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Effects of varying nitrogen fertilization on crop yield and grain quality of emmer grown in a typical Mediterranean environment in central Italy

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ABSTRACT

Experiments were carried out to study the effects of N fertilizer rates and timing of application on the yield and grain quality of a rainfed emmer crop (*Triticum dicoccum* Shübler) under Mediterranean conditions. The following parameters were analyzed: hulled and net grain yield, hulled index, spikes m^{-2}, spikelets per spike, kernels m^{-2}, thousand-kernel weight, biomass, plant height, lodging, grain protein and ash content. In the first experiment, different N rates (30, 60 and 90 kg N ha^{-1} plus a control not fertilized) were split at three phenological stages (seeding 20%, tillering 40% and stem elongation 40%). In the second experiment, three N doses (30, 60 and 90 kg N ha^{-1}) were applied to three crop stages (seeding, tillering and stem elongation). In the third experiment, the rate of 90 kg N ha^{-1} was distributed in different amounts (90-0-0, 0-90-0, 0-0-90, 45-45-0, 45-0-45, 0-45-45, 30-30-30) at the three mentioned crop stages. Increasing N rates resulted in higher hulled and net grain yield, as well as protein content. Fertilization (from 60 to 90 kg N ha^{-1}) applied to tillering maximized hulled and net grain yield. Fertilization (90 kg N ha^{-1}) applied to stem elongation gave the highest grain protein content (%) while splitting application (30 kg N ha^{-1} each) at three phenological stages maximized protein yield per hectare. Application of half or one-third of 90 kg N ha^{-1} to stem elongation improved grain protein content in comparison with applications at sowing, or at both sowing and tillering. The main factor determining higher yields with increasing N rates in this emmer crop was the number of kernels m^{-2}. None of the yield components accounted for differences in grain yield when timing and splitting application were varied.

1. Introduction

Emmer is an ancient cereal crop of the Mediterranean region (Zohary and Hopf, 1993). During the last century, the introduction of higher-yielding, free-threshing wheats has caused hulled wheats to fall into a state of neglect, to such an extent that they have become a relic crop as in the case of einkorn (Xie and Nevo, 2008; Galterio et al., 2001). More recently, hulled wheats have again become popular for social, cultural and economic reasons, as emphasized by the declaration of Human Rights, which states support mechanisms to prevent erosion and ensure the conservation and sustainable use of genetic resources for food and agriculture, including the promotion of traditional knowledge, bio-diversity, local and underutilized marginalized crops (Cordoba Food Declaration, 2008).

The increased demand by consumers for natural and traditional food has involved emmer in several food products: soups, but also the production of pasta, biscuits and bread (De Vita et al., 2006). Emmer is rich in starch, minerals, fiber, and poor in fats; it has been recognized as a very healthy cereal and is recommended in the diet of people suffering from allergies, colitis and high blood cholesterol. Scientists are also interested in emmer as a genetic depository for many agronomic traits (Barcaccia et al., 2002), such as abiotic (salt, drought and heat) and biotic (powdery mildew, rusts, and Fusarium head blight) stress tolerance, grain protein quality. Indeed, the slow digesting nature of dicoccum wheat compared to the common wheat (Mohan and Malleshi, 2006), in the preparation of pasta with good organoleptic quality and rich in fibers (Fares et al., 2008) and micronutrients (Xie and Nevo, 2008), has important social and commercial issues. Again, while current genotypes are vulnerable and susceptible to many abiotic and biotic stresses, the wild relatives have higher adaptive complexes (Nevo, 2004).

Nevertheless, there is a lack of information about the agronomic requirements of emmer crop. Castagna et al. (1992), Mariani et al. (1992), and De Giorgio et al. (1995) found a significant effect of N rate only on grain protein. Ferri et al. (1988), in an experiment with three N treatments (0, 60 and 120 kg N ha^{-1}) in the same area, found no significant effects of N fertilization on grain yield of durum wheat. Even in central and northern Italy, Castagna et al. (1996), applying three N treatments (0, 60 and 120 kg N ha^{-1} and 0, 50

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and 100 kg N ha^{-1}), did not find significant effects of N dressing on emmer grain yield, although significant increases in protein content and biomass accumulation were observed. Recently, Marino et al. (2009) have found that increasing N additions on emmer in central Italy has had a significant and positive effect on grain yield and protein; the former effect was caused by a higher number of kernels m^{-2}.

To our knowledge, there is no information on timing and splitting effect of N rate on emmer crop. In other cereal crops, fertilization management in terms of fertilizer rate and application timing seeks to avoid N deficiency in critical periods for yield and/or protein accumulation, while keeping the unused N in the soil at a minimum, in order to minimise leaching and gaseous emissions (Recous and Machete, 1999). In general, the efficiency of N applications for satisfying the demand for N by the crop depends on the type of fertilizer, timing of application, seasonal trend, and other factors (Borghi, 2000; Blankenau et al., 2002).

Various experiments have already shown that the date of application of N fertilizer significantly influences the use of N by the crop (e.g., Wuest and Cassman, 1992). Lòpez-Bellido et al. (2006), in a Mediterranean agro-ecosystem, recommended the application of N fertilizer to wheat preferably as top dressing, between tillering and stem elongation, which was considered a sound strategy both for the environment and farmer returns. Alcoz et al. (1993) found that N requirements prior to tillering were low, not exceeding 10% of the total. These studies have also suggested that crop N demand at the time of fertilizer application is the main factor determining its partitioning in the different competing processes. The application of N at an early stage might increase yield, but the supply of fertilizer at a later stage (boot and head-emergence stage) would significantly enhance the amount of all the protein fractions (Labuschagne et al., 2006).

