WEEDTURF: SOFTWARE FOR IMPROVING SUMMER ANNUAL WEED CONTROL IN TURF

WEEDTURF: SOFTWARE PER MIGLIORARE IL CONTROLLO DELLE INFESTANTI ANNUALI ESTIVE DEI TAPPETI ERBOSI

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Abstract
Summer annual grass species are problem weeds in turf. Understanding their emergence dynamics could be useful for timing herbicide treatments and maximizing their efficacy. With this aim, a prediction model was developed that can simulate the emergence of four summer annual grass weeds in turf (*Digitaria sanguinalis*, *Setaria glauca*, *Setaria viridis* and *Eleusine indica*). By using weather data and soil characteristics, the model provides the percentage of emergence reached by a certain weed species at any given time. This information can provide enhanced recommendations for programming application times of pre- and post-emergence herbicides. This paper presents the prototype of the software that implements the model. The software is designed to be intuitive and easy to use even by inexpert users, and is a modular and flexible system that can modify and extend model application to other species according to user requests.

Keywords: Weed emergence prediction, annual grass weeds.

Riassunto
Le infestanti graminacee annuali estive sono uno dei principali problemi dei tappeti erbosi. Conoscere la dinamica con cui queste infestanti emergono può essere utile nell'individuare l'epoca migliore per effettuare l'intervento in modo da massimizzare l'efficacia dell'erbicida. Su questa base è stato sviluppato un modello di simulazione della dinamica di emergenza di quattro graminacee estive infestanti dei tappeti erbosi, Digitaria sanguinalis, Eleusine indica, Setaria glauca e Setaria viridis.
Usando dati meteorologici e alcune informazioni sulle caratteristiche del terreno, il modello fornisce la percentuale di emergenza raggiunta da una data specie infestante in tempo reale. Tale informazione può essere utile per aiutare tecnici e consulenti del settore nella programmazione dei tempi di applicazione degli erbicidi sia di pre- che di post-emergenza. Nel presente lavoro viene presentato il prototipo del software che implementa il modello. Tale software è stato realizzato in modo da renderlo semplice e intuitivo per permetterne l'utilizzo anche da parte degli operatori meno esperti ed è stato concepito come un sistema modulare e flessibile in modo tale da consentire di modificare o di estendere il modello con l'inserimento di altre specie infestanti a seconda delle esigenze degli utilizzatori.

Parole chiave: *previsione delle emergenze, infestanti graminacee annuali estive*

Introduction
Efficient and economical weed control is one of the most important objectives for successful turf production and management. Losses due to weeds, which include both costs of control and undesirable effects if not controlled, may reach vast proportions. In most cases, far exceeding that attributed to insects and diseases combined (Coats, 2004).
Grass weeds in particular, with their eco-physiological similarity to the desirable species of the turf, are not easy to eliminate and require careful attention to herbicide choice and treatment timing (Veronesi *et al.,* 2002). Chemical control of annual grass weeds can be performed in two ways: as a preventive approach by treating in pre-emergence or a remedial approach with a post-emergence application. To be effective, pre-emergence herbicides must be applied before the germination of weeds. Improper application timing is a major cause of poor control with these herbicides. Post-emergence herbicides are applied once weeds have emerged. As these products are applied to the foliage, their action depends on leaf surface characteristics, growth habit and vegetative status of the plant, all characteristics which change as weeds age and according to weather conditions. So, using either a pre- or post-emergence herbicide, it is necessary that applications are timed properly in order to maximize the efficacy of each treatment and limit the use

of the chemical. There have been numerous studies with the aim of supplying indications on weed control methods and times (Harvey and Forcella, 1993; Finch-Savage and Phelps, 1993; Dehal and Bradford, 1994; Roman *et al.*, 1999; Grundy *et al.*, 2000; Colbach *et al.*, 2002; Main *et al.*, 2004; Myers *et al.*, 2004). Many of these investigated emergence dynamics as affected by the interaction of environmental and biological factors and integrated this knowledge in the form of seedling emergence prediction models. All these models were created to aid control of arable weeds. We have studied the biology and emergence dynamics of four annual grass weeds that are particularly difficult to manage (*Digitaria sanguinalis* (L.) Scop., *Setaria glauca* (L.) Beauv., *Setaria viridis* (L.) Beauv. and *Eleusine indica* (L.) Gaertn.) (Masin *et al.*, 2005) and developed a model of seedling emergence (WeedTurf model) for their control. WeedTurf is based on the hydrothermal time concept (Bradford, 2002), requires data on the daily site-specific values of soil temperature and water potential as input and produces the simulated emergence curve as output.

