston 2002 do not fit as well as the other location and year. If Crookston 2002 emergence data are omitted from the data set, the r^2 for the HTT model increases to 0.98 and the RMSE decreases to 6.8. Generally speaking, RMSE can be interpreted as a measure of potential model accuracy, with lower values representing more accurate models (Willmott 1982). Crookston 2002 was the only site and year where wild oat emergence occurred for 6 wk; at the other location and years, emergence occurred only for 4 wk. The extended emergence is perhaps one reason the model did not fit as well at Crookston 2002 as elsewhere.

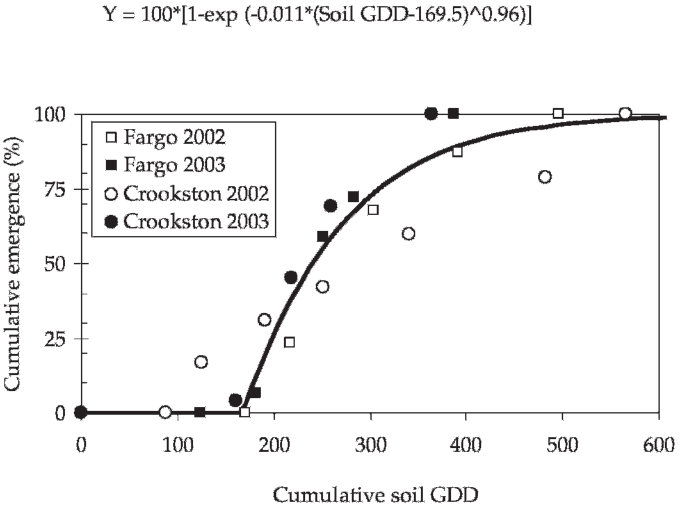

Figure 2. The emergence of wild oats as predicted by soil growing degree days (GDD) at Fargo, ND, and Crookston, MN, in 2002 and 2003 fitted to a Weibull function. For calculating soil GDD, the base soil temperature was set at 1 C. Each symbol represents the mean of six observations.

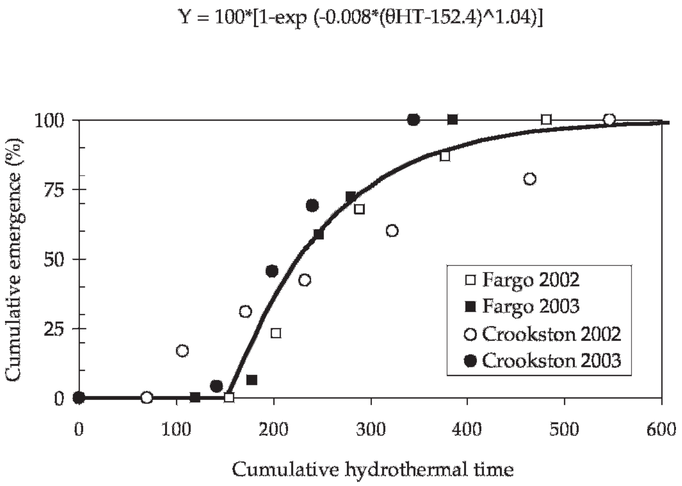

Figure 3. The emergence of wild oats as predicted by hydrothermal time at Fargo, ND, and Crookston, MN, in 2002 and 2003 fitted to a Weibull function. For calculating hydrothermal time, base soil temperature and base soil water potential were set at 1 C and −0.6 MPa, respectively. Each symbol represents the mean of six observations.

There is a potential explanation for the extended emergence: secondary dormancy. Nondormant wild oat seeds may undergo secondary dormancy if the conditions for their germination are not favorable. Wild oat tends to prefer cool, moist soil conditions for emergence (Sharma and Vanden Born 1978), and Sexsmith (1969) determined that temperature had a greater effect than soil moisture on wild oat seed dormancy. At Crookston 2002 from April 28 through May 8, just prior to wild oat emergence on May 10, soil temperatures were less than 1 C, the base soil temperature for wild oat, and should not have affected dormancy. In contrast, moisture was below −0.6 MPa, the base soil water potential for wild oat, and may have been sufficiently low to have triggered secondary dormancy, leading to an extended emergence period once moisture levels reached more favorable germination conditions.

