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Old tall durum wheat cultivars are suited for dual-purpose utilization

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A B S T R A C T

The lateness, tallness and high vigour of old tall durum wheat cultivars could be advantageous for dual-purpose use and their high propensity for lodging should be reduced by grazing. A 3-year field trial was performed in Sardinia, Italy, in a typical Mediterranean environment. Crops of the durum wheat cultivar Senatore Cappelli were sown in October, and grazing was simulated by clipping half of the plots at the terminal spikelet stage of development. The forage biomass derived from clipping varied greatly between seasons (from 0.8 to 3.3 t ha^{-1} dry matter) in response to the notable inter-seasonal variability in weather conditions. Cultivar Senatore Cappelli showed good recovery following clipping, with the ability to attain almost complete radiation interception well before anthesis. The high number of leaves that emerged after clipping might have contributed to this good recovery. Nevertheless, clipping reduced the dry matter produced by anthesis (16 t ha^{-1} in clipped compared to 21 t ha^{-1} in unclipped crops) as well as the final dry matter (DM_{MAT}) (19 t ha^{-1} in clipped compared to 23 t ha^{-1} in unclipped crops), although these differences disappeared when the clipped biomass was included. The lower lodging observed at anthesis in the clipped (21%) compared with unclipped crops (63%) likely reduced the difference between treatments. The lower DM_{MAT} of clipped treatments was reflected in a lower grain yield (GY) (3.4 t ha^{-1} *vs* 4.2 t ha^{-1} in the unclipped treatment). Clipping did not affect the amount of nitrogen present in the biomass, nitrogen uptake efficiency or radiation use efficiency. GY reduction after clipping was mediated by the reduction in spikes m^{-2} and kernels m^{-2} (KNO). Spike fertility was not affected by clipping, because the same amount of radiation was available for each spike (about 1 MJ). The period with reduced ground cover after clipping was reflected in an increased evaporation and reduced transpiration, which did not alter the total water used and increased the transpiration efficiency in terms of DM_{MAT}.

Old tall durum wheat cultivars manifested good suitability for dual-purpose use in environments with low attainable yields because their low grain yield potential contributed to reducing the negative effects of clipping on GY. Their high straw yield and kernel protein percentage represented an advantage with respect to semi-dwarf cultivars.

1. Introduction

The dual-purpose use of wheat, in which crops are grazed by animals and grain is harvested in the same season, is a valuable management option for mixed farming systems in the Mediterranean environment. In this environment, grazing fills the gap in the seasonal supply of herbage to animals (Francia et al., 2006; Kelman and Dove, 2009; Broumand et al., 2010) in a period when animal demands are high and forage availability is low. The suitability of a species/cultivar to dual-purpose use is defined by winter herbage productivity on the one hand, and grain yield (GY) after grazing on the other. Winter herbage productivity is largely dependent on the duration of the period available for grazing, delimited by sowing date on the one hand, and the onset of stem elongation on the other. At this point, the shoot apex is brought to the surface and becomes vulnerable to grazing damage, ultimately compromising GY (Giunta et al., 2015; del Moral, 1992; Broumand et al., 2010; Harrison et al., 2011a). Sowing crops earlier than usual is a common practice with dual-purpose cereals as it improves crop establishment and enhances early vigour due to warmer autumn temperatures (Harrison et al., 2011a). At the same time, early sown crops might subtract some nitrogen to the potentially relevant leaching expected in October and November. In Mediterranean environments, these are the months with the most rainfall, and some inorganic nitrogen may be still present in the soil because cereals usually follow pulses in these

Abbreviations: GY, grain yield; FIPAR, fraction of intercepted photosynthetically active radiation; IPAR, cumulated photosynthetically active intercepted radiation; TE, transpiration efficiency; NUE, nitrogen uptake efficiency; TS, terminal spikelet stage; PHY, phyllochron; KNO, number of kernels m^{-2}; FRUEFF, fruiting efficiency; DM_{SPANT}, dry matter allocated to the spikes at anthesis m^{-2}

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agricultural systems. Late cultivars must be used with early sowings, not only to lengthen the duration of herbage production, but also to avoid excessive early flowering. Old tall durum wheat cultivars are suited to early sowing because they generally flower late due to some cold requirements (Motzo and Giunta, 2007).

