Long-term simulation of productivity in crop sequences differing in intensification in the Argentina pampas

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Abstract

Wheat-soybean double crop is the main element of cropping intensification in the southeastern pampas of Argentina. The long-term impact of including double cropping in the entire crop sequence is unknown. Locally calibrated DSSAT models and climatic records (30 years) were used to estimate the yield of crop sequences combining wheat, soybean and maize. Annual glucose yield averaged between 5.9 and 8.7 t ha^{-1}. Intensification, quantified with the intensification sequence index (ISI; #crop per year) increased the average annual yield and its coefficient of variation. Annual glucose yield increased from 10 to 28% with increasing intensification sequence index (ISI = # crops per year). In parallel with the increase in yield, greater ISI resulted in higher coefficients of variation. Broader comparisons indicated both wheat-maize and double cropped wheat/soybean-maize could lead to highest annual yield. Lowest yields were obtained with wheat-soybean and double cropped wheat/soybean-soybean. Simulations highlighted the contributions of wheat to stability and of maize to productivity of cropping systems in the southern Pampas.

Media summary

This study highlighted the contributions of wheat to stability and of maize to productivity of cropping systems in the southern Pampas.

Keywords

Crop rotation, risk management, cropping systems, annual yield, Argentina

Introduction

The skills of farmers in growing individual wheat and soybean crops, combined with suitable infrastructure and markets, have made wheat-soybean double crop the key for intensification of cropping systems in the southeastern Pampas (Caviglia et al. 2004). Field experiments indicated this approach to intensification can improve production and profit per unit time and land area, enhance yield stability, and increase the amount of crop residues (Caviglia, unpublished). As in the majority of temperate agricultural systems, the most widespread crop sequence in our region includes a single crop per year in typical wheat - summer crop (maize, soybean or sunflower) rotations. Therefore, intensification involving wheat-soybean double crop would shift the configuration of current crop sequences, with major production and environmental impacts. The long-term impact of double cropping on annual yield is unknown. For this evaluation, we need to shift from the current criterion of yield per crop to annual yield of the whole crop sequence (Evans 1993). The aim of this paper is to compare the annual yield of cropping sequences of varying degrees of intensification.

Materials and Methods

Crop sequences were simulated using 30-year weather records at Balcarce (37.5? S; 58.2? W; 130 masl). The modelled soil was a 1.60m-depth Typic argiudoll. Details of site, soil, climate and experimental background to this study are in Caviglia et al. (2004). Three pairs of crop sequences were designed to compare sequences with the same crop composition but different degree of intensification through inclusion of wheat-soybean double crop (Table 1, blue sequences). Crop sequences which are widespread in the region or which are feasible were also simulated (Table 1, red sequences). Duration of sequences was evaluated computing each year from 1 May to 30 April.

Table 1. Crop composition, duration and intensification index (ISI, of cropping sequences simulated at Balcarce. W: wheat, S: soybean, M: maize,W/S: sequential wheat-soybean double crop.

Sequence		W/S	W-S	W/S-M	W-S-M	W/S-M-S	W-S-M-S	W-S-W-M	W-M	S-M	W/S-S
Crops	#	2	2	3	3	4	4	4	2	2	3
Duration	(y)	1	2	2	3	3	4	4	2	2	2
ISI[1] (y^{-1})		2	1	1.5	1	1.33	1	1	1	1	1.5

[1]Farahani et al. (1998)

Simulations were done with locally tested DSSAT models using the SEQUENCE mode that continues the soil water balance through the crops in the sequence (Hoogenboon et al. 1999, Thornton et al. 1995). No attempts were made to account for nutrient deficiency or diseases. Sowing date criteria were (a) soil water content higher than 50% field capacity, (b) soil temperature higher than 5 (wheat) or 10?C (soybean and maize), (c) sowing window from 20 July to 15 August for wheat, from 10 October to 15 November for maize, from 10 November to 15 December for soybean as individual crop, and from 20 December to 20 January for sequential double cropped soybean after wheat harvest. Glucose yield was calculated using reported production values for protein, lipids and carbohydrates (Penning de Vries 1972). We analysed the frequency distributions of (i) annual grain or glucose yield of crop sequences, and (ii) maximum attainable yield estimated as the ratio between actual yield of a sequence and maximum recorded yield. Differences among sequences were tested using Duncan test.

Results

Annual glucose yield increased from 10 to 28% with increasing ISI (Table 2, blue sequences). In parallel with the increase in yield, greater ISI resulted in higher coefficients of variation. Broader comparisons indicated both W-M and W/S-M could lead to highest annual yield (Table 2). Lowest yields were obtained with W-S and W/S-S. In sequences containing maize, variation in glucose yield of this crop accounted for most of the variation in the sequence. In sequences with no maize, wheat glucose yield accounted for most of the variation.

