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ORIGINAL PAPER

How reliable are crop production data? Case studies in USA and Argentina

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Abstract Reliability of crop production data has implications for yield gap analysis, production time trends, trading and policy decisions. In this paper, we compared databases of major grain crops estimated by a pair of independent organisations in Nebraska, USA (USDA-NASS, National Agricultural Statistics Service of USDA vs NRD, Natural Resources Districts of Nebraska) and a pair of independent organisations in Argentina (MA, Ministerio de Agricultura vs. BC, Bolsa de Cereales de Buenos Aires). The comparisons involved the yield of irrigated and rainfed maize and soybean reported by USDA-NASS and NRD, and the yield, acreage and production of maize, soybean and wheat reported by MA and BC.

The comparison between NASS-USDA and NRD yield data included 127 paired observations for maize and 87 for soybean. For the pooled data involving irrigated and rainfed crops, the average difference in yield between the two sources was small (<5 %). In both crops, however, the yield difference between sources increased with increasing yield suggesting that NRD reported higher yields than NASS-USDA in high-yielding, irrigated crops and lower yields in rainfed crops. For maize, NRD returned lower yield than NASS-USDA for average yield below 10 t ha^{-1}, and higher yield above this threshold. For soybean, NRD returned lower yield than NASS-USDA for average yield below 3 t ha^{-1}, and higher yield above this threshold.

For the pooled data comprising 13 regions and 9–10 cropping seasons per region in Argentina, differences between yield reported by MA and BC were larger and more scattered for maize than for soybean and wheat. The differences in acreage between the two sources increased with increasing acreage for soybean and wheat, and the same pattern was found for total production. Differences in production were more closely related to differences in acreage than to differences in yield, thus highlighting the need to improve the accuracy of crop acreage estimates. Disaggregation of data showed compensation between regions where positive differences (BC > MA) compensated negative differences (BC < MA). For both Nebraska and Argentina, relative differences between sources generally declined with larger regional cropping area and/or number of reporting fields.

All four organisations providing cropping statistics involved experienced professionals using rigorous methods; hence comparisons did not seek to establish the "right" estimate. The conclusions from these comparisons are thus asymmetric: where the two sources show statistical agreement, we can have some confidence on the reliability of the data, but where the sources disagree, we cannot tell which one is more reliable; we can, however, highlight the mismatch and recommend caution in the use and interpretation of crop yield and production data, particularly at regional level.

Keywords Wheat · Maize · Soybean · Statistics · Production · Yield · Acreage

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Introduction

Crop production records are required to estimate land-use change, yield gaps, production time trends, and contributions of technology to yield improvement (Kim and Dale 2004; Laborte et al. 2012; Bell and Fischer 1994; Fischer and Edmeades 2010; Hawkesford et al. 2013; Grassini et al. 2013). The reliability of data sources is therefore critical to the conclusions of these types of studies (Hauser and van Asten 2008). Reliability of production records also has implications for trading, policy decisions, for investment in infrastructure, research and development in agriculture and quantification of their impact (Campbell 2013; Sumberg 2012; Hawkesford et al. 2013; Hauser and van Asten 2008).

Crop production at regional to global scales has two components, yield and acreage which are generally estimated independently. Few comparisons of yield from different sources have been reported (Gaidashova et al. 2010; Okumu et al. 2011; Wairegi et al. 2010; Kim and Dale 2004; Brisson et al. 2010; Tittonell and Giller 2013); comparisons of acreage data sources are less common (Campbell 2013). Whereas comparisons of data from different sources do not necessarily allow establishment of the "right" estimate, a measure of the mismatch is important as a cautionary reminder of the uncertainty associated with crop production databases.

Kim and Dale (2004) compared yields of cereals and sugarcane from two sources, FAOSTAT and national data bases, for a number of countries between 1997 and 2001. The two sources were in close agreement for all reported crops in Canada and USA (difference below 1 %). Large mismatches were found for Mexico (up to 33 % for oats) and for rice in Japan, Korea and Mexico (>25 %). Tittonell and Giller (2013) compared two sources of yield for several crops in eastern and southern Africa. They concluded that, despite its wide coverage, FAO's national average yield was close to the mid-range yield reported in the scientific literature for maize, sorghum, millet and some grain legumes. In contrast, the FAO average yield for cassava and highland banana was closer to the lower end of the yield range found in the literature. In the case of banana, FAO national average yields were often less than half of the yields measured in farmers' fields in Kenya, Rwanda, and Uganda (Gaidashova et al. 2010; Okumu et al. 2011; Wairegi et al. 2010). This discrepancy may reflect flaws in data collection protocols including inability to account for within-farm yield variability and differences in crop cycle duration among environments and cultivars as well as inconsistencies in the method of harvest and reported bunch yields (Hauser and van Asten 2008; Okumu et al. 2011). Significant disagreement in the area planted to grapevine was detected in a comparison of data reported by New Zealand Winegrowers and the Marlborough District Council; part of the mismatch was because the former reported productive plantations whereas the latter reported established plantations (Campbell 2013).

In the assessment of data reliability, it is important to consider both the closeness and consistency between data sources. Bell and Fischer (1994) for example, estimated the time trend (1968–1990) of irrigated wheat yield in the Yaqui Valley of north-western Mexico using the daily time-step CERES Wheat model accounting for soil, crop, weather and management factors, and the single-equation photothermal model of Fischer (1985). The time trends of yield estimated with the two models were parallel (i.e. the models were consistent) but the trajectories were offset by 1 t ha^{-1}. For the objective of estimating time trends, both models returned a similar rate despite the significant differences in the estimates. In an analysis of time trends (1956–2007) of wheat yield in France, two data sources, FAOSTAT and Statistical Service of the French Ministry of Agriculture, returned the same inflexion point indicative of lack of yield improvement after 1996 (Brisson et al. 2010). In both cases, despite the yield mismatch, consistency between data sources resulted in similar inferences about the time trends.

USA ranks first in the production of soybean and maize worldwide, whereas Argentina ranks third and fourth, respectively. Both countries are significant exporters of grain and derived products. Among U.S. states, Nebraska ranks third in maize production and fifth in soybean production, with 60 and 45 % of total acreage of these two crops under irrigation respectively. In this paper, we compared databases of major grain crops estimated by different sources in the grain producing regions of Argentina and Nebraska. The aim was to probe for mismatches and to highlight the need to assess the reliability of primary data sources, particularly for policy decisions on issues of food security at different spatial scales. Conditions associated with unreliable data (e.g. sampling intensity) were explored.

