Nitrogen management of organic winter wheat: Decision-making through model-based explorations

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Introduction

In organic wheat, nitrogen is one of the key limiting factors responsible for irregular productivity and low quality (David et al, 2005b), 5 to 50 % less than conventionally managed crops (Nieberg and Schulze Pals, 1996). On arable farms, the decreasing use of N-organic sources such as forage legumes, manures and composts relative to mixed-farms requires the development of suitable fertility strategies based on the use of off-farm organic fertilizers. Numerous mechanistic crop models simulating the dynamics of crop requirements and N supply in the soil (e.g. CERES, EPIC, APSIM, ARCWHEAT STICS) have previously been developed (Whisler et al, 1996). Although these models are highly used in research, their complexity and input requirements have limited their practical use for farmers and advisers. The aim of this study was to develop an engineering approach (Passioura, 1996) by the development of a decision-making tool for assessing N management of organic wheat on commercial farms. Azodyn-Org crop model was developed in organic agriculture to predict the influence of spring N fertilization strategies on grain yield, grain protein content, mineral N in the soil at harvest and gross margin (David et al., 2004). This simpler model requires little input data, which are easily measured in farmers' fields (soil characteristics, climatic data, crop biomass and mineral N in the soil at the end of winter). The performance of Azodyn-Org was relevant for selecting appropriate strategies in a large range of environment and crop management conditions (David et al., 2005a). This paper focuses on the potential contribution of model-based explorations from Azodyn-Org for managing N fertilization in organic wheat crops at the regional scale.

Materials and methods

A scenario analysis exercise was conducted within the collecting areas located in the Rhône-Alpes region (France) under different cropping systems. The collecting areas were characterized by weather and soil conditions defining 12 different situations. In this illustration, two farming systems were compared - mixed farms *vs* arable farms. The mixed farm was characterized by a lucerne (3yr)-cereal (3yr) crop rotation and regular bovine manure N application of 30 t.ha-1 (every 2yr). The arable farm was characterized by a cereal crop rotation (4yr) without organic manure application.

Rule-based simulations (Rossing et al, 1997) were developed to (1) determine the influence of cropping systems and crop management on yield performance and grain protein content, (2) evaluate the benefits of an organic N application and (3) define optimal spring fertilization strategies (N amount, and timing of application and frequency) according to farmers' conditions. First, the incidence of N amount from 0 to 180 kg. N.ha-1 was evaluated under three reference stages of application (Zadocks 25, 30 and 32). Secondly, the optimal stage of application and frequency was defined, for the optimal N amount, from tillering stage to the last leaf emergence. The simulations were done over 15 years historical weather information.

The fertilization strategies were evaluated according to the gross margin, calculated as :

GM pred = CAPs + (Y pred * Pip) - Vc

CAPs : Community Agricultural Policy subsidy fixed at 275 €.ha-1

Y pred : Predicted yield in t.ha-1

Pip : Price in €.t-1considering the predicted protein level

The references, based on existing prices, defined the values of 21.3 €.t-1 under 9 g per 100 g and 29 €.t-1 at 9 g per 100 g. Above 9 g per 100 g, 0.8 €.t-1 was added for each 0.5 g per 100 g in protein concentration to reach 33.5 €.t-1 above 12 g per 100 g.

Vc : Variable costs in €.ha-1 with Vc = Vo + (Ni*Pf + a*10)

Vo : other costs including labour force and equipment (soil preparation, weed control and harvesting) as 198 €.ha-1

Ni : Nitrogen input in kg N.ha-1

Pf : Organic fertilizer price as 3.5 € per kg.N-1

a : number of N applications

The fertilization strategies were selected and ranked when the relative gross margin compared to non-fertilized treatment was above 75 €.ha-1; this threshold was defined to represent the mean significant difference (test with LSD<0.05) on gross margin between two treatments (David et al, 2005a).

Results and discussion

Influence of environmental conditions on N management

The first goal of the model-based approach was to determine the influence of soil and weather conditions on yield performance and protein content. Figure 1 illustrates the incidence of soil and weather conditions on an unfertilized wheat crop. This approach can be used to draw quality territories within the collecting area, taking into consideration existing farming systems and fertilization practices (information easily obtained through farm enquiries, advisers' expertise or statistical data).

