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Single and double crop systems in the Argentine Pampas: Environmental determinants of annual grain yield

José F. Andrade*, Emilio H. Satorre

IFEVA-Cátedra de Cerealicultura, Facultad de Agronomía, Universidad de Buenos Aires, CONICET, Avda. San Martín 4453, 1417 Buenos Aires, Argentina

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ABSTRACT

New avenues are being explored to increase food production in the extensive agriculture of highly productive temperate regions. Intensifying the use of land by sequencing two crops in a season (double cropping) may enhance annual land productivity in relation to single annual crops. Single soybean (*Glycine max* L. Merr.) and maize (*Zea maize* L.) are widespread in the Argentine Pampas while wheat (*Triticum aestivum* L.)–soybean double crop system is the most common land-intensive cropping system. The possibility for expanding the double cropping system is large although it has received insufficient attention. The objectives of the present study were to (i) describe the association between major environmental variables and grain yield of wheat–soybean double crop, maize and soybean single crops and (ii) compare their annual grain yield over a wide range of environments as a basis to evaluate the possible contribution to productivity expected from wheat–soybean double crop compared with maize and soybean single crops. Yield data from farms widely distributed across the Argentine Pampas and meteorological information from 30 stations distributed in the region were recorded and analyzed. A five-year period of on-farm yields were obtained from 132 groups of farmers nested in 11 zones. Variables analyzed were crop grain yields, glucose equivalents grain yields, rainfall, temperature, radiation, and frost-free period. The ratio between radiation and temperature (photo-thermal quotient; PTQ) was also considered as a grain yield determinant for wheat. Mean daily temperature during crop reproductive stages was an important determinant of maximum yields for all crops as described by a boundary-function fit. The highest grain yields of maize and soybean were obtained at moderate summer temperatures (21.8–23.5 °C and 21.8–23.8 °C, respectively). Wheat maximum yields increased with low spring temperatures (<18.3 °C), following high photo-thermal quotients during reproductive stages. In contrast, the highest yields of double crop soybean were obtained at high summer temperatures (>21.2 °C), which were associated with extended frost free periods. High yields of the wheat–soybean double crop system were obtained with cool temperatures during spring combined with a relatively extended frost free period and substantial summer rainfall. On-farm yields below the boundary-function appeared associated to low rainfall scenarios, especially in double cropped soybean fields. The geographical patterns of yield for wheat–soybean double crop system tended to be similar to that of maize and soybean single crops. The most highly productive area for the three cropping systems evaluated was located in the center of the Argentine Pampas. However, wheat–soybean double crops were more productive than soybean at any site, but their yields were slightly lower than those of maize. In addition, the work helped to identify possible areas where wheat–soybean double crop system may give relative higher advantages; particularly, in some of the currently least productive areas. Since nowadays, almost 60% of the studied area is sown with single soybean, the results suggest that there is an effective possibility to have a substantial increase in on-farm productivity, while still producing soybean, simply by expanding the double crop system.

1. Introduction

There is consensus that most of the increase needed in food production in the next decades will come from currently exploited agricultural land (Hall and Richards, 2013). Genetically improved varieties and changes in farm management are therefore needed

Abbreviations: PTQ, photothermal quotient; PCA, principal component analysis; PCP, principal component.

* Corresponding author. Tel.: +54 11 4524 8039x31; fax: +54 11 4524 8053.
E-mail addresses: jandrade@agro.uba.ar (J.F. Andrade), satorre@agro.uba.ar (E.H. Satorre).

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to sustainably increase crop systems productivities, including more holistic and complex approaches to decision-making, processes and novel technologies (Satorre, 2000, 2012; Tilman et al., 2002). A relevant, but somewhat unexplored, alternative to achieve these goals is land use intensification. In highly productive temperate areas, the understanding of interactions among environmental factors that define yield variations of both intensified and non-intensified cropping systems is a necessary first step to identify and evaluate possibilities of expansion of land-intensive crop production systems.

Wheat, maize and soybean are among the main few crops on which a great part of world food supply relies (Bunting et al., 1982; http://www.fao.org). The Argentine Pampas is one of the most highly productive areas of food in the world (Loomis and Connor, 1992). Argentina currently contributes 20% of global soybean (*Glycine max* L. Merr.) production, and 2% of both maize (*Zea maize* L.) and wheat (*Triticum aestivum* L.) global production, and it is among the main exporters of grain and products from these crops in the world market. Since the early 90s, there was a significant increase in overall grain production and sown area in this region; i.e. total annual production has almost tripled, from 35 to almost 100 million tons and sown area has expanded from 20 to almost 35 million hectares since then. Wheat, maize and soybean alone explain more than 90% of that production. The area cropped with soybean covers more than 20 million hectares every year, which is approximately 60% of overall cropland in Argentina (http://www.fao.org; http://www.siia.gov.ar). This transformation was partially supported by the adoption of new technologies, such as no-tillage cropping, an increased use of new crop varieties (mostly transgenic), agrochemicals, and fertilizers (Satorre, 2012).

