Europ. J. Agronomy 72 (2016) 28–37

Contents lists available at ScienceDirect

European Journal of Agronomy

journal homepage: www.elsevier.com/locate/eja

Maize grain yield enhancement through high plant density cultivation with different inter-row and intra-row spacings

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ARTICLE INFO

Article history:
Received 27 April 2015
Received in revised form 3 September 2015
Accepted 20 September 2015
Available online 22 October 2015

Keywords:
Seeding rate
Uniform planting pattern
Plant traits
Kernel traits

ABSTRACT

Increasing the maize plant population has undergone a constant evolution over the years, with the purpose of enhancing the crop yield. Field trials, in which 2 different experiments were considered, have been conducted in NW Italy in order to analyze the yield benefit of high plant density on recent hybrids, considering both intra-row and inter-row plant spacings. The first experiment, which was carried out during the 2013 and 2014 season, evaluated the effects of 4 growing plant densities (from 7.5 to 12 plants m^{-2}) combined with 2 row widths (the traditional 0.75 m and a narrow inter-row spacing of 0.50 m) on plant architecture and grain yield. Two hybrids, with different ear developments (fixed and flex), were taken into account. The higher plant density led to a decrease in the stalk area (−20%), leaf greenness (−5.2%) and cob length (−10.8%). It also negatively affected the kernel weight (−7.1%) and the number of kernels per row (−10%). The grain yield only increased significantly, for both hybrids (+7.4%), if a density of 10.5 plants m^{-2} was reached when the inter-row spacing was reduced (0.50 m). In the second study, an innovative system (narrow inter-row spacing combined with a plant population of about 10.5 plants m^{-2}) was compared with a standard planting system (7.5 plants m^{-2} sown on 0.75 m wide rows), considering 32 different production situations (PS) over 4 growing seasons (2011–2014). This study has confirmed that even though the single plant yield potential was reduced in terms of ear weight and thousand kernels weight by 18% and 6%, respectively for a high planting density, the final grain yield increased on 90% of the PS with an average gain of 11.7%. This work has proved that, in the conditions in which the experiments were conducted, a high planting density of up to 10.5 plants m^{-2} can lead to a significant yield increase, but only when it is combined with narrow inter-row spacing. These conditions increase plant stresses, and modify plant morphology and development to the detriment of the single plant yield. However, the lower yield per plant is fully compensated by the higher plant population.

1. Introduction

Increasing the population density of plants is an agronomical practice that has continuously been studied for maize crops. This crop technique has evolved and will continue to evolve over the years and it is the agronomic management factor that has changed the most over the past six decades (Tollenaar, 1992). After the introduction of the first hybrids, farmers started to steadily increase the plant density, at an average rate of 0.3 plants m^{-2} yr^{-1}. In the US Corn Belt of the 1930s, the mean population density was 3 plants m^{-2}, while it was 4 plants m^{-2} in the 1960s and 6 plants m^{-2} in the 1980s (Duvick, 2005). Nowadays, the average density in the USA, where maize cultivation is intense, is around 8 plants m^{-2} (Li et al., 2015), whereas in the EU, where the pedoclimatic conditions are more heterogeneous across countries, it can vary from 6 to 8 plants m^{-2} for medium-late maturing hybrids in fertile growing areas. On both continents, in which this crop is cultivated intensively, the most common inter-row spacing for the current planting density is approximately 0.70–0.75 m in order to facilitate inter-row tillage (Sharratt and McWilliams, 2005). The main purpose of increasing the plant density is to enhance maize yield in terms of grain or biomass, thus making the crop system more efficient and competitive per area unit. In the absence of biotic or abiotic stresses, grain yield is related to the amount of solar radiation intercepted by the crop, and the use of a high

Abbreviations: ECB, European Corn Borer; ESQ, ears per square meter; HI, harvest index; HiD, innovative high planting density system; HNT, hydro N-tester; KD, kernel depth; KL, kernel length; KPR, kernels per row; KR, kernel row; KSQ, kernels per square meter; KV, kernel volume; N, nitrogen; NIS, narrow inter-row spacing; PS, production situation; RR, relative ratio; SIS, standard inter-row spacing; StD, standard density planting system; TKW, thousand kernels weight; TW, test weight.

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http://dx.doi.org/10.1016/j.eja.2015.09.006

density population, with an earlier canopy closure, maximizes the leaf area index (Cox and Cherney, 2001).

The crop yield potential could be divided into three genotype components. The first one is the yield potential per plant, which, over the last 70 years, has remained stable for non-stressed plants under very low planting densities (1 plant m^{-2}) (Duvick et al., 2004a; Sangoi et al., 2002). The second component is the tolerance to various abiotic and biotic stresses, and the third one is responsiveness to inputs (Tokatlidis and Koutroubas, 2004). In the late 1930s, the average grain yield in the United States was around 2 t ha^{-1} (Duvick et al., 2004a). After this, the mean yield gain was increased each year by 115 kg ha^{-1} until the 1990s, when the yield expectation was around 8.8 t ha^{-1}. This occurred thanks to the positive interaction between enhancements in cultural practices and plant breeding, which improved components 2 and 3 of the crop yield potential (Duvick, 2005). Continuous changes in plant architecture have led to an increase in the efficiency of grain production under stresses for high planting densities, because of higher intra-specific competition, unfavorable weather, or low soil fertility (Duvick et al., 2004a).