Table 2. Simulated glucose yield in different crop sequences at Balcarce

Sequence	**W/S**	**W-S**	**W/S-M**	**W-S-M**	**W/S-M-S**	**W-S-M-S**	**W-S-W-M**	**W/S-S**	**S-M**	**W-M**
Glucose yield (kg ha^{-1} y^{-1})	**7739**[b]	**6039**[de]	**8269**[a]	**7114**[b]	**7065**[bc]	**6394**[cd]	**7440**[b]	**5903**[e]	**6668**[bc]	**8705**[a]

Coefficient of variation (%)	**31**	**12**	**25**	**21**	**20**	**17**	**14**	**20**	**32**	**19**

Glucose yields followed by the same letter are not significantly different at P< 0.05 (Duncan test)

Cumulative frequency of percent of maximum attainable yield was lower in sequences that included W/S than in their counterparts. Likewise, in half of simulated years the sequences including W/S reached at least 65% of attainable yield, whereas their counterparts reached 75-85% of attainable yield; this was a consequence of an improved water balance and better conditions for soybean in single-crop per year sequences. However, because maximum yields were much higher in sequences that included W/S, sequences with ISI > 1 had glucose yield greater than 7000-8000 kg ha^{-1} y^{-1} in 50% of years, whereas their counterparts with ISI=1 only reached 6000-7000kg ha^{-1} y^{-1}. Differences between sequences increased with increasing ISI.