Although regional productivity has increased by expanding the cultivated area with grain crops and by intensifying the use of energy subsidies, the possibilities for continued expansion of croplands within the Argentine Pampas is being reduced. As a consequence, new production avenues are being explored by farmers as an adaptive response to increase productivity and profitability of land. During the last decades, innovative growers intensified the use of land by intercropping different species or by frequently sequencing two crops in a season, i.e. double cropping (Calviño and Monzon, 2009). Land use intensification can enhance annual land productivity because of an increment in resource capture in relation to single crops (Caviglia et al., 2004; Rao and Willey, 1983; Van Opstal et al., 2011), improving the ratio between seasonal grain yield and annual available resources. Due to the amount and distribution of annual rainfall and the extension of the frost free period, it is possible to cultivate a winter crop followed by a late summer crop in a year in almost the entire Argentine Pampas. In fact, wheat–soybean double crop has been extensively practiced since the late 80s and is still the most representative land intensive production system in this region (approximately 2.5 million hectares). However, the proportion of overall area under double cropping has been steadily reduced in the last 20 years, from an estimated 21% to 6.5% in the last year, showing that the increase of sown area was mainly supported by the expansion of single crops. The reduction (http://www.siia.gov.ar) in the area sown to wheat due to internal regulations of grain market and low relative grain prices have also led to a recently less intensified land use in the region. Despite the influence of political, economic or social reasons on the change of cropping systems, environmental factors are a crucial determinant of yield and yield variability. Knowing how these factors affect productivity at a regional scale may certainly help to conduct successful adaptive responses by farmers as grain demand increases.

Both single and double crop system performances are subject to the availability of resources like water and radiation and to the influence of other environmental factors, such as temperature (Asseng et al., 2011; Lobell and Field, 2007; Lobell et al., 2005, 2011; Wang et al., 2014). However, a differential response of each crop to environmental variations could be expected since optimal temperatures for maize and soybean growth are higher than that of wheat (Andrade et al., 1993; Larcher, 1980), whereas wheat is commonly grown under low vapor pressure deficit in the cool season (Satorre et al., 2004), and double cropped soybean is usually sown with low initial water in soil due to wheat previous consumption (Calviño et al., 2003). Analyzing on-farm crops at a regional scale could lead to better understanding of interactions among environmental factors that define crop yield variation. This is necessary to develop a deeper insight into crops performance and identify where land-intensive crop systems are actually better than single crops, as a basis to design and evaluate possibilities of expansion for more land-intensive crop production systems. Despite the fact that the Argentine Pampas appears as a homogeneous region, the influence of environmental factors on individual crop yields may be large and different among crops (Satorre, 2000; Satorre et al., 2004). Moreover, the influence of such factors is expected not only to differ among individual crops but also with respect to double crops. Double crops tend to use more resources than single crops, so we hypothesize that the geographical pattern of double crop yield will tend to be similar to that of the yield of the more productive crops in the region; i.e. being higher the productivity of the wheat–soybean double crop system where more resources and less limiting factors are present. However, since double crops use resources differently from single crops, it is expected that the pattern of relative advantages of double crops will differ from that of productivity from single crops.

The main objectives of this study were to (i) describe the association between major environmental variables and grain yield of wheat–soybean double crop, maize and soybean single crops and (ii) compare their annual grain yield over a wide range of environments as a basis to evaluate the possible contribution to productivity expected from wheat–soybean double crop compared with maize and soybean single crops. For this purpose, yield data from farms widely distributed across the Argentine Pampas and meteorological information were recorded and analyzed.

2. Materials and methods

The studied area covered most of the Argentine Pampas, from 30° to 39°S and from 58° to 65°W. Soils, weather and agricultural management vary greatly across the region. The annual mean temperature ranges from 14 °C to 17 °C in the southern and northern regions, respectively. Annual rainfall varies between 600 and 1000 mm, increasing from south-west to north-east. The most frequently cropped soils in this region are Mollisols, with prevalence of the Typic Argiudoll (Hall et al., 1992; Satorre, 2000). Soils are either sandy or clayey in the north, sandy in the south-west, and loamy or clayey in the south-east (Dardanelli et al., 2004; Hall et al., 1992). In this last area, soils are shallow because of the presence of a petrocalcic horizon (Pazos and Mestelan, 2002).

In Argentina, the private farmer's association AACREA (Argentine Association of Agricultural Experimentation Consortiums; http://www.crea.org.ar) is one of the main sources of information on major cropping systems at on-farm level. In AACREA, professional consultants advise groups of 8–12 farmers (a CREA group) on the basis of both on-farm trials and records of crop, soil, weather and economic data. Along the past 15 years the association, which presently incorporates approximately 3000 farmers and 200 professional consultants, has developed a comprehensive database on local cropping systems that has been instrumental in the analysis of current and novel production techniques (Menéndez and Satorre, 2007; Mercau et al., 2001, 2007).