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Yield losses on wheat crops associated to the previous winter crop: Impact of agronomic practices based on on-farm analysis

Sebastián R. Mazzilli*, Oswaldo R. Ernst, Vanesa Pereira de Mello, Carlos A. Pérez

Facultad de Agronomía, Estación Experimental Mario Alberto Cassinoni, Universidad de la Republica. Ruta 3, km 363, Paysandú 60000, Uruguay

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ABSTRACT

Wheat is one of the most important cultivated cereals worldwide. In Uruguay, the area increased from 153.000 ha to 453.000 ha between 2004 and 2012, nowadays representing 80% of the total winter crops area. As the high area of the crop, is common planting wheat in a field with wheat as previous winter crop ("wheat after wheat"). This practice leads to a high inoculum pressure of necrotrophic pathogens which guarantees disease inoculation mainly of *Pyrenophora tritici-repentis* (tan spot—TS) and *Zymoseptoria tritici* (septoria leaf blotch—SLB). There is strong evidence that integrated crop management practices such as nitrogen (N) fertilization, genetic resistance to leaf diseases and fungicides could mitigate yield losses associated with monoculture. However, the impacts of integrated technologies based on actual field data have not been reported before. We based our study in an on-farm wheat yield and management database to assess the previous winter crop effect on wheat yield under no-till systems. This database corresponds to a set of farmers grouped in CREA (Consorcio Regional de Experimentación Agrícola). A complete database of 1292 no-till wheat fields was analyzed. The effect of previous winter crop on yield and the impact of different technologies were estimated based on two approaches: (i) yield quartile analysis and (ii) yield frontier analysis. The crop rotation had a significant impact on yield. The practice of growing "wheat after wheat" was associated with a yield loss of ca 500 kg ha^{-1}. The selection of a diseases resistant cultivar under "wheat after wheat" fields increases yields in ≈700 kg ha^{-1}. The percentage of fields with an efficiency higher than 80% improved from 49 to 77% when a resistant cultivar to TS and SLB was selected, and when N fertilizer was applied earlier and in higher rates. Unexpectedly, only 18% of the "wheat after wheat" fields are applying these two technologies in scenarios under high inoculum pressure. This study, based in on-farm data, highlights the relevance of integrated disease management, and remarks the potential of this approach to minimize the interference of foliar diseases in fields with high inoculum pressure of stubble-borne pathogens.

1. Introduction

Wheat is one of the most important cultivated crops worldwide, being spring wheat the major winter crop grown in South America. Particularly in Uruguay, the area allocated to wheat production increased from 153.000 ha in 2004 to 453.000 ha in 2012. In this country, spring wheat represents 54% of the total area planted with field crops and 80% of the total winter crops (DIEA, 2013). Agriculture in Uruguay is characterized by double cropping under no-till system, having wheat, barley, oat and canola as winter options, and sorghum, corn and soybean as summer crops (Garcia-Prechac et al., 2004; DIEA, 2013; Franzluebbers et al., 2014). Despite the diversity of field crop species in the country, double cropping with spring wheat for winter season and soybean for summer season is predominant, with an important part of the area planted in the presence of plant residues of the same species (DIEA, 2013), specially for wheat residues as remain in the field despite the summer crop (mostly soybean) grown during the summer in the same field (Ernst et al., 2002). Thus, field crop health is threatened by high inoculum pressure of necrotrophic pathogens that can survive in crop residues located at the soil surface, next to the emerging crop, ensuring inoculation (Bockus and Claassen, 1992; Carignano et al., 2008; De Wolf et al., 1998; Fernandez et al., 2009; Perez et al., 2009; Suffert et al., 2011).

* Corresponding author. Fax: +598 47227950.
E-mail addresses: smazzilli@fagro.edu.uy, sebastianmazzilli@gmail.com (S.R. Mazzilli).

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This new scenario has favored wheat foliar diseases caused by stubble-borne pathogens associated such as *Pyrenophora tritici-repentis* (tan spot) and *Zymoseptoria tritici* (septoria leaf blotch), along with head diseases caused by *Fusarium* spp. (Fusarium head blight) in Uruguay (Pereyra and Dill-Macky, 2008; Perez et al., 2009, 2011) and worldwide (Carignano et al., 2008; Fernandez et al., 2009; Fischer et al., 2002; Jørgensen and Olsen, 2007; Simón et al., 2011). Several authors analyzed the impact of sowing on the presence of stubble of the same species (Bailey et al., 2000, 2001; Duczek et al., 1999; Kutcher et al., 2011). The benefit of crop rotation for wheat production has been well reviewed by Kirkegaard et al. (2008). Crop rotation or the inclusion of a "break crop" into the rotation provides several benefits beyond its direct impact on inoculum density. Soil structure, water and nutrients availability, soil biology, and allelopathy are some variables primarily associated with those benefits (Kirkegaard et al., 2008).