Grundy (2003) believed that an understanding of dormancy mechanisms, especially the roles of microclimate in the relief of primary dormancy and induction of secondary dormancy, would be essential in the development of useful seedling emergence models. Unfortunately, dormancy mechanisms are notoriously complex in wild oat (Simpson 1990) and are difficult to model. Grundy (2003) also maintained the importance of keeping models as practical, yet accurate, as possible to ensure use by farmers and agricultural professionals.

Model Validation. Wild oat emergence from Crookston 2004 and 2005 and Morris 2005 were validated against both

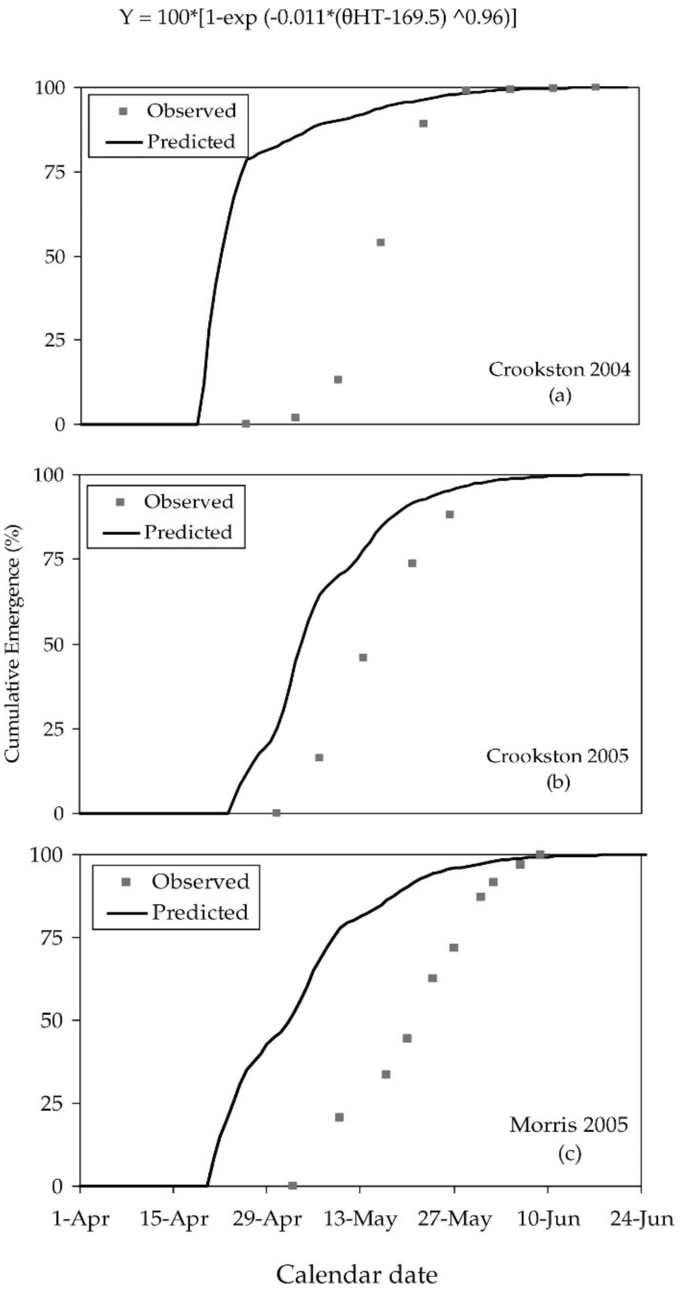

Figure 4. The emergence of wild oats as predicted by soil growing degree days (GDD) at Crookston, MN, 2004 (a), Crookston 2005 (b), and Morris, MN, 2005 (c), fitted to a Weibull function. For calculating soil GDD, base soil temperature was set at 1 C. Each symbol represents the mean of six observations at Crookston and 12 at Morris.

