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A Multi-level System for Delivering Biodiversity Knowledge, Data Analysis and Pest Management Recommendations to Growers, for Environmentally Sustainable Crop Protection

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Abstract

Agricultural systems in Canada are extensive in area, but not monitored or managed intensively. We developed informatics methods to better anticipate the severity, timing and geography of emerging pest risks to crops. The target insects, grasshoppers (Orthoptera: Acrididae), present special challenges in North America, as well as in China, because they occur as a complex of many species, only some of which represent significant risk to crops. We developed a Geographic Information System of insect and weather data in support of environmentally sustainable control methods. GIS-based maps of the outputs of simple weather-driven models of insect stage were provided to growers through a website containing current conditions. We combined delivery of this information with on-line training and non-technical tools for insect identification and selection of management actions. Color images for over 60 grasshopper species that assist recognition of pest versus non-pest species were provided on-line, with additional details provided in printed booklets (3500 copies were distributed free of charge). We also developed an iPhone application that provides similar information and assistance in recognizing species. We invited growers to attend on-line webinars (75 attendees) and in-person workshops (413 participants) for instruction on using the photographs and identification tips. A post-workshop survey completed by all the attendees indicated that most of the attendees (91%) scout their fields to check for the presence of grasshoppers, and that a majority of the farmers (90%) monitor or check their fields themselves, indicating that individual access to information is a valuable feature. Only 18 of the farmers at the workshops indicated that they had previously used species identification to determine pest risk status.

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1. Introduction

Reliable methods of acquiring environmental data and delivering timely recommendations are of critical importance to environmentally sustainable agriculture. Management methods for reductions in environmental impacts depend on accurate assessments of current conditions, and knowledge required for accurate interpretations by users. Current, detailed information is needed to meet the challenges presented by rapidly changing pest outbreaks that occur over large geographical regions. Reduced uncertainty regarding species identification and timing reduces pesticide use. The joint goals of the program are to reduce economic losses and to prevent environmental impacts of management actions.

Agricultural crops, hayfields and grazing land in Canada are extensive in area, but are not intensively managed or monitored. Consequently, in much of the large Canadian grassland region, crop management decisions are based on general forecasts with limited precision, and most users have limited technical knowledge of biodiversity and biogeography. Certain pests of crops recur periodically over large areas, presenting three management needs: 1) anticipation of the severity, timing and geography of emerging pest risks to agriculture, 2) reducing the potential economic costs and environmental side-effects of widespread applications of chemical insecticides, and 3) complications related to inefficiencies and delays related to confusion over pest status and estimation of risk. Some insect pests, notably grasshoppers (Orthoptera: Acrididae), not only appear in large numbers, but are present as a large group of species that contains pests and non-pests, but which managers perceive as generally similar in appearance. In some cases, control efforts have been initiated against harmless species in this group of insects, while damaging species have been overlooked elsewhere in the areas affected. Sparse and infrequent monitoring provides baseline estimates of risks at regional levels. Regional warnings heighten awareness, but do little to help the individual grower, advisor or manager make pest control decisions for particular cases and locations. When monitoring results indicate a need for more detailed field assessment and pest control action, effective species identification at the level of growers or pesticide applicators would improve the process of selection of appropriate management actions, by directing control efforts at the correct target insect species only when warranted. When management actions are indicated by the monitoring data and taxonomic identifications, control agents may be utilized. At present, the only registered control agents are chemical insecticides, typically applied by aerial (fixed wing) or ground (tractor-pulled) equipment. To expand the toolbox of environmentally sustainable pest control options, we are developing an alternative biopesticide, based on a naturally occurring pathogen that affects only insects. The effectiveness of living biopesticides is sensitive to weather and other environmental conditions, so we applied analysis of weather and pest data to the problem of predicting the geography and timing of probable usefulness of the biopesticide alternative. Therefore, the addition of chemical alternatives to the toolbox also depends on analysis and delivery of environmental information, in particular, weather and target insect survey results.

The current research and development of informatics support for grasshopper risk warnings includes three main directions: development and distribution of tools and software for pest identification; improved methods for estimating current field pest activity and disseminating that information; and integration of alternative, non-chemical pest control methods.

