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Variation in dry matter and nitrogen accumulation and remobilization in barley as affected by fertilization, cultivar, and source–sink relations

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ABSTRACT

Barley (*Hordeum vulgare* L.) is one of the most important cereals worldwide and is being increasingly grown in many areas of the world, but there is a lack of information about the physiological processes limiting grain yield. A two-year field study was conducted with the objective of determining the effect of different rates of nitrogen (N) (control, 60 kg N ha^{-1}, and 120 kg N ha^{-1}) on source–sink relations, dry matter and N remobilization, and grain yield. Therefore, the source–sink ratio was manipulated to examine the factor(s) limiting grain filling under rainfed conditions. The treatments were: I, control; II, half of the spike was removed; III, the entire spike was removed. The distribution of dry matter, N among grains, and culms and leaves were analyzed at anthesis and harvest. Dry matter accumulation and partitioning into different plant parts were affected by the fertilization treatments and increased as the N level increased. At anthesis, the amount of leaf + culm dry matter was greater than the amount of spike dry matter. N fertilization slightly affected the N concentration of the different plant parts at anthesis and at maturity. N content was affected by the fertilization treatments and was increased by 62% over the two years of the study compared with the control. In addition, dry matter remobilization was an average of 40% higher in the fertilized treatments compared with the control, which indicates that fertilization led plants to translocate higher amounts of dry matter. N remobilization was affected by the fertilization treatment and by the sink reduction. The spike reduction treatment increased the pre-anthesis assimilates and contribution to grain, indicating that the dry matter remobilization from vegetative tissues were very important for grain development. In contrast, N translocation efficiency was similar under sink reduction. Grain yield was determined by biomass and harvest index, and at the half spikes, there was a higher contribution at the harvest index. In addition, grain N yield was determined more by grain yield and less by the N concentration. The present study indicates that N fertilization and sink size can affect dry matter and N accumulation, partitioning, and remobilization in barley, which can affect grain yield.

1. Introduction

Barley (*Hordeum vulgare* L.) is an ancient and important cereal grain crop and is one of the main cereals that is grown in many areas of the world reaching 54 million hectares and total production of 152 million Mg (FAO, 2011). Barley was one of the first agricultural domesticates together with wheat, pea (*Pisum sativum*), lentil (*Lens culinaris*) dating from about 10,000 years ago in the Fertile Crescent of the Middle East (Smith, 1998). Barley was presumably first used as human food but evolved primarily into a feed, malting and brewing grain due in part to the rise in prominence of wheat and rice. Barley is arguably the most widely adapted cereal grain species with production at higher latitudes and altitudes and farther into deserts than any other cereal crop. It is in extreme climates that barley remains a principal food source today, e.g., Himalayan nations, Ethiopia, and Morocco. Also, generally grain yield of barley is more stable than other winter cereals especially under Mediterranean conditions (Cossani et al., 2011). However, there is a lack of information about factors affecting the grain yield in barley and especially how dry matter and N remobilization can relate with source or sink especially under different N levels.

In cereals, grains are the most active sinks for carbon and N assimilates after flowering and most carbohydrates are provided by current photosynthesis during grain filling (Wardlaw, 1990). However, a significant part can be remobilized from leaves, culm, chaff, and other vegetative parts of the plant (Dordas, 2009; Masoni et al., 2007; Gebbing et al., 1998, 1999). In contrast, the major fraction of grain N is derived from remobilization of N accumulated before anthesis from vegetative organs (Spiertz and de Vos, 1983; Van Sanford and MacKown, 1987). N export from vegetative tissue

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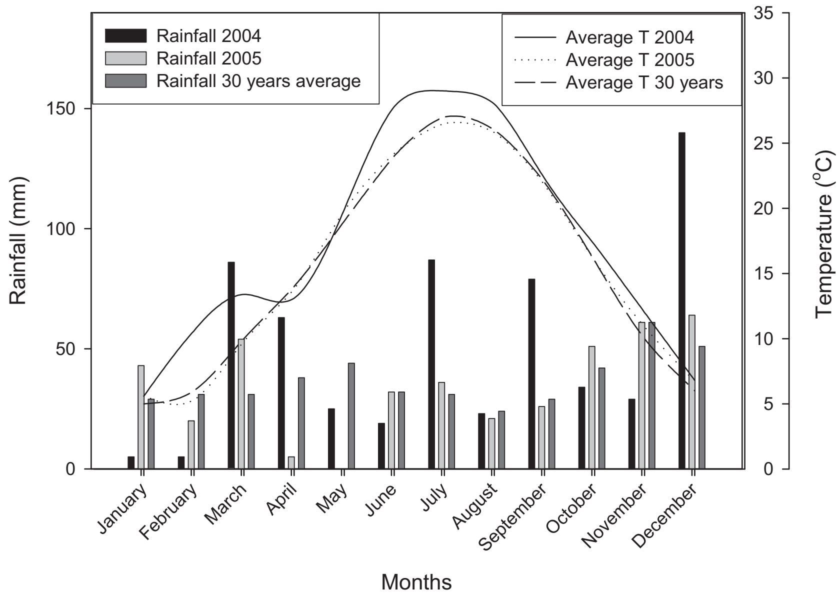