Hydrothermal time models have been used for emergence prediction by several researchers (Dehal and Bradford, 1994; King and Oliver, 1994; Forcella, 1998; Cheng and Bradford, 1999; Roman *et al.*, 1999; Grundy *et al.*, 2000; Alvarado and Bradford, 2002; Rowse and Finch-Savage, 2003). These models have improved the prediction accuracy and are potentially very useful for programming weed control, but are generally not very accessible to farmers. Implementing these models by user-friendly software greatly improves the possibility of their use. WeedCast (Forcella, 1998; Archer *et al.*, 2001) and WEEDEM (Archer *et al.*, 2002; Walsh *et al.*, 2002) are two examples of software to predict weed emergence in arable fields that are used successfully in various regions of the USA and Australia. Because of the positive opinions of farmers and crop advisors on the existing programs, we decided to implement the WeedTurf model with a software to make it available to turf managers. This paper describes the software prototype.

Model description

The WeedTurf model is the result of research carried out from 2001 onwards at the Padova University Experimental Farm at Legnaro (PD) (Masin *et al.*, 2005). The model predicts the time of emergence of four of the most troublesome weeds in turf (*Digitaria sanguinalis*, *Setaria glauca*, *Setaria viridis* and *Eleusine indica*). Fig. 1 represents a flow chart of the program. WeedTurf uses a pre-existing model, the Simultaneous Heat and Water (SHAW) model, developed by Flerchinger and Saxton (1989a, 1989b), to simulate soil temperature and soil water potential. This model predicts near-surface microclimatic parameters using weather data and site characteristics (a detailed description of these input data is given below).

Using soil temperature and soil water potential, the most important environmental factors governing weed emergence, the model calculates the hydrothermal time (Bradford, 1995; Bradford, 2002). A single equation considers the interaction between these two factors, calculating the Soil Growing Degree Days ($SGDD_i$) as follows:

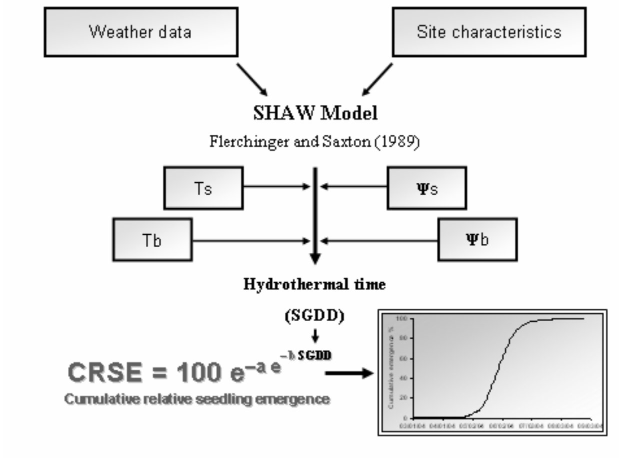

Fig. 1 - Flow chart of the model
Fig. 1 *- Diagramma di flusso del modello*

$$SGDD_i = n * \max(T_{si} - T_b, 0) + SGDD_{i-1}$$

When $T_{si} \leq T_o$:
$n = 0$ when $\Psi_{si} \leq \Psi_b$;
$n = 1$ when $\Psi_{si} > \Psi_b$;

when $T_{si} > T_o$:
$n = 0$ when $\Psi_{si} \leq \Psi_b + Kt\,(T_{si} - T_o)$;
$n = 1$ when $\Psi_{si} > \Psi_b + Kt\,(T_{si} - T_o)$.

