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Reduced inter-row distance improves yield and competition against weeds in a semi-dwarf durum wheat variety

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ABSTRACT

Weed and nutrient management in cropping systems of semi-arid areas is a major constraint to cereal yield. Where the use of herbicides is banned or discouraged, the competitive ability of a crop is crucial to reduce weed growth and diffusion. Genotypic differences in the competitive abilities of crops are an important trait to reduce weeds, especially for plant height. However, there is contrasting information about the interactions of other management practices and genotypic traits on wheat yield and competitive ability against weeds and weed growth. The present study investigated yield and quality of durum wheat (*Triticum durum* Desf.) and weed growth and composition for two wheat cultivars with contrasting competitive abilities against weeds. Wheat was grown under three spatial arrangements (5-cm, 15-cm, 25-cm inter-row distance) and three sowing densities, and broadleaf weeds were either removed or not. The sowing rate did not affect the yield of these wheat cultivars or the weed growth. Reduced inter-row distance dramatically reduced weed biomass for both wheat cultivars, and increased wheat yield and nitrogen uptake in the low-competitive, high-yielding, semi-dwarf cv. 'PR22D89', when both weed free and with weeds. These results have direct implications for weed and nutrient management in low-input and organic cropping systems.

1. Introduction

Weed control is a major concern for both organic and conventional farming systems, particularly where the use of herbicides is banned or can have high impact on production costs, food safety, and surface and groundwater pollution. For these reasons, sustainable cropping systems call for alternative strategies to reduce competition from weeds, including agronomic and genetic strategies to minimise weed growth and spread, and to decrease yield losses.

In organic weed management, the competitive ability of the cultivated genotype was shown to be important to reduce weed pressure on the crop and weed diffusion through the cropping system (Bastiaans et al., 2008). In particular, plant height, early growth, and tillering capacity were indicated as the most important genotypic traits that confer such competitive abilities to wheat and other cereals (Andrew et al., 2015; Mason and Spaner, 2006). However, the negative relationships between plant height on the one hand, and yield components and potential on the other (Austin et al., 1980; Rebetzke and Richards, 2000) raises the question of the choice of a tall, highly competitive, low-yielding genotype rather than a semi-dwarf, low-competitive, high-yielding genotype when growing wheat under low-nutrient or high-weed conditions. Indeed, the studies to date have suggested that reduced-height cultivars have yields that are more than or similarly to those obtained for tall genotypes under low N availability (Kowalski et al., 2016; Ortiz-Monasterio et al., 1997). In addition, the genotype variability for the yield is not related to the management system (i.e., organic or conventional) (Kitchen et al., 2003; Reid et al., 2011).

Agronomic efforts to reduce weed competition rely on increasing the asymmetric competition between the crop and the weeds (Weiner, 1990; Zimdahl, 2004), either through manipulation of the crop and weed sizes at the early stages of crop growth, or by directly reducing the weeds. The management strategies used to maximise the rate at which a crop occupies space early in the growing season usually minimise the competitive pressure of the weeds (Mohler, 2001). In particular, an increase in crop density and sowing density, use of an efficient seeding method, anticipation of the planting date, and choice of the correct crop rotation and a highly competitive crop genotype are the most important practices.

Nonetheless, the application of these management practices can also have drawbacks in terms of the crop growth and yields. For

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example, higher seeding rates will be accompanied by extra seed costs for planting potentially without increasing the yield or the net return (Kolb et al., 2012). Accordingly, a sowing date earlier than the optimum date for a certain cultivar in a given location can reduce the yield potential, and thus counterbalance the benefit of increased competitiveness against weeds.

Sowing systems for winter cereals in the Mediterranean basin generally use a mechanical or pneumatic seed drill that can distribute the seeds at a fixed inter-row distance (usually >12 cm and ≤25 cm). However, such inter-row distances allow for early growth of weeds in the inter-row spaces considering that the wheat root colonisation ability rarely exceeds 5 cm in the early stage of growth (White and Kirkegaard, 2010). An alternative weed-management strategy relies on an increase in the spatial uniformity of the seed distribution (Fischer and Miles, 1973; Kristensen et al., 2008; Mohler, 2001); i.e., a reduction in the rectangularity of the seed distribution (as the ratio of inter-row to intra-row distance). This should provide better uptake of the soil nutrients and better ground cover by the crop, which can reduce weed germination and growth. In addition, increased spatial uniformity should also reduce the intraspecific competition for light, and thus increase both transpiration of the crop and resource (especially photons) use efficiency (Furbank et al., 2015). However, information regarding the effects of a reduction in the inter-row distance (and an increase in the seeding distance within the rows) on wheat yield and competitive ability against weeds has been contrasting (Boström et al., 2012; Chen et al., 2008; Hu et al., 2015; Rasmussen, 2004; Roberts et al., 2001). This appears to depend on a range of factors, which include: wheat genotype; weed pressure, composition and germination pattern; weed and nutrient management strategies; water availability during the late season; and availability of the correct seed drill. It has been suggested that an increase in the seeding rate can partly compensate for an increase in the inter-row distance (and thus compensate for a reduction in the spatial uniformity). This should increase the crop competition against weeds (Hiltbrunner et al., 2007; Korres and Froud-Williams, 2002; Lafond and Gan, 1999; Mertens and Jansen, 2002; Peltzer et al., 2009). However, it has been shown that this can also increase the intraspecific competition, which can counterbalance the benefits of the reduction in the weeds, and can finally result in a reduction in the yield potential (Hakansson, 2003; Yao et al., 2015). An increase in the spatial uniformity of the seed distribution can be achieved, in theory, by distribution of the seeds with a fertiliser spreader. However, this usually results in an uneven sowing depth, which can negatively affect the outcome and homogeneity of the crop.

