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Does Integrated Weed Management affect the risk of crop diseases? A simulation case study with blackgrass weed and take-all disease

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ABSTRACT

Integrated Weed Management (IWM) is necessary to reduce environmental damages by herbicides. The modifications required for IWM in cropping systems can result in unexpected side-effects, e.g. an increased risk of bioagressors other than weeds, either because the new cropping systems favour these bioagressors or because they favour weeds that are potential bioagressor hosts, thus increasing the contagion risk for crops. To evaluate these risks, the present case study worked with two model pests, a grass-weed species (blackgrass, *Alopecurus myosuroides* Huds.) and a soil-borne cereal pathogen (*Gaeummanomyces graminis* (Sacc.) von Arx et Olivier var. *tritici* Walker, responsible for take-all disease) which strongly interact and depend on cropping systems. For each pest, a model quantifying the effects of cropping systems in interaction with pedoclimatic conditions on pest dynamics was chosen from literature (AlomySys for weed dynamics, TakeAllSys for disease incidence) and linked with a new interaction model predicting the effect of one bioagressor on the other. A simulation study was then carried out, testing a herbicide-intensive reference system identified in farm surveys and a series of IWM systems combining several modifications (e.g. mouldboard ploughing, mechanical weeding, delayed sowing) to compensate for herbicide reductions. Each scenario was simulated over 27 years and repeated 20 times, with randomly chosen weather series from two different pedoclimates. The best IWM systems were more efficient than the herbicide-intensive reference system to control the grass weed. In the case of weed-free simulations, none of the IWM systems increased disease incidence, and the best systems even slightly reduced it. Integrating the reduction in weed seed production due to the disease in the simulations did not significantly change the simulation outcome, irrespective of the tested cropping system. Conversely, when the role of weed in disease transmission was taken into account, disease incidence in cereals crops considerably increased, particularly when past non-host crops in the rotation were infested by the weed. Nevertheless, the best IWM systems presented negligible weed-induced disease increase. The present results can be extrapolated to similar pest types (e.g. with propagules surviving in soil and negligible dispersal between fields). The modelling and simulation approach were easily feasible thanks to the availability of consistent models of cropping system effects on the two pests and experimental data on their interaction.

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1. Introduction

Amongst bioagressors, arable weeds are responsible for the highest yield losses when they are uncontrolled (Oerke, 2006). Although herbicides are very efficient in most situations, their use must be reduced drastically because of the resulting environmental problems (i.e. water pollution, loss of vegetal and associated biodiversity) (e.g. www.ifen.fr; Marshall et al., 2001; Taylor et al., 2006). An alternative to intensive herbicide weed control is Integrated Weed Management (IWM) which combines several management techniques that only each has a partial and usually long-term effect, but are complementary to ensure a good level of protection with a limited reliance on herbicides (Bastiaans et al., 2008; Zoschke and Quadranti, 2002). In these conditions, the whole cropping system, i.e. crop succession and crop management (tillage, sowing dates, mechanical weeding...), must be adjusted (e.g. Chikowo et al., 2009). These considerable modifications can result in unexpected side-effects, e.g. an increase in bioagressors other than weeds, either because the new cropping systems favour these bioagressors (e.g. Colbach et al., 1994; Valantin-Morison et al., 2007) or because they favour weeds that are potential bioagressor hosts

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(Schroeder et al., 2005; Wisler and Norris, 2005). New IWM systems must therefore be evaluated not only for their efficiency in managing harmful weeds, but also for potential side-effects on other bioagressors (Norris, 2005).

Assessing cropping system effects on pest in experiments is complex (e.g. numerous factors and cumulative effects) as well as time and space-consuming (Debaeke et al., 2009; Colbach, 2010). Moreover, the effects of biological interactions are difficult to discriminate from those of environment and management practices. Consequently, cropping system models predicting pest dynamics are useful tools to explore *ex ante* the ability of new cropping systems to manage pests (Colbach, 2010). To date, only a few "pest dynamics = f(cropping system)" models are available (Aubertot et al., 2005; Colbach, 2010), among which two dealing with economically important bioagressors: a model for blackgrass dynamics (ALOMYSYS, Colbach et al., 2006b, 2007, 2010) and one for take-all incidence in winter wheat (Ennaïfar et al., 2007). Blackgrass (*Alopecurus myosuroides* Huds.) is a common grass weed, frequently found in autumn-sown cereals of Western Europe (Fried et al., 2008). The take-all disease, responsible for important winter cereal yield losses in the world (Hornby et al., 1998; Schoeny et al., 2001), is caused by the soil-borne fungus *Gaeummanomyces graminis* (Sacc.) von Arx et Olivier var. *tritici* Walker. These two pests are a particularly interesting case of IWM side-effect assessments, because (i) they both strongly depend on cropping systems (e.g. Colbach et al., 1994; Chauvel et al., 2001), and (ii) they show a host–parasite interaction (Nilsson, 1969). Indeed, blackgrass can be infected by the fungus, and it has been shown to enhance take-all disease progress on wheat (Nilsson, 1969; Dulout et al., 1997; Gutteridge et al., 2005) and to maintain the disease in the field in the absence of host crops (Dulout et al., 1997). To date, the impact of the weed on the disease in diverse cropping systems has not yet been studied, and the effect of take-all infestation on the weed seed production is unknown.