T_{si} is the average daily soil temperature (°C), Ψ_{si} is the average daily soil water potential (MPa), T_b and Ψ_b are the base temperature and water potential thresholds for each weed species, T_o is the optimum temperature, and Kt is the slope of the relationship between Ψ_b and T_{si} in the super-optimal temperature range.

Soil temperature and soil water potential are requested at a depth of between 2.5 and 5 cm. This depth was chosen because the majority of seeds, after removal from the parent plant, accumulate in the first centimetres beneath the thatch and roots of turfgrasses through the action of pedofauna and management practices.

SGDD accumulation starts from the first day of the year (January 1st). The basic concept of this function is that seeds of all species accumulate hydrothermal time according to the soil temperature only when the soil water potential is above a base value (Archer *et al.*, 2001).

Finally, cumulative relative seedling emergence (CRSE) is expressed by a Gompertz function, as follows:

$$CRSE = 100e^{-ae^{-b\,SGDD}}$$

Where a represents an SGDD lag before emergence starts, and b represents the rate of emergence increase once the process has begun.

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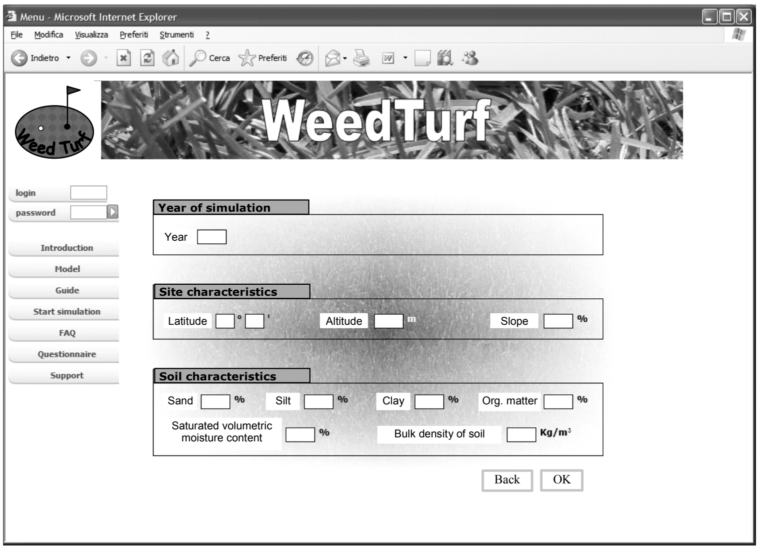


Fig. 2 - General site information and soil characteristics to enter as input data for SHAW model.

Fig. 2 - *Informazioni generali sul sito e sulle caratteristiche del suolo da inserire come dati di input per il modello SHAW.*

