

Environmental heterogeneity at a field scale and yield: what can combinations of yield and detailed soil maps tell us and what not

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ABSTRACT

- Site-specific management recognized that within-field variability in crop yield and soil properties should be assessed to improve crop management. Specifically, this study evaluated sunflower (*Helianthus annuus* L.) yield variability across soils of different water holding capacity (WHC).
- This study was carried out on farmer's fields in the West and Southeast of Buenos Aires province. Ninety eight no-till sites were used in this study, which corresponded to three different years depending on the region. Management practices were those used by each farmer; however, all sites were managed using a management zone (MZ) approach and sunflower fields were harvested using combines equipped with yield monitors. The main variable driven to delineate different management zones within sites was the WHC of the soil. On the West, WHC varies depending on the percentage of sand content of the soil; and on the Southeast, by the depth of a petrocalcic layer.
- Across all sites, the within-site yield variability was 17.8%, and the within-management zone variability was 15.6%, with values that ranged from 6 to 35%. This shows that an important part of the within-site yield variability cannot be explained in fields that are managed using a management zone approach defined by one variable. Furthermore, in sites with no clear soil variable that can be defined, the within-site yield variability results even harder to be accounted for.
- The study showed that to understand yield differences within and between sites it is important to manage the sites by differences in grain productivity. An analysis within sites showed yield differences of 15% on the West and 12% of variation on the Southeast when compared between the average of the site and by management zone approach, respectively. These yield differences were higher as the WHC of the soil decreased. The relationship on the West sites between relative yields of each management zone in comparison with the best yield of each zone, were 0.80, 0.83 and 0.74 for soils with 150-180 mm, 180-200 mm, and 200-220mm of WHC, respectively. On the Southeast, this relationship was 0.81 and 0.88 for soils with 60-90 mm, and 90-150 mm, respectively. No significant differences were found in soils with more than 200 mm of WHC.
- This study showed that sunflower yields have high variability within and between sites, and furthermore, with soils of different WHC. It is usual to have gaps between trials and production sites. The need for different management practices and crop breeding trials to be carried out on contrasting zones, even in the same production site, is of pivotal importance.

Key words: management zone, yield map, sunflower, grain productivity.

INTRODUCTION

Sunflower yield shows high variability when compared across years, and also between and within regions. These yield differences can be seen among farms, research trials and on the average of a region (Hall *et al.*, 2007). Hall *et al.* (2007) reported 25% yield difference between farms' average yields and the yield that can be achieved on research plots, on five different sunflower regions.

The main yield differences within a region and year are due to differences in management practices, and also in areas within a field that have different sunflower potential. On the southeast of Buenos Aires province, it was found that the sunflower crop has important yield differences when grown in soils of different petrocalcic layer depths (Sadras y Calviño, 2001). These differences were related to the water holding capacity (WHC) of the soil and the water deficits that these soils can generate.

Once the areas within a field of similar grain production are identified, the use of a management zone (MZ) approach provides an excellent alternative to apply the best management practices on those areas of similar production.

Sunflower breeding research is generally done in fields and zones of high yield production. Furthermore, most research comparing yield differences among materials are done in areas within a region better than were normally farmers grow sunflower (Hall *et al.*, 2007). Sunflower yield maps are important tools to recognize areas within farmer fields of different grain production.

The objective of this study was to quantify how much of the variation seen on yield maps is due to differences in crop management practices and how much is due to variations in areas within a field that have different grain potential.

MATERIALS AND METHODS

Fields, soils and climate

Two different geographic areas in the Pampas region of Argentina were included in this study. One area was the Southeast (SE) of Buenos Aires province, consisting of the departments of Tandil (37° S, 59° W), Gral. Madariaga (37° S, 58° W), and Necochea (38° S, 59° W). The other area was the West (W) of Buenos Aires province and included the department of Trenque Lauquen (35° S, 58° W), Pellegrini (36° S 16° W); and east of La Pampa province, specifically, the department of Chapaleufu (35° S, 63° W). Average annual rainfall in Tandil is 900 mm, 800 mm in Necochea, 820 mm in Trenque Lauquen, and 780 mm in Chapaleufu. Approximately, 45% of the annual rain falls during the sunflower growing cycle in SE and 65% in W.

This study was carried out on farmer's fields in the West and Southeast of Buenos Aires province. Ninety eight no-till fields were used in this study, which corresponded to three different years depending on the region.

