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Modeling the decision process for barley yellow dwarf management

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ABSTRACT

Since the 1980s, expert decision support systems (DSSs) have been explored for enhancement of agricultural decision-making. Combinations of expert DSSs and cyber-age technology, such as mobile devices, is increasing adoption and accuracy of these systems and will allow DSSs to be easily modified to incorporate new information and web-based resources as they become available. Using barley yellow dwarf (BYD), a disease complex caused by several aphid-vectored viruses, as a model system we created a DSS for winter wheat growers based on dependency networks. At key points throughout the growing season the networks interpret how field conditions may affect management recommendations for BYD in winter wheat. To address nine possible management recommendations the networks analyze 72,387 combinations of input field conditions. This method of decision modeling can potentially be used to provide support to enable the efficient management of other crop pests and diseases and enable a more sustainable agroecosystem. The DSS was created for use in a mobile device app which will produce real-time recommendations, emulating disease management experts. Coupling this expert DSS with high resolution weather, pest, and disease forecasts will prove to be a powerful management tool in the future.

1. Introduction

Barley yellow dwarf (BYD), a disease of cereals, has caused major losses in grain yields since the late 1800s (Manns, 1909; Webster and Phillips, 1912). Since then, management tactics have been developed to limit disease incidence in the field. These tactics include planting insecticide treated seeds, altering the crop planting date, and using foliar insecticide treatments (Kelley, 2001; Kennedy and Connery, 2012; Miller et al., 1991; Stewart, 2013). The effectiveness of these management tactics, however, can be enhanced if they are linked with interactive and personalized computer-based decision support systems (DSSs).

Decision support systems are computerized methods of acquiring data from a user to return management recommendations allowing a broader analysis of the effectiveness of those recommendations (Cox, 1996; Turban, 1993). For instance, a pesticide spray recommendation in a location that rarely sees the respective pests will have little effect on the yield, but will increase the input cost and decrease the net economic gain. DSSs have been used for crop management since the 1980s, when they were developed to improve pest control in various crops (El-Azhary et al., 2000; Rajotte and Bowser, 1991; Stone et al., 1986). Expert systems are a type of DSS in which the logic of a human expert is modeled to recommend actions for the user under specific circumstances, and there are four necessary components of an expert system: a database, a knowledge base, an inference mechanism, and a user interface (Travis and Latin, 1991). The database includes any information necessary to give management recommendations, and can include user-input data, predictive-model output (e.g. pest and weather forecasts), and action restrictions (e.g. pesticide re-entry periods) (Zili and Qiuxin, 1989). The knowledge base contains the 'reasoning structure' that includes rules on how known relationships lead to management practices, which can be captured by IF condition, THEN action statements (Travis and Latin, 1991). The knowledge may come from sources such as interviews with experts, scientific literature, simulation models, and data analysis (Cullen and Bryman, 1988). An inference mechanism is a computer program used to determine necessary queries of the database and user to construct a recommendation (Zili and Qiuxin, 1989). Dependency networks are simplified representations of the

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knowledge base's reasoning structure and necessary inference mechanism queries for a given decision. The rules embedded in the networks are interpreted by a computer to generate management recommendations representing the best recommendations that would be made by experts in the field. Finally, the user interface, such as a personal computer, or in recent years a mobile device or website (or a combination of the two) allows communication between the user and the system (Travis and Latin, 1991).

In the fields of agriculture and pest management, expert systems are not a recent tool (El-Azhary et al., 2000; McKinion and Lemmon, 1985; Travis and Latin, 1991). An early example is the Penn State Apple Orchard Consultant (Travis et al., 1992). This system was deployed and tested by Pennsylvania fruit growers, who altered production practices to improve integrated pest management (IPM) strategies (Rajotte et al., 1992; Travis et al., 1992). These early systems were developed before the general use of web-based technology in agriculture and relied on static decision frameworks (e.g., Lemmon, 1986; Travis et al., 1992). Modern expert systems generally require access to the internet where knowledge bases and databases can be dynamically updated with information such as weather, regional pest status, and crop price changes (e.g. Dubey et al., 2014; Small et al., 2015). With mobile devices and the ubiquity of internet access, expert systems have become extremely dynamic and sophisticated.

A more recent success story of a DSS is the US Department of Agriculture Soybean Rust Information System website, developed to monitor the potential soybean rust invasion in 2004 (Isard et al., 2006). Certified crop advisors (CCA), extension specialists and other trained personnel could input rust surveillance data from fields, and then meteorological/aerobiological models predicted the spread of the rust spores from Mexico and the southern U.S. The system helped growers determine necessity and timing of fungicide applications. The availability of this system across the US soybean belt resulted in up to a $299 million benefit during 2005 mainly because it gave growers the confidence to eliminate fungicide applications where they were not needed (Roberts et al., 2006). CCAs and extension personnel continue to use this program as a useful tool in managing soybean rust (Bradley et al., 2010). The Soybean Rust Information System later developed into the national Integrated Pest Management Pest Information Platform for Extension and Education (ipmPIPE), which can track many more crop pests and diseases (VanKirk et al., 2012). Pest and disease observations and forecasts are displayed by the ipmPIPE; however, management recommendations are mediated by a human expert. Expert systems can substitute for most expert mediation.

