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Productivity and production components of safflower genotypes affected by irrigation at phenological stages

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ABSTRACT

Drought and the scarce resource of water for irrigation can limit agricultural production under tropical conditions. The objective of this study was to investigate the growth and yield response of safflower genotypes to water deficit in the soil profile during vegetative, flowering and yield formation stages, both in clayey and sandy soils. The experiments were carried out in Engenheiro Coelho, SP, Brazil, in autumn-winter 2014. The experimental design was a randomized block in a factorial arrangement, consisting of the genotypes IMA-2232, IMA-4409, IMA-2109 and IAPAR, and irrigation schemes water deficit (WD), irrigation at the vegetative stage (V), irrigation at the grain formation stage (G), irrigation at the vegetative and flowering (VF) stages, irrigation at the vegetative and grain formation (VG) stages, irrigation at the flowering and grain formation (FG) stages and irrigation at the vegetative, flowering and grain formation (VFG) stages (control). The growth of safflower genotypes, yield components and grain and oil yield were weaken by gradual water restriction at the stages, especially at the vegetative stage in both soils. The water regime with irrigation at the flowering stage and grain formation (FG) only did not reduce the oil content in the genotypes in clayey soil. The IAPAR genotype produced more grains (2.7 Mg ha^{-1}), while the IMA-4409 genotype had higher oil content (42.8%) but they both had similar oil yield (0.75 and 0.79 Mg ha^{-1}, respectively) on the clayey soil with irrigation throughout the cycle (VFG). Oil yield in the sandy soil treatment was similar to that of clayey soil (0.72 Mg ha^{-1}) in VFG, in particular for the IMA-4409 genotype. The IAPAR and IMA-4409 genotypes were generally less sensitive to interruption of water supply at the growth stages. In general, the higher total water storage in soil profile of clayey soil, compared to sandy soil, did not benefit the safflower crop. On an average, irrigation only at vegetative and flowering stage (VG) stages can save 15% of water but with a corresponding 50% reduction in yield, both in clayey soil and sandy soil. The irrigation during the VFG stages might be practiced to attain the highest yield of safflower genotypes.

1. Introduction

Due to the need for introduction of plants with industrial potential as well as tolerance to abiotic stresses in tropical climate (Sampaio et al., 2016; Santos and Silva, 2015; Galant et al., 2015), safflower (*Carthamus tinctorius* L.), an annual oilseed species from the family Asteraceae, may be an alternative in production systems with crop rotation due to drought tolerance (Lovelli et al., 2007; Kar et al., 2007; Hojati et al., 2011). Moreover, it is a rustic plant with a deep root system (Merrill et al., 2002), with ability to extract soil water from the deeper depths, down to a depth of 1.6 m (Singh et al., 2016b). This has facilitated its expansion in areas around the world where the soil and climate constraints prevent the cultivation of food and conventional crops (Hussain et al., 2015).

Water deficit is the most unpredictable among abiotic stresses in terms of occurrence, severity, distribution and duration (Wery et al., 1993). It is expected to increase in frequency and severity in the future as a result of climate change, mainly in function of the reduction of regional rainfall, but also because of increased evaporation driven by global warming (Lobell et al., 2008). In this context, the identification of the right moment of irrigation and a safflower irrigation schedule are keys to water conservation in order to improve the performance of irrigation and to sustain the irrigated agriculture (Ngouajio et al., 2007).

The reduction in yield and production components in different safflower genotypes due to water deficiency has already been

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reported in other regions of the world (Kar et al., 2007; Lovelli et al., 2007). Movahhedy-Dehnavy et al. (2009) observed that, in general, there was reduction in seed yield, total biomass, number of buds per plant and plant height by withholding irrigation at various stages of growth of safflower genotypes, especially when water stress was imposed at the flowering stage. Since Istanbulluoglu (2009) and Istanbulluoglu et al. (2009) found that when irrigation was omitted during the vegetative stage, the grain yield was decreased. Omidi et al. (2012) reported little effect on productivity when irrigation was suspended after flowering.

The supply of water to a crop results from interactions that take place along the soil-plant-atmosphere system. As the soil dries, it becomes more difficult for plants to uptake water, because the retaining strength increases and the water availability to plants decreases in the soil. The movement of water from the soil to the atmosphere through the plants depends on the soil. At one extreme, there are sandy soils that have a smaller surface area and provide large pore spaces or channels between the particles; at another extreme, there are clayey soils with smaller particles and pores, which make drainage difficult and retain water more firmly (Santos and Carlesso, 1998).

Root growth may vary according to soil texture. Thus, it is important to determine the impact of the water systems related to the water regime in safflower genotypes, because previous studies indicate that the performance of other crops in relation to irrigation was influenced by soil texture (Gajri et al., 1991; Katerji and Mastrorilli, 2009; Arora et al., 2011). Arora et al. (2011) observed that irrigation caused an average yield gain of more than 40% in clayey soil compared with 5% in sandy soil.