GY is often reduced following grazing because defoliation affects the ability of crops to capture radiation and/or convert radiation into biomass. Dual-purpose use may also affect biomass partitioning into grain and straw by changing the assimilate storage capacity of the crops and hence the contribution of pre-anthesis assimilate to the growth of grains (Harrison et al., 2011). Working with dual-purpose triticale in a Mediterranean environment, Giunta et al. (2017) showed that the reduced ability of clipped crops to intercept radiation only affected GY under the most favourable environmental conditions, whereas GY was not reduced in seasons with severe terminal water stress. We hypothesize that, in general, dual-purpose use should not negatively impact GY in marginal Mediterranean environments where low soil fertility level and high environmental stress lead to low-input agricultural systems with medium-to-low levels of GY. Under these circumstances, tall durum wheat cultivars may represent a good choice for several reasons: their low grain yield potential is not penalizing compared with the more productive semi-dwarf cultivars; their tallness imposes low nitrogen levels (Berry et al., 2004); their greater vigour compared with semi-dwarf cultivars (Rebetzke et al., 2012) can positively affect both winter herbage production and recovery after grazing; and their susceptibility to lodging can be reduced by grazing, sometimes resulting in increased GY (Christiansen et al., 1989). Straw yield has economic value (Annicchiarico and Pecetti, 2003) in these types of agricultural systems, and the low harvest index (HI) of old tall durum wheat cultivars (Giunta et al., 2007) equates with high straw yields.

The old Italian cultivar Senatore Cappelli was one of the most important durum wheat cultivars grown in Italy and the Mediterranean basin in the first half of the 20th century due to its higher adaptability, productivity and semolina quality compared with other cultivars and landraces (Porceddu, 1987). It is the most representative of a large group of tall cultivars belonging to the '*Mediterranean typicum*' group (Ali Dib et al., 1992), and its value has been affirmed by its widespread use in durum wheat breeding (Vallega and Zitelli, 1973).

A 3-year field trial was performed to analyze the effects of clipping at the terminal spikelet (TS) stage on cultivar Senatore Cappelli to verify the suitability of old tall durum wheat cultivars for dual-purpose use. Clipping-induced changes on the capture and use of radiation, nitrogen and water, as well as on biomass partitioning were analyzed.

2. Materials and methods

2.1. Experimental design

Three field trials were conducted in Sardinia, Italy (Ottava, 41°N, 80 m asl), over the following seasons: 2013–14 (from here on '2014′), 2014–15 ('2015') and 2015–16 ('2016'); the site presented a typically Mediterranean climate with a long-term average annual rainfall of 552 mm. The soil consisted of a sandy clay loam of a maximum depth of about 0.6-0.7 m overlying a limestone bedrock (Xerochrepts); the volumetric water content of the soil was 36% at field capacity and 15% at the wilting point. The durum wheat (Triticum turgidum L. ssp.durum Desf.) cultivar Senatore Cappelli was sown on 21st October 2013, 22nd October 2014 and 12th October 2015, and the preceding crop was faba bean for all three seasons. Residues of faba bean crops were chopped and incorporated into the soil. The seed rate was 200 seeds m^{-2}, a common sowing rate for tall wheat cultivars in this type of environment. Seed density was calculated from kernel weight and germination percentage. Half of the plots were clipped at the terminal spikelet stage (TS) with a lawn mower (clipped treatment) so that their aboveground height did not exceed 5 cm. The clipping treatment was intended to simulate grazing, as some comparisons between grazing and clipping have shown that these methods are comparable (Dann et al., 1977; Francia et al., 2006). In each season, plots were arranged in a randomized complete block design with four replications. Each plot was formed by eight 8.4 m long rows, separated from one another by 0.15 m. The soil was dressed with 47 kg ha^{-1} P_2O_5 and 36 kg ha^{-1} N at sowing, followed by 40 kg ha^{-1} N after clipping. All weeds, pests and diseases were chemically controlled.

