Soybean Yield Increases When Maize Is Included in the Cropping System

Sebastián R. Mazzilli* and Oswaldo R. Ernst

Core Ideas
- Soybean yield with maize as previous crop was ≈10% higher than the average yield.
- Soybean yield with soybean as previous crop was ≈4% lower than the average yield.
- Monoculture is explained as producers not valued this impact in short term decisions.

ABSTRACT
Soybean [Glycine max (L.) Merr.] monoculture is the dominant cropping system in the Rio de la Plata region. Despite the benefits of crop rotation, monoculture systems are an actual problem in many soybean and maize (Zea mays L.) production areas worldwide. Soybean monocultures are especially problematic because of their negative impact on soil quality. Regionally, there are only a few reports about soybean monocultures and yield improvement when maize is included in the rotation. We used a producer’s database (849 records from 2009 to 2013) to evaluate the effect of maize–soybean rotation on soybean yields. Four frequent annual previous crop sequences were identified: winter fallow–maize, winter crop–maize, winter fallow–soybean, and winter crop–soybean. As all of them are unequally represented, a new database was generated using a bootstrap resampling with 1000 replicates. Each interaction was economically analyzed, generating a variable called the differential gross product (difference in gross product, in US$ ha−1, with respect to the gross product average). Results indicate that crop rotation with maize has an agronomic and economic advantage. Soybean yield was ≈12% higher than the average when winter crop–maize was the previous crop, whereas it was ≈5% lower than the average when the previous crop was winter crop–soybean. Soybean following maize resulted in a gain in gross product of ≈125 US$ ha−1. However, the relationship between areas of soybean and maize indicates local producers fail to profitably grow maize or are inadequately assessing the impact of its inclusion into the production system.

Abbreviations: FUCREA, Uruguayan Federation of Regional Consortia of Agricultural Experimentation (using its Spanish acronym); GP, gross product.

A huge increase in land under agriculture has occurred in the Rio de la Plata region since 2002 driven by the increase in prices of grains. Annual cropping systems increased by 6.2 million ha since 2012, including soybean [Glycine max (L.) Merr.], maize (Zea mays L.), and wheat (Triticum aestivum L.) as the primary grain field crops in Uruguay, Argentina, Bolivia, Paraguay, and southern Brazil (Rio Grande do Sul, Santa Catarina, and Parana States). Soybean is the dominant crop in this entire region representing 63% of the total cultivated area vs. 19 and 12% of maize and wheat, respectively (FAOSTAT, 2016).

The area of soybean was the one that grew the most in the region (Paruelo et al., 2006). In Uruguay it increased from 278,000 ha in 2005 to 1,321,400 ha in 2014, and in Argentina it increased from 14,032,198 ha in 2005 to 19,252,552 ha in 2014 (FAOSTAT, 2016). In this region, annual rainfall (amount and its distribution) allows double annual cropping systems, combining soybean, maize, and sorghum as summer crops with wheat and barley as winter crops. However, soybean represents about 77 and 86% of the summer crop area for Argentina and Uruguay, respectively (FAOSTAT, 2016). Most of the soybean area is sown under soybean–fallow–soybean or soybean–winter crop–soybean crop sequence. Under both crop sequences, soybean is sown as monoculture summer crop, even though when a winter crop is sown in between two consecutive soybean crops.