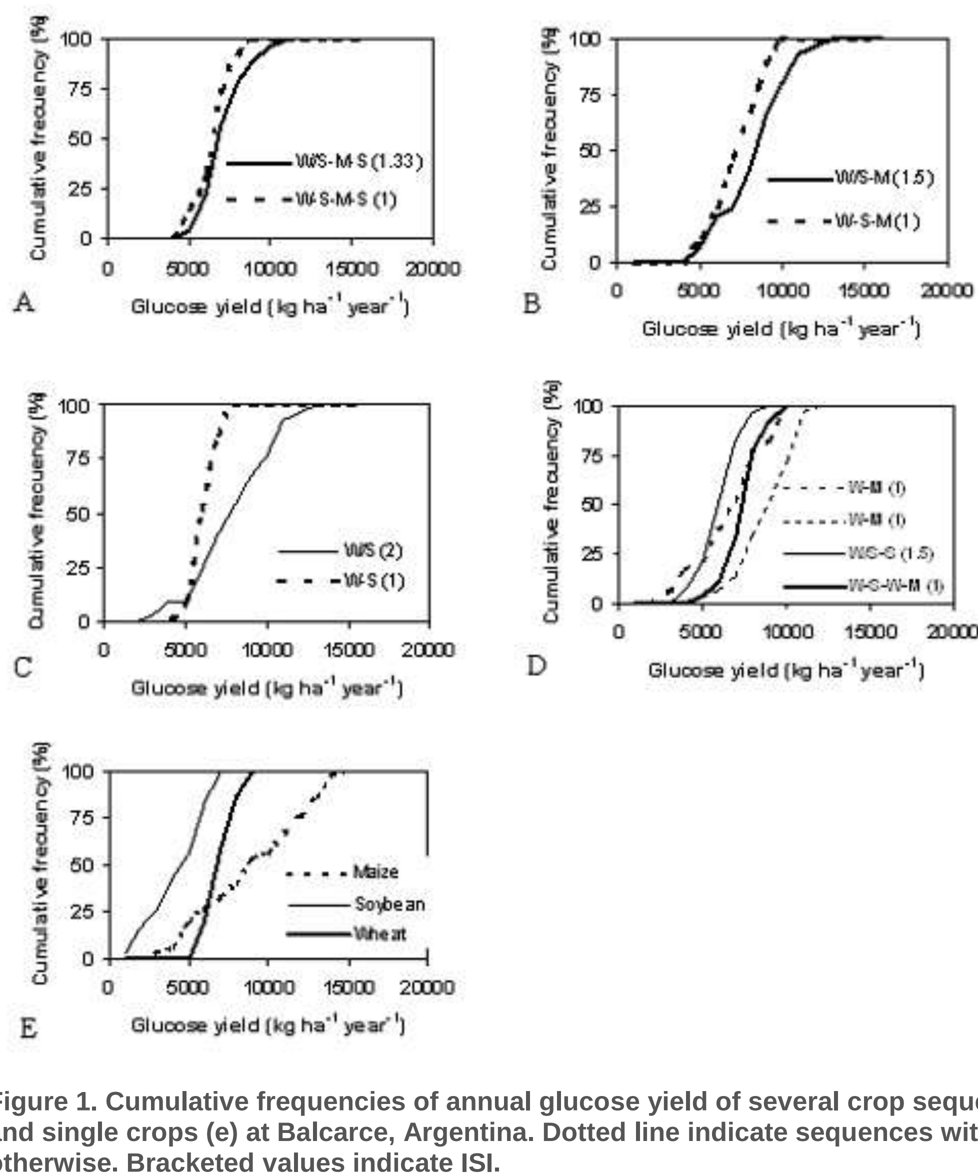

Figure 1. Cumulative frequencies of annual glucose yield of several crop sequences (a, b, c, d) and single crops (e) at Balcarce, Argentina. Dotted line indicate sequences with ISI=1, filled line otherwise. Bracketed values indicate ISI.

In 25% of years, glucose yield of single soybean and maize crops was less than 40% of attainable yield, whereas in half of the years yields were higher than 70%. It is worth noting that yield of single soybean crops was simulated for optimum sowing dates, more adequate to compare with soybean as a single crop per year instead of soybean as a second crop in a year. Glucose yield of wheat monocrop was less than 75% of attainable in only 25% of years, and it was higher than 85% in half of the simulated years; this reflects the large stability of crops in an environment that is regarded as the most productive wheat area of the Pampas.

Sequences S-M and W/S-M had less than 55% of attainable glucose yield in 25% of years, whereas in a half of years they were higher than 70%. More typical sequences of our region (W-M and W-S-W-M) yielded 65-75% of attainable yield in 25% of years, whereas in half of the years attainable yield was higher than 80%, i.e. as higher as wheat monocrop, explaining their widespread adoption (Fig. 1). In 75% of years glucose yield in monocrops were higher than 3000, 6000 and 12000 kg ha^{-1} for soybean, wheat and maize, respectively (Fig. 1). However, maize glucose yield was higher than 8000 kg ha^{-1} in half of the years whereas wheat and soybean were not able to reach that yield. Typical sequences of our region, in turn, yielded more than 6500 and 7500 kg ha^{-1} in 75% of years, whereas W/S-S and S-M only reached 5000 kg ha^{-1}. In half of the years W/S-S, S-M, W-S-W-M and W-M sequences yielded 6000, 7000, 7500 and 8500 kg ha^{-1}, respectively.

Discussion

Our analysis highlighted the contributions of wheat to stability and of maize to productivity of cropping systems in the southern Pampas. These findings are consistent with the massive adoption of sequences that alternate stable and high yielding wheat as sole crop with a summer crop in the next year. The role of wheat conferring stability to rainfed cropping systems is generally accepted, but quantitative evidence is scarce. The high yield potential of wheat in our region has been related to a high photothermal quotient; however, there was not previous evidence regarding its high yield stability.

In sequences including maize, this crop accounted for most of the variation of annual yield. This is related to both the high yield potential and low stability of maize (Andrade et al. 1999) (Fig. 1e), which is consistent with local measurements comparing the yield stability of maize and wheat in shallow soils (Sadras and Calvi?o 2001). In sequences with no maize, wheat was the most important source of variation in annual yield. Moreover, wheat contribution was reduced when ISI increased. While soybean yield was relatively unstable, low soybean yields meant this crop did not contribute much to the annual variation in yield. The role of soybean as a source of variation increased in sequences with no maize, however.

The role of crop rotations for sustainable production is widely acknowledged. Part of the complex “rotation effect” is related to variation in quantity and quality of soil organic matter and in key physical properties of soils (Bullock 1992). Other environmental benefits of crop rotations are improving biological diversity and stability of nutrient cycling, microclimate regulation, suppression of weeds, diseases, and insects, and detoxification of chemical compounds (Altieri 1999). Intensification of crop sequences also contributes to increase spatial biodiversity owing to coexistence of higher number of crops in a determinate area in a given time (Karlen et al. 1994) in opposition to crop sequences based on a few crops.

There are increasing global concerns about environmental consequences of intensive agriculture. It should be noted, however, that socio-economic conditions in non-subsidized agricultural systems of the Pampas are quite different from those in developed countries with strongly subsidized agricultures. Here, productive, environmental, and socio-economic sustainability can only be reached thorough a rational use of inputs aiming at maximizing yield per unit land and time according to Gregory et al. (2002) concept of type III intensification, or so called “double green revolution”.

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