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Effect of irrigation regime and application of kaolin on yield, quality and water use efficiency of tomato

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ABSTRACT

Modern agriculture is faced with two tasks: (1) to produce enough food for a growing global population, and (2) to ensure satisfactory crop quality while using water resources efficiently. A study of the effect of kaolin on the yield, quality and water use efficiency of tomato (*Lycopersicon esculentum* Mill.), grown under different irrigation regimes, is reported in the paper. The research was conducted in an open field with carbonate chernozem soil, at Stara Pazova (40 km north of Belgrade, Serbia). It lasted for three years (2011, 2012, and 2013). The experimental setup was a two-factorial, completely random block system, with three replications. The first factor was the irrigation regime and the second the application of kaolin. Two irrigation treatments were studied: (a) full irrigation (F), covering 100% of ETc (crop evapotranspiration), and (b) deficit irrigation (D) at 50% of ETc. The kaolin treatments were: (a) control treatment, without kaolin (C) and treatment with a 5% suspension of kaolin (K).

On average, the highest fresh tomato fruit yields were achieved under full irrigation, with kaolin (FK) (21.0 kg m^{-2}). The FK treatment also resulted in the greatest dry weight of the fruits (1.1 kg m^{-2}). The average fruit weight was rather uniform and ranged from 71.7 g with DC to 75.4 g with DK. The average sugar and lycopene content was quite uniform over the study period, while the irrigation regime had a significant effect on the average organic acid content and total antioxidant activity. Deficit irrigation treatments resulted in a higher organic acid content and higher total antioxidant activity than full irrigation. The application of kaolin had a greater effect of the water use efficiency of tomato than the irrigation treatment.

1. Introduction

Under climate change conditions, lack of precipitation becomes a limiting factor for farming. Serbia experiences drought nearly every year, to a greater or lesser extent. Given that water is a limited resource, there are numerous research projects aimed at devising various water saving approaches and measures, while achieving economically viable yields. Deficit irrigation and the application of kaolin could mitigate climate change/drought impact and save water in agriculture (Boari et al., 2015).

A deficit irrigation (DI) strategy exposes crops, in a pre-programmed manner, to some water stress during a certain period of time or over the entire growing season. This reduces yields but saves water and increases water use efficiency (English and Raja, 1996; Fereres et al., 2003; Ferreira and Carr, 2002; Pereira et al., 2002; Perry et al., 2009; Steduto, 2006; Steduto et al., 2007; Topcu et al., 2007). Mild deficit irrigation of tomato tends to improve root development (Marouelli et al., 2004; Marouelli and Silva, 2007; Shahnazari et al., 2007), as roots reach greater depths for water uptake. With deficit irrigation, vegetable crops, such as tomato (Topcu et al., 2007), sweet pepper (Kang et al., 2001), eggplant (Kirnak and Demirtas, 2006) or cucumber (Mao et al., 2003), improve water use efficiency proportionally to yield and fruit weight losses. In regions with sparse water resources, higher water productivity is more cost-effective for farmers than the achievement of high yields (Pereira et al., 2002). The water demand of tomato (*Lycopersicon esculentum* Mill.) is high, such that DI can save significant amounts of irrigation water (Costa et al., 2007).

According to Glenn and Puterka, (2005), the application of a kaolin-based particle film over the canopy improves fruit quality, controls some pests, and reduces heat stress. The kaolin creates

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a canopy cover (over the above-ground part of the plant and fruits), which reduces water use. Many research reports highlight the favorable effect of kaolin on sunburn, such as in the case of pomegranate, apple, walnut, citrus fruits and tomato (Boari et al., 2015; Cantore et al., 2009; Glenn, 2012; Pace et al., 2007; Saavedra Del et al., 2006; Weerakkody et al., 2010). The reduction in crop temperature with the application of kaolin can increase the average fruit weight (Cantore et al., 2009; Lalancette et al., 2005; Saleh and El-Ashry, 2006) and improve some fruit properties, such as color, total soluble solids, vitamin C content, and anthocyanin concentration (Chamchaiyaporn et al., 2013; Glenn et al., 2001; Melgarejo et al., 2004; Shellie and King, 2013a, 2013b; Wand et al., 2006; Yazici and Kaynak, 2009). It should be noted that kaolin is a natural substance, used in organic farming, such that treated crops can readily be consumed. Boari et al. (2014) studied the effect of kaolin application to tomato gas exchange. Their results indicate that kaolin had the greatest effect in reducing stomatal conductance, which decreased transpiration, improved the plants' water status, and reduced net assimilation. Moreover, the same authors underline that in pest control and heat stress mitigation, kaolin can effectively be used as an anti-transpirant, to reduce the effects of drought stress and soil salinity, and to conserve water in arid regions such as the Mediterranean. Kaolin decreases citrus fruit temperate by 1 to 6 °C, on average, and thus reduces sunburn and improves fruit quality (Miranda et al., 2007). The temperature of kaolin-treated tomatoes at noon on the warmest day was about 3.5 °C lower than that of untreated tomatoes. The application of kaolin increases the lycopene content of tomato fruits and thus improves their quality (Cantore et al., 2008; Pace et al., 2007; Saavedra Del et al., 2006), as well as results in a considerable WUE increase, with no effect on the organoleptic properties of the fruits (Lukic et al., 2012).