Barley yellow dwarf is an ideal disease to evaluate the ability of an expert system to capture the management complexity of an insect-vectored pathogen, and to test if the ipmPIPE infrastructure can accommodate such a dynamic system. Furthermore, BYD is intensely studied, and thus research results and expert opinions can be easily obtained and interpreted.

BYD disease is caused by the world's most economically damaging cereal grain viruses (Lister and Ranieri, 1995) and can infect over 150 species of *Poeaceae* [Barnhart] (D'Arcy and Burnett, 1995). BYD has historically been known to cause major problems in epidemic years (Oswald and Houston, 1953; Webster and Phillips, 1912), averaging 11–33% yield loss in winter wheat (*Triticum aestivum* [L.]) worldwide, with maxima over 80% (Gaunce and Bockus, 2015; Lister and Ranieri, 1995; Miller and Rasochová, 1997; Pike, 1990). In Australia, early planted wheat experienced up to 60% yield loss from BYD (Thackray et al., 2009), whereas yield loss in Kansas fields averaged 49% from 2005 to 2013 (Gaunce and Bockus, 2015). Wheat is one of the top three most economically important food crops in the world, thus even a small percentage loss in global yield can be substantial (FAOSTAT, 2012; Goldschein, 2011).

Five virus species cause the majority of BYD damage, and they are transmitted by certain aphid species. The viruses are in the Family Luteoviridae. Four aphid (*Aphididae*) species are responsible for the majority of BYDV transmission: *Rhopalosiphum padi* (L.) (bird-cherry oat aphid), *Sitobion* (formerly *Macrosiphum*) *avenae* (F.) (English grain aphid), *R. maidis* (Fitch) (corn leaf aphid), and *Schizaphis graminum* (Eastop) (greenbug); but, 25 species of aphids have been recorded as lesser vectors of BYDVs (Halbert and Voegtlin, 1995). The virus is persistently transmitted making the aphid vector a prime target for control. Virus secondary transmission can occur when aphids move from infected to healthy plants to feed, but primary transmission usually occurs as consequence of the high number of aphids migrating into a new area. Most aphid species have distinctive migratory patterns, which tend to coincide with spring or fall wheat-growing seasons. Thus, the timing of risk of BYDV infection extends over much of the wheat growing season (Coceano et al., 2009).

Many environmental conditions determine spread and damage of BYD and these vary regionally, affecting management recommendations. The magnitude and timing of aphid migrations are highly dependent upon temperature, moisture, wind fields, and size of aphid populations (De Barro, 1992; Thackray et al., 2009). Virus replication and movement within the host plant is also temperature dependent, with an optimal temperature of 25 °C, and symptoms decrease with deviation from this value (De Wolfe, 2002). Environmental constraints affecting transmission success of BYDV by aphids include temperature, host plant genotype, virus titer and age of infected plants (Jones, 1979; Lowles et al., 1996; Power et al., 1991). Climatic variables can also influence the proportion of viruliferous aphid vectors in a migration, which can be greater than 10% (Coceano et al., 2009; Plumb, 1976).

Optimal management recommendations are highly dependent on these variables. Insecticide treated seeds cost more than untreated seeds and are generally only necessary if the environment is conducive to high BYDV transmission (Royer et al., 2005; Stewart, 2013). Earlier planting of winter wheat typically results in more favorable conditions and more time for aphid vectors to transmit the virus to the crop, whereas later planting increases crop winter kill (Gaunce and Bockus, 2015; Knapp and Knapp, 1978; Stewart, 2013). Scouting the field to determine aphid population levels after planting is important to obtain an accurate count to determine when and if a critical economic threshold will be reached. Scouting may yield more useful information if conducted soon before populations reach critical thresholds. Once this critical threshold is reached, it is economically beneficial to spray insecticide. This level has been reported as 15 aphid vectors per 1 ft. row of plants (Herbert et al., 1999).

This paper describes the use of dependency networks in modeling BYD management in winter wheat, referred to as the BYD-DSS. Its inputs are environmental variables; pest assessments; crop production practices; and phenological models, meteorological forecasting, and aphid population dynamics. Some of these data were derived from human experts. BYD-DSS will offer management recommendations for a given field via a web/smart phone app. To our knowledge, ours will be the first dynamic, projective, and location-specific DSS to be developed that can be integrated into a website and mobile device app to address a complex insect-vectored viral disease cycle.

2. Development of dependency networks

Management options for BYD (Fig. 1) and the input conditions necessary to result in these management actions (Table 1 and Fig. 2) were determined by searching the literature (Table 1) and interviewing a BYD expert and co-author of this paper to allow the system to make recommendations similar to the ones an expert