Methods

Nebraska: comparison of two data sources reporting yield of maize and soybean in irrigated and rainfed systems

The National Agricultural Statistics Service of the United Stated Department of Agriculture (NASS-USDA, http://www.nass.usda.gov/) reports county-level harvested acreage and yield averages for irrigated and rainfed maize and soybean in Nebraska. The estimates of acreage and yields are based on farmer-provided data collected through two independent surveys: (i) a Quarterly Survey and (ii) a County Agricultural Production Survey. Both surveys - conducted for small grains in September and for row crops in December – collect data on total acres sown and production for irrigated and rainfed summer crops. The main difference between the two surveys is the sample size: while the quarterly survey reaches approximately 2,000–3,000 producers across Nebraska, the sample size of the supplementary survey is about 4–5 times larger. In both surveys, areas of the state with largest acreage are sampled more intensively. Accuracy and reliability of farmer-reported data have been corroborated in the past through panel studies. Data on acreage collected through the two surveys are pooled and adjusted using two other independent sources of data: the Farm Service Agency (FSA) and the Risk Management Agency (RMA). FSA data on farm size is used to corroborate farmer-reported sown acreage. RMA data on non-harvested acreage (due to hail, frost, flooding, drought, etc.) are used to estimate the final harvested acreage and average yields. No other sources of information (such as weather anomalies, elevators stocks, remote sensing, etc.) are used to validate or adjust the yield estimates. If estimated yield or acreage looks anomalous compared with previous years or contiguous counties, a follow-up with the reporting farmers on the specific county is performed to verify the accuracy of the data. NASS-USDA does not publish records for counties with small acreage or number of reporting producers.

State law divides Nebraska into 23 Natural Resources Districts (NRDs, http://www.nrdnet.org/), each serving as a local government entity with authority to establish regulations and incentives to protect and conserve natural resources within the district. Each NRD sets its own priorities and develops its own programs to best serve local needs. Farmers with fields located in pre-designated reporting areas have to provide field-specific agronomic information to the local NRD office, including crop species sown, water regime, yield, applied nitrogen fertiliser and amount of irrigation water used to grow crops. The reporting area and number of reporting fields is consistent among years but varies among NRDs. Information provided by farmers can sometimes be verified with the attached grain elevator tickets or yield maps, but the latter documentation is not mandatory.

For the present study, we compared NASS-USDA and NRD yields for selected counties in Nebraska. Counties were selected in order to maximise the spatial congruence between the NRD reporting areas and the counties for which the USDA-NASS average yields were reported. A total of 12 selected counties were grouped into 3 categories according to differences in weather and spatial distribution of the rainfed and irrigated crops: west, central, and east Nebraska, comprising 2, 7, and 3 counties, respectively (Fig. 1). Combinations of crop and water regime include irrigated maize (west, central, and east), irrigated soybean (central and east, except Brown county), and rainfed maize and rainfed soybean (east, except Gage county). Paired comparisons for each county were available for at least six cropping seasons since 2006.

Argentina: comparison of two data sources reporting yield, acreage and production of maize, soybean and wheat

Two independent organisations, the Ministerio de Agricultura Ganadería y Pesca (MA) and Bolsa de Cereales de Buenos Aires (BC) compile annual records of acreage and yield for major grain crops in Argentina. Both are based on telephone and mail surveys complemented by field checks. Reports are available online for MA (http://www.minagri.gob.ar/site/index.php) and BC (http://www.bolcereales.com.ar/pas).

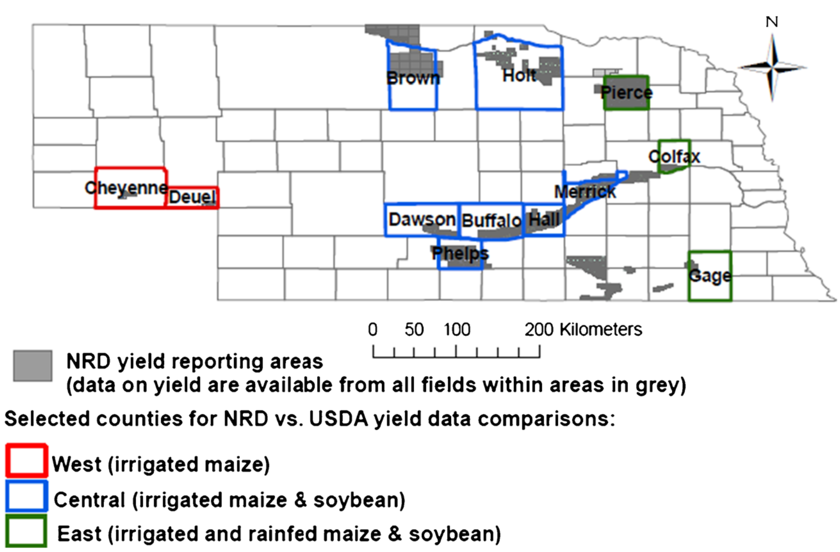


Fig. 1 Grain producing counties of Nebraska, USA. The geographical unit in the database of National Agricultural Statistics Service of the United Stated Department of Agriculture (USDA-NASS) is the county (the smallest bounded region in the map) whereas Natural Resources Districts (NRD) collected farmer-provided yield data from pre-designated reporting areas (grey areas in the map). A total of 12 counties (names are indicated in the map) were selected and grouped into 3 categories according to differences in weather and spatial distribution of the crops: west, central, and east Nebraska. Counties were selected in order to maximize spatial congruence between NRD reporting areas and the counties for which USDA-NASS average yields were reported. Dominant crops and water regimes in each region are also indicated

The surveys of MA and BC used to target partially independent populations; whereas MA has historically focused on farmers, BC targets not only farmers but also advisors, agronomists, grain cooperatives and traders. After 2008, however, MA has excluded farmers from their surveys. The organisations differ in the spatial aggregation of their data bases: MA uses provincial departments (counties) whereas BC aggregates the departments into 15 regions (Fig. 2).

The network of MA in the grain-producing area is managed from 36 regional offices with a geographical distribution that matches local levels of production; for example, 10 out of the 36 offices are in the province of Buenos Aires, the largest grain producer. Regional officers interview their target sources of information at weekly intervals during the period leading up to and shortly after sowing and harvest. The information of harvested acreage and yield estimates are then consolidated at head office, and scaled up to provincial and national levels.

The network of BC is managed from head office and involves more than 1,000 interviewees who contribute regularly to surveys; many have provided information for at least seven years and are familiar with the questions. Weekly surveys are carried out between the beginning of sowing and the finalisation of harvest in each region, and are consolidated into regional harvested acreage and yield estimates four to seven weeks afterwards. There is a 2.7-fold range in sampling intensity between core (higher) and marginal (lower) areas for each grain crop and the intensity of surveys increases under unfavourable conditions as assessed by climate anomalies, regional NDVI (Normalized Difference Vegetation Index) and soil water balance surveys provided by independent organisations including the National Meteorology Service (http://www.smn.gov.ar/), the National Institute of Agricultural Technology (http://inta.gob.ar/) and the Foreign Agricultural Service, USA Department of Agriculture (http://www.fas.usda.gov/). Quality checks include comparisons with yield in climate-analog years.