Despite the benefits of crop rotation as well as the negative effects of monoculture are well known and that rotations have been explored for centuries (Karlen et al., 1994), the...
monoculture systems are an actual problem. Examples could be found in many soybean and maize production areas in the world (Plourde et al., 2013). Soybean monocultures are especially problematic because of their negative impact on soil quality as compared to cereal crops. Soybean returns little crop residue and with a low C/N ratio to the soil (Wright and Hons, 2004). The fast decomposition of soybean residues increases the susceptibility to soil erosion under fallow periods and the rate of soil organic C losses (Novelli et al., 2011). Many authors have demonstrated the advantages of a maize–soybean rotation over the practice of soybean or maize as monocultures. Several experiments in the United States showed an increase of between 4 and 25% in the yield of soybean when comparing soybean monoculture with systems that include maize in the rotation, under several tillage systems, soil type, climatic conditions, and agronomic management (Copeland et al., 1993; Crookston et al., 1991; Edwards et al., 1988; Pedersen and Lauer, 2002; Wilhelm et al., 2004). Recently, penalty for soybean monoculture of 10.3% was estimated in the US Midwest, using databases from commercial producers’ fields (Seifert et al., 2017). At regional scale, there are few reports about soybean monocultures and yield improvement when maize is included in the rotation. In these reports, soybean shows improvement in yield that ranges from 6 to 8% that remains the same after as much as 3 yr of continuous soybean if the system included at least one maize crop (Bacigaluppo et al., 2009; Felizia et al., 1994; Díaz-Zorita et al., 2014).

Improvements in soybean yields that occur after only one summer maize crop in comparison to soybean monoculture are explained by several factors as the decline of soil diseases, the lower incidence of nematodes (Dabney et al., 1988; Howard et al., 1998) and the improvements in soil water availability (Copeland et al., 1993; Lattanzi et al., 2005). The rotation effects are more important in less favorable environments (Porter et al., 1997; Seifert et al., 2017), but although the effects seem to be consistent, soybean is actually produced under a monoculture system in the region.

Our hypothesis is that yield losses under soybean monoculture systems are not evident to producers or that the economic advantage associated to crop rotation is not strong enough. A maize–soybean rotation implies that the soybean area decreases, affecting the annual financial results. Producers expect a higher income from soybean monoculture than from a system that combines other summer crops. But, can their expectations be met? Therefore, our objectives are (i) to quantify the difference between the yields of soybean grown as a summer monoculture system and in rotation with maize under on-farm conditions and (ii) to assess the economic impact of the system.

MATERIALS AND METHODS

Database Used

The crop management database used contains a total of 1024 records obtained from producer’s members of the Uruguayan Federation of Regional Consortia of Agricultural Experimentation (FUCREA, using its Spanish acronym) during five growing seasons (from 2009 to 2013). Each record corresponded to a single field in one growing season. The average field size was 67 ± 22 ha and the soils in most of the agricultural fields are Typic Argiudolls. The database had the following information: grain yield (14% grain moisture content), geographic zone, previous summer and winter crops, cultivar, and sowing date. Although records were available for the entire country, the largest amount of data was concentrated along the western coast of the country, and so only this zone was used in the analysis, separating the southern coastal zone (South) from the northern coastal zone (North) (Fig. 1). The South and North region correspond to a region III and II, respectively, of a local regionalization made by Corsi (1982), and it differs mainly by the accumulated temperature during the growing season, being approximately 300°C days higher for the North than for the South region (Fig. 1).

All incomplete records were not considered and only those with registered previous summer and winter crops were kept in the database. Each of these previous crops was separated as a single or double summer crop. A single summer crop, either maize or soybean, was defined as one in which a grain crop was not sown during the previous winter (fallow–maize and fallow–soybean). Usually for the analyzed period, chemical fallow is performed during winter. A double crop (winter crop–maize and winter crop–soybean) was defined as a summer crop that during the preceding winter for the same site had a winter grain crop, which for the working period are typically wheat and/or barley (*Hordeum vulgare* L.) (Table 1).
In absolute terms, the yield of soybean sown after maize as the previous summer crop was between 100 and 600 kg ha\(^{-1}\) higher than when sown after soybean as the previous summer crop; this difference represented between 3 and 25% of the yield increase due to the incorporation of maize into the crop sequence (Table 2). As the total number of soybean fields following maize as the previous crop resulted much lower than the soybean fields following soybean (Table 3), producers could be selecting better fields for maize than soybean and soybean seeding date adjusted according to the previous crop (soybean following maize could be sown earlier in the growing season). Both previous crop and soybean seeding date might be affecting grain soybean yield, and this is the major difficulty for crop yield diagnosis under on-farm conditions (Doré et al., 1997).