The objective of the present research was to study the effect of kaolin on the yield, fruit quality and water use efficiency of tomato grown under different irrigation regimes, or, in other words, to gain insight into the possibility of saving water and increasing water use efficiency.

2. Material and method

2.1. Experimental setup

The experiment was conducted over a period of three years (2011, 2012 and 2013), in an experimental field of the Napredak AD farm in Stara Pazova (44° 59′ N; 19° 51′ E, alt. 96 m), located 40 km north of Belgrade, Serbia. The setup was a two-factorial, completely random block system, with three replications. The first factor was the irrigation regime and the second the application of kaolin. Two irrigation treatments were studied: (a) full irrigation (F), covering 100% of ETc (crop evapotranspiration), and (b) deficit irrigation (D) at 50% of ETc. The kaolin treatments were: (a) control treatment, without kaolin (C), and treatment with a 5% suspension of kaolin (K). These two treatments were selected because, based on past experience, unexpected rainfall events make it difficult to ensure treatment consistency with a milder deficit. The tomato was of the determinate type, Rio Grande cultivar. The tomato was transplanted in paired rows. The space between the rows was 0.5 m, and between the plants in a row 0.3 m. The center distance between two paired rows was 1.5 m. Each treatment covered five rows, 20 m long. The stand density was 30,000 plants per hectare. Buffer rows of tomato were planted along the perimeter to reduce any impact of adjacent plots. The size of the entire study area was 1200 m^2. The soil in the paired rows, under the plants, was covered with black plastic mulch. In the year 2011 the growing season of tomato lasted 87 days (from 18 May to 12 August), 92 days (from 19 May to 18 August) in the year 2012, and 97 days in 2013 (from 20 May to 24 August).

The soil in the study area is of the carbonate chernozem type, developed in loess. Its morphological, hydrophysical and agrichemical properties are conducive to farming. It features a great cross-sectional depth and the mechanical composition is with nearly equal proportions of sand, silt and clay fractions. The texture is fine—clayey loam (USDA, 2006). It is a deep soil, whose water storage capacity is high and where roots can spread arbitrarily and draw moisture and nutrients from a considerable depth. Water accessible in the active part of the tomato's rhizosphere (0.6 m) amounted to 103.62 mm. The field capacity of the tomato's rhizosphere (0.6 m) was 31.3 $cm^3\,cm^{-3}$ and the wilting point 14.0 $cm^3\,cm^{-3}$. The soil provided an average supply of nitrogen, readily accessible phosphorus, and an abundant supply of potassium. The soil was mildly alkaline, due to the presence of carbonates whose content increased with depth.

The climate in the study area is continental, with Central European and Mediterranean components. The annual precipitation average over the past 20 years is 637 mm (high 911 mm and low 352 mm). The average precipitation total during the growing season (from April to September) is 366 mm (high 663 mm and low 193 mm). All three study years were hot, with extremely dry periods in July and August. The hottest year was 2012 while 2013 was relatively mild. Fig. 1 shows average monthly precipitation totals and mean monthly air temperatures. The average air temperatures and precipitation totals in the study area during the study period are shown in Table 1.

2.2. Evapotranspiration

For an accurate assessment of water use by a certain crop in real time, evaporation and transpiration need to be addressed separately. Accordingly, ETc was determined as the product of reference evapotranspiration (ETo) and the dual crop coefficient (K_c). Reference evapotranspiration was calculated applying the FAO Penman-Monteith method. Daily values of weather parameters from a meteorological station at Surčin, in relative proximity to the study area, were used.

In D treatment, the plant was not well-supplied with water, on the one hand, such that the stress coefficient (K_s) was calculated, and on the other hand there was plastic mulch (65% coverage), such that K_e (evaporation coefficient) was reduced by 32.5% (Allen et al., 1998).

For full and deficit irrigation treatments the following formulas (1) and (2) were applied, respectively:

$$ET_c = ET_o \times (K_{cb} + K_e) \quad (1)$$

$$ET_c = ET_o \times (K_s \times K_{cb} + K_e) \quad (2)$$

where: ETc—crop evapotranspiration (mm), ETo—reference evapotranspiration (mm), K_{cb}—basal crop coefficient, K_e—evaporation coefficient, and K_s—stress coefficient.

To accurately assess the effect of kaolin on water use, additional calculations were made applying the water budgeting method, using available rainfall, irrigation depth and soil moisture variation data.

$$ET_a = \frac{P + I \pm \Delta\theta}{n} \quad (3)$$

where: ET_a—actual evapotranspiration (mm day^{-1}), I—irrigation (mm), Δq—soil moisture variation between two measurements (mm), and n—number of days between two measurements.

Fig. 2 shows evapotranspiration by type of irrigation treatment during the study period, calculated via the dual crop coefficient.