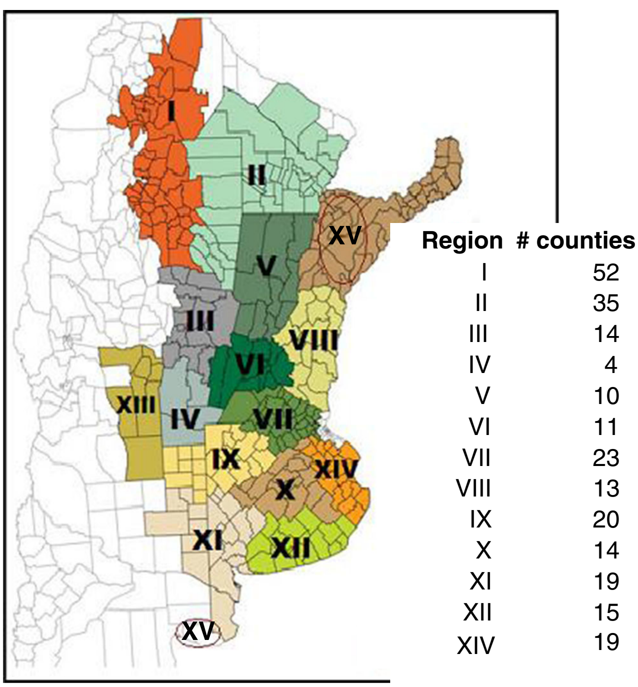


Fig. 2 Grain producing districts of Argentina. The geographical unit in the database of Ministerio de Agricultura (MA) is provincial department (county, the smallest bounded region in the map) whereas Bolsa de Cereales de Buenos Aires (BC) aggregates departments in 15 regions shown in the map. Owing to scarcity of data, Regions XIII and XV (red ovals) were not included in the analysis

A database was compiled for all BC regions comprising 10 cropping seasons starting 2000–01. For 13 out of the 15 regions (Fig. 2), paired MA-BC data were available for at least 9 cropping seasons. Common data from the two sources comprised 4 years or less for regions XIII and XV, which were therefore excluded from the analysis.

Data analysis

We compared the yield of irrigated and rainfed maize and soybean reported by USDA-NASS and NRD in Nebraska, and the yield, acreage and production of maize, soybean and wheat reported by MA and BC in Argentina. Yield and production are reported at standard commercial moisture content for each crop.

We used the approach of Altman and Bland to compare the two sources of data, which were labelled "A" (BC in Argentina, NRD in Nebraska) and "B" (MA in Argentina, NASS-USDA in Nebraska); details of the approach are in Altman and Bland (1983) and Bland and Altman (1986). Briefly, we calculated the differences between sources ($d=A-B$) and plotted the difference against (A + B)/2, the average. The mean difference ($\bar{d}$) measures how much A and B differ on average, and the standard deviation (SD) measures the scatter of the differences. A two-tailed *t*-test was used to test the null hypothesis that the population mean of the differences is zero. Linear regression was used to probe for associations between d and (A + B)/2; model-II regression (reduced major axis method) was used to account for errors in both variables (Niklas 1994; Ludbrook 2012) and for asymmetries (Smith 2009; Piñeiro et al. 2008). We report slopes calculated with reduced major axis method (b_{RMA}) and, for comparison, we also present slopes calculated with ordinary least squares (b_{LS}) (Niklas 1994). We used a two-way ANOVA for comparisons of d among crops, regions and water regimes in Nebraska and among crops and regions in Argentina. Additional statistics include the 10th and 90th percentiles of d, thus reflecting a range that excludes the outermost points in the dataset.

Large, crop-specific differences is a key feature of the datasets analysed (Table 1); for example maize yield is much

Table 1 Average and standard deviation (SD) of yield of irrigated and rainfed maize and soybean in Nebraska, and average and SD of yield, acreage and production of maize, soybean and wheat in Argentina. Source A is BC in Argentina, NRD in Nebraska and B is MA in Argentina, NASS-USDA in Nebraska

Variable	Crop	Source A		Source B	
		Average	SD	Average	SD
Yield (t ha^{-1})	Maize - irrigated	11.1	1.58	10.9	1.26
	Soybean -irrigated	3.9	0.47	3.7	0.43
	Maize - rainfed	8.0	1.33	8.7	1.34
	Soybean - rainfed	3.4	0.71	3.4	0.59
	Maize - all	10.7	1.83	10.7	1.44
	Soybean - all	3.8	0.54	3.7	0.47
Yield (t ha^{-1})	Maize	6.3	1.90	6.1	1.86
	Soybean	2.4	0.61	2.4	0.61
	Wheat	2.3	0.89	2.4	0.87
Acreage (ha × 10^5)	Maize	1.92	1.281	1.91	1.334
	Soybean	11.22	9.211	10.90	8.430
	Wheat	4.15	4.105	4.14	3.795
Production (t × 10^5)	Maize	13.36	11.313	12.87	11.394
	Soybean	29.63	29.187	28.68	26.661
	Wheat	10.43	12.170	10.20	10.648

larger than the yield of soybean in both Nebraska and Argentina, and acreage and production in Argentina is much larger for soybean than for maize and wheat. To account for this in some comparisons, we calculated percentage difference between sources of data, 100*(A-B)/[(A + B)/2].

The number of years with reported data was not consistent among NRDs in Nebraska. Collection of farmers data by NRDs started in different years, ranging from 1995 (Cheyenne and Deuel Counties) to 2006 (Pierce County). All years were included in the Altman and Bland scatter plots, while only 2006–2011 yield data (available for all NRDs) were used in comparisons among crops, regions and water regimes.

Results

Comparison of data sources in Nebraska, USA

Figure 3 shows the Altman and Bland plots comparing NRD and NASS-USDA yield data comprising 127 paired observations for maize and 87 for soybean and Tables 1 and 2 presents complementary statistics. For the pooled data involving irrigated and rainfed crops, the average difference was small, slightly larger for soybean but more scattered for maize (Table 2). The average difference was, however, positive for irrigated crops and negative for rainfed crops (Table 2). Whereas the small sample of rainfed crops means that this

