Regional agronomic diagnosis for greenhouse tomato in south Uruguay: identifying pathways to reduce yield gaps

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1. Introduction

Knowledge about contributing factors to yield loss in crops is essential for sustainable intensification of agriculture, which has the objective to increase both, yield and environmental sustainability of crop production (Garnett et al., 2013). The sustainability of most vegetable farms in south Uruguay is threatened by low family income, driven by low crop yields which are on average 50% or less of the attainable crop yields in the region, with similar production resources and proper management (Dogliotti et al., 2014). There is a huge variability between farmers in crop yields, product quality and economic results. The challenge of linking cropping systems performance (crop yield, quality or environmental impact) to farmers' practices has been already addressed under the name of 'regional agronomic diagnosis' (Doré et al., 2008). At global and regional level, magnitudes and causes of yield gaps between actual farmers' yields and an estimate of a reference yield at a specific area and time have been studied applying 'yield gap analysis' (Lobell et al., 2009; Van Ittersum et al., 2013; FAO-DWFI, 2015). This study aimed to identify strategies to reduce the distance between under-performing and best-yielding greenhouse tomato crops in the south region of Uruguay. For this purpose, the gap to attainable yield was described and the main causes of yield variability were explored by combining regional agronomic diagnosis and yield gap analysis.

2. Materials and methods

110 tomato greenhouse crops within 23 farms during 2014/15 and 2015/16 were assessed, representing 10% of region's tomato producers. The variables assessed by direct measurements, farmers' records and open interviews were classified in four groups: growth defining, growth limiting, growth reducing factors and yield components (Van Ittersum and Rabbinge, 1997). Path analysis and Spearman correlations were carried out to identify the most important yield components and growth defining factors responsible of yield variations. We explored the relationships between most relevant yield components and growth defining factors with "attainable yield" by building bi-dimensional scatter plots and fitting boundary line models. Since cumulated PAR intercepted was the growth defining factor that showed highest correlation with yield, we used it to classify production situations in three levels of cumulated PAR intercepted by cluster analysis. Within each group, we used Classification and Regression Trees (CART) analysis to identify main growth limiting and reducing factors responsible of yield gap variation. Relative yield gap to attainable yield was the response variable, calculated as the

difference between actual and boundary line yield estimation, at the same level of cumulated PAR intercepted, expressed relative to boundary line yield.

3. Results - Discussion

We observed high yield variability among crops ranged from 0.9 to 24.3 kg m^{-2} with an average of 10.9 kg m^{-2}. Attainable yield overcame the average when number of trusses per plant was higher than 6, cumulated PAR intercepted was higher than 440 MJ m^{-2} and fraction PAR intercepted at harvest beginning exceeded 0.7 (Fig. 1). Only crops with more than 2 stems m^{-2} reached more than 20 kg m^{-2}.

