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A conceptual model of farmers' decision-making process for nitrogen fertilization and irrigation of durum wheat

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ABSTRACT

With a 2 millions of tons production, France is the second country in the European Union to produce durum wheat. Durum wheat production requires high grain nitrogen concentration. Irrigation and nitrogen fertilization must be managed simultaneously to maximize grain yield and also avoid low protein concentration and environmental impacts. To help advisors and farmers to better manage together these two agricultural operations and to develop innovative managements, developing a biodecisional model is an interesting possibility. However, knowledge is still missing on how farmers already managed these operations and how these two operations are linked. We developed the conceptual model for the decision part of this computer model. We performed a survey of 28 farmers conducted over the five French production areas investigating a diversity of growing conditions to identify the set of possible constraints and farmers' decision rules. To analyze the survey, we first used a general inductive approach on individual cases and then built a conceptual model of the decision with a bottom-up approach. We identified four decision sequences for fertilization (N splitting, choice of N fertilizer, rate of application, fertilization triggering) and five for irrigation (irrigation period, anticipated number of irrigation cycles, irrigation cycles organization, irrigation triggering and irrigation cycle specificities). For each operation, the first three decision sequences refer to strategic decisions. The other decision sequences refer to tactical decisions. Coupling this model with a crop model could provide guidelines for managing durum wheat in the current climatic and economic changing context.

1. Introduction

With a production of two millions of tons, France is the second country in the European Union to produce durum wheat (FranceAgriMer, 2010). Durum wheat production requires high grain nitrogen concentration for transformation into pasta and semolina, which is its only market (Di Fonzo et al., 2000; Troccoli et al., 2000). Nitrogen (N) fertilization ensures that farmers obtain production that satisfies this characteristic (Haberle et al., 2008). However, since water deficit reduces grain yield (Eck, 1988), irrigation might also be required to ensure an economically profitable grain yield for farmers in certain regions. This may become a major issue due to climate change. Several negative effects of irrigation could be (i) decreased grain protein content through dilution of N with carbohydrates if N availability is not adequately increased (Eck, 1988;Guttieri et al., 2005) and (ii) increased risk of N leaching if badly managed. Irrigation and N fertilization must be managed simultaneously to maximize grain yield production and to avoid low protein concentration and environmental impacts (Saint Pierre et al., 2008).

To analyze the combined effects of crop management practices, a valuable option is to couple a biodecisonal model and a biophysical model with a decision model of farmer decision-making processes (Loyce and Wery, 2006; Bergez et al., 2010). Examples of such published models are MODERATO to manage maize irrigation (Bergez et al., 2001); IRRIGATE to manage furrow irrigation and hay making for pasture (Merot and Bergez, 2010); and, DECIBLE to manage tillage, sowing and fertilization of winter wheat (Aubry et al., 1996; Chatelin et al., 2005). Several studies on durum wheat fertilization (Aubry et al., 1998; Agreste, 2004; Agreste, 2008) already exist. Most of these studies focus on describing technical operations, but how farmers make decisions is rarely explained (Aubry et al., 1998). Because durum wheat is seldom irrigated (Morardet et al., 1998), little knowledge is available about

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its irrigation (Deumier et al., 2008). No study exists that examines how farmers simultaneously manage irrigation and N fertilization in durum wheat cultivation.

The goal of our study is (i) to identify on-farm practices concerning N fertilization and irrigation management of durum wheat, (ii) to identify whether farmers simultaneously manage these two operations, (iii) to propose a conceptual decision model of technical operations for irrigation and fertilization of durum wheat based on decision rules, and (iv) to scheme the links with a biophysical model. The study lies within a larger project that aims to develop a biodecisional model for irrigation and N fertilization for durum wheat cultivars.

2. Materials and methods

2.1. Theoretical framework

We are interested in identifying and formalizing the technical decisions concerning irrigation and N fertilization management of durum wheat. The technical operations performed on a crop during a cropping year (i.e., from the harvest of the previous crop to that of the current crop) are organized in an ordered interrelated sequence called a "crop management sequence" (Sebillotte, 1974). Modeling crop management decision-making at the field level implies including (i) temporal relations between the technical operations of a crop management sequence, (ii) rules based on crop development and states of the environment that determine when to implement a specific operation, and (iii) optional operations performed based on predictions of the biophysical crop model. In reality, the effects of a single technical operation on a crop and the soil depend on what previously occurred and what will subsequently occur (Boiffin et al., 2001). For example, applying more N fertilizer implies more protection against fungi because of more leaf area development (Meynard et al., 2002). Some technical operations are mandatory (e.g., sowing), while others are optional. Farmers perform them based on observation and assessment of the crop, the climate and the soil. For instance, the number of irrigation applications scheduled at the beginning of a cropping year are later performed (or not) based on soil moisture and crop-development stage (Bergez et al., 2001; Mérot and Bergez, 2010).

