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Gaps between farmer and attainable yields across rainfed sunflower growing regions of Argentina

A.J. Hall[a,*], C. Feoli[b], J. Ingaramo[c], M. Balzarini[d]

[a] IFEVA, Facultad de Agronomia-Universidad de Buenos Aires/CONICET, Av. San Martín 4453, C1417DSE Buenos Aires, Argentina
[b] INTA-ASAGIR Agreement, Instituto Nacional de Tecnología Agropecuaria-Asociación Argentina de Girasol, Av. Corrientes 119, C1043AAB Buenos Aires, Argentina
[c] ASAGIR, Asociación Argentina de Girasol, Av. Corrientes 119, C1043AAB Buenos Aires, Argentina
[d] Cátedra de Estadística y Biometría, Facultad de Ciencias Agropecuarias, Universidad Nacional de Córdoba/CONICET, Av. Valparaíso s/n, CC 509, 5000 Córdoba, Argentina

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ABSTRACT

We computed three estimators of attainable yield for each of between 5 and 8 rainfed sunflower-growing regions of Argentina using between 5 and 9 years of data over the 2000–2007 interval. The estimators were based on comparative yield trial (CYT) data for commercial hybrids, on individual commercial field (ICF) data, and on reporting district (RD) yield information. Contrasts between these estimators led us to prefer the attainable (CYT) yield estimator over the other two. Attainable (CYT) yields ranged from 2.21 to 2.83 t ha^{-1} across regions. Yield gaps between mean farmer (RD data) and attainable (CYT) yields were computed using best linear unbiased estimator (BLUE) values for both variables obtained using mixed linear models. These gaps were statistically significant ($p \leq 0.05$) for all 8 regions and ranged from 0.37 to 1.18 t ha^{-1} across regions, for a country average of 0.75 t ha^{-1}, equivalent to 41% of the mean country yield of 1.85 t ha^{-1}. We also used CYT data to examine the issue of recurrent, albeit infrequent, reports of unusually high yields. Mean yields for the top decile of comparative yield trial data ranged from 3.2 to 4.2 t ha^{-1} across regions, and the highest yields for this decile in any of the years of record ranged from 3.9 to 4.8 t ha^{-1} across regions. Individual commercial field yields were available for 5 regions. Gaps between BLUEs for this variable and attainable (CYT) yields were smaller than those between reporting district and attainable (CYT) yields, but were nevertheless significant in all 5 regions. A notable feature of reporting district, individual field, and yield trial data was their variability. At reporting district level within regions, contributions of spatial and temporal variability were roughly similar. The mean relative contribution of the trial effect to non-error variance of the CYT data exceeded 85% across regions, dominating the contributions of genotype and of genotype by trial effects. We conclude that the magnitude of mean farmer/attainable (CYT) yield gaps for this crop in Argentina justifies further research aimed at reducing regional gaps; and that CYT data can be used to generate an appropriate benchmark for attainable yields.

1. Introduction

The yields obtained by farmers for several crop species and in many cropping systems around the world have almost always been shown to be lower than those attainable using locally optimised agricultural best practices and adapted, current, cultivars (e.g., Cassman, 2010; Fischer et al., 2009; Fischer and Edmeades, 2010; Lobell et al., 2009; Aggarwal et al., 2008; Laborte et al., 2012). Attainable yield (Yatt) is a context-dependent variable that is affected by environmental, economic and sociological factors. Provided this is understood, it constitutes an appropriate benchmark in yield-gap analysis. It should be noted that Yatt in rainfed systems is not the same as water-limited yield (Yw, as defined in Van Ittersum et al., 2013), although for a given region it may approximate the latter if local good farming practice approaches optimal practice. In this paper, we use Yatt as defined in Fischer and Edmeades (2010) and Fischer et al. (2009) and, following these same authors, we estimate yield gaps as the difference between mean farmer and attainable yields.