Consequently, the present paper focused on two questions: (1) do IWM strategies optimized for weed control result in an increased disease risk? And (2) does the weed-disease interaction influence the effect of IWM strategies on each bioagressor? To answer these questions, (i) we linked the take-all model to ALOMYSYS and developed a new submodel quantifying interactions between blackgrass and take-all, and (ii) we used the resulting model to evaluate contrasted IWM cropping systems.

2. Materials and methods

2.1. *The* AlomySys *model*

2.1.1. *The initial structure of* AlomySys

AlomySys is a mechanistic model that predicts the effects of cropping systems on the dynamics of blackgrass (*A. myosuroides* Huds.). The structure and evaluation of AlomySys were described in details by Colbach et al. (2006a,b, 2007, 2010). The model requires the following input variables: (i) the initial blackgrass infestation, (ii) daily weather data and soil hydrothermal conditions, and (iii) the cropping system characteristics consisting in crop sequence and management for each crop. The management details are the sowing date and density, tillage and mechanical weeding operations (date, tool, depth, speed), herbicide applications (date, active ingredient, relative rate, and treatment conditions), nitrogen fertiliser (date, amount), and harvest dates (including mowing in perennial crops and set-aside). AlomySys was developed as the aggregation of mechanistic submodels, where the effect of each cultivation technique on blackgrass was described as a biophysical process depending on environmental conditions, crop stage and density, as well as blackgrass stage and density. Effects of management techniques on the annual life-cycle of blackgrass are summarized in the electronic annex. The model output variables are the densities of all weed life-stages in the field, at a daily time-step over the years. The evaluation of AlomySys model showed satisfactory predictions of blackgrass dynamics over time in contrasted cropping systems (Colbach et al., 2006a, 2007). The mechanical weeding sub-model has not been evaluated by comparing model outputs with real data; however, the simulations showed consistent results with literature (Colbach et al., 2010).

2.1.2. *Improving* AlomySys *with a new submodel for yield loss in cereals due to blackgrass*

The initial version of AlomySys predicts densities of weed stages over time but gives no indication of probable crop yield loss, the critical variable for most farmers. Consequently, a new submodel was added to AlomySys in the present work to remediate this deficiency. This submodel consisted in the relation established by Doyle et al. (1986) to predict yield loss in cereals due to blackgrass infestation (YL_{WE}, % in [0, 100]):

$$YL_{WE} = \frac{0.2 \cdot \mathrm{WD}}{1 + 0.002 \cdot \mathrm{WD}} \tag{1}$$

with WD the density of blackgrass at harvest (plants/m^2).

2.2. *The* TakeAllSys *model*

2.2.1. *Disease in cereal crops*

The data and the methodology used by Ennaïfar et al. (2007) to develop models for take-all incidence were adapted here by adding a few data (Colbach, 1995) and calibrating an improved model equation based on prior knowledge on the pathogen (Table 1). The most pertinent variable for predicting the effect of disease incidence on yield loss, i.e. the proportion of diseased plants at growth stage (GS) 33 (Schoeny et al., 2001) was chosen as output variable for the TakeAllSys model. The effect of crop succession was structured to reflect (1) the amount of infectious host residues in the top soil layer which increases with the frequency and the temporal proximity of host crops in the succession (Colbach et al., 1994), and (2) the disease suppression due to antagonistic soil microflora favoured by monocultures and reduced by amplifier crops (Colbach, 1995; Hornby et al., 1998). Similarly, the model distinguishes deep and soil-inverting tillage tools (i.e. mouldboard ploughing) from any other operations to integrate the effect on burial vs. excavation of infectious host residues. Mouldboard ploughing was thus constrained to reduce disease incidence after a previous host crop, to increase disease after non-host crops preceded by a host crops and to allow for negligible effect in successions without host crops (Colbach, 1995). No hypotheses were used to structure the soil texture effect. Seed treatments with silthiofam were made to reduce disease incidence (Schoeny and Lucas, 1999). Catch crops were assumed to reduce disease incidence in the subsequent host crop (Ennaïfar et al., 2005). Ammonium nitrogen fertilizer should decrease take-all because it stimulates disease-antagonistic microflora (Smiley, 1978; Sarniguet et al., 1992; Colbach et al., 1997b). Early sowing of host crops was made to increase disease risk because it leaves more time for the pathogen to infest the host crop before winter onset; this effect was translated into the thermal time from sowing to winter onset (Colbach et al., 1997a). Sowing density was assumed to increase disease risk because of increasing the probability of fungal mycelium encountering host roots (Colbach et al., 1997b). Finally, to take account of the fungus requiring moist conditions when growing and infesting host roots, the cumulated rainfall approximately three weeks after

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