Improvement of the soil-crop model AZODYN under conventional, low-input and organic conditions

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Key words: nitrogen management, soil-crop model, wheat, organic, validation

Abstract

The use of mechanistic crop modelling, simulating the dynamics of crop N requirements and nitrogen supply from the soil and fertilizers, can provide sound advice to users. This paper describes a methodological way to improve soil-crop modeling used for N management of conventional and organic wheat.

Introduction

Nitrogen (N) is a key nutrient in achieving acceptable yield and quality performance of wheat bread-making. Previous results have shown that organic and conventional wheats grown with low-input practices are characterized by low and irregular grain yield and protein content (David et al. 2005a; Rolland et al. 2003). One reason is that the contribution of N from organic sources as crop residues, manures and composts, is difficult to predict and thus to synchronize with crop N requirements. Furthermore, the development of specialized cereal-based systems mostly relying on off-farm N sources, requires references to identify the best fertilization strategy according to the field characteristics. Jeuffroy and Recous (1999) had developed the AZODYN model in conventional to predict the consequences of fertilization management on yield, grain protein content and soil mineral N at harvest. Furthermore, David et al. (2004) had adapted the AZODYN model under organic conditions in order to build a decision making tool to assist farmers for the fertilization management. The AZODYN model is divided in three modules.. The soil module simulates changes in the amount of mineral N in the soil over the crop cycle from the net N contributions of previous crop residues, humus and organic amendments. The fertilizer module simulates the daily net mineralization, volatilization and nitrogen use efficiency of the fertilizer. The crop module simulates leaf area time-course change, according to nitrogen accumulation in the crop, and above-ground parts growth on the basis of intercepted radiation. The nitrogen requirements are estimated from the crop biomass and the nitrogen dilution curve. The model simulates changes in leaf area index and above-ground biomass production over time as a function of the deficiency. At anthesis, the model calculates grain number from the characteristics of the N deficiency (duration and intensity), suggested by Jeuffroy and Bouchard (1999). After anthesis, the model simulates the accumulation of biomass and nitrogen in the grains. This model has already been evaluated in a broad range of conditions, under conventional, low-input and organic conditions. Previous results have shown the high performance of Azodyn model to assist farmers in evaluating the economic benefits of a fertilization strategy and

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selecting the optimal strategies according the farmers constraints and conditions (Jeuffroy et al. 2001; David et al. 2005b). The aim of this study was to improve the predictive performance of the Azodyn model through new findings on (i) the incidence of water stress on soil N release and crop growth, (ii) the volatilization process from organic and mineral fertilizers, (iii) the reduction of grain number linked with N nutrition dynamics and finally (iv) the grain filling process.

Materials and methods

1. Methodology

The method was based on the comparison of 32 versions of the Azodyn model, varying in one or several mathematical functions derived from literature or previous experiments, on a large database from field trials (21 trials under conventional conditions and 17 trials under organic conditions).The new versions of the model differed on:

- The prediction of the water stress on soil-crop system. Six functions were compared to predict the incidence of water stress on soil N mineralization. Twelve other functions were compared to predict the incidence of water stress on crop growth and N nutrition;
- The prediction of the NH3 volatilization from fertilizer N applied determined by the rainfall – time and quantity – and/or the crop growth rate just after the date of N application (7 functions);
- The relationship between the nitrogen content decrease in the vegetative part of the crop during senescence and the reduction of green leaf area index (3 functions);
- The reduction of grain number linked with the N nutrition index at flowering or the dynamics of N deficiency during the vegetative period (3 functions).

The validation procedure was developed in 7 steps:

Steps 1 to 3= Incidence of water stress on soil-crop system

First, the incidence of water stress on soil N contribution was tested using 7 functions including the initial model with no water stress. The different versions were run on the data base with no N application. The model giving the best predictions on crop N uptake at harvest was selected as model M1.

From the initial model, we compared the 13 versions comparing the functions of water stress on the crop system. The model M2 was selected with the best predictions on crop N uptake and above-ground biomass at harvest, on the sites with no N application.

Finally, we compared the M1 and M2 models. If M1 gave better results, we compared the 13 versions including a function of water stress on the crop system from the best M1 model, and if M2 gave better results, we compared the 7 versions including a water stress on the soil system from the M2 model. The best model, called M3 model, was selected from the prediction values of crop N uptake and above-ground biomass at harvest.

Steps 4 to 5= Prediction of volatilisation and incidence of water stress on N treatments

From the M3 model, we compared the 7 versions predicting the volatilisation process on the N fertilized treatments. We identified the best model, called M4 model, from the prediction value of crop N uptake, yield and grain protein content.