Abbreviations: Yatt, attainable yield; BLUE, best linear unbiased estimate; CI, confidence interval; CRF, cumulative relative frequency; CYT, comparative yield trial; ICF, individual commercial field; MLM, mixed linear model; RD, reporting district; REML, restricted maximum likelihood; Top10, mean, across years, of CYT values included in the top decile of the corresponding cumulative relative frequency distributions; ULRY, upper limit to rainfed yield; Yw, water-limited yield.

* Corresponding author. Tel.: +54 11 4524 8000x8116; fax: +54 11 4524 4040.
E-mail addresses: hall@agro.uba.ar, hall@ifeva.edu.ar (A.J. Hall), carlosfeoli@asagir.org.ar (C. Feoli), ingaramovan@arnet.com.ar (J. Ingaramo), mbalzari@gmail.com (M. Balzarini).

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Most yield-gap analyses have focussed on the main cereal food grains (rice, wheat, maize), although Aggarwal et al. (2008) also looked at these gaps for cotton and mustard. These yield gaps can be substantial. Expressed as a percentage of current farmer yields, Fischer et al. (2009) and Fischer and Edmeades (2010) cite many cases of gaps of between 45% and 100%. Data compiled by Lobell et al. (2009), expressed on the same basis, are broadly consistent with this range, although their list includes a number of examples of gaps in the 100–200% range or even higher.

The demonstration of important yield gaps for particular crops and cropping systems provides an essential framework within which to prioritize research and policy efforts aimed at reducing these gaps (e.g., Tittonell et al., 2008; Aggarwal et al., 2008; Abeledo et al., 2008; Laborte et al., 2012). It is acknowledged that yield gaps cannot be reduced to zero due to widespread practical and economic constraints applying to commercial farming (Fischer et al., 2009). Empirical analyses suggest minimum limits to gaps of 20–25% of current farmer yield (Fischer et al., 2009) or 20% of potential (or water-limited yield in rain-fed systems) yield (Lobell et al., 2009). In a few very intensively managed systems (rice in Egypt, Fischer et al., 2009; irrigated maize in the Western US cornbelt, Grassini et al., 2011a,b), yield gaps may be approaching (or have actually fallen below) these estimated minima.

Various approaches have been suggested or used for estimating yield gaps (cf. Fischer et al., 2009; Lobell et al., 2009; Aggarwal et al., 2008; Licker et al., 2010; Abeledo et al., 2008; Grassini et al., 2011a,b; Laborte et al., 2012). Each of these approaches has particular advantages and disadvantages. Farmer yields have been estimated using regional or national statistics, and by sampling farmers' fields, either directly or using remote sensing (Lobell et al., 2007, 2010). Attainable and potential yields have been estimated using on-farm experiments, yield contest results, research station experiments, crop models, and breeders' trials. Licker et al. (2010) and Gerber et al. (2010) have proposed a system based on a detailed analysis of regional statistics. In their procedure, regions across the globe are classified into a limited number of bins (defined by combinations of duration of growing season and an index of water availability) and reported yields within each bin are sorted to identify the 95th percentile value, which is taken as an Yatt for that bin.

The temporal and spatial scales across which quantification of yield gaps has been attempted has varied widely. Explicit consideration of temporal variations in yield gaps, something which can be particularly important in rain-fed systems, has received little attention, save when models or remote sensing have been used to analyse extended estimated yield or climatic records (e.g., Lobell et al., 2007; Abeledo et al., 2008). In the spatial dimension, yield gap estimation has covered the ranges from local (e.g. the Yaqui and Ebro valleys, Lobell et al., 2009; Abeledo et al., 2008) through to regional (Grassini et al., 2011a,b; Lobell et al., 2010; Laborte et al., 2012), national or mega-environment (Fischer et al., 2009; Aggarwal et al., 2008), and on to global scales (Licker et al., 2010; Gerber et al., 2010).