Yield and delineation of management zones

Grain yields were measured and recorded every second using combines equipped with yield monitors and real-time differential global positioning systems (DGPS) receivers. The yield monitors used were impact flow-rate sensors (Ag Leader Technology, Ames, IA; Green Star, John Deere Inc.). Yield data were unaffected by field borders due to the MZ being located at least 40 m from any field border. The raw yield data recorded by the yield monitors were carefully analyzed for common errors. Such errors included incorrect geographic coordinates due to total or partial loss of good differential correction, the effects of waterways or grass strips, and incorrect settings in the time lag for the grain path through the combine (from the combine head to the yield monitor). The data were imported into spreadsheets and then exported to ArcGIS (ESRI, 2011) for GIS management and later to InfoStat (Di Rienzo *et al.*, 2011) for statistical analyses.

Yield input data were means of yield monitor points for areas delineated by the width of the combine head (4.5 m) and 10 to 15 m length. The individual data points were not directly considered because of known diminished accuracy of yield monitors over distances shorter than 10 m. A covariate value corresponding to each yield observation was calculated using the mean yield value of four neighbors of each yield observation (one from each north, south, east, and west coordinate). The yield data were analyzed by percentiles. Percentile 0.9 was considered a good indicator of the maximum sunflower yield in each zone. And the highest yield achieved in a zone within a field was considered the maximum yield production of that field.

Management practices were those used by each farmer; however, all fields were managed using a management zone approach and sunflower fields were harvested using combines equipped with yield

monitors. The main variable driven to delineate different management zones within fields was the WHC of the soil. On the West, WHC varies depending on the percentage of sand content of the soil; and on the Southeast, by the depth of a petrocalcic layer. Secondary variables were those that create changes in the WHC of the soil such as salt content and slope. Boundaries for each MZ were set with tools such as remote sensing and image interpretation (Landsat 5), topography, history of yield monitor maps, and maps showing depth of petrocalcic layer of the soil. Each field had already its own management map, and each management zone had at least 15% difference in yield production and a minimum of eight hectares. Table 1 provides information about field locations and the predominant soil series where sunflowers were grown for each region. In SE, the available WHC is 1.5 mm cm^{-1} of soil (Travasso y Suero, 1994), and in the W region this value ranged from 0.8 to 1.25 mm cm^{-1} (Quiroga, 2010, personal communication).

Table 1. Field location, predominant soil types and descriptive soil properties.

Region	Predominant soil type	Topographic position	Slope range	WHC ⁽¹⁾	Petrocalcic layer depth	Sand content
			%	mm	m	%
SE	Typic argiudoll	Lower and mid slope	0.5 - 2.0	> 300	> 2.0	-
	Typic argiudoll or Petrocalcic paleudoll	Lower and mid slope	0.5 - 2.0	150 - 300	1.0 - 2.0	-
	Petrocalcic paleudoll	Mid and upper slope	2.5 - 3.5	90 - 150	0.6 - 1.0	-
	Petrocalcic paleudoll	Mid and upper slope	2.0 - 4.0	60 - 90	0.4 - 0.6	-
W	Typic Hapludoll or Hapludoll thapto natric	Lower slope	0.5 - 1.0	> 260	-	< 65
	Typic Hapludoll	Mid slope	1.0 - 1.5	180 - 260	-	65 - 80
	Entic Hapludoll	Upper slope	1.5 - 3.5	160 - 180	-	80 - 85

⁽¹⁾ WHC: Water holding capacity of the soil at two meters depth except in soils with limitations.

RESULTS AND DISCUSSION

Average yield across all fields was 10 to 15% higher than the average yield of the department where the fields were located. This was the case for all three years under study. Furthermore, yield values were 2374 kg ha^{-1} for the W region and 2370 kg ha^{-1} for the SE. In an analysis within regions, these yields corresponded to a 15% and 12% lower yield than the 0.9 percentile of the W and SE regions, respectively. The analysis of yield monitor maps suggested that there are areas within the field that had more homogenous yield values and it is recommended to manage and analyze these areas separately than averaging the yield of the entire field. Furthermore, there are areas with higher and lower yields than the average of the field, and this study showed that 50% of the data had lower yields than the average of the field.

Table 2 shows that, between years, there was a significant yield variation, and there was no correlation between regions. Also, yield variability within each management zone showed no significant differences ($p > 0.05$) between high, medium and low zone production. But there were differences between fields, as shown by the range of the coefficient of variation (CV). These differences may be due to variability in management practices done by each farmer and hard to be detected by the delineation process of zones carried out in this study. In summary, each management zone was not completely homogenous as could have been expected. The average CV across all zones and fields was 17.8%.