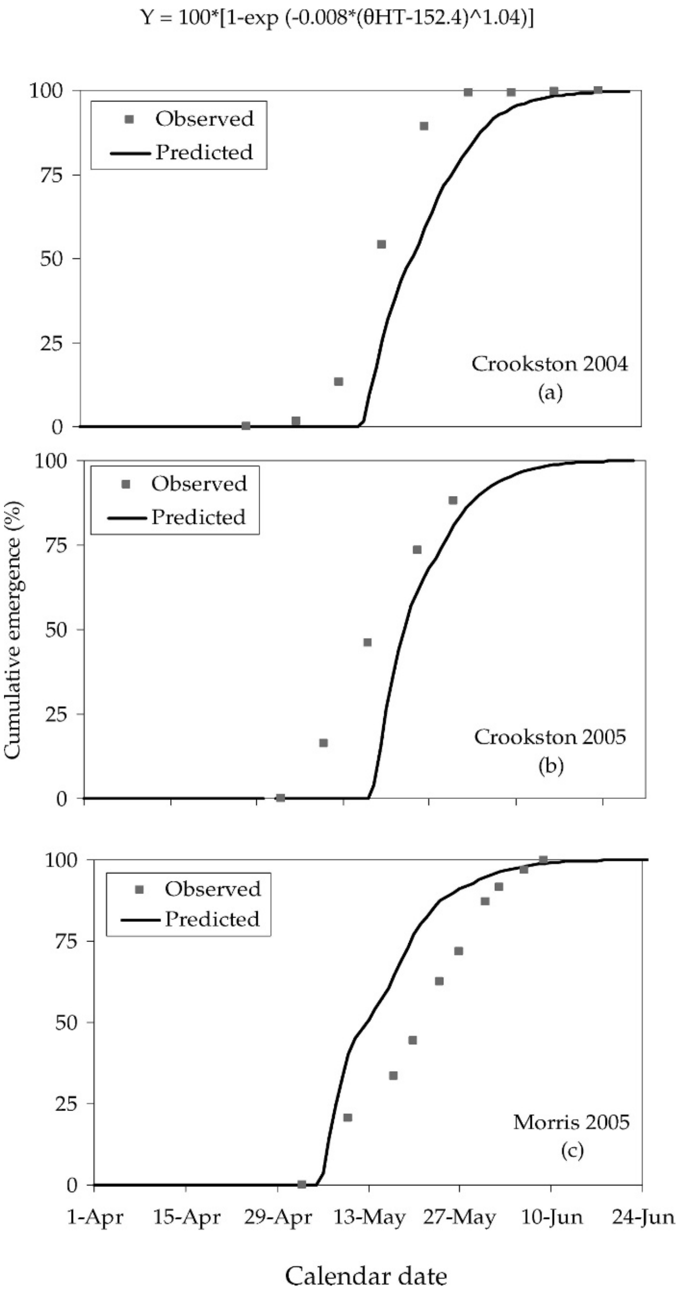

Figure 5. The emergence of wild oats as predicted by hydrothermal time at Crookston, MN, 2004 (a), Crookston 2005 (b), and Morris, MN, 2005 (c), fitted to a Weibull function. For calculating hydrothermal time, base soil temperature and base soil water potential were set at 1 C and −0.6 MPa, respectively. Each symbol represents the mean of six observations at Crookston and 12 at Morris.

the GDD (Figure 4) and HTT (Figure 5) models. The HTT model provided a better fit, based on r^2 and RMSE, compared to the GDD model for Crookston 2004 and 2005 and Morris 2005. The HTT model statistical evaluations are as follows: Crookston 2004: n = 9, r^2 = 0.93, RMSE = 15.57; Crookston 2005: n = 8, r^2 = 0.90, RMSE = 18.03; Morris: 2005 n = 10, r^2 = 0.86, RMSE = 18.74; and the overall model (all years/locations combined): n = 27, r^2 = 0.81, RMSE = 17.53. The GDD statistical evaluations are as follows: Crookston 2004: n = 9, r^2 = 0.88, RMSE = 47.98; Crookston 2005: n = 8, r^2 = 0.88, RMSE = 23.30; Morris 2005: n = 10, r^2 = 0.79, RMSE = 35.57; and the overall model (all years/locations combined): n =27, r^2 = 0.59, RMSE = 37.06.

The GDD and HTT models had similar fits during model development, because of the fact that soil moisture was rarely limiting in either location or year. However, during model validation at Crookston 2004 and 2005, and Morris 2005, moisture conditions were limiting at times during the emergence period. As a result, the GDD model overpredicted wild oat emergence because it can not account for dry periods that were observed. Because the HTT model can account for soil moisture and temperature, it is not surprising that it more accurately predicted wild oat emergence compared to the GDD model.