The range of sowing date in the region is between mid-October and the end of December. Therefore, fields were grouped by sowing date for 10-d periods, by previous crops and by zone (Supplemental Table S1). Since 84 and 82% of the sites with soybean and maize as previous summer crops, respectively, were sown between 21 October and 30 November, we only used this range, so the final number of record analyzed was 849 (490 for the South and 359 for the North) (Table 3).

### Data Analysis

**Standardization of Yields, Random Sampling, and Assessment of the Previous Crop Effect**

With the objective of eliminating a possible year effect for the soybean yield records and to use the data for all the years together, the yields for each field record and year were standardized in relation to the average yield for each year and zone independently (Eq. [1]). Therefore, the response variable was the relative yield and not the absolute yield.

\[
Y_{\text{rel}} = \frac{Y_i}{\bar{Y}_X}
\]  

where \(Y_{\text{rel}}\) is relative yield; \(Y_i\) is absolute yield of one soybean field in one of the years (2009, 2010, 2011, 2012, or 2013) and geographic zone (North or South); and \(\bar{Y}_X\) is average absolute yield of soybean fields in one of the years (2009, 2010, 2011, 2012, or 2013) and geographic zone (North or South).

To reduce the possible effect of selecting sites where producers could have produced maize and to homogenize the number of fields for each previous crop, a new database was generated using a bootstrap resampling with 1000 replicates with reposition (Zheng et al., 2009) for each of the zones (South and North). The objective was to compare the same number of sites with different previous crops, reducing possible effects of selecting the best site with one or the other previous crop. The number of repetitions for each sample was defined with the least represented previous crop, winter crop–maize in all the cases. The software Infostat 2016/p (Balzarini et al., 2008) was used for this procedure. A new database was compiled with the 1000 random samplings of 45 and 55 yield records for each previous crop for South and North zones, respectively. Each of these samplings...
represented a combination of sites with their respective relative yields. An analysis of variance was performed where the response variable was the relative yield and the classification variables were the sample, the previous crop, and the interaction. Fisher’s LSD test was used to separate the means.

**Economic Analysis**

To assess the differential economic impact of the previous crop, we used the results generated in the previous samplings (4500 and 5500 relative yield values for the South and North zones, respectively). Therefore, for each zone, there were four random input variables corresponding to the relative yield of the four systems (fallow–maize, winter crop–maize, fallow–soybean, and winter crop–soybean). The value assigned to the soybean grain was the referential international for all the years (price was not a variable because Uruguay has no influence on the international price) (DIEA, 2015) (Table 4). A new response variable was generated, called the differential gross product (GPdif), which is calculated using the following equation:

\[
GP_{dif} = (Y_{relp} - 1) \times Y_{X} \times P_{yr}
\]

where \(Y_{relp}\) is relative yield of one soybean field of one zone separated for the previous crop and \(P_{yr}\) is price in US$ kg⁻¹ of the year being analyzed.

The GPdif (US$ ha⁻¹) quantifies the variation of gross product generated by soybean after different previous crops in relation to the gross product (GP) obtained with the average yield per zone at the average sale price. These variables were organized for each zone, assuming that every output has the same probability of occurrence, which allowed us to estimate the probability of occurrence of the different GPdif for each previous crop.

**RESULTS**

**Relative Yields**

No significant interaction was detected in any zone between previous crop and sample (\(P < 0.1631\) and \(P < 0.2437\) for South and North, respectively) so only the previous crop effect was analyzed. These results confirmed the importance of previous crops in our database. In both zones, there were significant differences in relative soybean yield as a consequence of the previous crop (\(P < 0.0001\)). The soybean yield when winter crop–maize was the previous crop ranged between 13 and 11% higher than the average, whereas when winter crop–soybean was the previous crop it was between 6 and 5% lower than the average. Comparing both sequences, the difference in relative yields was approximately 18% (1.12 vs. 0.94 for soybean after winter crop–maize and for soybean after winter crop–soybean, respectively) (Fig. 2). As the most representative range of sowing dates cover over 80% of the cases (between 21 October and 30 November), it is not possible to assess what happens with the sites outside of this range since the representativeness of some previous crops is very low; however, the range of sowing date corresponds with the optimum recommended for the region (Andrade et al., 2015; Andrade and Satorre, 2015; Caviglia et al., 2004).

