O.49 - WHEATPEST: a simulation model of yield losses caused by multiple injuries for wheat in Europe

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Abstract

It is necessary to diagnose damages caused by multiple pests in order to design efficient cropping systems less dependent on pesticides. These diagnoses should quantify and classify hierarchically yield losses caused by various pests (pathogens, weeds, and insects) in order to help design crop management plans, or cropping systems, less vulnerable to the most detrimental pests. However, there is a lack of data on the incidence, severity and damages of various pests in European commercial fields. In order to address this issue, WHEATPEST, a production situation-based simulation model for wheat, was developed to incorporate drivers of variable production situations and their related injury profiles. It is a simple mechanistic agrophysiological model which incorporates damage mechanisms to simulate the physiological effects of several injuries (caused by pathogens, pests, and weeds) on crop growth and yield. Model inputs consist of weather data (daily temperature and radiation) and drivers for production situation and for injury profiles. Model outputs are series of dynamic variables over time: development stage, dry biomass of organs, Leaf Area Index, and final yield. Simulation drivers were derived from published reports, in particular through a meta-analysis of highly detailed farmers' field surveys in the United Kingdom and the Netherlands. Preliminary analysis of the model's performances indicates that WHEATPEST conforms with available published reports in a range of production situations and injury profiles. This work highlights the need for the collection of standardised data on both production systems characteristics and multiple pest injuries at the European scale, and the usefulness of modeling tools for basic research and policy.

It is necessary to diagnose damages caused by multiple pests in order to design efficient cropping systems less dependent on pesticides. These diagnoses should quantify and classify hierarchically yield losses caused by various pests (pathogens, weeds, and insects). An injury profile is the combination of injury levels caused by multiple pests (pathogens, insects, weeds) that affect a crop during a growing cycle (Savary et al., 2006). Production situations, which can be defined as the bio-physical and socio-economic environments under which a crop is grown, and injury profiles are strongly linked (Zadoks, 1984). However, there is a lack of data on the injury profiles associated with various production situations at the European level, especially for wheat, the most heavily cultivated crop in Europe. In order to help address this issue, a mechanistic simulation model, WHEATPEST (Willocquet et al., 2008), was developed to simulate the harmful effects of pathogens, pests, and weeds in a simple, open, generic manner. This paper briefly presents the overall structure of WHEATPEST and simulation results.

Model structure

WHEAPEST is a simple agrophysiological model which incorporates damage mechanisms to simulate the physiological effects of injury on crop growth and yield. Its general structure is derived from RICEPEST, a model developed for rice yield loss analysis (Willocquet et al., 2002). WHEATPEST predicts yield losses caused by weeds, aphids (*Sitobion avenae*), viruses (barley yellow dwarf viruses), brown rust (*Puccinia triticina*), yellow rust (*Puccinia striiformis*), powdery mildew (*Blumeria graminis*), Septoria tritici blotch (*Mycosphaerella graminicola*), Septoria nodorum blotch (*Septoria nodorum*), take-all (*Gaeumannomyces graminis* var. *tritici*), eyespot (*Oculimacula yallundae* and *O. acuformis*), sharp eyespot (*Rhizoctonia cerealis*), Fusarium stem rot (*Fusarium graminearum*, *F. culmorum*, and *Microdochium nivale*) and Fusarium head blight (*Fusarium graminearum*, *F. culmorum*, *F. avenaceum*, *F. poae*, and *Microdochium* nivale), on wheat crop physiology.

Model inputs consist of weather data (daily temperature and radiation) and drivers for production situation and for injury profile. The driver for production situation includes an array of driving functions that can vary over time (e.g., radiation use efficiency), and parameters. Similarly, the driver for injury profile consists of an array of driving functions or parameters that represent the dynamics (or maximum levels) of individual injuries during a cropping season. These combined injury time-courses represent the injury profile a given crop stand has been exposed to during its cycle. Model outputs are a series of dynamic variables over time: development stage, dry biomass of organs, leaf area index, and final yield.

The system considered is $1m^2$ of winter wheat crop, with a simulation time step of 1 day. Biomass production through photosynthesis is classically computed using Monteith's equation: the daily rate of biomass growth is proportional to the radiation intercepted by the canopy, which is derived from the LAI using Beer's law. Assimilates produced by photosynthesis are partitioned towards the different organs of the plants (roots, stems, leaves, ears) as a function of the development stage. Remobilisation of carbohydrates and leaf senescence are represented by the model.