The shoot and seed density per area unit of modern maize hybrids is theoretically the same, since these plants have lost their tillering ability (Duvick et al., 2004b), to the advantage of a higher harvest index (HI) on the single plant. Thus, the only way that maize plants can moderately compensate for planting density changes on the final yield is through an adaptation of ear development. A flex ear hybrid adjusts its ear growth according to the conditions that are encountered in the field, by modifying the number of kernels per ear that reach full maturity. This feature allows, for example, to better compensate for plant vacancies and hence preserve the yield if harsh field conditions occur (Mascagni and Bell, 2004). On the other hand, a fixed ear development keeps the total number of kernels per ear relatively steady, regardless of the environmental conditions. Maize is one of the herbaceous species that offers the highest grain yield potential, yet it is one of the most sensitive crops to variations in plant density (Vega et al., 2001). Modern hybrids can generally withstand higher population densities, because they can support stressful environmental conditions caused by a higher intra-specific competition more easily, and this results in a lower incidence of barren plants and reduced stem lodging (Tollenaar, 1989; Widdicombe and Thelen, 2002). In order to overcome the problems of high density planting, these hybrids are characterized by more upright and shorter leaves, and the synchrony between the differentiation of the female and male florets is higher (Sangoi, 2000), thus limiting barrenness. However, in order to place the crop in the best growing conditions possible, even for high plant populations, the planting pattern has to be re-thought with a reduction in the inter-row spacing and a more balanced equidistance. Plants spaced more uniformly in fact compete minimally for the main growing factors. Among these factors, the one that is affected most is light, and this is followed by nutrients and water (Li et al., 2015; Sharratt and McWilliams, 2005). According to this line of reasoning, an increase in planting density, obtained by reducing the within row plant spacing, could be a limiting factor. In fact, if plants are sown too close to each other in the same row, their full yield potential could be restrained.

The objective of this work was to evaluate the effects of plant density on maize yield and on the ear and plant morphology of hybrids with different ear development for full-season varieties under irrigation conditions. The interaction between the plant density, considering the reference plant population generally applied in temperate areas and different increments of up to 40%, and inter-row spacing, has been considered. Since the plant arrangement is one of the most important practices employed to increase maize yield (Okumura et al., 2014), this information could help to identify the best actual planting pattern for intensive high-yield maize cultivation in temperate areas, which could contribute significantly to an improvement in the competitiveness of this cereal.

2. Materials and methods

2.1. Experimental sites and agronomical management

The study on the effects of different planting densities on the morphological development of plants and ears and grain yield was performed over four growing seasons, from 2011 to 2014, and it involved two different experiments conducted in the same agricultural area in the Piedmont region in North West of Italy, characterized by a temperature continental climate according to the Köppen climate classification (Peel, 2011).

2.1.1. Experiment 1

Field trials were conducted in the 2013 and 2014 growing seasons at Buriasco, in the North West of Italy (44°51′53″ N, 7°26′21″ E), an area that is characterized by a deep and fertile loamy soil (40% sand, 46% silt, 15% clay, Typic Hapludalfs, USDA classification) and a medium-high content of organic matter (3.2%) with a balanced C/N ratio (11.0). The N, P_2O_5 (available) and K_2O (exchangeable) soil content were respectively high (1.7 g kg^{-1}), medium (23 ppm) and low (18 ppm). The soil pH was sub-acid (6.3) and the Cation Exchange Capacity was medium (16.3 meq 100 g^{-1}).

The compared treatments were a factorial combination of:

- 2 inter-row spacings:
  - 0.75 m wide, standard inter-row spacing (SIS), representing the reference spacing for the maize crop system;
  - 0.5 m wide, narrow inter-row spacing (NIS)

- 4 planting densities:
  - D1: 7.5 plants m^{-2} (reference planting density)
  - D2: 9 plants m^{-2}
  - D3: 10.5 plants m^{-2}
  - D4: 12 plants m^{-2}
- 2 hybrids characterized by a different ear development according to the environmental conditions that occur during the growing season:
  - Syngenta NX7234, FAO maturity class 500; 127 relative days to maturity, characterized by a fixed ear development.
  - KWS Korimbos, FAO maturity class 500; 125 relative days to maturity, with a flex ear development.

The experiment was carried out according to a split plot design: the inter-row space and hybrid were considered as the main factors, whereas the planting density was considered as a sub-plot factor, with 3 randomized replicates. The whole field was planted at a maximum planting density of 12 plants m^{-2}, and then each plot was thinned at the four leaf stage (growth stage GS 14) (Lancashire et al., 1991) to adjust the plant population to the desired levels. The plant density was then checked again by counting the plants from GS 65 to GS 75. The sub-plots for the 0.5 m inter-row spacing were 10 m. long and 12 rows wide, and were 8 rows wide for the 0.75 m inter-spacing. The plot alleys, which were orthogonal to the maize rows, were 1 m wide.

The previous crop was maize each year. Mechanical planting was carried out on April 17th and March 17th, respectively, for 2013 and 2014, after an autumn 0.3 m deep ploughing, followed by disk harrowing. All seeds were treated with fludioxonil and metalaxil-m (Celest XL®, Syngenta Crop Protection S.p.A., Milan, Italy). All the plots received the same amount of nutrients: before sowing 100 kg ha^{-1} of K_2O (as potassium chloride) were applied, whereas during sowing 39 kg ha^{-1} of N and 100 kg ha^{-1} of P_2O_5 (as diammo-