Influence of farming systems on N management

Another goal of our approach was to evaluate the N contribution of the cropping systems to yield performance, grain protein content, and gross margin. Figure 2 illustrates the incidence of farming systems on gross margin; On mixed farms, N contribution from lucerne and organic manures induced yields that frequently were above 4.5 t.ha-1 linked with variable protein content from 9 to 11.5 g per 100g. On arable farms, yield was frequently under 4.5 t.ha-1 linked with protein content around 10 g per 100g.

Agronomic and economic interest of spring N application

Rule-based simulations allow one to define optimal fertilization strategies according to agronomic conditions (soil and weather conditions, influence of other limiting factors, cropping systems); For instance, the optimal rate of N applied varied from 30 to 150 kg N ha-1 and timing of N application varied from Feekes 5 to Feekes 7 on a wheat crop where limiting factors were controlled (data not shown). Thus Azodyn-Org helps to define agronomic conditions where spring N application was of economic interest or guaranteed improvement of the grain protein content above the millers' requirement (i.e; 10.5% in France).

Influence of limiting factors

David et al, (2005a) concluded that Azodyn-Org was relevant for selecting appropriate strategies only if the effects of major limiting factors (e.g. weeds, diseases, soil compaction) on yield were well known (the model could accept an estimation error around 20%). Figure 3 illustrates the effect of limiting factors (weed competition, soil compaction, water stress, etc.) on relative gross margin given by optimal strategies. The relative gross margin was between 100 and 300 €.ha-1 under controlled situations, while it was under 150 €.ha-1 under uncontrolled situations. The development of an early risk-assessment method to predict the effect of major limiting factors is required before this tool is provided to users (David et al, 2005b).

Conclusion

This model-based approach could help users to adapt the farmer's production according to their agronomic conditions (weather and soil conditions, farming systems, control of limiting factors) and to optimize segregation of harvested organic wheat related to agro-industrial requirements (millers, biscuit, noodles, livestock feed), on the basis of their possible grain protein content predicted from the model. Furthermore, this rule-based simulation models could be used for tactical exploration of wheat management aimed at adjustment of farmers' constraints and firms requirement. Further development of the tool is an ongoing activity that should improve the ability to consider the influence of others limiting factors, its user-friendliness, and its performance.

