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Research paper

Factors of winter wheat yield robustness in France under unfavourable weather conditions

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ABSTRACT

To face increasing uncertainties, future farming systems must be sustainable not only under average conditions but also in extreme climatic and economic situations. Various concepts such as stability, robustness, vulnerability or resilience have been proposed to analyze the ability of agricultural systems to adapt to changing production conditions. The operational effectiveness of these concepts remains nevertheless limited. In this paper, we developed an original analytical framework allowing characterizing and quantifying crop yield robustness, as well as identifying agricultural practices linked to cropping systems differentiated according to their robustness pattern. This framework was applied to 2300 bread wheat plots belonging to 145 cropping systems in various regions of France over the period 2011–2014. The analysis was performed at the scale of the cropping system. In a first step, we defined a regression statistical model allowing us to link wheat yield variability to an index of abiotic perturbations constructed using the STICS agronomic model; the cropping systems were taken into account through the use of dummy variables. In a second step, the different cropping systems were positioned within four quadrants using the regional average wheat yield in conditions of average abiotic perturbations and the regional average estimated robustness to abiotic perturbations as cut-offs for the quadrants. In a third step, the cropping systems of the different spaces defined by the four-quadrant approach were compared on the basis on three types of agronomic practices, i.e., management intensification, rotation and heterogeneity practices. Empirical results show that abiotic perturbations had an impact on wheat yield variability. This impact differed from one system to another which means that there is a "cropping system effect" of abiotic perturbations on wheat yield robustness. Several agronomic practices allowed differentiating high *versus* low wheat yield cropping systems. High yield cropping systems relied more intensively on chemical inputs (fertilizers and pesticides) and used more diversified rotations, with more frequently legumes as preceding crops and a lower frequency of cereals. Fewer agronomic practices allowed differentiating robust *versus* sensitive wheat cropping systems. In addition to the sowing date (later for robust systems) and the sowing density (greater), these practices were essentially linked to spatial adjustments of the sowing date, total pesticide use, variety earliness at heading stage and variety disease resistance.

1. Introduction

Even if hunger is primarily a question of insufficient access to food due to poverty, and even if there is currently enough food worldwide for a sufficient diet for everyone, there is a consensus that global demand for agricultural products will rise significantly by 2050, e.g., by 60% with respect to 2007–09 levels according to the FAO (Alexandratos and Bruinsma, 2012), under the combined effect of demography, urbanization and economic development. As in the past, the increased demand for food is projected to be satisfied mainly through productivity gains with much more modest changes in crop area and livestock numbers (Godfray et al., 2010). For example, according to the OECD/FAO agricultural outlook 2016–2025, yield improvements should account for 80% of the crop output increase in the next decade (OECD/FAO, 2016). A large part of the huge rise in agricultural production and productivity across the second half of the 20th century can be attributed to the massive use of chemical inputs, notably mineral fertilizers and synthetic pesticides (Kropff et al., 2001). However, increasing environmental and health concerns associated with the intensive agricultural production model are prompting more and more

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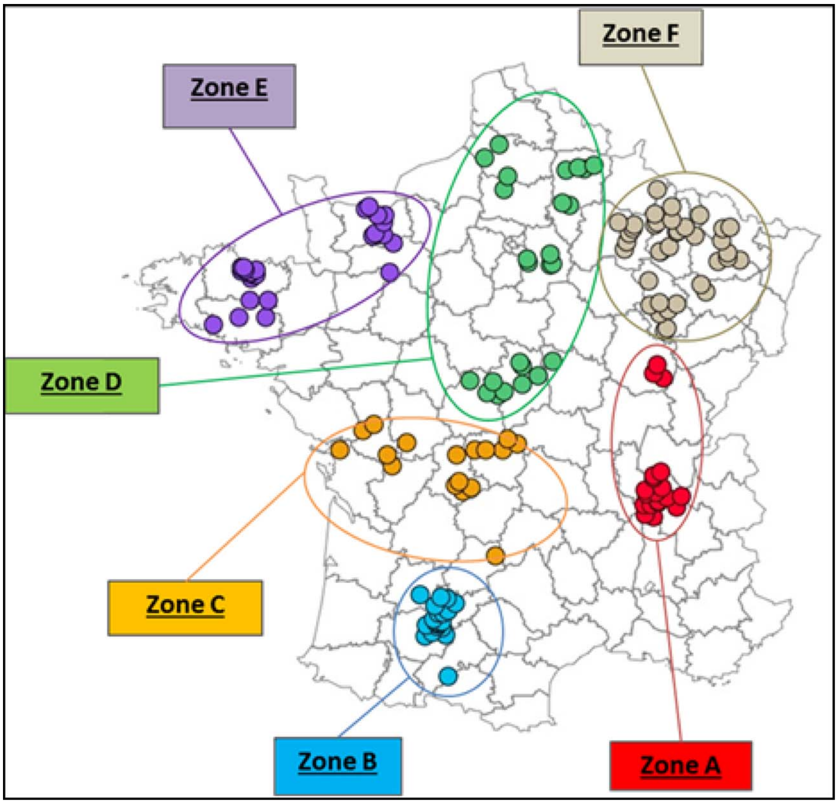