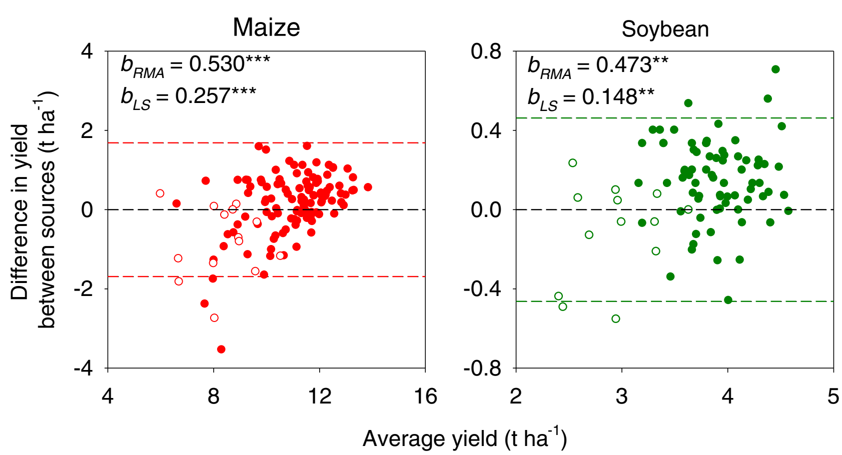


Fig. 3 Difference between two sources of grain yield for maize and soybean in Nebraska against the average of the two sources. Yield sources are NRD, Natural Resources Districts, and NASS-USDA, National Agricultural Statistics Service of the United Stated Department of Agriculture. Data are from 12 overlapping counties (USDA-NASS) and NRD reporting areas in Nebraska. At least data from 6 cropping seasons were available for all counties/reporting areas. *Black lines* are $y=0$ and dashed coloured lines±2 SD. Regression slopes (b, unitless) are also shown; asterisks indicate $P<0.0001$ (***), and $P<0.01$ (**). Closed symbols are irrigated and open symbols are rainfed crops

Table 2 Average, standard deviation (SD), 10th and 90th percentiles of the difference in the yield of irrigated and rainfed maize and soybean reported by NRD and USDA-NASS in Nebraska, USA, and the difference in yield, acreage and production of maize, soybean and wheat reported by BC and MA in Argentina. Owing to small number of observations, percentiles were not calculated for rainfed crops in Nebraska

Country	Variable	Crop	Average[a]	SD	Percentile		Number of observations	
					10th	90th	Total	Agreeing to within 10 %
USA	Yield (t ha^{-1})	Maize - irrigated	0.16*	0.780	−0.78	1.01	113	107
		Soybean -irrigated	0.15***	0.207	−0.12	0.40	74	66
		Maize - rainfed	−0.80**	0.896			14	14
		Soybean - rainfed	−0.11	0.246			13	13
		Maize - all	0.05	0.844	−1.15	−0.20	127	121
		Soybean - all	0.11***	0.231	0.94	0.35	87	79
Argentina	Yield (t ha^{-1})	Maize	0.26**	1.074	−0.72	1.57	130	93
		Soybean	−0.04	0.294	−0.32	0.25	129	109
		Wheat	−0.07	0.563	−0.37	0.41	128	102
	Acreage (ha × 10^5)	Maize	0.01	0.485	−0.55	0.71	130	83
		Soybean	0.32	2.061	−1.66	2.75	129	92
		Wheat	0.01	0.771	−0.89	1.09	128	88
	Production (t × 10^5)	Maize	0.49	3.31	−3.61	5.14	130	83
		Soybean	0.94	5.64	−4.67	5.90	129	92
		Wheat	0.23	2.68	−0.89	1.09	128	88

[a] Asterisks indicate significantly different from 0 using a two-tailed *t*-test; ***$P<0.001$, **$P<0.01$, [a] $P<0.05$

finding has to be interpreted cautiously, it seems that on average NRD reported higher yields than NASS-USDA in high-yielding irrigated crops, and lower yields in rainfed crops.

In both crops, the difference in yield reported by the two sources was positively associated with average yield (Fig. 3). On average for maize, NRD returned lower yields than NASS-USDA for average yield below 10 t ha^{-1}, and higher yield above this threshold. On average for soybean, NRD returned lower yields than NASS-USDA for average yield below 3 t ha^{-1}, and higher yield above this threshold. The correlation between yield difference and average yield depicted in Fig. 3 is partially driven by the positive difference for irrigated crops and negative difference for rainfed crops (Table 2). In maize, however, the correlation persisted when the data set was constrained to irrigated crops (r=0.42; $P<0.001$) reinforcing the conclusion that the difference between maize yields reported by NRD and NASS-USDA increased under more favourable cropping conditions in irrigated systems. In soybean, the correlation broke down when rainfed and irrigated crops were considered separately, thus supporting the conclusion that the correlation derived primarily from the systematic differences in yield reported by NRD and NASS-USDA in irrigated and rainfed systems. A factor that may have contributed to the associations depicted in Fig. 3 is that estimates from NRD were less precise (have larger standard deviation) than those from NASS-USDA. Comparison of sources showed similar or higher standard deviation for NRD, but differences were small (Table 1); thus the difference in precision was likely a minor component of the associations in Fig. 3.

For individual crops, water regimes, counties and seasons, the percentage yield difference between the two sources ranged from approximately 20 to −20 % in data reporting below≈100 fields per county, except for three cases that exhibited differences betwee*n* −25 and −43 % (Fig. 4). These cases were Cheyenne 2010 where NRD reported 6.5 t ha^{-1} and NASS-USDA 11.0 t ha^{-1}, Colfax 2010 (6.6 vs 9.4 t ha^{-1}) and Colfax 2006 (5.8 vs 7.6 t ha^{-1}). The difference reduced to +10 to −10 % with a greater number of reporting

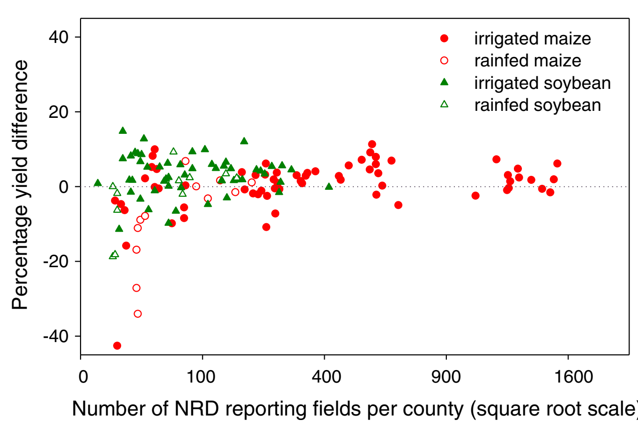


Fig. 4 Percentage difference between two sources of yield as a function of number of NRD reporting fields per county where each point represents a single county, year, crop, and water regime in Nebraska, USA

fields (>100 fields). Large differences between data sources were buffered for the pooled data; the average difference between USDA-NASS and NRD yield averages was reduced to −0.2 t ha^{-1} for both irrigated maize and soybean, 0.8 t ha^{-1} for rainfed maize and 0.1 t ha^{-1} for rainfed soybean. On average, NRD yields for maize and soybean, respectively, were 1 and 4 % higher (irrigated) and 8 and 4 % lower (rainfed) than those reported by USDA-NASS. Finally, there was a small, though consistent, positive yield difference between NRD and NASS irrigated yield data in counties with >100 reporting fields (71 % of the irrigated crops exhibited a positive yield difference). The causes for this discrepancy between data sources under high-yield, intensive-sampling conditions are unknown, and warrant further research.