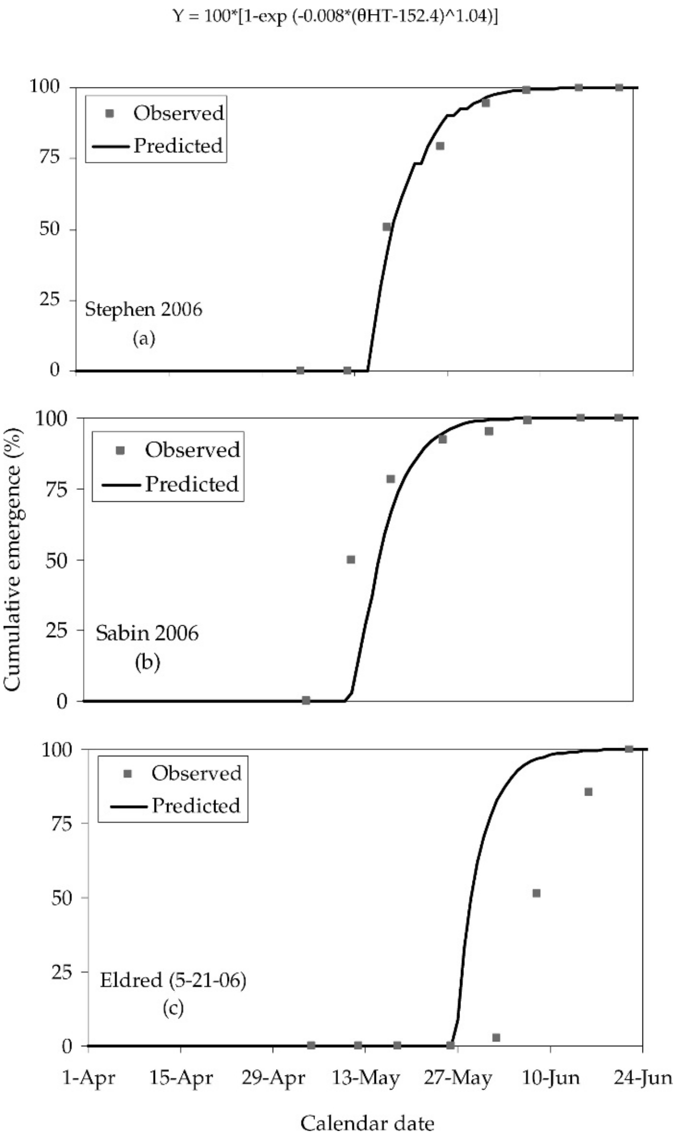

Figure 6. The emergence of wild oats as predicted by hydrothermal time at Stephen, MN (a), Sabin, MN (b) and Eldred, MN (c), fitted to a Weibull function. For calculating hydrothermal time, base soil temperature and base soil water potential were set at 1 C and −0.6 MPa, respectively, $n = 8$ for all locations. Each symbol represents the mean of six observations.

Because the HTT model predicted wild oat emergence better than the GDD model in 2004 and 2005, only the HTT model was used to predict wild oat emergence in 2006 in the production fields. Table 1 lists RMSE and r^2 for all nine fields. Figure 6 shows three representative examples of model fit in these fields. Wild oat emergence at Stephen (Figure 6a) was predicted accurately by the HTT model and is representative of model accuracy at Mallory and Warren. Wild oat emergence at Sabin (Figure 6b) was predicted less accurately by the HTT model, but was still acceptable based on RMSE and r^2. Sabin is also representative of the model accuracy at Perley and Hillsboro. Wild oat emergence at Eldred (Figure 6c) (both locations) was not predicted as accurately as the other locations. Wild oat emergence was overpredicted at both Eldred locations.

One major difference between the sites used to develop the model (Crookston and Fargo 2002 and 2003) and the sites used to validate the model (Crookston 2004 and 2005, Morris 2005, and 2006 production fields) was the use of spring tillage. Sharma et al. (1976) suggested that shallow tillage that lightly covered the wild oat seeds could stimulate germination by removing the influence of light, and by ensuring more favorable moisture conditions. Banting (1962) suggested that tillage encourages wild oat germination compared to wild oat seeds that remain in undisturbed soils. However, by beginning the accumulation of HTT and GDD the day following a tillage event, the effect of tillage on the model probably is minimal. In theory, a tillage event should remove actively growing wild oat seedlings, thus beginning the emergence process and accumulation of HTT and GDD once again. After the tillage events in our experiments, no previously emerged wild oat seedlings were obvious.

