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In-season wheat root growth and soil water extraction in the Mediterranean environment of northern Syria

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ABSTRACT

Wheat is the most important cereal crop in the semi-arid eastern Mediterranean region that includes northern Syria. Knowledge of wheat root depth and the vertical distribution during the winter growing season is needed for sound scheduling of irrigation and efficient use of water. This article reports evaluation of root development for three winter-grown bread (*Triticum aestivum* L.) and durum (*Triticum turgidum* L.) wheat under four soil water regimes (rainfed and full irrigation with two intermediate levels of 33 and 66% of full irrigation). Roots were sampled by soil coring to a depth of 0.75 m at four occasions during 2005–2006 growing season. Two distinct phases of root development were identified, a rapid downward penetration from emergence to end tillering phase, followed by a substantial root mass growth along the profile from tillering to mid-stem-elongation phase. Roots were detected as deep as 0.75 m during the initial rapid penetration, yet only 29% of the total seasonal root mass was developed. This downward penetration rate averaged 7 mm d^{-1} and produced 10.8 kg ha^{-1} d^{-1} of root dry-biomass. The bulging of root mass from tillering to mid-stem-elongation coincided with vigorous shoot growth, doubling root dry-biomass at a rate of 52 kg ha^{-1} d^{-1}, compared to the seasonal root growth rate of 18.3 kg ha^{-1} d^{-1}. A second-degree equation described the total root dry-biomass as a function of days after emergence ($r^2 = 0.85$), whereas a simpler equation predicted it as a function of cumulative growing degree days ($r^2 = 0.85$). The final grain yield was a strong function of irrigation regimes, varying from 3.0 to 6.5 t ha^{-1}, but showed no correlation with root biomass which remained similar as soil water regimes changed. This observation must be viewed with care as it lacks statistical evidence. Results showed 90% of root mass at first irrigation (15 April) confined in the top 0.60–0.75 m soil in bread wheat. Presence of shallow restricting soil layers limited root depth of durum wheat to 0.45 m, yet total seasonal root mass and grain yield were comparable with non-restricted bread wheat. Most root growth occurred during the cool rainy season and prior to the late irrigation season. The root sampling is short of rigorous, but results complement the limited field data in literature collectively suggesting that irrigation following the rainy season may best be scheduled assuming a well developed root zone as deep as the effective soil depth within the top meter of soil.

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1. Introduction

The Mediterranean region of West Asia is a prime example of the subtropical dry areas of the world (Kassam, 1981; Ryan et al., 2006) that includes the low lands in northern Syria. The prevailing Mediterranean climate in the northern Syria is characterized by a single rainy season, starting in the fall and extending through the spring (Fig. 1), during which cereals and food legumes dominate. Wheat is the most important cereal crop in northern Syria. It is normally planted in mid-November, tillers by mid- to end February, heads in April, and is mostly harvested in early June. In normal years and over the period December to March, wheat grows with adequate soil water due to frequent rainfall and low evaporative demands (Fig. 1). This recharge period in early season is followed by a late season characterized by soil profile drying and rising air temperatures. This period usually coincides with the water sensitive growth stages from booting to grain filling (Zhang and Oweis, 1999) when irrigation is needed to achieve high yields (Perrier and Salkini, 1991; Oweis et al., 1998). Most irrigation practices are, however, water consuming and over-exploited aquifers are of major concern (Ward and Smith, 1994; Varela-Ortega and Sagardoy, 2003; Salman, 2004). One of the reasons for wasteful practices is the lack of a proper on-farm water management (Farahani et al., 2006), or more specifically, inadequate scheduling of irrigation. Irrigation scheduling concerns the decision process of "when" to irrigate and "how much" water to apply in order to meet a specific management objective. Scheduling irrigation on the base of threshold soil water depletion is a sound practice that requires knowledge of the effective root zone depth, and preferably of the vertical distribution of the roots, at the time of the irrigation event. For winter-grown wheat, this information is most needed during the mid to late season when rainfall decreases making the irrigation essential. The crop root zone depth varies over time and it is difficult-to-determine and impractical to measure. Poor estimates of the root zone depth result in improper scheduling (under or over irrigation) and inefficient use of water, which is particularly weighty in water-scarce environments.