Average yield difference for each combination of crop and water regime was disaggregated by region (Fig. 5). Average yield difference was greater in maize than soybean in the east and central regions, under both irrigated and rainfed conditions. There was a significant interaction between crop and water regime in the east: while the average yield difference of irrigated and rainfed soybean was similar in magnitude (though not in sign), it was about 3 times higher in rainfed than in irrigated maize. Percentage yield difference ranged from 2 % (east, irrigated maize) to −8 % (west, irrigated maize and east, rainfed maize) (Fig. 5b). The average percentage yield difference in irrigated crops was small and similar for soybean (3 %) and maize (2 %) but under rainfed conditions in the east, it was larger for maize (−8 %) than for soybean (−2 %). The largest average yield difference was observed for irrigated maize in the west region and rainfed maize in the east region (−8 %) which was, in turn, explained by the large difference in the 2010 crop season (Fig. 5b, inset). The discrepancy in the estimates for irrigated maize between east and central versus west counties can be attributed to differences in either the intensity of NASS-USDA sampling or the number of NRD reporting fields per county (average: 693, 208, and 43 NRD reporting fields in the east, central, and west counties, respectively). In the case of rainfed maize in the east region, the difference can be attributed to the limited sampling of rainfed maize fields in Colfax County (average: 25 NRD reporting fields). It is also interesting that, in the case of rainfed maize in Colfax County, the largest yield mismatch corresponded to the 2010 crop season which exhibited the lowest average rainfed maize yield among the six crop seasons analysed (2006–2011), which suggests that rainfed production areas with low sampling intensity are especially prone to large yield differences in harsh years.

Comparison of data sources in Argentina

Figure 6 shows the Altman and Bland plots for the pooled data comprising all 13 regions and 9–10 cropping seasons per region, for yield, acreage, and production of maize, soybean and wheat and Tables 1 and 2 present complementary statistics. Average yield differences and scatter of differences were larger for maize than for soybean and wheat (Table 2). Yield differences larger than 10 % were recorded in 28 % of cases for maize (37 out of 130), 16 % for soybean and 20 % for wheat (Table 2).

The differences in acreage between the two sources increased with increasing acreage for soybean and wheat (Fig. 6e, f). Likewise, the differences in production between the two sources increased with increasing production for soybean and wheat (Fig. 6h, i). The differences in reported acreage and production of maize were similar across the range of average acreage and production. Soybean, the crop with the largest acreage and production (Fig. 6, Table 1), showed the

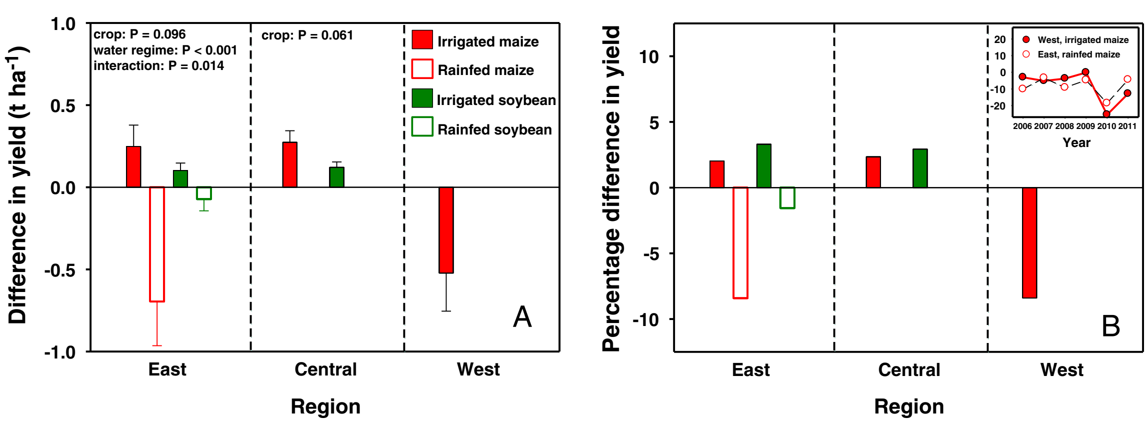
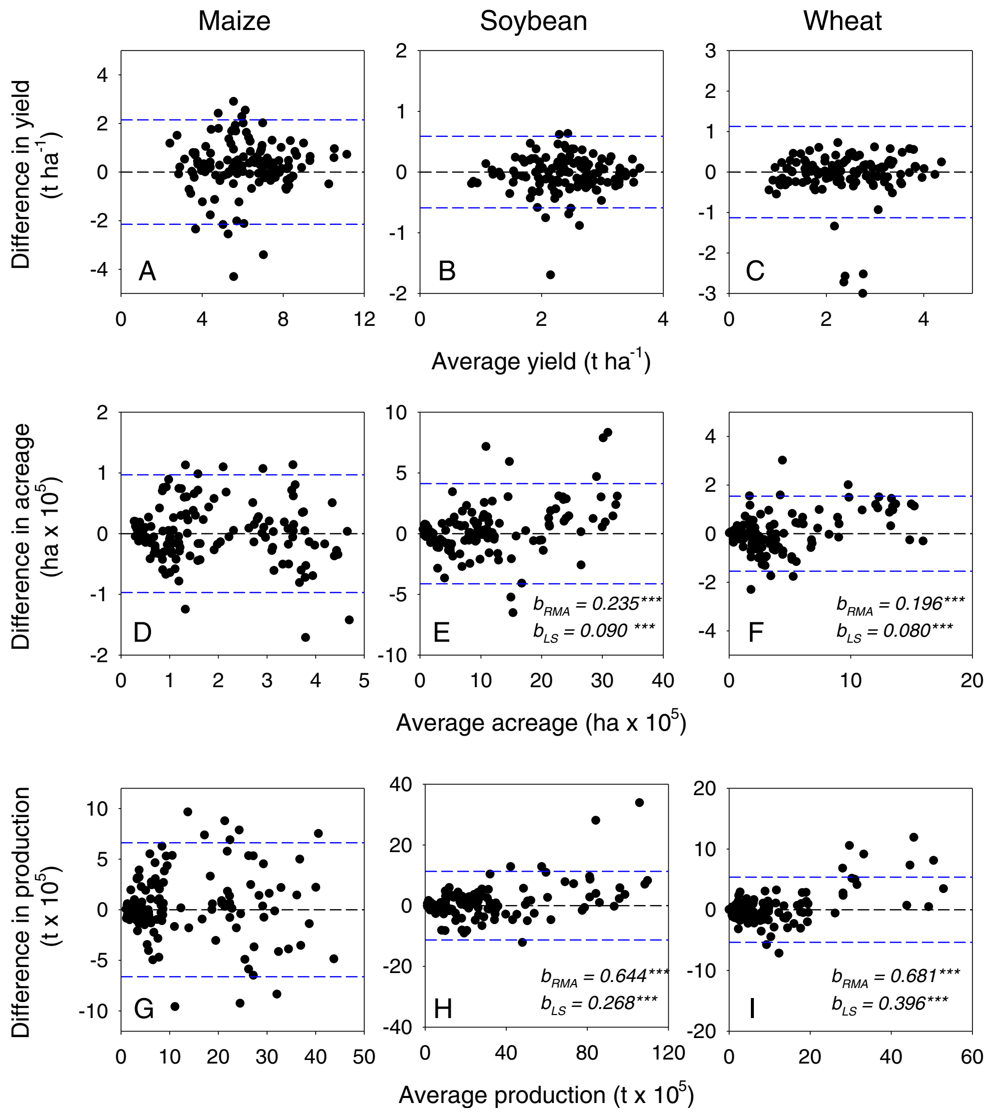


