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Maize grain yield components and source-sink relationship as affected by the delay in sowing date

Lucas E. Bonelli[a,b,*], Juan P. Monzon[b], Anibal Cerrudo[a,c], Roberto H. Rizzalli[a], Fernando H. Andrade[a,b,c]

[a] *Facultad de Ciencias Agrarias (UNMdP), Ruta 226 km 73.5, 7620 Balcarce, Argentina*
[b] *Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Argentina*
[c] *Instituto Nacional de Tecnología Agropecuaria (INTA), Argentina*

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ABSTRACT

Delaying maize (*Zea mays* L.) sowing date can diminish grain yields through reductions in the number, size and activity of growing grains (sink strength) and/or reductions in the assimilate supply (source capacity) to grains during the grain filling period. Whether the source capacity or the sink strength is the limiting factor for grain yield in late sown maize still remains unclear. Understanding source-sink relationships is relevant to optimize crop management practices, to identify critical processes for crop modelling and to develop breeding strategies. The objective of this work was to assess the effect of delays in maize sowing date on grain yield components and on the source-sink relationship during the grain filling period. Three well irrigated and fertilized maize field experiments were conducted at Balcarce, Argentina (37° 45′ S, 58° 18′ W; 130 m a.s.l.) during 2009–10; 2010–11 and 2011–12 cropping seasons. Sowing dates ranged from October to January covering a broad range of the seasonal photo-thermal variation. Grain yield was affected by sowing date and varied from 1680 $g\,m^{-2}$ (early sowings) to 203 $g\,m^{-2}$ (late sowings). Grain number per unit area was reduced proportionally less than weight per grain as sowing date was delayed. Variations in grain yield were related to the harvest index, and were closely associated with dry matter accumulation during the post-silking period. The variation of source capacity was higher than that of sink strength during the grain filling period and the source/sink ratio decreased from early to late sowing dates. Results indicate that crop growth during the grain filling period was limited by the sink strength in early sowing dates and by the photosynthetic source capacity in the late ones.

1. Introduction

Sowing date is one of the main management practices used to adjust the timing of occurrence of crop phenological phases and therefore, to determine the environmental conditions under which crops develop and grow. Changes in maize sowing date alter crop growth rate and the length of crop phenological phases which, in turn, modify potential grain yield and its components (Cirilo and Andrade, 1994a). These alterations are particularly significant in cool-temperate short season environments, where solar radiation and temperature change considerably around the beginning and the end of the maize cropping season (Shaw, 1988; Wilson et al., 1995).

Variations in grain yield can be analyzed in terms of the crop carbon economy during the grain filling period. This approach, commonly described as source-sink relationship, aims to identify when grain yield is limited by the supply (source capacity) or by the demand (sink strength) of assimilates during the grain filling period (Tollenaar, 1977). In maize, source capacity is mainly determined by assimilate production by crop photosynthesis during the grain filling period. Sink strength is defined by the ability of the growing grains to accommodate these assimilates. Maize grain yield has been generally reported as to be sink limited (Tollenaar and Lee, 2011; Westgate et al., 2004). As a consequence, most recommended management practices (Andrade et al., 2005) and major breeding efforts in maize (Echarte et al., 2000; Tollenaar et al., 1992) have been focused in maximizing the number of grains per unit area.

Abbreviations: ECG, end of crop growth; RUE, radiation use efficiency; TT, thermal time; PAR, photosynthetically active radiation; EGFP, effective grain filling period; CGR, crop growth rate; GGR, grains growth rate; HI, harvest index; fi, fraction of intercepted PAR; RMSE, root mean square error.

[*] Corresponding author at: Facultad de Ciencias Agrarias (UNMdP), Ruta 226 km 73.5, Balcarce 7620, Argentina.

E-mail address: bonelli.lucas@inta.gob.ar (L.E. Bonelli).

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In temperate and cool-temperate environments, when maize sowing is delayed, crop flowering occurs far after the summer solstice and grain filling period takes place close to the end of the cropping season. Thus, as sowing date is delayed in these environments, both the critical period for grain set and the grain filling period are subjected to a progressive deterioration of photothermal conditions for crop growth. In accordance, delays in maize sowing date can diminish grain yields through reductions in: i) the number, size and activity of growing grains and/or ii) the assimilate production by photosynthesis during the grain filling period (Cirilo and Andrade, 1996, 1994b; Tsimba et al., 2013a).

Information about grain yield components and source-sink relationships during the grain filling period helps in the selection and optimization of key crop management practices such as hybrid selection, plant density, irrigation strategies, crop protection, etc. (Andrade et al., 2005). This information is also relevant to identify critical processes for crop modelling and to develop breeding strategies (Hall and Sadras, 2009). Previous investigations on maize sowing date have described grain yield components and, to some extent, indicative variables of the source-sink relationship during the grain filling period. However, whether the source capacity or the sink strength is the limiting factor to grain yields in late sown maize still remains unclear. The objective of this work was to assess the effect of sowing date delays on maize grain yield components and on the source-sink relationship during the grain filling period.

