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Sowing date and nitrogen fertilisation effects on dry matter and nitrogen dynamics for durum wheat: An experimental and simulation study

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ABSTRACT

The effects of sowing date and nitrogen (N) fertilisation on the dynamics of dry matter (DM) and N accumulation during grain filling and on final grain yield and protein concentration for durum wheat were studied in two field experiments. In addition, the ability of the wheat simulation model *SiriusQuality*1 to simulate grain yield and protein concentration for durum wheat was evaluated. The model simulated the anthesis date and the grain filling duration with a root mean square error of 1.7 and 2.2 days, respectively. The model simulated reasonably well the changes in the dynamics of leaf, stem and grain DM and N in response to sowing date and N fertilisation. Harvest grain yield and protein concentration were simulated with a root mean square error of 0.045 kg DM m^{-2} and 1.25%, respectively. The longer vegetative period with autumn sowing compared with winter sowing resulted in higher crop DM and N at anthesis, which was associated with higher final grain yield. Independently of the sowing date or N fertilisation, post-anthesis DM accumulation contributed 70% to final grain yield. Post-anthesis N accumulation contributed between 25% and 40% to final grain N yield depending on the sowing date and N fertilisation. The efficiency of vegetative DM and N remobilisation was not modified by the sowing date or N fertilisation, averaging 21% and 74%, respectively. Sowing date had larger effects on grain DM yield than on grain N yield and grain protein concentration was significantly higher for the late sowing date than for the normal sowing date. N treatments did not affect crop phenology, but N fertilisation allowed the crops accumulating more DM and N during the vegetative period. In addition, high-N crops, because of their larger canopy, accumulated more DM and N during grain filling than low-N crops, resulting in higher grain yield and protein concentration at harvest. Both grain number per unit ground area and grain yield were closely correlated with crop DM and N at anthesis. Single grain DM was not modified by N availability. Averaged across N treatments, single grain DM varied from 44.2 to 57.3 mg DM $grain^{-1}$. These variations were almost entirely accounted for by the mean daily maximum temperature calculated for the 15 days prior to anthesis, suggesting that the temperature during the period of active cell division in the ovary is a major determinant of the final size of durum wheat grains.

1. Introduction

Durum wheat (*Triticum turgidum* L. subsp. *durum* (Desf.) Husn.) is cultivated over more than 13 million hectares world wide and Italy is the main European producer with 3.5 million tons per year. The protein concentration of durum wheat is the main determinant of its end-use value. Its cultivation involves large land areas with intensive nitrogen (N) fertilisation to achieve high yields and protein concentrations. N use efficiency of cereals (i.e. grain yield per unit of available soil and fertiliser N) is still very low, around 33 kg DM kg^{-1} N for most cereals (Raun and Johnson, 1999). In order to optimize the use of chemical N fertiliser by the crop and minimize N volatilisation and the risk of surface and ground water pollution, it is necessary to get a better understanding of the effects of crop management practices on crop dry matter (DM) and N accumulation.

Sowing date is one of the most important management factor affecting cereal production and quality (McLeod et al., 1992). In a given region, the optimum sowing date depends mainly upon the timing of rainfall (Jackson et al., 2000). In most cases, delaying sowing beyond the optimum period reduces wheat yields (Anderson and Smith, 1990; Bassu et al., 2009). Differences in DM and N contents at anthesis in response to sowing date were related to differences in the number of days from sowing to anthesis (Ehdaie and

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Waines, 2001), which for winter bread wheat (*Triticum aestivum* L.) results in large differences in N accumulation (Widdowson et al., 1987). As a consequence, delaying sowing date can cause significant differences of environmental conditions during grain filling, usually causing grains to grow with increasing temperatures and diminishing moisture conditions (Panozzo and Eagles, 1999; Subedi et al., 2007). For durum wheat, post-anthesis DM assimilation accounts for 50–80% of grain DM yield, depending on N and water supplies (Ercoli et al., 2008), the genotype (Arduini et al., 2006; Masoni et al., 2007) and the sowing density (Arduini et al., 2006). By changing the relative duration of the pre-anthesis period and the environmental conditions during the grain filling period, sowing date may significantly modify the contribution of the post-anthesis DM and N accumulation to grain DM and N yields, respectively, as well as the efficiency of vegetative DM and N remobilisation.

N is the major nutrient influencing grain yield and protein concentration (Gauer et al., 1992; Ehdaie and Waines, 2001). Prior to anthesis, N supply affects crop growth and photosynthetic capacity. In winter wheat, N application has large effects on leaf area expansion and duration (Langer and Liew, 1973); which have been associated frequently with grain yield (Slafer and Savin, 1994). The supply of assimilate to grain originates both from current assimilation and from remobilisation of assimilates stored temporarily in vegetative parts during the vegetative period (Austin et al., 1980; Gebbing and Schnyder, 1999; Santiveri et al., 2004). Remobilisation of N accumulated prior to anthesis has been suggested to be the major determinant of mature grain N content (Austin et al., 1977; Cox et al., 1985). However, the contribution of post-anthesis N uptake to mature grain N content may vary between 10% and 70% depending on soil N and water availability and temperature during the grain filling period (Palta and Fillery, 1995; Martre et al., 2006; Mi et al., 2000) and on the genotype (Kichey et al., 2007).