Because the HTT model underpredicted the initiation of emergence by several days at Crookston in 2004 and 2005 (Figure 5) and Sabin (Figure 6), users of the model, such as crop consultants, should continue to rely on in-field scouting. This model is not meant to replace scouting, but provides an additional tool to be used with other integrated weed management strategies for effective and accurate control of wild oat.

The HTT model did predict the timing of final wild oat emergence (i.e. 95 to 100%) across locations in 2004 to 2006 (Figures 5 and 6). Having the ability to accurately predict the timing of final wild oat emergence has practical implications on POST herbicide application timing and efficacy. Many growers would prefer to time the control operations in their fields as soon as 100% of the wild oat population emerges. Because the model predicts 95 to 100% of wild oat emergence within a few days of observed emergence, growers and agricultural professionals can use this tool to assist in more timely and efficacious POST herbicide applications.

At the Crookston site in 2004 and 2005 (Figure 5) and Sabin (Figure 6), wild oat emergence, including initial emergence, was underpredicted. At Morris in 2005 (Figure 5), initial wild oat emergence and emergence between 80 and 100% was predicted accurately; however, emergence between 25 and 80% was overpredicted by the model. The model also overpredicted wild oat emergence at Eldred (Figure 6).

Models that greatly overpredict wild oat emergence, as was the case at Eldred (Figure 6c), can result in weed control tactics that occur too early. Early weed control applications may allow later-germinating wild oat seedlings to escape control, leading to competition and seed production. However, later-emerging wild oat plants tend to be smaller and produce less seed compared to earlier-emerging plants (Martinson, unpublished data). Models that greatly underpredict wild oat emergence, as was the case at Crookston 2005 (Figure 5b), can result in delayed weed control tactics, leading to possible prolonged weed–crop competition, increased herbicide applications, and a reduction in crop yield (Stougaard et al. 1997). Fortunately, this model predicts culmination of wild oat emergence within days of observed values, giving growers and agricultural professionals a good reference point for timing of weed control tactics aimed at controlling 100% of emerged wild oat seedlings. Weed control tactics aimed at controlling 25 to 75% of germinated wild oat seedlings (i.e., tillage), should continue to rely on in-field scouting.

Even though the initiation of wild oat emergence may have been under- or overpredicted at some locations, the general shape of the emergence curves at all locations closely matched observed emergence patterns. A likely explanation for these discrepancies is the general inability to precisely estimate and predict the water potential of the thin veneer of soil containing seeds near the soil surface. This inability reflects the current, state-of-the-art technology used in soil physics modeling. Until our ability to predict soil water content improves, both base soil water potential calculations and emergence predictions may continue to be imprecise

Summary. Wild oat emergence began between May 1 and 15 at all locations and years and continued for 4 wk and occasionally to 6 wk. Cumulative wild oat emergence was correlated with GDD and HTT, but not with calendar date. A base temperature of 1 C and base soil water potential of -0.6 MPa were determined as appropriate for wild oat. The base temperature and soil water potential were used to calculate cumulative soil GDD and HTT.

Wild oat emergence was well described by the emergence curve from the HTT and GDD models. The HTT model is the first developed for wild oat emergence based on soil temperature, soil water potential, and field observations. The HTT and GDD models were evaluated against 12 independent data sets (Crookston 2004 and 2005, Morris 2005, and nine production fields in 2006), and fit with varying degrees of success. Overall, the HTT model was a better predictor of wild oat emergence compared to the GDD model. However, model validation would benefit by repetition in other regions infested with wild oat (specifically arid, irrigated regions, and/or regions where fall emergence may occur). Until data sets from different regions of the world infested with wild oat are validated with the HTT model, the utility of this model outside of the Red River Valley of Minnesota and North Dakota is unknown. The HTT model did accurately predict wild oat emergence in research plots and production fields, and in the presence and absence of both tillage and a crop (wheat).

Using the HTT model to predict wild oat emergence can provide growers and agricultural professionals with another tool to aid in planning the control of wild oat and may also help facilitate future wild oat emergence studies. However, these models should not replace in-field scouting but should be used in combination with scouting and other integrated weed management practices to achieve maximum wild oat control. The wild oat emergence response based on HTT is being incorporated into WeedCast (Archer et al. 2006; Forcella 1998).

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