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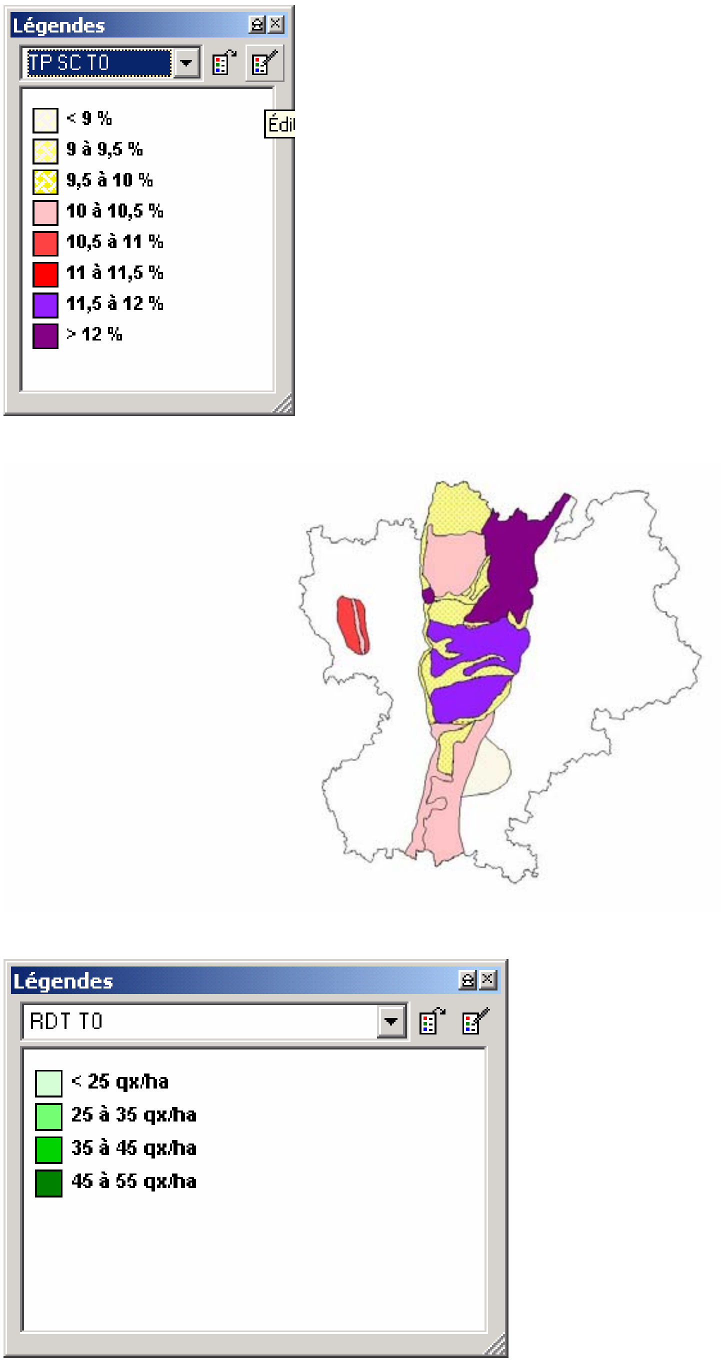
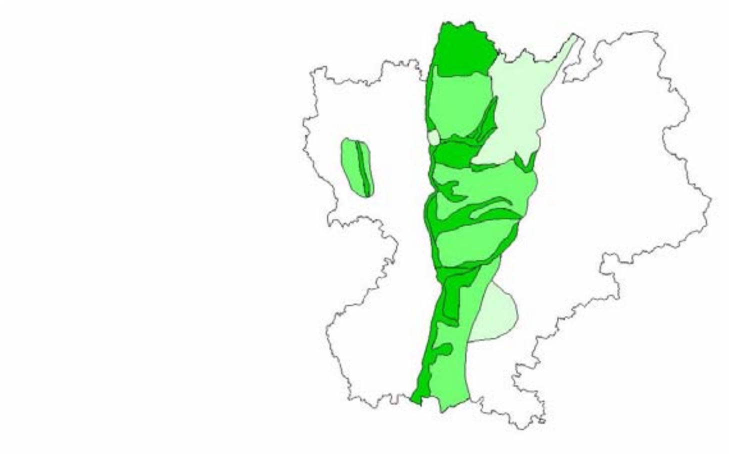
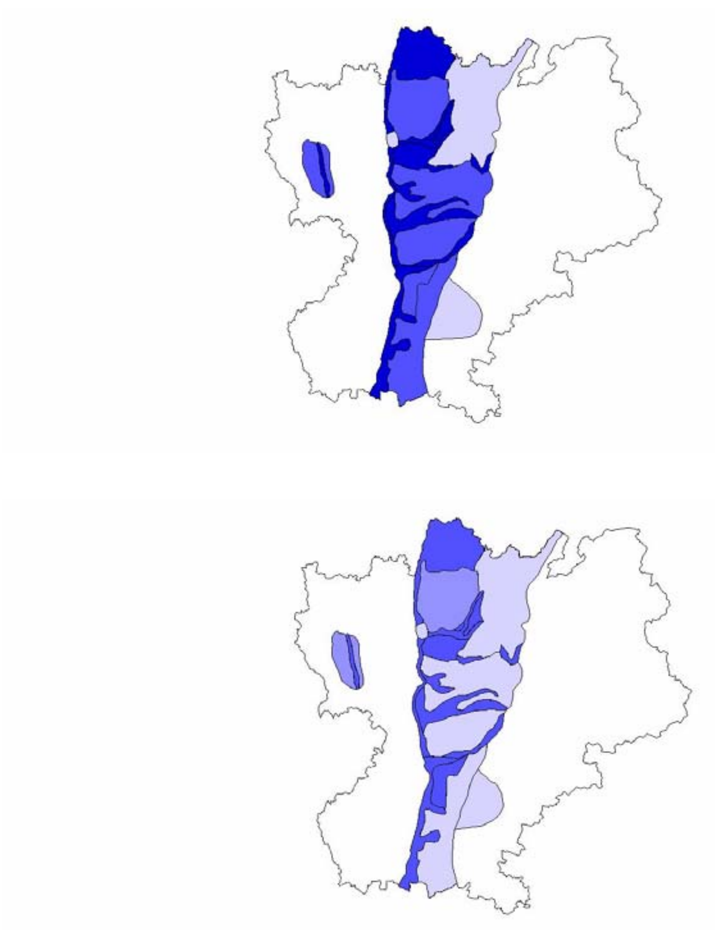
Figure 1. Influence of environmental conditions on protein level - illustration with non-fertilized treatment on wheat crop preceded by wheat

