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Land use intensification in the Rolling Pampa, Argentina: Diversifying crop sequences to increase yields and resource use

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ABSTRACT

Increasing and maintaining high productivity levels presents a major challenge facing farmers today and will continue into the near future. More integrative and complex approaches to decision-making, besides adopting new technologies, are necessary for redesigning more productive, stable, and sustainable farming systems. Thus, novel crop sequences should be implemented to improve these properties of farming systems. The aim of our research was to characterize how different preceding crops that open recurrent sequences will impact on the productivity and resource use of the following crops, in order to determine the possibilities of increasing the frequency of double crops in rotations. Three field experiments were conducted under rainfed conditions at three sites in the Rolling Pampas of Argentina. The effects of seven cropping systems on the productivity of succeeding crops were evaluated at each location. The seven cropping systems included five double crops (rapeseed/soybean, wheat/soybean, barley/soybean, field pea/soybean, and field pea/maize) and two single crops (maize and soybean). The seven cropping systems were followed by the same crop sequence: wheat/soybean double crop and maize single crop in the first and second growing seasons, respectively. Radiation use and grain yield, water use and nitrogen uptake were evaluated for each crop in the sequence. Results indicate that repeating cereal crops in the cropping sequence reduces their productivities, while well balanced sequences that include legumes resulted in the highest productivities of cereal crops. Our findings highlight that diversifying cropping systems by adopting different double crops are practical options that can contribute to a more sustainable intensification of cropping systems specialized for grain crops. Increasing crop diversity in sequence influenced nitrogen uptake, among other factors, and may explain the enhanced crop yield in such systems. Our research highlights that crop diversification is critical in designing efficient and sustainable intensified crop sequences.

1. Introduction

The global capability for producing grain commodities will have to be increased to cope with future demands in the next decades (Bruinsma, 2009; Cassman, 2012; Godfray et al., 2010; Tilman et al., 2002; van Ittersum et al., 2013). Most of the productivity increase needed will come from measures applied in arable lands that are currently under continuous farming (Hall and Richards, 2013). However, being able to achieve and maintain higher productivity levels represents the major challenge that agriculturalists are going to face in the near future (Foley et al., 2005; Bommarco et al., 2013). Besides adopting novel technologies, more integrative decision-making approaches are necessary for redesigning more productive farming systems, which should be stable and sustainable as well (Tilman et al., 2002; Foley et al., 2005; Bommarco et al., 2013). Thus, novel crop sequences are needed to improve such properties of farming systems.

Double cropping has been largely implemented by farmers in many regions around the globe (Fischer et al., 2014), not only because annual land productivity and stubble inputs are increased (Amthor, 2000; Andrade et al., 2015; Caviglia et al., 2004; Calviño and Monzon, 2009; Francis and Smith, 1985; Graß et al., 2013), but also because double crops yields are usually more stable than those of single crops (Andrade and Satorre, 2015; Graß et al., 2013). Increasing the frequency of double cropping in rotations may lead to improve overall land productivity. However, most studies on double cropping are restricted to a single season (Caviglia

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et al., 2004; Graß et al., 2013), and therefore, the consequences of increasing the frequency of double crops in rotations are still uninvestigated.

One of the most widespread double crops in temperate regions around the world is that composed of wheat (*Triticum aestivum* L.) and double cropped soybean (*Glycine max* L. Merr.; Calviño and Monzon, 2009; Cordell et al., 2007; Kyei-Boahen and Zhang, 2006; Mercau and Otegui, 2014; Monzon et al., 2007). In the Argentine Pampas, almost one out of three years is grown with that double crop, usually composing the sequence soybean-wheat/soybean-maize. Since growing wheat or maize in consecutive seasons leads to declines in grain yields (Berzsenyi et al., 2000; Seymour et al., 2012), we hypothesize that including alternative crops, such as rapeseed (*Brassica napus* L.), barley (*Hordeum vulgare* L. var. *Distichum*) or field pea (*Pisum sativum* L.), grown as double crops with soybean or maize (*Zea mays* L.) may allow designing more intensified crop sequences without yield reductions. This is based on recognizing several benefits of crop rotation, such as improving water and nutrient use efficiencies (Reeves, 1994). Moreover, the volume and composition of crop harvest residues may also differentially affect the following crops in the sequence by modifying soil nutrient dynamics (Danga et al., 2009; Domínguez et al., 2005; Kumar and Goh, 1999; Seymour et al., 2012). Also, double cropping increases resource capture and delays the maturity and harvest dates of summer crops (Andrade et al., 2015). For these reasons, it is of interest to compare the effect of single and double crops on the initial conditions and productivity of following crops.

The aim of our research was to characterize how different preceding crops that open recurrent sequences will impact on the annual productivity and resource use of the following crops, in order to determine the possibilities of increasing the frequency of double crops in rotations. In a previous study, the resource use patterns and productivity of various single and double cropping systems were experimentally described in three contrasting sites in the Rolling Pampa, Argentina (Andrade et al., 2015). These opening cropping systems were followed by the wheat/soybean double crop in the first growing season and then by a maize single crop in the second season.