Fig. 5 **a** Difference between two sources of data for grain yield of irrigated and rainfed maize and soybean in three regions of Nebraska, USA. Values are averages of 6 years per region, error bars are one standard error of the mean and P values are from analysis of variance. Sources are NASS-USDA, National Agricultural Statistics Service of the United Stated Department of Agriculture, and NRD, Natural Resources Districts. **b** Average percentage differences in yield between sources. Inset shows the average percentage difference between NRD and USDA-NASS for six cropping seasons for irrigated (West) and rainfed (East) maize. Regions are mapped in Fig. 1; note that not all combinations of crop and water regimes were available for all regions

Fig. 6 Difference between two sources of grain yield, acreage and production for maize, soybean and wheat in Argentina against the average of the two sources. Sources are MA, Ministerio de Agricultura and BC, Bolsa de Cereales de Buenos Aires. Data are from 13 regions and 9–10 cropping seasons per region. *Black lines* are $y=0$ and coloured lines±2 SD. Regression slopes (b, unitless) are shown when statistically significant; asterisks indicate $P<0.0001$



largest difference between BA and MA in both acreage ($\bar{d}\approx$ 32,100 ha), and production ($\bar{d}\approx$ 95,000 t).

Scatter of data (Fig. 6) may involve some degree of compensation if BC estimates are larger than those of MA in some regions, and smaller in others. To assess this, we used analysis of variance to test for effects of crop, region and their interaction on the differences between the two sources reporting yield, acreage and production (Fig. 7). Differences between BC and MA for yield varied with crop, region and crop x region interaction. For example, the average difference between BC and MA yield estimates was negligible for all three crops in region VII comprising the original corn belt of Argentina, where there is a long history of high cropping intensity and technological innovation (Fig. 7a, b). In region XIV, BC average yields were consistently lower than MA estimates for all three crops (Fig. 7a, b); this is a low-lying area, often poorly drained and subject to patchy water-logging with a shorter history of cropping. In comparison to MA, BC average yield estimates were 30 % higher for maize and 17 % lower for wheat in region II, highlighting the region x crop interaction; livestock and regional crops such as cotton have been the main activities in this subtropical region, but grain crop acreage has increased over the last decades. Year-to-year variation in the start of rains after a dry winter in region II also contributes more opportunistic sowing decisions by producers. Separate analysis of variance comparing regions and seasons for each crop showed significant region effects ($P<0.0001$).

The average difference between BC and MA for acreage varied with crop, region and crop x region interaction (Fig. 7c, d). In region I for example, BC acreage was larger than that of MA, particularly for maize for which the percentage difference between sources averaged 42 %. In comparison to MA, BC average acreage was 27 % larger for maize and 18 % smaller for soybean in region XI. Differences between BC and MA for production did not vary with crop but varied with region and crop x region interaction (Fig. 7e, f).

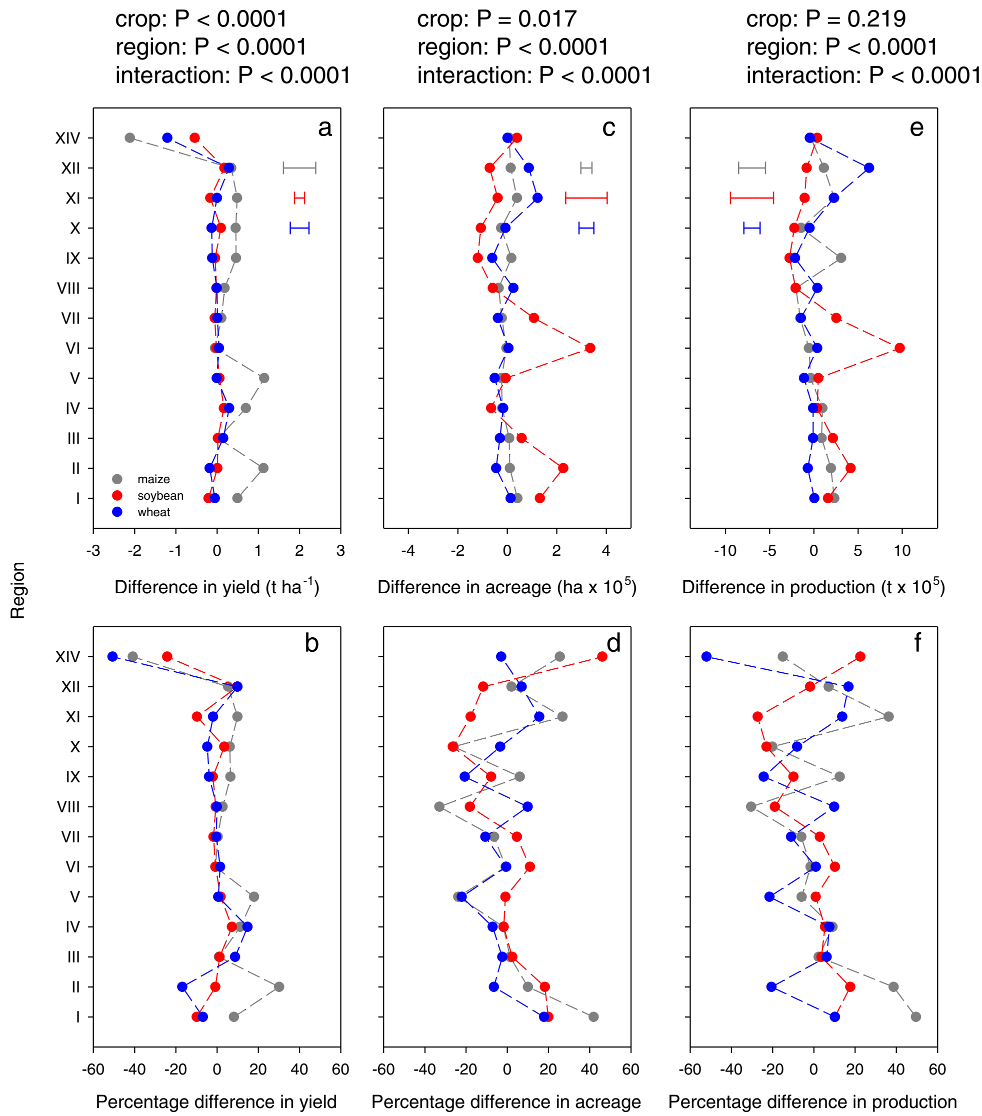


Fig. 7 Average difference between two sources of data for (**a**) grain yield, (**c**) acreage and (**e**) production of maize, soybean and wheat in 13 regions of Argentina. Values are averages of 9–10 years per region, and *P* values are from analysis of variance accounting for three sources of variation: crop, region and their interaction. Error bars are the square root of error mean square obtained from ANOVA for each individual crop. Average percentage differences (**b**, **d**, **f**) are also shown. Sources are MA, Ministerio de Agricultura, and BC, Bolsa de Cereales de Buenos Aires. Regions are mapped in Fig. 2