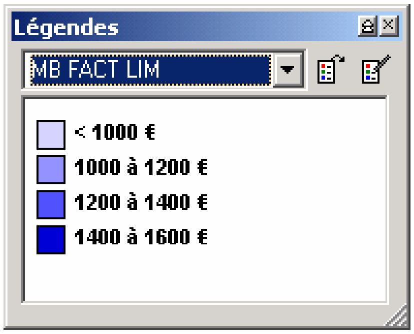




1a. Protein content (g/100g) *1b. Yield (dt.ha-1)*

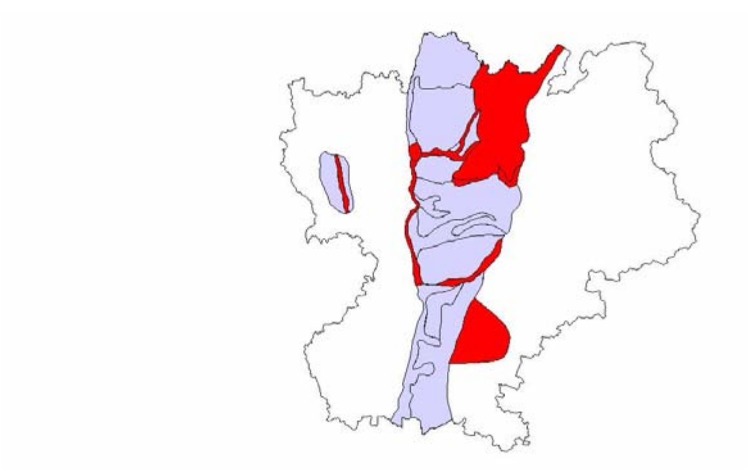
Figure 2. Influence of the farming systems on gross margin - illustration with non-fertilized treatment

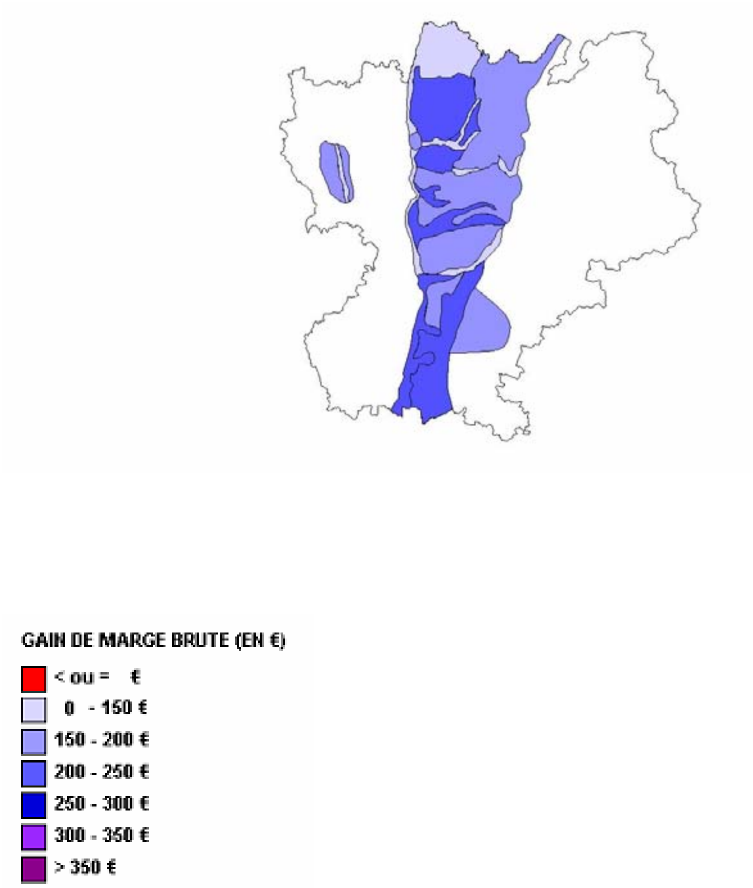




2a. Arable farms *2b. Mixed farms*

Figure 3. Influence of the limiting factors on relative gross margin obtained with optimal N application - illustration on wheat crop preceded by wheat





Controlled situations *Uncontrolled situations*