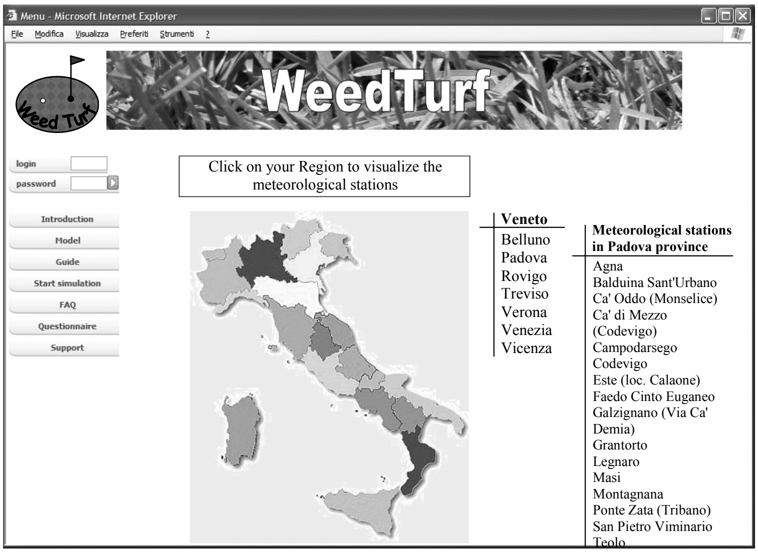
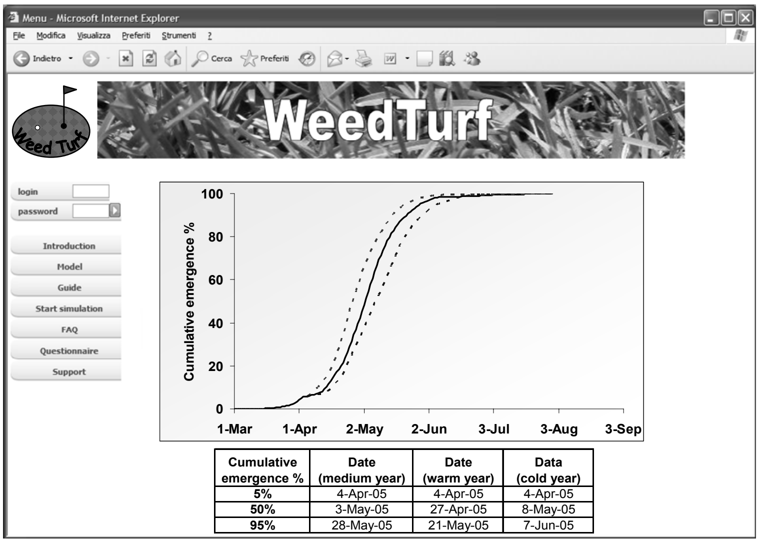


Fig. 3 - On the Italian map, the user can select region, province and the meteorological station closest to the site and weather data are automatically transferred from the ARPAV data base to the program.

Fig. 3 - *L'utente può selezionare sulla cartina geografica dell'Italia la sua regione, la sua provincia e la stazione meteorologica più vicina al sito di interesse, in questo modo i dati meteo sono automaticamente trasferiti dal data base dell'ARPAV al programma*



Cumulative emergence %	Date (medium year)	Date (warm year)	Data (cold year)
5%	4-Apr-05	4-Apr-05	4-Apr-05
50%	3-May-05	27-Apr-05	8-May-05
95%	28-May-05	21-May-05	7-Jun-05

Fig. 4 - Program output. The graph shows the emergence curve of Setaria viridis in silty-loam soil. The curves in dashed line represent the emergence dynamics in a particularly warm year (simulated using the weather data of the warmest year in the last ten years), and in a particularly cool year (simulated using the data of the coolest year in the last ten years). The curve in solid line represents the emergence dynamic in a year with average climate (simulated using the average of the last ten years' data). The program reports the dates on which the cumulative emergences have reached or will reach 5% (beginning), 50% and 95% (end) in the three different scenarios.

Fig. 4 - *Output del programma. Il grafico riporta la simulazione della curva delle emergenze di Setaria viridis in un terreno franco-limoso. Le curve con linea tratteggiata rappresentano le emergenze nel caso di un anno particolarmente caldo (i dati meteo usati sono quelli dell'anno più caldo dell'ultimo decennio) e di un anno particolarmente freddo (i dati meteo usati sono quelli dell'anno più freddo dell'ultimo decennio). La curva con linea continua rappresenta la dinamica di emergenza di in anno medio (è stata usata la media dei dati meteo dell'ultimo decennio). Il programma riporta le date in cui l'emergenza ha raggiunto o raggiungerà il 5% (inizio), il 50% e il 95% (fine) con i tre ipotetici andamenti climatici.*

The software

WeedTurf is an interactive software designed to be intuitive and guide the user in the introduction of input data through simple web pages. To start simulation, the user can enter soil temperature and soil water potential data into the program (e.g. if there is an on-site data-logger that monitors soil parameters for different uses, such as pest control or an irrigation programme). Otherwise, if these data are not available to the user, the program requires the input parameters for simulating soil temperature and soil water potential by the SHAW model.

The first data required are site characteristics (latitude, longitude, slope, soil texture, saturated volumetric water content, bulk density) (Fig. 2). When all the property values have been entered, air weather data (temperature, wind speed, relative humidity, precipitation, solar radiation) are requested. These data are usually not available to the users, so the program displays a map of Italy where it is possible to select region, province and then the weather station closest to the site (Fig. 3). The daily weather data are then automatically transferred from available databases accessible via Web.