2. Materials and methods

2.1. Sites and environmental conditions

In the Rolling Pampa of Argentina, three field experiments were conducted under rainfed conditions from April 2011 to March 2013. One experiment was close to Junín (34° 23′ S; 60° 48′ W), another in Pergamino (33° 55′ S; 60° 23′ W), while the third was placed next to San Pedro (33° 47′ S; 60° 00′ W) in the Buenos Aires province (see Supplementary Fig. S1 in the online version at DOI: http://dx.doi.org/10.1016/j.eja.2016.09.013). Soils in all locations were Mollisols, deep Typic Argiudolls, with about 3% of topsoil organic matter. However, soil argillic horizons (from 0.4 to 0.8 m depth) largely differed among locations. Clay content in the argillic horizon is high in San Pedro (50% clay; Ramallo series), intermediate in Pergamino (38% clay; Urquiza series), and low in Junín (28% clay; Rojas series; INTA, 1989). These differences define contrasting water storage capacities (Andrade et al., 2015).

Average annual rainfall is similar among the experimental sites (ca. 1050 mm; 1971–2010). Annual rainfall was slightly lower than the historical average during the first experimental season (April 2011 to March 2012), being 879, 920, and 953 mm for Junín, Pergamino and San Pedro, respectively. In the second experimental season (from April 2012 to March 2013), annual rainfall exceeded the historical average, reaching amounts of 1176, 1244, and 1482 mm for Junín, Pergamino and San Pedro, respectively (see Supplementary Fig. S2b in the online version at DOI: http://dx.doi.org/10.1016/j.eja.2016.09.013). Rainfall in both experimental seasons was relatively high during spring and summer (October to March), while it was low during winter (from June to July). However, rainfall in the first experimental season was very low during December, especially in Junín. Rainfall was low during January in the second experimental season, but abundant precipitation during the preceding months prevented crop water stress during summer (see Supplementary Fig. S2b in the online version at DOI: http://dx.doi.org/10.1016/j.eja.2016.09.013). Incident solar radiation was similar for all locations in the first experimental season. Nevertheless, incident radiation differed between sites during the warm season of the second experimental season, when incident radiation was the highest in Junín and the lowest in Pergamino. In addition, Pergamino tended to be the coolest site in both seasons (see Supplementary Fig. S2a in the online version at DOI: http://dx.doi.org/10.1016/j.eja.2016.09.013).

2.2. Experimental design and management

The effects of seven cropping systems established in April 2010 to March 2011 on productivity of crops that follow in rotation were evaluated. The cropping systems consisted of five double crops [rapeseed/soybean (R/SB), wheat/soybean (W/SB), barley/soybean (B/SB), field pea/soybean (P/SB), and field pea/maize (P/MZ)] and two single crops [maize (MZ) and soybean (SB)]. The cropping systems were followed by a sequence composed of wheat/soybean double crop in the first season and followed by maize in the second season (Fig. 1). Details on the productivity and resource use of the seven cropping systems in the preceding season are published elsewhere (Andrade et al., 2015).

A completely randomized block design with two replicates was used in all experiments. Each experiment comprised 14 plots, each measuring 22 m wide and 200 m long (4400 m^2). Thus, each experiment covered 6 ha. Field activities were conducted following regular commercial field operations with typical machinery used by farmers in the region. Hence, no-till sowing system was implemented and crop varieties with high potential yield in the region were cultivated (Table 1). Sowing date, plant density, and row spacing used in the experiments were based on regional recommendations to achieve high yields (Table 1). Crop row spacing varied slightly depending on the planter available at each experimental site.

Soil nutrient status was analyzed (N: $CuSO_4$/Snedd; P: Bray & Kurtz; S: $AcONH_4$ pH 5) 20 days before sowing wheat and maize crops. Fertilizers were applied at sowing in the 2011/2012 cropping season to complement soil nutrient status and fulfill the combine demand of wheat/soybean double crop according to recommendations for the Rolling Pampa (i.e. soil nutrients plus fertilization at wheat sowing: N = 160 kg ha^{-1}; P-Bray > 15 ppm). Double cropped soybean was sown after harvesting wheat crops, later than its optimum date. Soybean seeds were inoculated with *Bradiryzhobium japonicum* before sowing. Following maize crops were sub-fertilized with nitrogen to supply an initial status of 100 kg N ha^{-1} at sowing, considering soil and nitrogen fertilizer. Sub-fertilization was performed in order to amplify preceding crops effects on maize. Weeds, insects, and diseases were maintained below damage thresholds by applying chemical controls using a self-propelled sprayer when necessary. Thus, to prevent *Drechslera tritici* attack, wheat crops cultivated after W/SB received an additional fungicide application (Strobilurin combined with Triazole).

2.3. Sampling and analysis

At least three aboveground biomass samples (1 m^2) were harvest from each plot at maturity by cutting plants at ground level,