Here we report the results of a yield gap analysis for the sunflower growing regions of Argentina. The analysis was conducted on behalf of the Asociación Argentina de Girasol (ASAGIR), the Argentine sunflower value chain association. The objective was to quantify the magnitude of the farmer/attainable yield gap for this crop, and its temporal and spatial variability. ASAGIR wished to determine whether the size of current yield gaps justified further research into yield gap reduction. ASAGIR was also seeking a framework which would allow infrequent, but recurring, reports of high grain yields (4–5 t ha^{-1}) to be placed in the context of national yield averages in the order of 1.7–1.9 t ha^{-1} (sunflower yields are usually reported at 11% moisture content). Distinctive features of our analyses are that they apply to rainfed crops (irrigated sunflower crops in Argentina are usually only used for hybrid seed, as opposed to grain, production) of current commercial hybrids, they cover eight separate regions of the country, the data for the most important crop-reporting districts within each region were used to estimate farmer yields, and the number of years considered ranged between 5 and 9 according to region.

We used three different methods to estimate Yatt, based on data from comparative yield trials (CYT), from individual commercial farmers' fields (ICF), and from crop-reporting districts (RD) (see Section 2.3). To the best of our knowledge, our analyses are the only country-wide exercise aimed at quantifying yield gaps for the sunflower crop and the one of the very few (cf. Aggarwal et al., 2008) in which several techniques for estimating Yatt for a given crop are compared.

Comparison of the three estimates of Yatt described above led us to select the CYT-based estimate as the most useful for our purpose. Using this estimator, we computed farmer/attainable yield gaps, and their regional and temporal variation. We also explored the magnitude and variability of the highest yields achieved in the CYTs. Our interest here was to provide a quantitative overview, across years and regions, of unusually high yields. This overview provides a reference framework in which to place the recurrent, but infrequent, reports of very high yields for the crop. Reports of this type often feature in advertisements for seeds and in discussions between farmers skilful enough or lucky enough to achieve these unusually high yields.

2. Materials and methods

2.1. Regionalisation

Sunflower is grown extensively in several distinct agroecosystems in Argentina, which are distinguished by seasonal rainfall, radiation and temperature patterns; soil properties (texture, soil depth, organic matter content); the role of sunflower in the cropping system (sole within-season crop, lead crop of a seasonal sequence of two crops); and crop management (time of sowing). Several approaches have been used to classify this diversity. Breeders, for example, distinguish Southern, Central and Northern regions (e.g., de la Vega and Chapman, 2010). By contrast, the Buenos Aires Grain Exchange (Bolsa de Cereales de Buenos Aires, 2011) distinguishes, for the area in which sunflower is grown, 12 grain-crop reporting districts, based on several main crops for each district. A further dimension to this issue is that yield-reporting districts for national statistics are based on departmental, rather than biophysical, boundaries. For the purpose of this analysis, a consensus set of eight regions was developed with input from breeders, farmers, and traders (Table 1 and Fig. 1).

Fuller details on soils, rainfall and temperature regimes for regions included in the Pampas (i.e., all regions listed in Table 1 except NEAR) may be found in Hall et al. (1992). Briefly, important SE to NW gradients across the Pampas region reflect increasing temperature and rainfall, and a gradation in soil texture from coarse to fine. Petrocalcic layers limit soil depth in the SEBA region, and annual rainfall distribution in this region is almost isohygrous, in contrast to the summer-dominant patterns for the remaining Pampean regions. Petrocalcic layers are also a feature in some soils of the SLLP region, but these layers tend to be deeper in the profile than those of the SEBA region. Sunflower is grown as a sole crop within a season across all the Pampean regions, with sowing date occurring later from N to S. Chapman and de la Vega (2002) have described weather (rainfall, temperature) conditions for the NEAR region. Soils in the NEAR region are fairly heterogenous, but lighter and deeper soils are more frequent in the W of this area, and shallower and heavier soils in the E (Mosconi et al., 1981; Ledesma