EXPLAINING YIELD VARIABILITY BETWEEN FARMERS AS A FIRST STEP TO REDUCE YIELD GAPS

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1 Introduction

Reducing yield gaps is one of the major pathways identified to meet the future food demand (Keating *et al*., 2014). A prerequisite to design strategies to reduce the yield gap of crops is to understand its causes. The sustainability of most vegetable farms in south Uruguay is threatened by low family income and deteriorating soil quality. The main cause of low income is that most farms obtain 50% or less of the attainable crop yields in the region, with similar production resources and proper management (Dogliotti *et al*., 2014). Low yields are the main cause of low labour productivity and resource use efficiency. There is a huge variability between farmers in crop yields, product quality and economic results. To explain the main causes of this variability and to identify strategies to reduce the distance between the average yield and the top yielding fields and farms, we started a project to study important vegetable crops in south Uruguay (onion, tomato, sweet potato and strawberry). In this paper we present the method developed to explain variability in physical and economic results, the main causes identified in the seasons studied on strawberry and onion, and discuss strategies to reduce the observed gaps.

2 Materials and Methods

We adapted and combined the methods of the Regional Agronomic Diagnosis (Dore *et al*., 2008) and Yield Gap Analysis (Lobell *et al*., 2009; Van Ittersum *et al*., 2013). The region under study is 60 km around Montevideo, radiation and temperature was considered homogenous within this radius, rainfall was measured at each farm. Based on Census data, we built a typology of vegetable farms growing the selected crops using cluster analysis. Combining farm types and location, we selected a representative sample of 10% of the farms in strawberry (13) and 5% in onion (30). From each farm we selected one to three fields to be monitored and evaluated throughout the growing season. Bio-physical and economic data was gathered at the farm system and at the crop/field level. Growth and yield of the crop was evaluated in 4-6 plots per field. Variables were classified as growth-defining, growth-limiting, and growth-reducing, according to Van Ittersum & Rabbinge, (1997). Statistical analysis combined different tools: path analysis, boundary lines, and regression trees. We studied two seasons of strawberry crop (76 fields) and one season of onion crop (69 fields).

3 Results - Discussion

The strawberry average commercial yields were 18.6 ± 12.2 and 24.9 ± 8.1 Mg ha^{-1}, the top 10% average yields were 41.3 and 40.0 Mg ha^{-1} and the average yield gap was 55% and 38% in 2012 and 2013, respectively. Strawberries are planted end of summer and early autumn. To reduce costs, farmers use one third of the plants required to complete the target plant density. Planting is completed with the first two daughter plants of each plant.

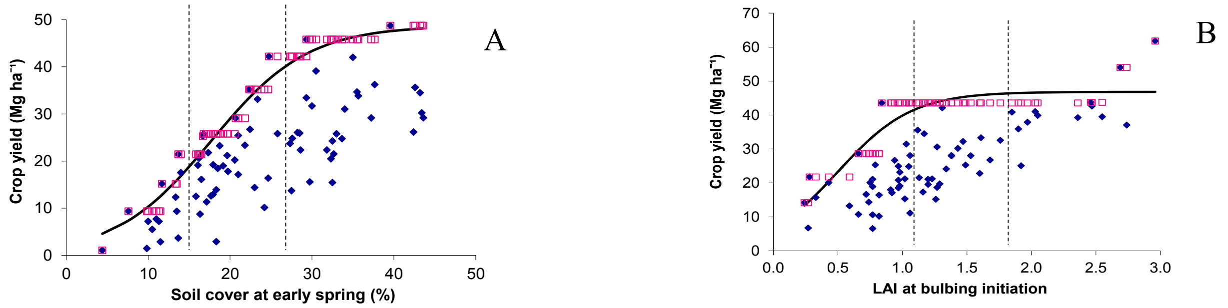

Fig. 1. Relationships between strawberry yield and soil cover at early spring (A), and onion yield and leaf area index at bulbing initiation (B). Boundary line models fitted to all observations, A (n=76): y_i=49,27/(1+20,40 * exp (-0,17 * x_i)); B (n=69): yi=46,82/(1+5,81 * exp (-3,5 * x_i)).

Strawberry yield was determined by soil cover at early spring (Fig. 1A), which was explained by the initial planting date, the date planting is completed, and the final plant density. We found that to yield over 30 Mg ha^{-1} strawberries should be planted before April 15th, the plant density should be over 40 thousand plants per ha and this number of plants should be completed before May 31th (Table 1). Using cluster analysis we divided the fields in three groups according to the soil cover at early spring to study the causes of yield gap within each group. We found that relative yield gap ((boundary line yield–observed yield)/boundary line yield) on the medium and high soil cover groups was mainly explained by N and K fertilization management and water balance. Most farmers applied more than enough N and K, but they applied them mostly at pre-planting. Farmers applying more N and K by fertigation since August had the best results. We couldn't identify causes of relative yield gap in the low cover group due to the reduced number of fields in this group.

Table 1. Strawberry soil cover, yield, relative yield gap and management variables associated to determinant factors for each soil cover group (Date 1st January = 1).

Group	N	Soil cover al early spring (%)	Crop yield (Mg ha^{-1})	Relative yield gap	Planting date	Complete crop density date	Plant densitiy (10^3 ha^{-1})
1 (low)	14	11 ± 3	8,7 ± 6,1	0,30 ± 0,30	117 ± 47	160 ± 34	32 ± 5
2 (medium)	32	20 ± 3	20,0 ± 8,1	0,29 ± 0,23	80 ± 17	144 ± 30	41 ± 7
3 (high)	30	34 ± 5	28,9 ± 8,5	0,37 ± 0,18	85 ± 19	125 ± 28	45 ± 6

Table 2. Onion Leaf Area Index at bulbing initiation, yield, relative yield gap, length of period from planting to bulbing initiation and plant density.

Group	N	Crop yield (Mg ha^{-1})	LAI at bulbing initiation	Relative yield gap	Leaf area per plant (cm^2)	Planting to Bulbing initiation (days)	Plant density (10^3 plants ha^{-1})
1 (low)	33	19,2 ± 7,6	0,78 ± 0,24	0,41± 0,23	448 ± 190	87 ± 16	216 ± 49
2 (medium)	23	26,4 ± 6,8	1,36 ± 0,18	0,40± 0,15	671 ± 165	84 ± 15	223 ± 40
3 (high)	13	41,4 ± 8,8	2,30 ± 0,37	0,15± 0,12	1045 ± 162	97 ± 8	237 ± 49

Onion crops in south Uruguay are mostly installed by transplanting in winter. The onion average commercial yield was 25.8 ± 11.1 Mg ha^{-1}, the top 10% average yield was 47.0 Mg ha^{-1}, and the average yield gap was 45% in 2014. Crop yield was determined by Leaf Area Index at bulbing initiation (Fig. 1B), which was explained by the initial plant density, the plant density at harvest and the length of the period from planting to bulbing initiation, which depends on the planting date (Table 2).

4 Conclusions

The average commercial yield of strawberry and onion in south Uruguay could be improved by more than 40% by adjusting timing of operations and crop management without significant increase in inputs and production costs. The first step to reduce yield gap would be to increase soil cover at early spring and LAI at bulbing initiation by adjusting planting dates and planting densities, which requires better planning of soil preparation and of plant nurseries. Second step to improve strawberry yield is to reduce relative yield gaps within the high soil cover group by adjusting crop fertilization management and irrigation. In the onion crop the relative yield gap within the group with high LAI at bulbing initiation was only 15%.

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