2.2. Measurements

Destructive sampling was performed every 3–4 days on five plants per plot to pinpoint the timing of TS (Bonnett, 1936). Emergence, anthesis and physiological maturity were recorded by periodical inspections of the plots when more than 50% of plants in the plot had reached the phenological stage. The Haun stage (Haun, 1973) of the main stem was recorded on a set of 10 plants per plot every 3–4 days until the flag leaf had completely emerged and its ligule had become visible (DC 39 according to Zadoks et al., 1974).

Plant height – from the soil surface to the ligula of the last emerged leaf or to the tip of the spike (excluding awns) – was recorded once a week. Lodging was assessed at anthesis by a visual assessment of the proportion of lodged area in each plot.

A tube solarimeter (Sun-Scan Canopy Analysis System SS1-UM-1.05. Delta-T Devices Ltd.; Cambridge, UK), which allowed simultaneous measurements of photosynthetically active radiation above (using external sensor) and below (using a probe) the canopy, was used to obtain both an indirect measure of leaf area index (LAI) and an estimate of the fraction of the intercepted photosynthetically active radiation (FIPAR). Measurements were made at noon on several occasions from emergence until the plants had yellow flag leaves by placing the probe parallel to the soil surface at right angles to the row direction of each plot. The probe was positioned at ground level in the first samplings, and then subsequently at increasing height from the soil to stay above the dead leaves. On different occasions between clipping and anthesis, the following parameters were measured on a sample of 30 uppermost fully expanded leaf blades per plot: leaf chlorophyll content, estimated using the SPAD-502 chlorophyll meter; leaf area, using an electronic Leaf Area Meter; leaf dry weight after oven drying at 80 °C; and leaf nitrogen percentage using the Carbon/Hydrogen/Nitrogen Determinator (CHN 628 Series, Leco Corporation, St. Joseph, MI, USA). Using these data, specific leaf area (SLA, $cm^2\ g^{-1}$) was calculated as the ratio between leaf area and leaf dry weight, and specific leaf nitrogen (SLN, g N m^{-2}) as the ratio between g of N and leaf area.

In each season, clipping with a lawn mower was performed immediately after observing TS on the entire 10 m^2 plot assigned to 'clipped' treatment. The fresh weight of the whole plot was recorded and used to calculate the dry weight of the clipped biomass based on the humidity of a 1 kg sub-sample that was oven-dried at 60 °C for 48 h. The number of stems and spikes, the total dry matter (DM_{ANT}, t ha^{-1}) and the dry matter allocated to the spikes (DM_{SPANT}, g m^{-2}) were subsequently evaluated at anthesis on samples of 0.3 m^2 uprooted plants, excluding the roots. The physiological maturity sample of aboveground biomass was hand-cut from the internal rows. Spikes were then separated and counted. The number of spikes m^{-2} was calculated as the mean of the determinations made at anthesis and at maturity. Both spikes and straw were oven-dried at 80 °C for 48 h and weighed, after which the spikes were threshed. Kernel weight (KW, mg) was obtained from two subsamples of 500 kernels. The harvest index (HI) was determined on the maturity sample, and used to calculate the final biomass (DM_{MAT}, t ha^{-1}) from the GY obtained on a plot basis with mechanical harvesting. All of the biomass samples analyzed with the CHN Determinator to obtain their nitrogen percentage. Kernel number m^{-2} (KNO) was calculated from the GY/KW ratio and fruiting efficiency (FRUEFF, n° of kernels g^{-1} DM spikes at anthesis) was calculated from the KNO/DM_{SPANT} ratio.

The amount of nitrogen removed per unit surface (kg ha^{-1}) was