To complete the input data set for simulating soil temperature and soil water potential, further information is requested: irrigation dates and amounts. If irrigated areas differ in terms of amounts and times, simulations are necessary for each area. The irrigation data will be integrated with the weather data by the software.

When all the information needed to simulate soil temperature and soil water potential are inserted, the next step is to select one or more weed species infesting the turf. To facilitate weed species identification, the program has a guide with pictures and a brief description of each species. When the species have been selected, the software is ready to calculate the hydrothermal time and plot the emergence curves.

Model output is the predicted emergence curves for the selected species. The model also gives information on the emergence percentage already reached and specifies the dates on which 5%, 50% and 95% emergence is reached. When the simulation is done at the beginning of the emergence period, the model simulates the emergence curve in three possible scenarios: average year (the model uses the weather data given by the average of the last ten years for the simulation), cool year (the simulation is made using the weather data of the coolest year in the last ten years) and warm year (the model uses the weather data of the warmest year in the last ten years). The software gives the date of 5%, 50% and 95% emergence for the three scenarios (Fig. 4).

The model is still a prototype and is only available on request to authors. Two software versions are under construction: a version available via the World Wide Web for users who are connected to the Internet or as a software package to be installed on personal computers. In the latter case, it will be necessary to have the weather data to insert through a data file. Also, if the program is installed in the computer, it will be possible to automatically transfer weather data at any time from the Web database or any other database if an internet connection is available.

Possible applications

A common problem for turf managers is timing pre-emergence herbicide applications. To be effective, these chemicals must be applied before annual grass weeds germinate. However, if they are applied too early, they will volatilize and lose effectiveness. Because grass weed emergence is neither uniform among species nor simultaneous within a species, the timing of pre-emergence herbicide applications can change from year to year, even by weeks. Weed seedling emergence is also usually difficult to detect visually, especially in turf, and this further complicates the turf manager's decision on when to apply pre-emergence herbicides. Using the simulated emergence curves, the user can know when a given weed species begins to emerge and thus correctly time pre-emergence herbicide applications.

Post-emergence application is a different problem. There are fewer post-emergence herbicides than pre-emergence herbicides. Because of this, there is often an excessive use of the same product, which may lead to the selection of resistant weeds. It is therefore necessary to maximize the efficacy of each post-emergence herbicide application in order to limit their use. All post-emergence herbicides have to be applied after seedling emergence of grass weeds and are most effective if applied at specific times. By knowing the cumulative emergence curves of every weed species, it is possible to decide the date of application based on the percentage of individuals that have already emerged and the percentage that will emerge subsequently. In other words, the turf manager is informed about the percentage of infestation that has already escaped the herbicide treatment and how many individuals can be controlled if the herbicide is applied immediately.

With the simulation done using the three different scenarios, the users have the possibility to program the pre-emergence treatment and predict in which cases another treatment will be necessary. For example, if the season is average or warm, the emergences finish early, and the pre-emergence herbicide may be persistent enough to cover the whole emergence season, but if the year is cold the user is alerted to the necessity for another treatment (Fig. 4).

The program is also useful for understanding past phenomena. For example a simulation done at the end of the season can explain: why a herbicide treatment was successful or not; the percentage of escaped and controlled weeds; what would have happened if the herbicide treatment had been done at another time.

Future developments

The software is currently available only on request to authors. The next step will be to distribute the program as a software package to be installed in a PC or usable as a web page. The WeedTurf model was validated at the Padova University Experimental Farm at Legnaro (PD), as described in Masin *et al.* (2005), and must now be tested in other locations across Northern Italy. Model implementation by the software will allow the area of testing to be widened. Software verification and validation is an aid in determining that the software requirements are implemented correctly and completely and are traceable to system requirements.

If Italian turf managers are satisfied with WeedTurf and consider it useful for programming weed management, our future aims will be to extend its application to other species according to user requests.

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