Figure 8 further supports the proposition that the disagreement between the two sources of yield diminishes where the industry is more developed, individual crop acreages are greater, and sampling intensity higher. The scatter plot of yield difference against acreage partially reflects the higher yield, and hence the larger yield differences, of maize relative to the other crops (Fig. 8a). To account for this, Fig. 8b shows average percentage yield difference. Using acreage as a surrogate for industry development, the difference between the two sources ranged from +50 to −100 % where crops are poorly represented. Extreme discrepancies are of particular interest. To narrow the focus on these extremes, we used±2 SD to select cases for discussion (rather than establishing a particular statistical criterion). Pooled across species, 21 out of 387 yield data points were outside the± 2SD interval (Fig. 6). Of these extreme values, 80 % clustered in average acreage <150,000 ha (Fig. 8c), thus suggesting that these are legitimate differences in data between sources rather than artefacts. Two-thirds of these extreme values were from region XIV, as reflected in Fig. 7a, b. No associations were found between percentage yield difference between sources and other variables putatively related to industry development at regional scale, including yield, coefficient of variation of yield, and coefficient of variation of acreage (not shown).

The percentage difference between sources diminished with increasing acreage for both acreage and production (Fig. 8d, e). Grain production, however, is derived from estimates of yield and acreage. Analysis of regression for the data pooled across crops and regions showed that differences in production between sources were closely related to differences in acreage (r=0.74, P<0.0001) thus accounting for the coincident number of observations agreeing to within 10 % for production and acreage (Table 2). The association between differences in production and differences in yield was significant but weaker (r=0.50, P<0.0001).

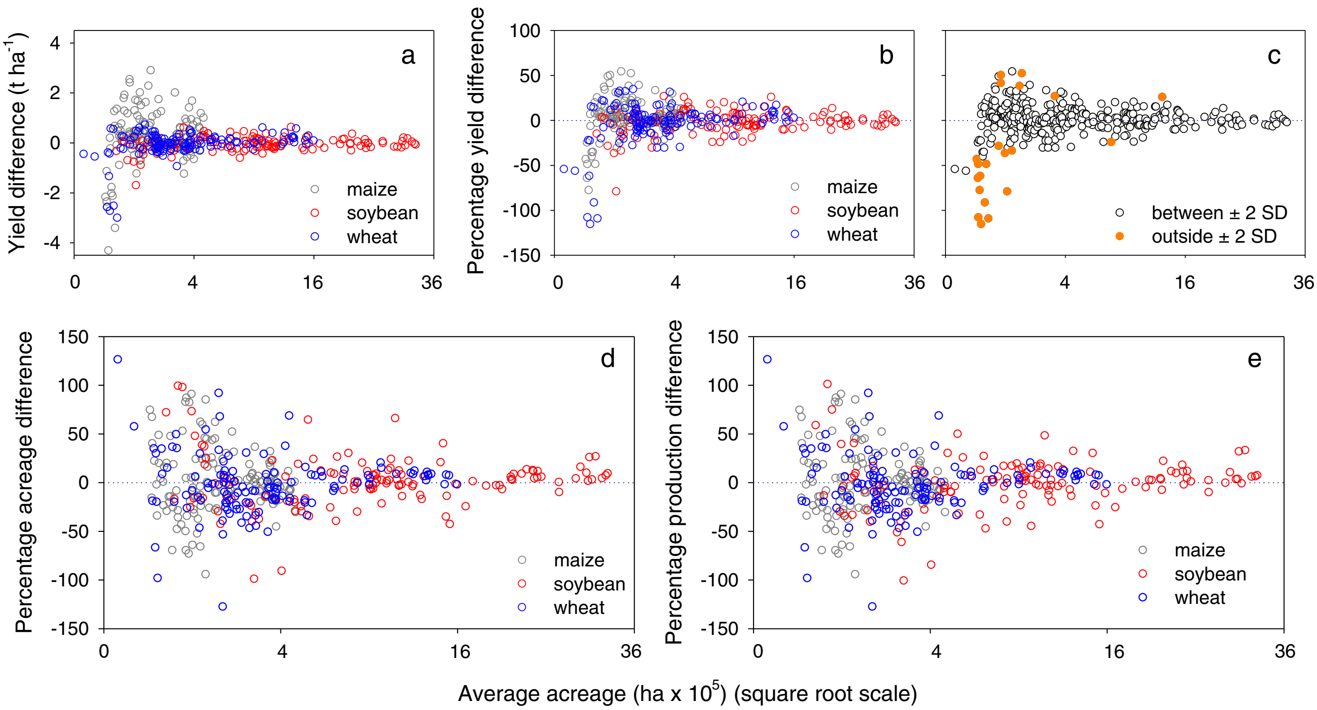


Fig. 8 **a** Difference in yield between two sources of data as a function of average acreage. Percentage difference in **b**, **c** yield, **d** acreage and **e** production between two sources of data as a function of average acreage. Sources are MA, Ministerio de Agricultura, and BC, Bolsa de Cereales de Buenos Aires. Each point represents a single crop, region and year. In **a**, **b**, **d** and **e** symbols correspond to crops, whereas in **c** symbols emphasise data between and outside the interval±2 SD

Discussion

Reliability of crop production data in the context of food security

Food security spans from household to global scales and involves four aspects: (1) availability and stability of supply, (2) access and affordability (3) nutrition and food safety, and (4) environmental sustainability (Pinstrup-Andersen 2009; Cassman 2012). The reliability of basic data to answer questions in any of these four domains is critical for two reasons. First, to present the problems and solutions within the boundaries of their intrinsic uncertainty. Second, to avoid a false sense of accuracy that might be misleading, particularly for end-users from disciplines removed from the original data sources. In this context, this paper focuses on the reliability of grain production.