From the M4 model, we compared the 12 versions with a function of water stress on the crop system and selected model M5 from its predictive quality on crop N uptake, yield and grain protein content.

Steps 6 and 7= Prediction of grain filling process

From the M5 model, we tested the 3 versions predicting the senescence on all treatments. The model giving the best prediction on above-ground biomass at harvest was selected as model M6. Therefore, we tested from the M6 model, the 3 versions predicting the grain number on all treatments. Finally, the model giving the best prediction on grain number was selected as model M7, the final version of the model.

2. Assessment method

The comparison of the different versions of the model was based on the Root Mean Square Error of Prediction (RMSE), comparing the observed and simulated values (Wallach and Goffinet, 1987) on intermediate variables closely test (crop N uptake, grain number or above-ground biomass), but also on yield and grain protein content. The bias and the mean squared variance were determined to confirm the model choice. The bias indicates the systematic under- or over-estimation of the values by the model. The mean squared variance indicates the ability of the model to give a good account of the variability of the observed values.

3. Database

The database included field experiments on conventional and organic wheat. The experiments on conventional wheat were located in 19 various locations in France, from 1991 until 2002. The database has 9 non fertilised treatments and 82 N treatments with quantity varying from 40 to 300 kg $N.ha^{-1}$. The dates of application varied from the end of winter to the ear emergence. In theses experiments, diseases, insects and pests were controlled by applying pesticides. The experiments on organic wheat were located in 15 various locations in France, from 1994 until 2003. Four types of organic fertilizers were tested: feather meal (66 various N treatments), guano (11), sugar beet vinasse (26) and poultry manure (6). The rate of application varied from 0 to 210 kg $N.ha^{-1}$. The date of application varied from the end of winter to the ear emergence. The first results presented in this abstract are essentially extracted from the conventional database. Specific results on organic wheat will be delivered at the conference.

Results

The insertion of water stress functions on soil-crop system improved the prediction on grain protein content and yield on non fertilised treatments (N0) but also on N treatments (Steps 1 to 3 -Figures 1a and 1b). The best functions to predict water stress simultaneously affected (i) the net N contributions of previous crop residues and humus and (ii) the radiation use efficiency. The insertion of volatilisation process did not improve the prediction of yield and grain protein content on fertilized mineral-N treatments. Nonetheless, previous results have shown that volatilisation process from fertilisers can be determined by soil water availability and crop growth (Limaux et al, 1999). The highest difference between the minimum and the maximum values of RMSEP vas observed for step 5, when testing the water stress function on crop growth. On non fertilized treatments, grain protein content was highly sensitive on steps 2, 3 and 5. This means that the predictive quality of the model was highly sensitive to the water stress, particularly to its effect on crop growth on fertilized treatments. On the contrary, for steps 4, 6 and 7, there was a very low difference between the minimum and maximum values of RMSEP. In most tested models, the mean squared variance was higher than the biais, indicating a difficulty of the models to give a good account of the observed variability.

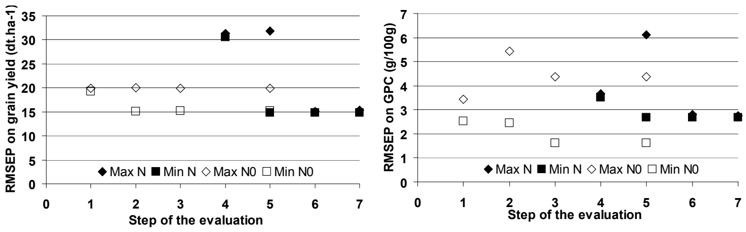

Figure 1: Evolution of the RMSEP on grain yield (1a) and grain protein content (1b) during the model evaluation : minimum and maximum values obtained on the various models tested at each step, on N treatments (N) and non fertilized treatment (N0) in conventional agriculture.

Discussion

This methodological way allows us to improve the model prediction, mainly by the insertion of a water stress function. However, the use of Azodyn model under organic conditions requires the prediction of yield limitation induced by weed competition, pest and diseases. On going research are focussed on the setting up of early indicators to assess the incidence of weed population, soil compaction and pest and disease on yield limitation (Casagrande et al, 2006).

Acknowledgments

The authors gratefully acknowledge funding from the European Community financial participation under the Sixth Framework Programme for Research, Technological Development and Demonstration Activities, for the Integrated Project QUALITYLOWINPUTFOOD, FP6-FOOD-CT-2003- 506358.

We sincerely acknowledge Myriam Laurent (Agrotransfert Poitou-Charentes) and Luc Bauer (Chambre Agriculture Eure et Loir) for their contribution to the work.

Disclaimer

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