Table 2. Average yield per year and CV within similar management zones

Year	Southeast region		West region	
	Average yield	CV range	Average yield	CV range
	kg ha-1	%	kg ha-1	%
2006			2720	7.8 - 20.2
2009	1774	6 - 28	2892	18.9 - 33.8

2010	2101	18 - 29		
2011	2824	17 - 29	1634	8.8 - 20.9

Figure 1 A shows that variability within zones was lower than variability within a field, for most of the fields under study. Only 14% of the zones showed higher CV than the entire field. Moreover, there were no significant trends at the scale of variability.

As the yield difference between zones of a field increases, the variability of the entire field also increases. This shows that to better understand the field yield it is important to manage fields by production (Figure 1B). There were differences within zones of low and high productivity according to the weather and crop management.

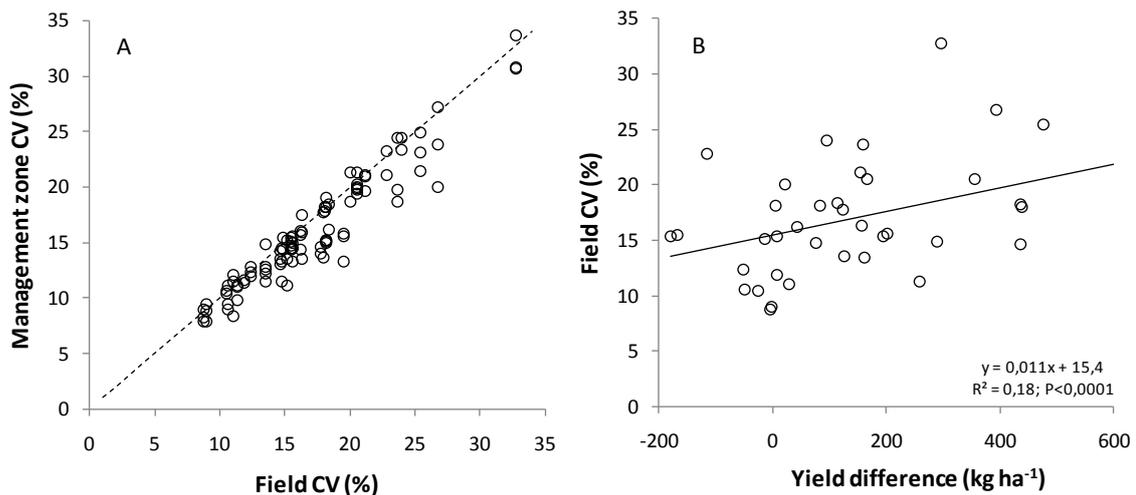


Fig. 1 A. Relationship between CV of the field and CV of the management zone.

Fig. 1 B. Relationship between the yield difference within management zones and the CV of the field.

Figure 2A shows that in the W region, 38% of the management zones had an average yield higher than 85% of the 0.9 percentile. In contrast, for the SE this was 66% of the cases (Figure 2B). Thus, homogeneity is more evident within the SE zones than for the W zones.

In the W region, there was a tendency to increase the percentage difference between the 0.5 and 0.9 percentile as yields increased ($P = 0.01$). In contrast, in the SE the trend was to increase percentagewise as yields declined ($P = 0.03$).