Durum wheat (*Triticum durum* Desf.) is the main crop in many countries of the Mediterranean basin, and it is the preferred raw material for the worldwide production of pasta, couscous and burghul. Over the last 15 years, the rapidly growing market for organic pasta has created favourable conditions for specialised arable farming systems. However, organic wheat-based farming systems face various agronomic drawbacks, including excessive weed pressure and diffusion. This hampers the use of semi-dwarf, low-competitive varieties. The aim of the present study was to determine the role of the spatial arrangements of the wheat plants in terms of both the grain yields of two contrasting durum wheat genotypes and the weed biomass and composition, at varying sowing densities and weed control. In particular, the spatial arrangements of the wheat plants were modulated by reduced inter-row distance from 25 cm to 15 cm and 5 cm (while maintaining a constant seed rate), which nearly compared to the 5.7-cm spread of the root plate that is theoretically needed by an ideal wheat genotype to achieve the highest yield (Reynolds et al., 2009). This spatial arrangement was achieved using a new seed drill prototype (SEMINBIO project, RM2013A000332 and/or 202015000006429) that was equipped with interchangeable working parts and could be used to sow seeds every 5 cm.

2. Materials and methods

2.1. Experimental site

This study was performed at the Cereal Research Centre (CREA-CER, Foggia, Italy; 41° 28′N, 15° 32′E; 75 m a.s.l.) in the 2012–13 and 2013–14 growing seasons, on a clay-loam soil (Typic Chromoxerert). Soil traits were: 36% clay, 47% sand; pH 7.8; 17.3 g kg^{-1} total C; 1.5 g kg^{-1} total N. The mean long-term rainfall of the experimental site is 479 mm, and the mean air temperatures are 12.2 °C in autumn, 8.2 °C in winter, and 17.6 °C in spring. The mean minimum and maximum annual temperatures are 9.9 °C and 21.0 °C, respectively.

2.2. Experimental design and crop management

The experimental design was a split-split-plot design (six replicates) with the following treatments: main plots were cultivar: cv. ‘PR22D89’ (a medium flowering, semi-dwarf cultivar, released in 2005) and cv. ‘Cappelli’ (a late flowering tall cultivar, released in 1915), and inter-row distance (*RD*; 5 cm, 15 cm, 25 cm). The split-plot was sowing density (*SD*; 190, 380, 570 viable seeds m^{-2}); the split–split plot was weed control (*WC*; weed free, with weeds). The size of the plot was 4.5 m × 20 m. The preceding crop for both of the growing seasons was durum wheat. Before sowing, the soil was ploughed in late August and harrowed twice in September and October, to prepare a suitable seedbed and to control the summer weeds. In both of the growing seasons, the pre-sowing fertilisation consisted of 36.0 kg N ha^{-1} and 40.1 kg P ha^{-1} (as diammonium phosphate), top-dressing fertilisation consisted of 54 kg N ha^{-1} (as ammonium nitrate). The top-dressing fertilisation was applied at wheat growth stage 31 (Zadoks et al., 1974). Sowing was performed using a seed drill prototype (SEMINBIO project, RM2013A000332 and/or 202015000006429) that was equipped with a series of delivery elements spaced at 5 cm. This allowed more uniform spatial distribution of the wheat plants compared with conventional sowing using wide (15 or 25 cm) inter-row distances (see Supplemental material Table 1 for the sowing pattern and rectangularity of the seed distribution in the various combinations of inter-row distances × sowing densities). In particular, the seed falling from the hopper through the seed tubes reached the furrow randomly, so a 5-cm inter-row distance was not visible. Previous studies have suggested that a high degree of seed-spacing uniformity is not necessary to achieve major improvements in weed suppression, while sufficient improvement in crop-sowing uniformity can be achieved through the combination of a reduction in the inter-row distance and increased uniformity within the rows (Olsen et al., 2005). The sowing of the 15-cm and 25-cm inter-row distances was performed with the same seed drill, by allowing seeds to pass from every three or five seed bins, respectively, while maintaining the corresponding furrow opener. Durum wheat was sown on 16 December, 2012, and 22 December, 2013.

2.3. Weeds and crop analysis

During growth, each plot was characterised in terms of weed biomass and composition, plant density, grain yield and its protein content. Germinating weeds were removed from the plots for the weed-free treatment, until the end of tillering. At the end of tillering (growth stage 29; Zadoks et al., 1974), plant density (*PD*) was measured in a 1-m^2 microplot inside each subplot. In addition, the weeds were sampled, counted and identified, with the analysis based on the main weed species of *Fumaria*, *Veronica* and *Lamium*.