In this sense, due to the fact that the effects of water deficit on growth and productivity are dependent on genotype (Bannayan et al., 2008), especially in specific developmental stages (Ozturk et al., 2008), the identification of safflower cultivars adapted and able to grow in limited water environments is important. In order to supply the lacking of information on safflower management in Brazil, the objective of this study was to investigate the growth and yield of grains and oil of safflower genotypes under deficit irrigation imposed during vegetative, flowering and yield formation stages, cultivated in both clayey and sandy soils.

2. Materials and methods

2.1. Site description

The experiments were carried out in Engenheiro Coelho, SP, Brazil, during the fall and winter of 2014, in two experimental areas with different soils, one Rhodic Acrudox and one Arenic Hapludult (Soil Survey Staff, 2014). The chemical (Van Raij and Quaggio, 1983) and physical (Embrapa, 1997) characteristics of the soils before implementation of the experiments are shown in Table 1.

According to the Köppen classification, the climate is humid subtropical Cwa type, with temperatures in the warmest month above 32 °C and in the coldest month, below 18 °C. Annual rainfall in the region is 1328 mm. Daily and historical weather precipitation data were obtained from a meteorological station located near the experimental area and are shown in Table 2.

2.2. Experimental design

The experimental design was a randomized block in a 4 × 8 factorial arrangement, with three replications. Genotypes IMA-2232, IMA-4409, IMA-2109 and IAPAR were seeded on April 14, 2014 in both locations. Each plot was sized with 1.35 m wide × 4.0 m long (3 lines per plot). Inter-row spacing was 0.45 m and plant spacing was 0.10 m.

Table 1
Chemical and physics characterization at a depth of 0–0.20 m in the experimental areas.

Soil characteristics	Soil	
	Sandy	Clayey
Soil pH	4.8	5.6
Clay (g kg^{-1})	172	408
Silt (g kg^{-1})	123	105
Sand (g kg^{-1})	705	487
Organic matter (g kg^{-1})	10	17
Available P (mg kg^{-1})	7	12
H + Al ($cmol_c$ kg^{-1})	28	29
Al saturation (%)	7.55	0
Exchangeable Al ($cmol_c$ kg^{-1})	2	0
Exchangeable K ($cmol_c$ kg^{-1})	23	28
Calcium ($cmol_c$ kg^{-1})	1.7	3.2
Magnesium ($cmol_c$ kg^{-1})	0.5	1.1
CEC ($cmol_c$ kg^{-1})	5.2	7.5
Soil base saturation (%)	47	61

CEC = Cation Exchange Capacity.

Table 2
Average temperature, precipitation and long-term precipitation (27-year) measured in Engenheiro Coelho, SP, Brazil.

Month	Average temperature (°C)	Long-term temperature (°C)	Precipitation (mm)	Long-term precipitation (mm)
April	22.07	22.9	51.2	66.9
May	19.3	19.4	9.9	52.7
June	19.3	18.4	10.9	37.0
July	20.8	18.1	20.8	34.7
August	21.01	19.8	7.2	23.0
September	23.02	21.1	97.3	70.7

2.3. Field preparation and planting

Fertilization, planting, cultural practices and harvesting were performed manually. Sowing depth was three centimeters. The seeds were treated with a Tiram-based fungicide. For fertilization, 500 kg ha^{-1} of 4-14-8 (N-P_2O_5-K_2O) formula was applied.

Similarly to water entry into the system by precipitation, the output by evapotranspiration (ETP) was calculated by Hargreaves and Samani's equation, which offers accurate estimations in arid environment (Raziei and Pereira, 2013). Water levels were maintained above 70% of available water, between field capacity (CC) of 29% and permanent wilting point (PWP) of 15% for clayey soil, and between 20% and 10%, respectively, for the sandy soil in the soil layer of 0–0.30 m. All treatments were irrigated to replace the evaporative demand. The area was irrigated with a local system, using a Naan Dan Jain drip tape with a self-compensating issuer at every 0.2 m, with flow rate of 1.7 L h^{-1}, and service pressure of 90 kPa. Dripper tubes were placed in the central row of each plot at 0.10 m from the planting row.

2.4. Irrigation treatments

In the selection of irrigation treatments, three growth stages were considered for safflower: vegetative (V) flowering (F) and grain formation (G). Water application stages were determined in accordance with Doorenbos and Kassam (1979). These were the treatments: water deficit (WD), irrigation at vegetative stage (V), irrigation at flowering stage (F), irrigation at grain formation stage (G), irrigation at vegetative and flowering stage (VF), irrigation at the vegetative and grain formation (VG) stages, irrigation at flowering and grain formation (FG) stages and irrigation at the vegetative, flowering and grain formation (VFG) stages. The VFG was considered treatment as control (Table 3).