Fig. 1. Geographical distribution of the 145 farms in six geographic regions.

research, development, and innovation efforts to define and promote more sustainable farming practices and systems. In many countries, these efforts are accompanied by public policies aimed at reducing synthetic pesticide use, nitrate leaching, fossil-fuel energy consumption, biodiversity loss, etc. (Underwood et al., 2013). This is notably the case in the European Union (EU) Member States (MS) within the framework of the successive reforms of the Common Agricultural Policy (CAP).

In this context, considerable debate exists as to whether these alternative farming practices and systems offer better productive, environmental, public health, economic and social outcomes. This can be illustrated by the expanding literature on organic farming performances: since crop yields are generally lower in organic farming than in conventional agriculture (De Ponti et al., 2012; Seufert et al., 2012), more land is required to produce the same amount of food, leading to unambiguous environmental benefits on a per-hectare basis but more ambiguous gains on a per-unit of product basis and when land use changes are taken into account (Tuomisto et al., 2012). In addition, there are growing concerns about the ability of agricultural systems, whether alternative or conventional, to resist and adapt to unpredictable conditions, such as abnormal weather or economic shocks (Naylor, 2008; Darnhofer et al., 2010).

Various concepts such as stability, robustness, vulnerability or resilience have been developed and applied to assess the ability of agricultural systems to maintain or recover functionality in challenging environments. These concepts have been used both as equivalent notions (National Research Council, 2010) and as ideas to be combined to arrive at a more comprehensive and integrated approach (Callo-Concha and Ewert, 2014). Following Urruty et al. (2016) which provided a literature review of the similarities and differences of these four concepts within the agricultural context, this paper uses the concept of robustness as the latter corresponds to the ability of a system and its components (crops, varieties, herds, animals, *etc.*) to maintain performances in the face of perturbations (ten Napel et al., 2011; de Goede et al., 2013; Urruty et al., 2016). Based on ecological principles, the outstanding management strategy cited in the literature to reduce the impacts of weather variability on crop yields is to increase agroecosystem diversity, including temporal and spatial diversity (Tilman et al., 2006; Lin, 2011; Wezel et al., 2014; Altieri et al., 2015). Although the idea of building robustness has been studied in various agroecosystems including livestock production systems (ten Napel et al., 2011) and grassland agroecosystems (Sabatier et al., 2013), it has not been well studied with respect to individual crops. In this paper, we focus on winter wheat yield in cropping systems in France over the period 2011–2014. We designate as more robust those systems with lower variations or losses in yield in response to specific weather patterns.

Winter wheat (*Triticum aestivum*) is the most important annual crop in France. The increased frequency and magnitude of adverse agroclimatic events are considered a major threat for wheat production in Europe including France (Trnka et al., 2014). Although many studies have described the effects of wheat management practices and crop rotation characteristics on average yield (Easson et al., 1993; Meynard et al., 2003; Brisson et al., 2010), to our knowledge no one has attempted to explicitly analyze their effects on yield robustness, especially under unfavourable weather conditions. Understanding the role of agricultural practices on crop yield response to environmental perturbations may help in the design of cropping systems able to maintain high yield under abnormal weather scenarios.

To address this question, we used wheat yield, weather, and agronomic data obtained from a large farm network in France surveyed over the period 2011–2014. Yield robustness was studied through an analytical framework that links wheat yield to weather conditions expressed as an index of abiotic perturbations. The framework allowed us to test whether yield sensitivity to abiotic perturbations differs from one cropping system to another. Next, we divided the different cropping systems into four quadrants on the basis of their yield under average weather conditions (high *versus* low yield) and yield robustness to