2. Materials and methods

2.1. Site description and crop management

Three experiments were conducted at INTA-Balcarce experimental station, Argentina (37° 45′ S, 58° 18′ W; 130 m a.s.l.) during 2009–10 (Exp. 1), 2010–2011 (Exp. 2) and 2011–2012 (Exp. 3) cropping seasons. Data of two complementary experiments conducted during 2012–13 (C. Exp. I) and 2011–12 (C. Exp. II) were also included in an analysis that merged all observed grain yields. Experiments were established on a fine-loamy typic argiudol with an effective depth of 1.5 m. Topsoil organic matter was 5.6% and extractable phosphorous content was 32 ppm. The field was managed under conventional tillage in Exp. 1 and under no-till in Exp. 2, Exp. 3, C. Exp. I and C. Exp II. Wheat (*Triticum aestivum* L.) was the previous crop in all instances.

Plots were over-sown with hand planters and were thinned to a uniform plant population immediately after V_2 crop phenological stage (Ritchie et al., 1989). Final plant population was 8.7 plants m^{-2} in Exp.1 and 10 plants m^{-2} in Exp. 2, Exp. 3, C. Exp. I and C. Exp II. Rows were 0.52 m apart. Soil water content was kept above 65% of the maximum soil available water by complementing precipitations with sprinkler irrigation. In order to provide an adequate mineral nutrition, plots were fertilized before sowing with 30 kg of P ha^{-1} (diammonium phosphate). A mix of 50 kg of S ha^{-1} (calcium sulfate) and 400 kg N ha^{-1} (urea) was also applied in three equal splits at i) emergence, ii) V_5 and iii) R_1 crop phenological stages. Potassium requirement was assumed to be covered by the natural abundance of K^+ in the illite-rich soils where experiments were conducted. Weeds, insects, and diseases were effectively controlled.

2.2. Plant material and experimental design

Three commercial hybrids were used: P39B77 Herculex® LibertyR® (relative maturity rating: 92; Pioneer, Arg.), I550 MGRR2 (relative maturity rating: 102; Illinois, Arg.) and DK692 MGRR2 (relative maturity rating: 119; DeKalb, Arg.). In Exp. 1, the hybrid P39B77 was tested in a randomized complete-block design with two replications. Treatments consisted of seven sowing dates ranging from November to January. Plots were four rows wide by 10 m long. In Exp. 2 and C. Exp. I, the hybrid DK692 was tested in a randomized complete-block design with four replications. Treatments consisted of four contrasting sowing dates ranging from October to January. In Exp. 3, hybrids P39B77, I550 and DK692 were tested in a split-plot randomized design with four replications. Treatments involved the factorial combination of four contrasting sowing dates (main plot) and the three abovementioned hybrids (subplot). In C. Exp. II, a total of 16 commercial hybrids sown on a single sowing date (Oct-3) were tested in a randomized complete-block design with three replications. Plots in Exp. 2, Exp. 3, C. Exp I and C. Exp II were nine rows wide by 12 m long. Sowing dates and hybrids of three main experiments are detailed in Table 1.

2.3. Measurements and estimations

2.3.1. Crop phenology

Crop phenological stages were determined according to Ritchie et al. (1989). Number of expanded leaves was weekly recorded from emergence to V_T in five plants per plot. Leaves number 5 and 10 were paint-marked to keep a leaf number reference. Duration of phenological stages was expressed in days and in thermal time (TT) units. Daily TT degrees were calculated as follows (Eq. (1)) and accumulated between phenological stages:

$$TT\left({}^{\circ}Cd^{-1}\right) = \frac{Tmax + Tmin}{2} - Tb \quad (1)$$

where *Tmax* and *Tmin* are daily maximum and minimum temperatures, respectively. The base temperatures (*Tb*) for TT estimations were previously estimated following the methodology descripted by Tsimba et al. (2013b). Briefly, a Tb-iterative procedure was performed to find the lowest TT CV% for each of the main phenological phases of each hybrid across sowing dates and growing seasons. The most accurate Tb did not differ from 10 °C (for emergence to silking period) and 0 °C (for silking to physiological maturity). These Tb were in agreement with those proposed by Tollenaar et al. (1979) for the pre-silking period and by Birch et al. (1998) and by Muchow (1990) for the post-silking period.

Grain samples were taken every 7–10 days starting at 10 days after 50% silking and ending at least three weeks after black layer formation. At each sampling date 15 grains were taken from the central portion of two ears per plot. A total of 8 different plants (two plants by 4 blocks) were randomly selected at each sampling date. Grains were dried at 90 °C for 7–10 days in an air forced oven and weighed. Mean growth rate per grain and duration of effective grain filling period (EGFP) were estimated following the lineal-plateau fitting method (in which the weight per grain is expressed as a function of the days after silking) described by Egli (1998). Physiological maturity[1] was estimated as the day when the maximum weight per grain was achieved.

2.3.2. Dry matter accumulation, PAR interception and grain yield

Aboveground dry matter was periodically measured in Exp. 2 and Exp. 3 by taking samples of 8–10 plants (sample area of about 1 m^2) from the five central rows. A total of 5–6 samples were taken every 15–25 days during each crop cycle. Three to four plants were left as border between successive samples. Aboveground dry matter in Exp. 1 was determined at harvest from 10 plants (sample area

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[1] The "**physiological maturity**" term in the current work is used to refer to the moment when grains stopped growing, even for those cases of premature cessation of grain growth. We also used the term "**end of crop growth" (ECG)** to refer to the moment at which crop aboveground dry matter accumulation ceased, which may not be coincident with physiological maturity (Uhart and Andrade, 1991).