Fig. 1. Monthly means of average air temperatures (*T*) and rainfall for 2004, 2005 years and the 30-year average at Thessaloniki, Greece.

is influenced by biotic and abiotic stress (such as high temperature, water stress), genotype and the crop source–sink ratio (Blum, 1998; Barbottin et al., 2005; Dordas, 2009; Madani et al., 2010). The impact of the source–sink ratio during grain filling can affect dry matter and N remobilization since the removal of reproductive sinks can accelerate (Guitman et al., 1991) or have no effect on (Feller, 1979) leaf senescence in wheat. Because of such conflicting results, it is difficult to predict the effect of source–sink alteration on grain filling in terms of supply and demand of N by vegetative and reproductive organs, respectively.

During grain filling, source capacity can be defined as the ability of the crop to supply assimilates to the developing grains, whereas sink capacity represents the potential of the grains to accumulate assimilates. An understanding of source–sink relationships of cereals could be used to identify physiological traits suitable for genetic selection and modification of grain yield (Borrás et al., 2004; Bingham et al., 2007; Schnyder, 1993). Sink manipulation experiments performed in winter wheat suggest that grain size is mostly sink-limited under non-growth-limiting conditions (Cartelle et al., 2006; Jenner et al., 1991; Slafer and Savin, 1994; Borrás et al., 2004; Ahmadi et al., 2009). However, in rainfed environments, grain size often increases in response to a sink reduction treatment (Blum et al., 1988), which can be interpreted as the result of a source limitation for grain growth. However, there are other studies that show that grain yield was limited by both assimilate supply (source limitation) and assimilate demand (sink limitation) (Aggrarwal et al., 1990). Therefore, despite the fact that there is a big mass of literature whether the grain yield in barley is either source or sink limited the data are inconclusive and in order to answer these questions there is a need for a better understanding of the mechanisms involved in the variations of grain yield and of its components. One of the mechanisms that affects grain yield is dry matter and N remobilization (Papakosta and Gagianas, 1991; Przulj and Momcilovic, 2001a,b).

Artificial reduction in grain number per inflorescence or defoliation per plant has been used in different cereals to manipulate source:sink ratio and to provide more evidence whether grain filling in cereals is source or sink limited (Borrás et al., 2004; Bingham et al., 2007). Also artificial reduction of grain number per inflorescence can be used to determine the effect of sink size on dry matter and N remobilization (Dordas, 2009). Despite the fact that there are several reports on the effect of source–sink alteration on grain weight and several other physiological aspects of winter cereals (Ahmadi et al., 2009; Aggrarwal et al., 1990; Bingham et al., 2007; Blum, 1998; Borrás et al., 2004; Cartelle et al., 2006; Dreccer et al., 1997; Ma et al., 1995, 1996; Madani et al., 2010; Reynolds et al., 2005; Voltas et al., 1997; Dordas, 2009) there is not enough information about the interrelationships between source–sink and dry matter and N remobilization in different cultivars of barley. The use of different cultivars can provide more information about the mechanisms of dry matter and N remobilization and the factors that affect them. The objective of this study was to determine the effect of different N rates and source–sink alteration and their interaction of different barley cultivars during grain filling period with particular emphasis on dry matter and N partitioning and remobilization in barley.

2. Materials and methods

2.1. Setup of the experiment

The experiment was carried out at the experimental farm of the Aristotle University of Thessaloniki in northern Greece (22°59′6.17″E, 40°32′9.32″N) during the growing seasons of 2004 and 2005. The different cultivars that were used to determine their response to N fertilization and sink-source alteration were as follows: Carina (a late-flowering cultivar used for malting), Thessaloniki (an early-flowering cultivar), Konstantinos (a late-flowering cultivar), and Mucho (an early-flowering cultivar and the only one that was six-rowed). The soil type where the experiment took place was a calcareous sandy loam (Typic Xerorthent), and the soil was sampled pre-planting at a depth of 30 cm and before the application of the fertilizers. The soil contained 7.2 g kg^{-1} organic matter, 60 kg ha^{-1} of NO_3, 26 kg ha^{-1} of P, and 198 kg ha^{-1} of exchangeable K and had a pH of 7.96 (1:2 water). The soil characteristics were determined according to methods detailed in Sparks et al. (1996). The preceding crop was durum wheat (*Triticum turgidum subsp. durum* L.). Weather data (i.e., rainfall maximum and minimum and average temperatures) were recorded daily in the experimental site and reported as mean monthly data for the two years of the study together with the thirty-year averages for temperature and rainfall (Fig. 1). During 2004, the spring was quite mild and there