**Economic Results**

The economic result of the four options evaluated in terms of the differential gross product generated by soybean with respect to the average is presented in Fig. 3. In both zones, the highest differential gross product generated by soybean occurred in the winter crop–maize sequence and the lowest occurred in the winter crop–soybean sequence. Meanwhile, the results achieved for the fallow–soybean and

**Table 4. Reference price for soybean in US$ kg⁻¹ for the period analyzed.**

<table>
<thead>
<tr>
<th>Year</th>
<th>Soybean price† US$ kg⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>0.396</td>
</tr>
<tr>
<td>2010</td>
<td>0.380</td>
</tr>
<tr>
<td>2011</td>
<td>0.485</td>
</tr>
<tr>
<td>2012</td>
<td>0.547</td>
</tr>
<tr>
<td>2013</td>
<td>0.499</td>
</tr>
</tbody>
</table>

† Adapted from DIEA, 2015.
fallow–maize sequence differed between zones. The results for the North zone show that the system with maize as previous crop clearly differs from soybean (Fig. 3b) regardless if there was winter fallow or winter crop prior to the soybean crop. For this zone, the probability of achieving a gross product lower than the average was 28% for winter crop–maize and 35% for fallow–maize whereas that probability increases to approximately 65% for both fallow–soybean and winter crop–soybean. In contrast, for the South zone, the winter crop–maize as previous crop stands out, because its gross product was equal to or less than the mean of the period in only 20% of the cases. On the other hand, nearly 65% of the cases with a winter crop–soybean previous crop had a lower gross product than the average of the period, in addition to a higher probability of having higher negative differences (Fig. 3a). For this zone, the $GP_{df}$ of soybean after fallow–maize and after fallow–soybean as previous crops showed similar behavior. Although the fallow–maize previous crop was slightly superior to the fallow–soybean, it did not reach the level of winter crop–maize.

**DISCUSSION**

The use of producer’s database is an alternative approach to estimate the effects of different crop sequences on soybean yields, when traditional split-plot field trials were not widely available in the region for this topic. In our case, the analysis of (soybean) farm records allowed the quantification of yield differences and their distribution depending on previous crops defined as combinations of soybean, maize, winter crops, and winter fallow. Our results show that introducing maize as a previous crop can increase soybean yield between 6 and 13% compared to the average yield of each area studied. Meanwhile, the yield obtained for the system fallow–soybean was around the average yield of each zone and for the system with winter crop–soybean as previous crop the yield was between 4 and 6% below the average (Fig. 2). In absolute terms, these differences correspond to a yield increase rate of 170 to 400 kg ha$^{-1}$ for the South zone and 195 to 307 kg ha$^{-1}$ for the North zone for fallow–maize and winter crop–maize, respectively. The system with winter crop–soybean as previous crop results in a loss of between 200 and 111 kg ha$^{-1}$ in comparison to the average (Fig. 2). In absolute terms, these differences correspond to a yield increase rate of 170 to 400 kg ha$^{-1}$ for the South zone and 195 to 307 kg ha$^{-1}$ for the North zone for fallow–maize and winter crop–maize, respectively.

The system with winter crop–soybean as previous crop stands out, because its gross product was equal to or less than the mean of the period in only 20% of the cases. On the other hand, nearly 65% of the cases with a winter crop–soybean previous crop had a lower gross product than the average of the period, in addition to a higher probability of having higher negative differences (Fig. 3a). For this zone, the $GP_{df}$ of soybean after fallow–maize and after fallow–soybean as previous crops showed similar behavior. Although the fallow–maize previous crop was slightly superior to the fallow–soybean, it did not reach the level of winter crop–maize.