In its current version, WHEATPEST takes into account 13 pests. These harmful organisms can be classified as pests that cause injuries on roots (take-all and fusarium stem rot), pests that cause injuries on stems (eyespot, sharp eyespot, and fusarium stem rot), pests that cause injuries on leaves (brown rust, yellow rust, powdery mildew, septoria tritici, septoria nodorum, aphids), pests that cause injuries on ears (fusarium head blight), and pests that affect the overall yield performance of a wheat stand (barley yellow dwarf viruses, weeds and aphids). These pests can be described according to the damage mechanisms they cause. These damages can be i) a reduction of the light intercepted by the leaves due to foliar pests which cause lesions and consequently a reduction of the photosynthetic area (these pests can be described as 'light stealers'); ii) a decrease in photosynthetic efficiency due to reductions in nutrient and water uptake following a disturbance in the phloem vessels (barley yellow dwarf viruses, take-all, eyespot, sharp eyespot and fusarium stem rot), or following competition (weeds) or honeydew deposition (aphids); iii) a diversion of assimilates by lesions for the production of propagules or by sucking insects such as aphids; iv) a direct and indirect impact on grain biomass induced by grain colonisation (fusarium head blight), or lodging effect (eyespot). These damage mechanisms are incorporated in the model as reductions of leaf area index (e.g. presence of lesions on leaves), reduction of radiation use efficiency (e.g. presence of lesions on stems hampering transportation of nutrients), and in assimilate diversion (e.g. phloem sapping by aphids).

Simulations

A meta-analysis of country-year pest data was conducted on two series of studies, in England and Wales, and in the Netherlands. These studies provide a comprehensive and detailed account of many organisms harmful to wheat over several hundreds of farmers' fields and over a period of several years. A hierarchical cluster analysis using the Ward criterion and a Euclidean distance along with additional data on pests not monitored in these studies was used to generate the framework for injury profiles. Three clusters of injury profiles (denoted A, B, and C) were identified. Moreover, results from a published experimental study conducted in on-farm experiments on a series of representative wheat varieties for two years was used to introduce the effects of production situations on injury profiles. In this study, most of the harmful organisms addressed in the present work were considered, in three crop management systems: ‘conventional’ (C), ‘integrated’ (I), and 'biodynamic' or 'organic' (O). A two-way matrix, production systems (C, I, and O) by injury profiles (A, B, and C), was built.