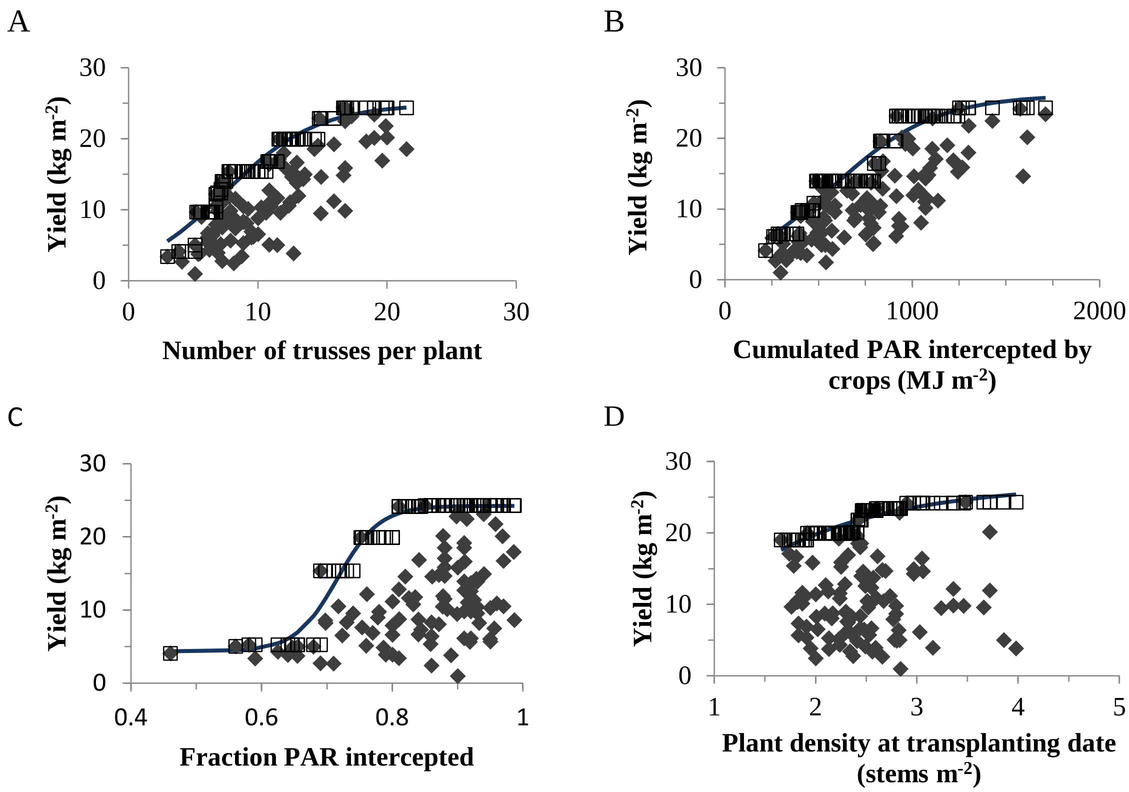

Fig. 1. Actual yield (♦), boundary points (□) and fitted boundary lines (attainable yield) as a function of: (A) number of trusses per plant ($y_i = 24.87 / (1 + (8.04\ e^{-0.28\ x_i}))$, R^2 adjusted: 0.94), (B) cumulated PAR intercepted by crops (considering the greenhouses transmissivity) ($y_i = 26.16 / (1 + 7.81\ e^{-0.0036\ x_i})$, R^2 adjusted: 0.95), (C) fraction PAR intercepted by canopy on the row at harvest beginning ($y_i = 19.90 / (1 + 4372715488.54\ e^{-0.31\ x_i}) + 4.35$, R^2 adjusted: 0.92), (D) plant density at transplanting date ($y_i = 26.90\ (1 - (1.26\ e^{-0.78\ x_i}))$, R^2 adjusted: 0.81).

Cumulated photosynthetic active radiation (PAR) intercepted was the most correlated with yield (Spearman correlation coefficient of 0.8, p-value <0.0001). Average yield gap calculated as the difference between actual and attainable yield, estimated as a function of cumulated PAR intercepted, for both years was 5.4 kg m^{-2} and 34% of attainable yield (5.7 kg m^{-2}, 33% in 2014/15 and 5.4 kg m^{-2}, 36% in 2015/16). We found that K nutrition was highlighted by CART analysis as yield limiting factor for all three groups of cumulated PAR intercepted. Under low intercepted PAR (216–588 MJ m^{-2}) yield gap variations were explained also by hydric welfare index, seedling height and soil exchangeable Na. For medium PAR intercepted crops (636–843 MJ m^{-2}), yield gaps could be reduced by reducing whitefly damage and increasing N fertigation. In high PAR intercepted group (907–1712 MJ m^{-2}), excess of Mg, soil organic carbon in soil, hydric welfare index and whitefly incidence explained observed yield gaps.

We analyzed two complementary ways of increasing yield: (1) modifying growth-defining factors to increase cumulated PAR intercepted by crops and (2) modifying growth-limiting and reducing factors responsible for the gap to attainable yield at a given level of cumulated PAR intercepted (Fig. 2). PAR interception could increase by changing transplanting dates to modify daily incident radiation, improving transmissivity of greenhouses (current transmissivity varies between 42 – 83%) and fraction PAR intercepted by canopy by reducing leaf pruning and increasing plant density. Without modification of intercepted PAR, yields could increase in average 34%. The strategy to apply vary according to PAR intercepted group.

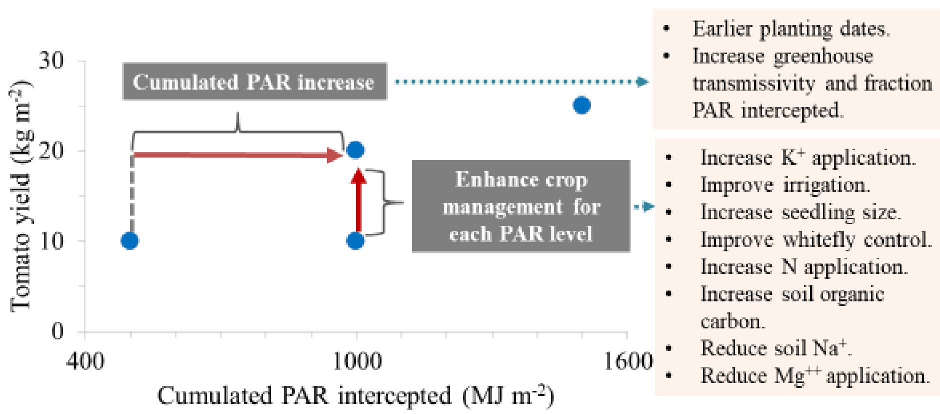

Fig. 2. Graphical representation of pathways to yield increase for greenhouse tomato in south Uruguay.

Results and conclusions reached by this study allowed us to deliver timely, relevant, and actionable information to better inform discussions among farmers and their technical advisors and contribute to reduce knowledge gaps. This approach allowed better targeting of recommendations to improve crop performance in different situations.

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