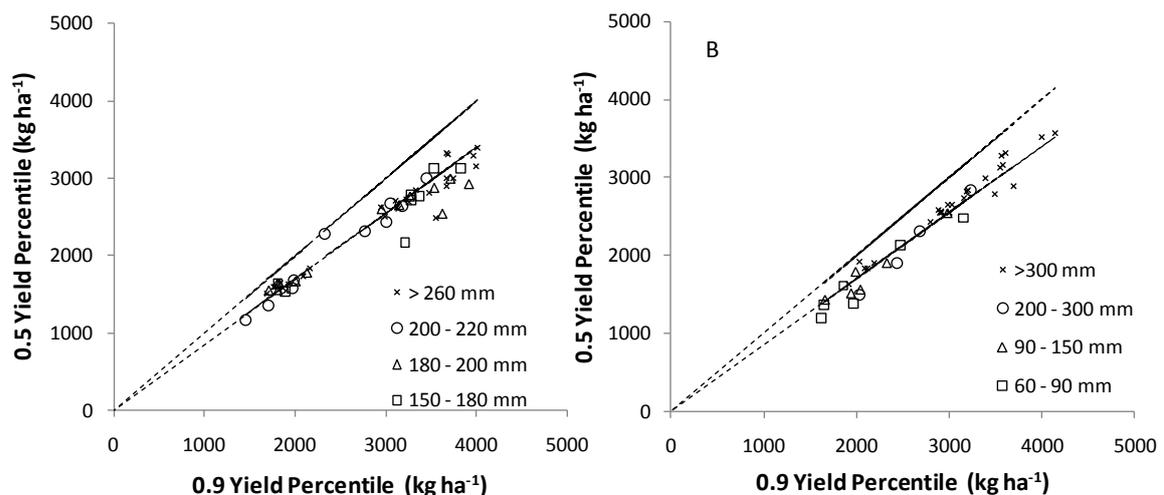


Fig. 2. Relationship between average and high yield of each field. A. West region and B. Southeast region. Average yield corresponds to 0.5 percentile and high yields to 0.9 percentile. The upper dash line corresponds to a 1:1 relationship and the lower dash line to a 1:0.85 relationship.

Figures 2A and 2B shows that relative yield of each production zones compared to the highest yield obtained in a production zone within the same site, varied between fields. This was particular the case for all the fields with the highest WHC of the soil, suggesting that the variable chosen by the farmer to delineate management zones was very strong.

The relationship on the W fields between relative yields of each management zone in comparison with the best yield of each zone, were 0.80, 0.83 and 0.74 for soils with 150-180 mm, 180-200 mm, and 200-220 mm of WHC, respectively. The weakness of the relationship found on the 200-220 mm of WHC is due to other variables such as salt content in the soil that increases the variability. On the SE, this relationship was 0.81 and 0.88 for soils with 60-90 mm, and 90-150 mm, respectively. No significant differences were found in soils with more than 200 mm of WHC. The relative yield found in each region was higher than those reported by Sadras y Calviño (2001) and Calviño *et al.*, 2010. Part of these differences could be explained by the methods and the scale used in each research. The first study used small plots of few meters, and the second study used an area of 1 hectare within different management zones. In the current study, it was used the entire area of the management zone with areas bigger than 8 hectares that considered a range of WHC and other variables that could increase the variability.

Figure 3 shows that at equal WHC of soils between regions, the SE showed relative yield lower than the W region. The main reason for this yield difference lies in the petrocalcic layer at different soil depths, which prevents the roots to explore the soil profile in the SE. On the other hand, in the W region the WHC of the different soils were considered at 2-m depth and there are several studies that showed that roots can explore below this depth.

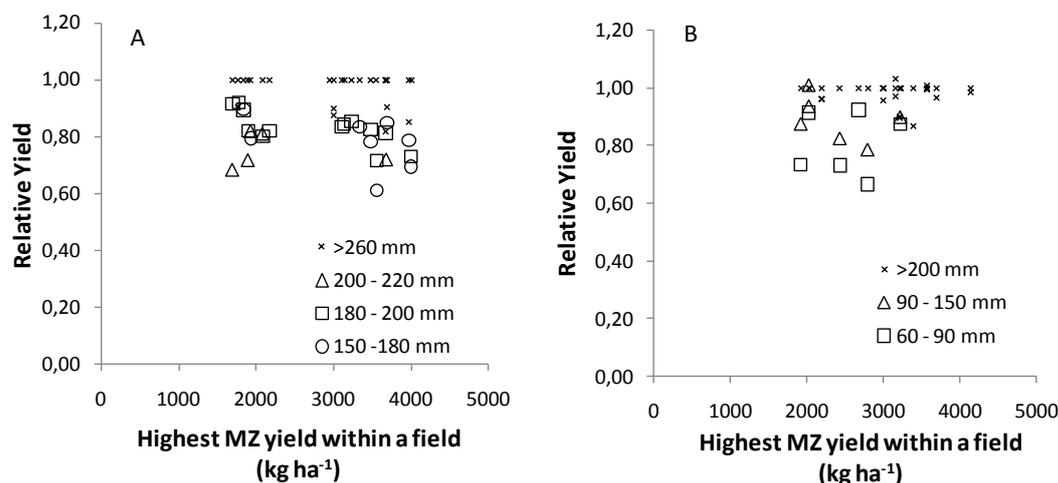


Fig. 3. Relationship between relative yields (management zone yield within a field relative to the highest yield of each field) and the highest MZ yield within a field. A. West region. B. Southeast region.

CONCLUSIONS

Across all sites, the within-site yield variability was 17.8%, and the within-management zone variability was 15.6%, with values that ranged from 6 to 35%.

The study showed that to understand yield differences within and between sites it is important to manage the sites by differences in grain productivity. An analysis within sites showed yield differences of 15% on the West and 12% of variation on the Southeast when compared between the average of the site and by management zone approach, respectively. These yield differences were higher as the WHC of the soil decreased.

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