The contribution of post-anthesis DM and N accumulation to grain DM and N yields and the efficiency of vegetative DM and N remobilisation to grains have often been quantified from crop growth analysis (e.g. Cox et al., 1985; Arduini et al., 2006; Ercoli et al., 2008). This method of quantification of N remobilisation and post-anthesis accumulation has been shown to give similar results compared with calculations based on ^{15}N-labelling experiments, although the ^{15}N-labelling method gives lower coefficient of variation (Kichey et al., 2007). As for DM remobilisation and post-anthesis accumulation, several authors have found that the growth analysis method significantly overestimates the contribution of DM remobilisation to grain yield compared with ^{13}C- or ^{14}C-labelling experiments, mostly because the growth analysis method does not take into account the loss of DM due to respiration (e.g. Gebbing and Schnyder, 1999). However, labelling experiments are expensive and difficult to carry out in the field. For this reason very few studies have quantified post-anthesis N and DM remobilisation and accumulation using labelling experiments. In the present study the growth analysis approach has been used to quantify the contribution of post-anthesis DM and N remobilisation and accumulation to grain DM and N yields and the efficiency of vegetative DM and N remobilisation.

Although several studies have documented the effects of sowing date and N nutrition on winter cereal yield and protein concentration, in particular for winter bread wheat, studies on durum wheat are very limited. The aim of this work was to examine the effect of sowing date and N fertilisation on the dynamics of DM and N accumulation during the grain filling period for durum wheat. In addition, the aim was to evaluate the ability of the wheat simulation model *SiriusQuality*1 (Martre et al., 2006) to simulate grain yield and protein concentration for durum wheat in response to sowing dates and N treatments. Few of the existing wheat simulation models have been evaluated for durum wheat. Published studies show either poor (Donatelli et al., 1997) or reasonably accurate (Pala et al., 1996; Pecetti and Hollington, 1997; Bassu et al., 2009) simulation of grain yield responses to N fertilisation or sowing date, but no study has evaluated the ability of wheat simulation models to simulate grain protein concentration for durum wheat.

2. Materials and methods

2.1. Plant material and growing conditions

The durum wheat (*Triticum turgidum* L. subsp. *durum* (Desf.) Husn.) cultivar Creso was grown in two rain-fed field experiments carried out at the University of Florence, Italy (11°13′E, 43°46′N; 42 m elevation) during the 2002–2003 and 2004–2005 growing seasons (referred below as 2003 and 2005), respectively. In 2003, the experiment was in a field where the previous crop was a 3-year lucerne stand, the soil was a sandy loam (7.0% clay, 39.9% silt) to 1.5 m. The top soil (0–40 cm layer) had an apparent bulk density of 1.59 Mg m^{-3} and contained 4.5 Mg N ha^{-1} of organic N with a C-to-N ratio of 12.1 and a pH of 6.9. In 2005, the experiment was in a field where the previous crop was a sunflower. The soil was a clay loam (36.1% clay, 30.7% silt) to 1.2 m. The top soil had an apparent bulk density of 1.30 Mg m^{-3} and contained 6.12 Mg N ha^{-1} of organic N with a C-to-N ratio of 13.3 and a pH of 8.5.

Seeds were sown at a density of 150 seeds m^{-2} on 11 December 2002 and 05 November 2004 (normal sowing, treatments termed 03SD1 and 05SD1, respectively), and 27 January 2003 and 18 January 2005 (late sowing, 03SD2 and 05SD2, respectively) using a 12-row planter with 0.22-m row spacing. Four N treatments were applied with a total of 0, 6, 12 and 18 g N m^{-2} (treatments termed N0, N6, N12 and N18, respectively); one-third of which was applied as ammonium sulphate at growth stage (GS) 15/22 (5th leaf emerged at 50%, 2 tillers visible) and the remaining two third as ammonium nitrate at GS 31 (first stem node detectable). The plots were arranged in a randomized complete block split-plot design with three blocks, where the main plots corresponded to the sowing dates. The sub-plots were 3 m × 2 m. The gaps between the sub-plots were sown as the experimental sub-plots.

2.2. Phenophase, plant sampling and total N concentration determination

Within each sub-plot, 20 plants were randomly tagged and their phenological development monitored. The occurrence of a phenophase was set when it was reached by the 50% of the monitored plants. In both years GS 10 (first leaf through coleoptile), GS 31, GS 39 (male meiosis), GS 59 (heading) and GS 65 (anthesis) were determined as described in Tottman (1987) by daily inspection in the field. In 2005, GS 11 (first leaf emerged at 50%) to 16 (6th leaf emerged at 50%) were also determined and the phyllochron were estimated as the slope of decimal leaf number against thermal time accumulated since emergence (all $r^2 > 0.995$, $P < 0.001$, $d.f. = 5$). The final leaf number was estimated from the date of GS 39 and the calculated phyllochron for leaf 1–6.

In 2005, two samplings were carried out at GS 15/22 and 31 one day before N fertilisers were applied. Two adjacent 0.5-m long rows were sampled within each plot. The whole samples were oven dried at 80 °C for 48 h and their DM and N concentrations were determined.

After anthesis, 16 whole main shoots were randomly sampled from each sub-plot every 5–7 days starting at GS 71 (kernel watery ripe; in 2003) or at GS 65 (in 2005). In the laboratory, leaves, stems, and spikes were separated; spikes were hand threshed and grains were counted. For each plant component, DM was determined after oven drying at 80 °C for 48 h. Grain DM was determined on subsamples (ca. one-third of the whole sample weight), the remaining