However, when wheat is planted after wheat as the previous winter crop ("wheat after wheat"), some complementary practices were identified to mitigate yield loss. These practices include nitrogen (N) management (Cox et al., 1989; Bockus and Davis, 1993; Roberts et al., 2004), the selection of wheat cultivars that are resistant to leaf diseases (Carignano et al., 2008), and the use of foliar fungicides (Elen, 2002; Carignano et al., 2008). Despite the identification of these variables and their potential effect on yield, to our knowledge there is no literature that quantifies the interaction of these variables, especially under commercial farm conditions. Regardless the known detrimental effect of monoculture on wheat yield, in Uruguay wheat is frequently grown on wheat stubble from the previous year under no till system. We hypothesized that because farmers do not have many profitable winter crops options, they reduce yield losses by combining complementary management practices that mitigate the detrimental effects of wheat monoculture. Therefore we explored the analysis of available on-farm wheat yield and management dataset to assess the previous winter crop effect on wheat yield under no-till systems. Specific objectives of this study were to: (i) estimate the actual yield gap between "wheat after wheat" and wheat planted after other winter crops or winter fallow, and (ii) assess the impact of agronomic practices on the yield of commercial "wheat after wheat".

2. Materials and methods

2.1. Database description and analysis

The database used in this study was obtained from data that belong to a set of farmers grouped in CREA (Consorcio Regional de Experimentación Agrícola, i.e., farmers who join to discuss agronomic and business aspects). Every CREA group belongs to a major organization named FUCREA (Federación Uruguaya de Grupos CREA). A complete database of 1292 wheat fields was analyzed, all of them under no-till systems. Data was collected over four consecutive seasons (from 2008 to 2011). Collected data included: geographic zone (North, South, Center and others), field identification, previous winter crop (PC_W), previous summer crop, cultivar, crop fertilization (type of fertilizer, timing and dosage), crop protection management (type of fungicide, timing and dosage) and grain yield. The total amount of nitrogen (N) applied was estimated based on the amount of fertilizer applied. For fungicide spraying, the number of days from sowing until the first application and the number of applications in each field were considered. Varieties were grouped for resistance to *P. tritici-repentis* (tan spot) and to *Z. tritici* (septoria leaf blotch) based on the official characterization performed annually by INASE (Instituto Nacional de Semillas) (http://www.inia.org.uy/convenio_inase_inia/resultados/index_00.htm).

The effect of previous winter crop on yield and the impact of management practices were estimated based on a descriptive approach: (i) yield quartile analysis and a statistical approach (ii) yield frontier analysis.

2.2. Yield quartile analysis

The database was ordered by yield and separated in quartiles (323 data per quartile). Then, the fields were grouped according to the previous winter crop: wheat or others. The estimations for each group included the number of fields in each group, the average and range of yields, the average sowing date (expressed as Julian day), the percentage of fields planted with cultivars susceptible to septoria leaf blotch (caused by *Z. tritici*) and to tan spot (caused by *P. tritici-repentis*) (according to the classes described below), number of days until first fungicide application, number of fungicide applications, number of days until the first N application and total N applied.

2.3. Frontier analysis

The stochastic frontier production function represents the maximum attainable output for a given set of inputs. This function describes the relationship between inputs and outputs, and can also be used to estimate the highest yield attainable with a specified input combination (Neumman et al., 2010). The ratio among observed data and the frontier production function indicates the relative yield obtained compared with the highest yield achievable under each input combination. This index ranges between zero and one, and is defined as the "technical efficiency". Several authors have applied frontier production functions to estimate economical farm efficiency (Battese, 1992; Battese and Broca, 1997; Iraizoz et al., 2003), inter-country agricultural yield differences (Kudaligama and Yanagida, 2000; Carberry et al., 2013), and yield spatial variations and production efficiencies within a region (Neumann et al., 2010).

We applied a stochastic frontier production function to estimate the effect of previous winter crop on the technical efficiency for yield. The frontier production was estimated using the static software "Frontier Analysis" (Frontier v 4.1c) (Coelli, 1996). Variables representing crop growth factors define the maximum yield that could be obtained in each field and they were included as independent variables in the frontier function. They represent weather conditions (season, geographic zone, and sowing date) and yield potential (cultivar and total N fertilizer). Following Lobell et al. (2009), the sowing date was introduced as days outside the optimal (DOO). The optimal sowing range for each cultivar was estimated from the database plotting sowing date *vs.* yield for each year and cultivar, and selecting the range where yields were the highest. We used upper asymptotes or "more is better" up to a threshold value range above which "lower is better" (Liebig et al., 2001).

Inefficiency of production represents limiting factors, being causes the observed yield to lie below the frontier production function. Three limiting factors integrated the inefficiency function: the presence of wheat in the previous winter season (PC_W) (wheat = 1 and no wheat = 2), cultivar resistance to tan spot (TS), and cultivar resistance to septoria leaf blotch (SLB) (1–5 where 1 = resistant and 5 = highly susceptible).

The stochastic frontier production function was estimated as:

$$\mathrm{Ln}(\mathrm{Ya}_i) = \beta_0 + \beta_1 \mathrm{Ln}(\mathrm{DOO}_i) + \beta_2 \mathrm{Ln}(\mathrm{NT}_i) + \beta_3 \mathrm{Ln}(\mathrm{Year}_i) + \beta_4 \mathrm{Ln}(\mathrm{Zone}_i) + \beta_5 \mathrm{Ln}(\mathrm{Cultivar}_i) + (\mathrm{v}_i - \mu_i) \quad (1)$$

where

Ya_i = actual wheat yield (kg ha^{-1}) of the ith field (i = 1, 2, ..., 1292)
DOO = days outside the optimal sowing range