Contrasting results have been reported about the effect of splitting N rate in one or several applications through the development cycle of a wheat crop. Garrido-Lestache et al. (2004) observed that timing and splitting of N fertilizer influenced grain protein content, which peaked when half or one-third of the N rate (150 kg N ha^{-1}) was applied at stem elongation, and in some cases when N was applied only at tillering. However, the effect of splitting N rate on grain quality was unclear in other studies (Garrido-Lestache et al., 2005). Ayoub et al. (1994) described that splitting N rate affected the quantity of proteins but not the quality. Fuertes-Mendizábal et al. (2010) found an improvement in grain protein content not only due to the increase in the N fertilization rate but also to the splitting of the same rate in three amendments instead of two. Abdin et al. (1996) found an increase in yield when 120 kg N ha^{-1} was split three times and when 160 kg N ha^{-1} was applied in three and four splits. Mercedes et al. (1993) found higher plant uptake when N fertilizer was split, but no yield increase. Ottman et al. (2000) showed an increment in protein content when N fertilizer was applied late in the season rather than at the beginning of the crop cycle.

The aim of the present study was to investigate the relationship between N rates, timing and splitting applications on grain yield and protein content of emmer under typical rainfed Mediterranean conditions. We hypothesized that the cropping conditions in this hilly area of central Italy might be particularly suitable for emmer, maximising grain quality and crop yield when appropriately fertilized, with plants scarcely affected by lodging.

2. Materials and methods

2.1. Experimental conditions

Field experiments were conducted in a hilly area of Molise, central Italy (latitude 35° 6′ N, longitude 13° 10′ E), on emmer crop (*Triticum dicoccum* Schübler, Molise population), in two experimental sites near Campobasso, whose physical and chemical selected soil properties are listed in Table 1. According to the USDA classification (2003), the soils were clay with a uniform soil profile, and contained an average amount of N, P, and K, and were scarcely calcareous. Soil was sampled from surface horizons (0–30 cm) at the beginning of the cropping season.

Table 1
Selected physical and chemical soil properties for the two experimental sites.

Properties	Exp. 1	Exp. 2 and 3
Sand[a] (%)	32	30.8
Silt[a] (%)	21.2	25.4
Clay[a] (%)	46.8	43.8
Organic matter[b] (%)	1.5	1.3
pH [c]	6.7	6.8
Available P[d] (mg kg^{-1})	24	27
Available K[e] (mg kg^{-1})	170	150
Total N[f] (g kg^{-1})	1.6	1.5

[a] Particle size distribution determined using pipette method (Indorante et al., 1990).
[b] Organic matter using the Walkley and Black (1934) method.
[c] Soil pH was determined in a 1:5 soil/water extract (mixture) (Sorensen, 1909).
[d] Available P determined by the method of Olsen et al. (1954).
[e] Available K ammonium acetate extractable-K (AAE-K) by extraction with 1 M ammonium acetate at pH 7 (Richards, 1954).
[f] Total nitrogen (N) was determined by the Kjeldahl method (Hesse, 1971).

Fertilization rate (exp. 1) was conducted over a two-year period (2004 and 2005) as a randomized complete block, with four N (NH_4NO_3) treatments: 30 (N_{30}), 60 (N_{60}) and 90 (N_{90}) kg N ha^{-1} and a control plot receiving zero N (N_0 treatment); applied at seeding (20%), at tillering (40%) and at stem elongation (40%).

Fertilization rate and timing experiment (exp. 2) was carried out in 2005 as a randomized complete block. The three different N rates (30, 60 and 90 kg N ha^{-1}) were applied at sowing, tillering and stem elongation.

In the same site of exp. 2, the rate of 90 kg N ha^{-1} was also split (exp. 3) at different phenological stages (sowing, tillering and stem elongation) and amounts (30, 45, 90 kg ha^{-1}); therefore the following treatments were tested: 90-0-0, 0-90-0, 0-0-90, 45-45-0, 45-0-45, 0-45-45, 30-30-30.

In both field sites, soil received 40 kg P ha^{-1} as P_2O_5 after ploughing (30 cm depth), following *Avena sativa* L. as the previous crop. A 6-row precision sowing machine was used for sowing in the first decade of December 2003 and in the third of November 2004. The seed density was 200 seeds m^{-2} and each treatment (unit plot 10 m^2) was replicated three times. Harvest was done in the second decade of July, in each year and experiment, by means of a precision combine harvester. Each experimental field was surrounded by a buffer strip to allow for uniform growing conditions. Weeds were controlled with recommended chemical herbicides.

Daily maximum and minimum temperatures and rainfall were recorded through a standard agro-meteorological station (Skye instruments Ltd., Llandrindod Wells, UK) placed beside the two experimental fields. Daily reference evapotranspiration (ET_o) was estimated by Hargreaves and Samani (1982) equation. The phenological stage of the emmer crop was periodically recorded following Zadoks et al. (1974).

2.2. Crop traits

Morphological traits were recorded in both experiments on each of the three replicate plots. Plants from 1 m^2, for each plot, were hand cut for the calculation of yield-related traits. Whole plant dry mass accumulation (below and above ground) was determined after oven drying plant material at 75 °C until reaching constant weight. The number of spikelets of 50 spikes was counted at head-