2. Methods

2.1 Development and distribution of tools and software for pest identification

Growers (Pulse Canada) conducted an internal needs assessment and determined that in-field recognition of pest versus non-pest grasshopper species was a significant impediment to rational pest management. We prepared a 40-page booklet that included 50 original color photographs, to facilitate recognition of the 20 most common species of grasshoppers (and closely related insects) found on the Canadian Prairies and Northern Great Plains of the US. The list of species included high-risk pests, lower-risk pests, and non-pests. To facilitate use of the photographic guide by individuals without immediate access to computers, for example when surveying agricultural crops, a prototype iPhone application was developed using the iPhone SDK (Software Development Kit), Xcode, and objective C programming language (programming by J. Boldt). The database was built using SQlite3. The proposed iPhone application was designed to assist users in identification of pests by reference to photographs and simple questions regarding traits of the specimens in question. An additional goal was to provide basic information regarding pest status, geographic range, timing and relative level of crop risk, without the need for highly technical methods or specialized entomological knowledge.

2.2 Improved methods for estimating current field pest activity, and disseminating information

Empirical, biophysical, physiological and ecological models of insect timing and development have typically tracked the insect life cycle from egg to maturity, based on analysis of insect stage passage rate (the inverse of the amount of time required to graduate to the next discrete stage) as a function of temperature. Such models use basic daily weather data to forecast insect activity and life history events. Early models of insect development were based on modeling development time as a function of temperature [1]. More recent modified sigmoid models of insect development (for example, [2-4]) are still based on the rate-temperature relationship that results from the poikilothermic condition of insects, in which insect body temperature is largely dependent on environmental temperature. The relative precisions of such models have been compared, when used to describe the relationship between developmental rates of different stages of insects and temperature. For example, Medeiros et al. [5], compared four models for their ability to predict the growth and development of a natural enemy of other insects (Podisus nigrispinus) and concluded that “the models of Sharpe and DeMichele [3] and of Lactin et al. [2] are appropriate to describe the relationship between developmental rates of different instars and stages of P. nigrispinus and temperature.” We are using this approach to refine predictions of insect appearance and activity. A simplified approach is used to generate current maps of expected insect stage progression, which growers can consult when choosing the appropriate time to monitor or prepare for possible control actions.

“Physiological time” is used as a simple measure of the integrated (accumulated) heat needed for an ectothermic organism to complete a life stage. The approximations of physiological time are often expressed in degree-day (sometimes call day-degree) units, and typically are computed based using a sinusoidal model of daily temperature [6]. We applied an improved method to daily weather data from 86 Environment Canada weather stations in 2009, and 61 stations during the first 2010, on the Canadian Prairies (Alberta, Manitoba and Saskatchewan, Canada) to compile and map estimates of heat accumulation in air and soil, using a cosine integration of the maximum and minimum daily temperatures (subsequent refinements were made using determinations of the predicted time of day of the maximum temperature). Future weather data from over 100 stations is available beginning in 2010. A stochastic phenology model based on a logistic probability density function is used to predict insect stage (age class) progression over the growing season. The logistic probability function is based mainly on environmental temperature from recent and current weather station observations, and on weather forecasts, to produce predicted maps of emergence and progress of development (approximate expected populations median value) of pest grasshoppers. The predicted developmental progression (5 discrete immature stages) of the insect pest is contoured, mapped and posted for internet access by growers. Improved algorithms and additional information on the known biophysical relationships of grasshopper body temperature to environmental temperature [7-12], are being incorporated into the information system.

3. Results

3.1 Development and distribution of tools and software for pest identification

A total of 3500 copies of the grasshopper photographic guide were printed and distributed on request to growers, agriculture groups, agricultural advisors, educators, researchers, environmental officers and interested members of the public. The material was presented in on-line webinars designed to teach pest recognition and methods of reducing the use of insecticides. The on-line webinars on this topic had a total of 75 participants, consisting of farmers and advisors of farmers. The great majority indicated that the availability of this information would help to reduce pesticide spraying. A PDF file of the booklet was made available free of charge on websites of the Saskatchewan Pulse Growers, University of Lethbridge, and government agriculture departments.

