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Evaluating wheat yield potential determination in the Argentine Pampas

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Abstract

The Argentinean Pampas are considered among the most productive areas of the world. However, few research has been done to explore its potential and constraining factors for wheat production. The objective of this paper was to evaluate variability of wheat *yield* and *yield* components potential in the Pampas. For this purpose, a modelling approach was used using 30 years climatic series of various locations distributed along the Pampas. Two biologically founded assumptions related to wheat *yield* determination were used: (1) potential grain number (GN) is associated with a photothermal quotient (PTQ); and (2) potential grain weight (GW) depends on mean temperature during the grain filling period (TGF). Mean wheat *yield* potential in the Pampas varied between 5000 kg ha^{-1} in northern locations to 7300 kg ha^{-1} in southern ones. GN showed greater variability than GW both, among locations (spatial scale) and years (temporal scale). Anthesis date appeared as a strong *yield* potential determinant factor; A 10-day delay in anthesis date produce substantial changes in GN and GW, depending on location *latitude*. This was related to the specific combination of crop phenological development and *radiation* and temperature changes in the region. A temporal decrease in PTQ during the period 1971–2002 was observed. This decrease was more associated with a *radiation* decrease than with a temperature increase during this period. TGF did not show any trend during the same period. The importance of estimating wheat *yield* potential *yield* and yield-gap reduction is discussed.

Keywords: Wheat; Pampas; Photothermal quotient; Yield potential; Temperature; Radiation; Grain number; Grain weight

1. Introduction

The Argentinean Pampas is one of the major grain production regions in the world (Loomis and Connor, 1992). It is a flat area that extends over 52 Mha from 29°S to 39°S and from 57°W to 65°W. Although it is considered a uniform region, soil type, *temperature*, *radiation* and *rainfall* show great variability (Hall et al., 1992). In the Pampas, wheat crops are sown over almost 6 million hectares along the whole region (Satorre and Slafer, 1999) and 14 million metric tons are produced, on average every year. Despite its importance, few research has aimed to analyse the variability of factors determining wheat *yield* potential at a regional scale.

Crop *yield* potential is an estimate of the maximum producing capacity of a region. It is defined as that attainable when no nutrient or water limitations occur (Van Ittersum and Rabbinge, 1997). Under such conditions, incident radiation (iR), temperature (T) and physiological and phenological crop genotype characteristics determine *yield* potential. Soil characteristics such as depth, texture or chemical properties and other crop management conditions are therefore not taken into account when crop *yield* potential is explored.

Yield determination of extensive crops, such as wheat, has been frequently analysed considering its numeric components, i.e. grain number per unit area (GN) and individual grain weight (GW). Separating the effects of

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environmental variables on numeric components in the analysis of crop *yield* determination is relevant since there are differences both in the time during crop cycle when these components are defined and in their control variables.

Functional and robust relationships between *yield* components and environmental factors have been used to assess differences in grain crops *yield* (e.g. Fischer, 1985; Cantagallo et al., 1997). In the case of wheat, both temperature (T) and absorbed radiation (aR) during the spike growth period have been shown to affect *grain number* (Slafer et al., 1990). The amount of aR determines the amount of energy available and crop growth rate, while T governs the duration of the spike growth period, further determining the effective amount of *radiation* captured by the crop (aR). Thus, variations in *kernel number* have been interpreted from the photothermal quotient, i.e. the ratio between aR and mean T above a base *temperature* during the spike growth period (Nix, 1976; Fischer, 1985; Savin and Slafer, 1991; Magrin et al., 1993; Abbate et al., 1997). Furthermore, Savin and Slafer (1991) showed that the photothermal quotient in the period from 20 days before to 10 days after anthesis could be used as a good estimator of a wheat critical stage (i.e. the spike growth period, during which the kernel number is determined) for crops growing in temperate regions. In *yield* potential analysis, incident radiation (iR) is used instead of aR in the calculation of photothermal quotient because an implicit assumption of canopy full interception is done. This assumption becomes valid since no other factor than *radiation* or *temperature* is considered to affect wheat growth and time between sowing and the beginning of the spike growth period is suppose large enough to achieve complete *radiation* interception of iR.

Wheat individual *grain weight* depends on the rate of grain filling and the duration of grain filling period. Many authors have shown that, during this phase, wheat is mainly sink limited (Borrás et al., 2003) and aR has relatively small or null effects on *grain weight*. However, T is one of the factors constraining large individual *grain weight* (Wardlaw et al., 1980; Stone and Nicolas, 1995; Gooding et al., 2003). High T increase the grain filling rate, but this does not compensate the reduction in the grain filling period duration that wheat crops experience under high *temperature* conditions (Wardlaw et al., 1980). Consequently, individual *grain weight* may be expressed as a negative function of T during the grain filling period.

To the best of our knowledge, Magrin et al. (1993) have published the only work referring to the estimation of wheat *yield* potential in the Pampas. They characterized the spatial and inter-annual variations in the potential *kernel number* of wheat at four locations between 31°S and 37°S in the Pampas. They showed that the potential *kernel number* may vary between 3500 and 17,000 grains m^{-2} and that photothermal quotient was strongly correlated with maximum yields. Furthermore, photothermal quotient was identified as the main source of *yield* variation between the studied locations in the same year and among years in the same location. Their work explored a narrow set of conditions and factors limiting the potential individual kernel weight were not analysed. Therefore, the objective of our work was to estimate wheat *yield* potential and wheat *yield* potential variability in the Argentine Pampas, exploring the relative importance of its numeric components and the influence of the main factors affecting them. For this purpose a modelling approach was used using 30 years of weather data from various locations along the Pampas.

2. Materials and methods

2.1. Methodological framework

The work was based in two biologically founded assumptions related to wheat *yield* determination. Potential *grain number* is strongly associated with a photothermal quotient calculated in the crop critical stage and potential *grain weight* depends on mean *temperature* during the grain filling period. Therefore, a three steps approach was used to estimate wheat *yield* potential. The photothermal quotient, the mean *temperature* during grain filling and their inter-annual variability were estimated. Potential *yield* numerical components were then calculated, i.e. *grain number* and *grain weight* were estimated from the photothermal quotient and the mean *temperature* during grain filling period. Finally, grain *yield* potential was estimated from GN and GW values.

The analysis was done using series of daily weather data (30 years) of 15 locations covering almost the whole region (Fig. 1).

In two out of the three steps of this methodological framework the CERES-Wheat simulation model (Ritchie et al., 1985) was used for different purposes (see below for details). CERES- Wheat predicts *yield* of wheat in response to *temperature*, solar *radiation*, soil water and N, but does not account for other soil nutrients, or pest or disease stresses. Briefly, the model uses daily weather (*temperature*, *radiation* and *rainfall*), soil, genotype and crop management data as inputs to predict wheat development, growth, *yield* and numerical components.

CERES-Wheat simulation model has been shown (when appropriately calibrated and evaluated) to be an appropriate tool for the estimation of crop growth and development (Ritchie and Ne Smith, 1991; Sinclair and Seligman, 1996). This model uses robust physiological relationships that reproduce crop growth and development under a number of environmental and management conditions. In the Pampas, it has been calibrated and extensively validated for grain *yield* and phenology (Magrin and Rebella, 1991; Calderini et al., 1994a,b; Ruiz et al., 1998; Salvagiotti et al., 2003).

2.2. Estimation of anthesis date and calculation of photothermal quotient and temperature during grain filling

PTQ and TGF were estimated as affected by anthesis date inter-annual variability. To estimate anthesis date for each year and location CERES-Wheat (Ritchie et al.,