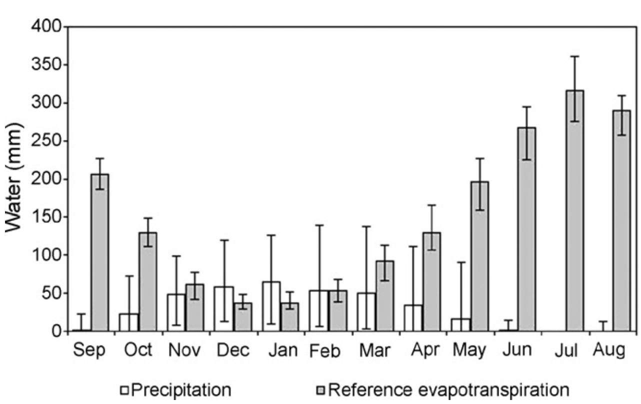

Fig. 1 – Long-term (1979–2006) mean monthly rainfall and reference evapotranspiration (using the procedure by Allen et al., 1998) at Tel Hadya, Syria. (Vertical bars represent minimum and maximum values.)

The importance of plant roots as suppliers of water and minerals for growth has been discussed by many (e.g., Russell, 1977; Barraclough, 1986), but its measurements are limited under field conditions (Zuo et al., 2004). Generally, root studies have lagged behind that of shoot (Tsutsumi et al., 2003; Sarker et al., 2005) mostly because roots are hidden and not easily instrumented or observed due to relatively high cost and labor needed for sampling and analysis. This is in spite that it is the integrated action of shoots and roots that determines productivity. Roots are often much more variable than shoots, and are affected by variations of climate, soil conditions, plant varieties, soil nutrient and water availability throughout the season (Zuo et al., 2004). These are discussed for wheat in, e.g., Barraclough and Leigh (1984) on sowing date and soil type effects, Weir and Barraclough (1986) on drought effects, Gregory et al. (1978), Meyer et al. (1990), Kaetterer et al. (1993), Robertson and Giunta (1994), Brady et al. (1995), and Asseng et al. (1998) on water and nutrient effects, and Wilhelm et al. (1982), Sow et al. (1997), Pikul and Aase (1999), Galantini et al. (2000), and Ishaq et al. (2003) on tillage systems and fertilizer rates. Root studies in crops of cotton (Taylor and Klepper, 1974; Ishaq et al., 2003), soybean (Huck et al., 1987), maize (Varsa et al., 1997) and grain sorghum (Robertson et al., 1993) are also noted, in addition to discussions in Box et al. (1989), Upchurch and Ritchie (1983), and Smucker et al. (1987) on root measurement techniques based on image analysis and minirhizotron. Many of these studies discuss specific root functions and physiology, topics that are beyond the intended context of this article on the need of a deeper knowledge on root depth and vertical distribution during the wheat-growing season for irrigation scheduling.

Literature suggests (as inferred by Asseng et al., 1998) that the in-season peak of wheat root biomass and length is mostly near anthesis and that too irrespective of dry or wet growing conditions. This is of significance in northern Syria where anthesis normally coincides with the late season low rainfall when irrigation, and thus scheduling, is required. Furthermore, experimental observations show that in semi-arid regions, with the exception of particularly wet years, the depth of the wetting front generated by seasonal rainfall is a good estimate of the rooting depth (Gregory et al., 1984; Cooper et al., 1987; Xue et al., 2003), suggesting the use of changes in soil profile water content as surrogate measure of rooting depth. Application of this indirect method for in-season analysis is preferred in instances where root water extraction is the dominant mechanism of soil water change, and thus most suited for analysis of deeper soil layers not greatly influenced by soil evaporation, in situations of limited deep percolation (no irrigation or heavy rain) and deep water table. These conditions prevail in much of the rainfed cereal lands in the Mediterranean region, where deep percolation from the soil profile is limited because of seasonal rainfall amounts that are well below evaporative demand (Fig. 1). In northern Syria, assessment of roots are reported for some important winter-grown crops like barley and food legumes (Gregory et al., 1984, 1994; Gregory, 1988; Brown et al., 1987, 1989; Wahbi and Gregory, 1989; Sarker et al., 2005), but field data for wheat and application of the above techniques for root assessment are very limited (Matar and Brown, 1989; Sato et al., 2006).