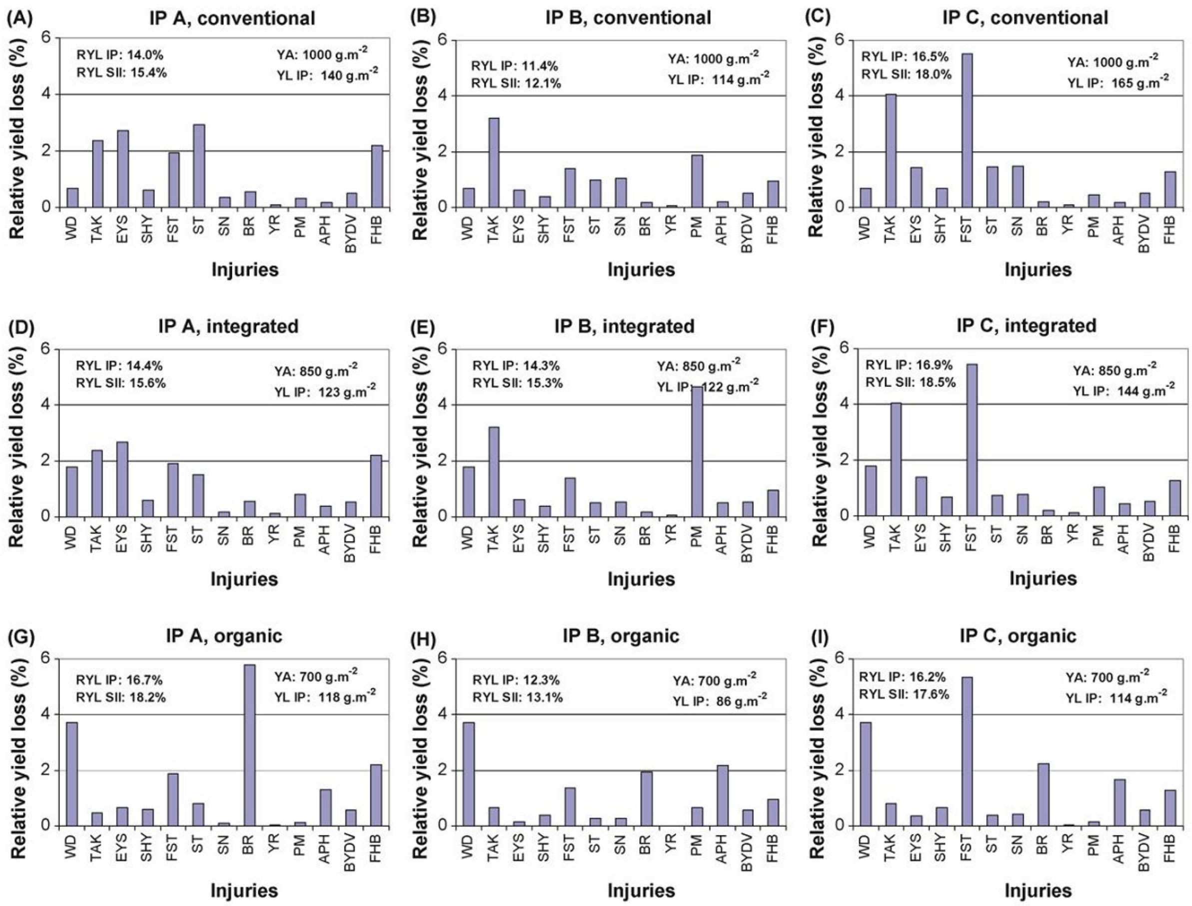

Figure 1. Simulated wheat yield losses caused by individual injuries, and by their combination into injury profiles, for combinations of production situation by injury profile. A, B, C: conventional system; D, E, F: integrated system; G, H, I: organic system; A, D, G: injury profile A; B, E, H: injury profile B; C, F, I: injury profile C. RYL IP: relative yield losses caused by the injury profile; RYL SII: relative yield losses cumulated over the individual injuries; YA: attainable grain yield; YL IP: grain yield loss caused by the injury profile. WD: weed dry biomass ($g.m^{-2}$), TAK: take-all severity (%), EYS: eyespot incidence (%tillers), SHY: sharp eyespot incidence (%tillers), FST: Fusarium Stem Rot (%tillers), ST: septoria tritici blotch severity (%), SN: septoria nodorum blotch severity (%), BR: brown rust severity(%),YR: yellow rust severity (%), PM: powdery mildew severity (%), APH: aphid density ($nb.m^{-2}$), BYDV: barley yellow dwarf virus incidence (% plants), FHB: fusarium head blight (%kernels).

Simulated yield losses caused by wheat injury profiles and their corresponding individual injuries for different combinations of production situations (conventional, integrated, organic) by 3 injury profiles

(A, B, C) are shown in Figure 1 (Willocquet et al., 2008). Relative yield losses are expressed as fractions (%) of attainable yield (YA) for each individual pest, and yield losses caused by the entire injury profile are also indicated in terms of grain dry biomass (YL IP) and fraction of grain dry biomass lost (RYL IP). Across the nine possible combinations, relative yield losses range from 11.4 % (Fig. 1A; conventional, IP A) to 16.9% (Fig. 1; integrated, IP C). In all cases, relative yield losses caused by an injury profile are lower than the accumulated yield losses caused by combined individual injuries. Yield losses in terms of grain dry biomass range from 84 (Fig. 1H; organic, IP B) to 165 $g.m^{-2}$ (Fig. 1C; conventional, IP C). These figures are to be linked to attainable yields, which increase from 700 (organic) to 1000 $g.m^{-2}$ (conventional). WHEATPEST simulates varying patterns of relative yield losses, caused by the individual injuries within a given PS x IP combination, as is reflected by the differences of loss patterns shown in Figures 1A to 1I. Relative yield losses caused by individual injuries are always below 6%, and are below 1% in more than 50% of the cases.

Discussion

Although no formal evaluation of WHEATPEST is possible at this stage, a partial evaluation suggests that both individual and combined injury effects on crop growth and yield are satisfactorily well modelled (Willocquet et al., 2008), at least within the objectives set for this modelling work. A specific four year experimental dataset encompassing contrasted cropping systems will be available in 2009 to assess the quality of prediction of WHEATPEST. The structure of the model, and the different damage mechanisms it includes, incorporate processes that have been proven to represent satisfactorily physiological pathways involved in crop growth and in the effects of injury on crop physiology. However, further refinements could be added in the future, which should respect a balance in the details of representation of both crop physiology and the damage mechanisms process, and keep the model as simple as possible.

Within the Research Activity 2.1 of ENDURE, it is programmed to adapt WHEATPEST to spring wheat. For this purpose, an experiment was set up in Poland, where wheat crops are mainly spring wheat, to characterise the injury profiles associated with contrasted wheat management strategies. The collected data will thus permit us to enlarge the domain of validity of WHEATPEST. Moreover, the generic structure of WHEATPEST, which is the same as the one used for the development of RICEPEST (Willocquet et al., 2002), could be easily applied to other crops. In a further stage, if the efficiency of pest management tools is accounted for in simulation scenarios, analyses from simulated outputs under specified scenarios of pest management could be used as a component to guide research priorities for wheat pest management in Europe. Another use of WHEATPEST could be to provide a baseline to structure and guide large-scale data collection and impact assessment. Surveys conducted at the European scale to characterise production situations and injury profiles for wheat could use WHEATPEST as a framework to design standardised protocols for data collection.

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