Questions in each of the domains of food security need to be framed in proper spatial and temporal coordinates. If the questions are about food security on a global scale, then relevant data sources need to account for the high level of spatial aggregation at the appropriate time scale. For example, Monfreda et al. (2008) snap-shot world map of crop yield and acreage around year 2000 included 206 countries, 2299 political units one level below the country from 150 countries, and 19,751 units two levels below the country for 73 countries. In this example, raw data for grain crops in Argentina were from FAOSTAT (Table 2 in Monfreda et al. 2008), which in turn sources its data from Ministerio de Agricultura, one of the data sources used in this paper. Also using the FAOSTAT Database – Agricultural Production (http://faostat.fao.org/), Grassini et al. (2013) recently evaluated yield trajectories and plateaus for wheat, maize and rice at the national level during the period 1965–2011 and performed complementary analyses at smaller scales using wheat, maize, and rice yield data from the National Agricultural Statistics Service — Crops US state and county databases (http://www.nass.usda.gov/index.asp). Here we asked questions about the reliability of grain production data at small scales in space and time. Bias in estimates of short to medium term production at regional scales may have implications for logistics of food distribution, and in the case of the large grain producers targeted in this study, USA and Argentina, bias in estimates might contribute to price volatility with impacts on affordability.

Comparisons of data sources in Nebraska and Argentina

Discrepancies between NASS-USDA and NRD yield data in Nebraska ranged from 20 to −35 % for individual counties, crops, water regimes and seasons in counties with less than≈ 100 reporting fields, and were reduced to 3 to −8 % for yield data at higher levels of aggregation or of number of reporting fields (Figs. 4 and 5). In the eastern and central counties, average irrigated and rainfed yields derived from NRD-collected data were higher and lower, respectively, than the NASS-USDA county yield averages. However, average NRD yield of irrigated maize was below the USDA-NASS yield reported for the western counties. The magnitude of the yield difference was related to the number of NRD reporting fields per county (Fig. 4). The degree of spatial congruence between NRD reporting area and USDA-NASS surveyed area might have also contributed to the disagreement between the two sources of yield data in some counties but this cannot be corroborated without knowing the location of the NASS-USDA surveyed farms.

Analysis across regions showed that the degree of agreement in the data reported by BC and MA in Argentina depended on both the crop and the variable (Table 2, Fig. 6). The average yield difference between sources was larger for maize than for wheat and soybean (Table 2). The acreage difference between reporting sources for wheat and soybean increased with increasing acreage, and the same pattern was found for total production. Analysis of the differences between data sources at regional level showed marked differences between crops and regions, and relevant interactions between crop and region (Fig. 7). For example, the average difference between BC and MA for wheat and soybean yield was small in general; for wheat however, it ranged from 15 % in region IV to −51 % in region XIV. Therefore, the lack of significant difference for the average yield of wheat and soybean, and for the acreage and production of maize (Table 2) partially resulted from compensation between regions where positive deviations (BC > MA) compensated negative deviations (BC < MA). For maize, the average differences in yield were dominantly positive (BC > MA), up to 30 % in region II. Pooling the data for crops and regions, the difference between the two sources of yield ranged from approximately 50 to −100 % (Fig. 8a). For soybean in region VI, average yield differences between sources were small, but the average acreage was 3.4×10^5 ha larger for BC than for MA, and the average difference in production was 9.7×10^5 t (Fig. 7a–e), highlighting again the propagation of inaccuracy from acreage to production estimates. Owing to the large scale of soybean production (Table 1), these differences were in the order of 10 % and comparable with those for wheat and maize (Fig. b–f).

For yield, production and acreage the scatter of the percentage differences decreased with increasing acreage (Fig. 8). At least three factors underlie this pattern. First, high acreage indicates higher cropping intensity; regions where cropping is better established, like region VII for maize, is more likely to return more reliable estimates. Second, the intensity of sampling is also larger in regions with greter cropping intensity; as outlined in methods, Buenos Aires province, containing the core of the wheat and maize belt of Argentina, accounts for 28 % of MA's regional offices. Third, there is an element of circularity that applies to acreage, to a lesser extent to production but not to yield. By definition, percentage difference in acreage is an inverse function of average acreage, hence the expected decline in percentage acreage difference when the scatter of actual differences is roughly the same as the acreage increases. This applies partially to production which has acreage (and yield) as a component in its definition. Yield difference is independent of acreage, thus the decline in scatter with acreage is fully accounted for by the first two factors, cropping intensity and intensity of sampling.

Implications for data interpretation

Many studies have used diverse data sources to assess the productive and environmental trajectories of farming systems, hence the importance of evaluating the reliability of the underlying data. In long-term studies of deforestation, Gasparri et al. (2008) emphasised inaccuracies in early estimates of land use patterns derived from surveys in comparison with more recent, satellite-derived information. Our analysis also highlights the importance of accurate estimates of acreage, as this was the main source of discrepancy in production data between the sources analysed for Argentina.

We compared a pair of independent organisations in the USA, the National Agricultural Statistics Service of USDA and the Natural Resource Districts of Nebraska, and a pair of independent organisations in Argentina, the Ministerio de Agricultura and Bolsa de Cereales de Buenos Aires. Whereas the organisations in each pair are independent and generate production statistics for different stakeholders, their methods and sources of raw data overlap partially. The spatial aggregation of data differs between MA (counties) and BC (regions), and between NASS-USDA (counties) and NRD (reporting areas). All four organisations involve experienced professionals using rigorous methods; hence comparisons did not seek to establish the "right" estimate. The conclusions from these comparisons are therefore asymmetric: where the two sources show statistical agreement, we can have some confidence on the reliability of the data, but where the sources disagree, we cannot tell which one is the more reliable; we can however highlight the mismatch and recommend caution in the use and interpretation of crop yield and production data.

For yield of both soybean and maize in Nebraska, and for production and acreage of wheat and soybean in Argentina, the differences between sources increased with the average size of the variable (Figs. 3 and 6). In relative terms, however, comparisons between elements of the two pairs of data sources highlight that the agreement is greater if regional cropping area and/or number of reporting fields is greater (Figs. 4 and 8). Use of yield data provided by these data collection systems is likely to return more robust conclusions if analyses are restricted to cropping area sizes and field numbers that exceed the threshold required to attain less variable estimates. When dealing with aggregated data (e.g., national yield, acreage and production statistics) these uncertainties are likely to weigh less given the association between degree of certainty and size of contribution to national statistics. For grain crops, the methods and allocation of effort to collecting production data at different spatial scales deserve further attention and standards developed in other industries maybe useful references (Hauser and van Asten 2008).

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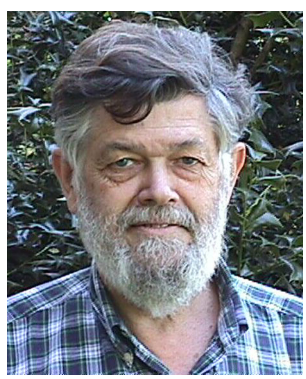

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