The impact of substituting soybean with maize in the crop sequences can be quantified by summing the $GP_{df}$ (Fig. 3) of each sequence and assessing the risk of obtaining a negative GP. When the soybean is sown after a winter crop–soybean sequence it results in a negative $GP_{df}$. Summing (in absolute terms) this $GP_{df}$ (negative values) together with the $GP_{df}$ of the fallow–maize or winter crop–maize previous sequences (positive values) allows to determine the total gains that result from the maize as previous crop with the loss that could have resulted from the soybean as previous crop. Our results indicate that with a 50% probability, the winter crop–maize previous sequence generated a total $GP_{df}$ of 179 for the South and of $166$ ha$^{-1}$ for the North, which in addition to the avoided loss of between $96$ and $37$ ha$^{-1}$ if the previous sequence had been winter crop–soybean generates a positive $GP_{df}$ for maize estimated at $215$ and $202$ ha$^{-1}$ for the South and North zone, respectively.

The risk of obtaining a negative GP in soybean when it is sown after maize as previous crop was between 20 and 25% compared to 50% to 60% when the previous crop was soybean. This effect was independent of whether or not the maize or soybean summer previous crop was combined with a winter crop (double annual cropping system vs. full-season summer crop), but the results suggest an additional positive effect from double cropping. Therefore, if the economic result from winter cropping is positive, the immediate substitution of soybean with maize will result in a positive $GP_{df}$ for the soybean crop during the following year.

Although our results are strongly demonstrating the agronomic and economics advantages of including maize in the cropping systems, we cannot elucidate: (i) the process that causes these differences, (ii) the duration of the positive effect of including a maize crop, and (iii) if the negative effect of repeating soybean is cumulative. For the first aspect, although the literature is not conclusive, the cause of these differences is most likely a combined effect of the absence of soybean for 1 yr in the system (fallow–maize vs. fallow/soybean) and of the possible benefits generated by the permanence of the winter crop stubble on the soil in addition to the harvest of the summer crop at the end of the fall. This combination (winter crop–maize) reliably allows a better recharge of water to the soil profile than the fallow–soybean sequence as more residues are left on the surface (Monzon et al., 2006).

With regard to the point (ii) above, our database does not allow quantification of how much the positive effect of the previous maize lasts. Results obtained in the region show that it can last up to 3 yr, which would allow to maintain a high frequency of soybean in the rotation (Bacigaluppo et al., 2009; Felizia et al., 1994; Díaz-Zorita et al., 2014). However, the duration of this effect would be conditioned by a possible cumulative negative effect generated by the soybean frequency (Novelli et al., 2017, 2011). In practice for the region, the relationship between areas of soybean and maize indicate that, on average, data for the year 2005 show that maize was grown every 6.3 yr and every 8.5 yr for the year 2013. This shows that local producers fail to profitably grow maize or that they are not adequately assessing the impact of its inclusion in the production system.

Our results suggest that producers are only taking into account the economical result of each year independently. This would be the reason why soybean is the main crop in a monoculture system. If they take into account not only the increase in soybean yield after maize but they also consider the yield loss associated to sowing soybean every summer, more area of maize should be sown. Therefore, the economic result as a whole should be quantified considering not only the benefits from a crop but also from the established crop sequence.

Several possible reasons why producers decide not to substitute soybean with maize are the low current average yield of maize (4500 kg ha$^{-1}$) (http://www.yieldgap.org/gygamaps/app/indexLat.html), the production risks due to high year-to-year variability under rainfed production conditions and the higher production costs, which generates a probable negative gross margin scenario for maize production. Further research is necessary to improve the yield of maize, reducing its interannual variability and a more emphatic transference of information should help to avoid the actual soybean monoculture system.
SUPPLEMENTAL MATERIAL

Supplemental Table S1. Number of fields in each sowing period for each zone.

ACKNOWLEDGMENTS

We want to acknowledge FUCREA and its producers and technicians for providing the database. We are also thankful to Agustín Ferreira for help with the first analysis of data in his final degree work, and Pilar Etcheoginimber for her support in the construction of Fig. 1.

REFERENCES