A total of 413 clinic participants attended a series of three training sessions regarding use of the colour photographic guide, in booklet or electronic form. A post-workshop survey completed by all attendees indicated that almost all of the attendees (91%) scout their fields to check for the presence of grasshoppers, and that a majority of the farmers (90%) monitor or check their field themselves. Eighty-two of 151 farmers questioned about forecasting said that they use tools such as grasshopper maps. Only 18 of the farmers at the workshops indicated that they had previously used species identification to ensure that the grasshopper trapped is in fact a targeted pest species. Of the 151 growers questioned, most (83%) spray the perimeter of the field for control of the pest while only 17% spray the entire field, based on recommendations to reduce insecticide use.

The prototype iPhone application (Fig. 1) was completed, using the iPhone SDK and objective C programming language, and tested in preparation for release. The objective C applications run on a MVC or Model View Controller framework. The programming was designed in such a manner that the data could be easily updated and substituted with new database versions, as current information and images become available. The code of the application was kept flexible so that it can be reused for other catalogue/identification applications, for example other insects and subjects in biodiversity or agricultural monitoring. The application allows the user to use photographs and simple insect descriptions to identify an insect collected during monitoring. The application contains photographic images of over 60 species of grasshoppers, only 6 of which are significant pests of agriculture, and provides knowledge on the ecological roles of the non-pests species. Testing of the application is underway, including testing on a simulator that is provided with the iPhone SDK. The application will be released in 2010, and data on adoption and user opinion will be collected in cooperation with grower groups.

3.2 Improved methods for estimating current field pest activity and disseminating that information

We used daily weather data as described above, to compile and map estimates of heat accumulation as degree-days above 12 C in air and soil, using a cosine integration of the maximum and minimum daily temperatures. Subsequent refinements were made using determinations of the time of day of the maximum temperature. Maps were placed on a website for growers to access. These dynamic maps are separate from but in support of the baseline risk maps produced by provincial government agencies, using standardized surveys of breeding populations the previous year (population trends and survey methods were analyzed, assessed and adapted to GIS methods by Johnson [13,14] and Johnson and Worobec [15] and by subsequent researchers in other provinces and states).

Grasshopper degree-day models in the US typically use lower temperature thresholds of more than 17 C, but we have found soil thresholds of 12 C and air temperature thresholds of 15 C more accurately reflect development. Our thresholds agree in general with research results in China and Inner Mongolia, e.g., Hao and Kang [16].

Weekly maps of predicted grasshopper hatching and development were constructed using ESRI Arc GIS Spatial Analysis (inverse distance weighting), converted from units of heat accumulation to expected insect stage in the field, and posted on the website during the growing season in 2009 and 2010. The site was publicized in grower publications. There were 1600 visits to the site during the pest management season. We are currently testing a Microsoft "Silverlight" application that will allow rapid, interactive examination of the monitoring data by participants.

Colour
gray

Hind Wing
clear

Leg Colour
same as body

Distinct Features
silver-gray antennae

Pest:
range grass and pasture

Species
Aeoloplides turnbulli

Common Name

Fig.1. Example screen from the grasshopper identification and information iPhone application.

3.3 Other applications of pest monitoring and weather informatics

One reason for developing an information system regarding these insects and weather variables is to support future alternative management options. The information would be useful when using alternative or proposed control methods that are sensitive to weather. In separate research programs, we have developed a biocontrol agent, Metarhizium anisopliae "S54", isolated from soil collected in southern Alberta, Canada. In this case, the biopesticide is a fungus isolated from Canadian soil, tested in laboratory trials, compared to other world biocontrol agents in bioassay experiments, characterized (DNA,[17,18]), and further tested in the laboratory and field. Other isolates and species of this insect pathogen are being developed by other research teams in China, Australia, Africa, the USA, South America, and Europe (previous efforts to develop this biocontrol agent are reviewed by [19,20]). This fungus is an effective control agent for certain pests, but it is safe for other living things (e.g. [21,22]). Research and development of a pest control product based on this indigenous soil fungus appear to be warranted, based on recent field tests in Canada. Living insect pathogens applied as a control agent are generally sensitive to weather, therefore the weather-based forecasts may provide supporting information for future environmentally sustainable control of this wide-spread pest.

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