In addition, each technical operation must be performed during a period defined by crop development, the state of the environment, and the farmer's objectives (e.g., expected yield or quality, environmental management) (Aubry et al., 1998). Each operation has an optimal starting date, before which it would not help meet objectives, and an optimal finishing date, by which the farmer wants the operation finished. Since some constraints (e.g., adverse climatic conditions, mechanical breakdown, competition with other tasks that must be completed at the same time) can preclude performing the operation during the optimum period (Sebillotte and Soler, 1990; Papy, 2001), farmers also determine less optimal dates (either for starting or finishing) and create a time window to accomplish the operation (for examples, see flax harvesting in Joannon et al. (2005) or maize sowing in Maton et al. (2007)).

Sebillotte and Soler (1988) proposed the "model for action" to represent farmers' technical decision-making processes. The model for action is composed of (i) one or several general objectives that guide technical decision making, (ii) an anticipated planning schedule of the technical operations that must be conducted to reach the objectives, and (iii) a set of decision rules and indicators designed to run the operations (Sebillotte and Soler, 1988). For annual crops, this approach was used successfully to represent the management of winter wheat (Aubry et al., 1998) and cotton (Dounias et al., 2002). We use this theoretical framework to analyze the survey and to design our conceptual model.

2.2. Study areas and survey

We investigated a diversity of growing conditions to identify the set of possible constraints and farmers' decision rules. In France, durum wheat is grown in five production regions: the Centre region (C), Poitou-Charentes (PC), the Midi-Pyrenees (MP), Languedoc-Roussillon (LR) and the Provence-Alpes-Cotes d'Azur region (PACA) (Fig. 1A). C is the coldest region during spring, with the lowest evapotranspiration (E_o). The water deficit ($P - E_o < 0$) starts in April and is the lowest of the five regions. PC has a maritime climate with a cool and rainy winter and spring, and the water deficit starts in May. Winter in MP is cool and humid. Spring and early summer are hot and humid, and the water deficit starts in March. PACA and LR have a Mediterranean climate with hot and dry summers. The water deficit is strong and starts in February.

These five regions have varying growing conditions and water constraints in crop management. To choose the farms in the regions, a second criterion was included: the availability and amount of water dedicated to durum wheat.

Following the Case-Based Analysis protocol (Eisenhardt and Graebner 2007; Yin 2013) we selected the surveyed farmers in order to enhance the diversity of production systems instead of focusing on a statistical representation. Following a literature review to analyze the conditions of durum wheat production, a list of factors that may affect fertilization and irrigation was proposed to regional agricultural advisors. These criteria were then ranked by relevancy depending on geographical areas. The first three main criteria were identified as key selection by region. Agricultural advisors then provided a list of farms meeting the different criteria. After verification by a first telephone survey, six farmers were randomly interviewed in C, PC and MP and five in LR and PACA making the sample size 28 farmers (Fig. 1B). The interview was semi-structured and organized into three phases. The goal of the first phase was to identify farmers' production objectives for durum wheat cultivation and major production system constraints that influence durum wheat production. Questions were asked about farmers' general production objectives, type of crop production, land, equipment and water resources. The second phase of the interview focused on N fertilization and irrigation management. Farmers were asked to place technical operations on a timeline and describe their irrigation and N fertilization practices. The third phase consisted of making explicit the choice made to conduct the operation and identifying the different indicators considered. The interviewer asked farmers to comment on how they make decisions, what information they use, and the operations to accomplish when an option is selected.

2.3. Analysis of interviews and conception of the decision model

To analyze the survey, we first used a general inductive approach on individual cases and then built a conceptual model of the decision with a bottom–up approach (Blais and Martineau, 2006). In the first step, we created individual monographs comprising items from the multiple parts of the "model of actions". The individual monographs were sent to each farmer for modification and validation. Twenty-two farmers out of 29 returned the monograph as validated. The remaining seven farmers did not return the monograph. However we kept their monograph as valid.

The second step consisted of the illustrative representation of the technical operations encountered in each studied region along a unique timeline per region. Based on an illustrative representation of practices of one or more previous farmers, the practices of the current farmer were reported, with emphasis on similarities and differences between those of the previous farmers. The process was repeated as many times as there were farmers surveyed by region. This step helped to identify decisions common to several farmers,