Agricultural Water Management 172 (2016) 18–30

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

# Effects of irrigation strategies, planting methods and nitrogen fertilization on yield, water and nitrogen efficiencies of safflower

Mohammad Hossein Shahrokhnia, Ali Reza Sepaskhah*

*Irrigation Department, Shiraz University, Iran*

A R T I C L E I N F O

*Article history:*
Received 25 June 2015
Received in revised form 5 March 2016
Accepted 12 April 2016
Available online 22 April 2016

*Keywords:*
PRD irrigation
Variable alternate furrow irrigation
WUE
Oil
Protein
Yield response to water

A B S T R A C T

Safflower (*Carthamus tinctorius* L.) is a multipurpose crop that is used as food dyeing spice, edible oil, livestock feed, biofuels and medicinal applications in many areas of the world. Drought and scarce resource of irrigation water are serious concerns in agricultural production and global food security that have occurred in Iran and other arid and semi-arid regions. The objective of this study is to investigate the effects of partial root drying (PRD) irrigation, planting method and different nitrogen application rates on yield, water and nitrogen use efficiencies of safflower. The experiment was designed as split-split plot that arranged in randomized complete blocks with irrigation strategy as the main plot, planting method as the subplot and nitrogen levels as the sub-subplot in three replications. The irrigation strategies consisted of ordinary furrow irrigation (OFI) and variable alternate furrow irrigation (VAFI) as a PRD technique. The planting methods included of on-ridge planting (ORP) and in-furrow planting (IFP) methods. The fertilizer levels were 0 ($N_0$), 100 ($N_1$) and 200 ($N_2$) kg ha$^{-1}$ of urea as 0, 46 and 92 kg N ha$^{-1}$. In present study, VAFI technique dominantly saved applied irrigation water by 30.2% against only a 13% reduction in safflower seed yield that was not statistically significant among treatments. The coefficient of crop response to water ($K_y$) obtained as 0.83 which shows that safflower is a tolerant crop to VAFI strategy which is recommended in areas with limited water resources. Furthermore, in-furrow planting method resulted in 13.5% enhancement in safflower seed yield due to the better soil conditions (temperature and moisture) that is provided by this technique. Therefore, this method is considered as an appropriate alternative for safflower planting due to its favourable influence on water use efficiency (WUE) and other safflower traits, especially in semi-arid and arid regions. Most of safflower traits were definitely enhanced by application of 46 kg N ha$^{-1}$ such as yield production, WUE and nitrogen use efficiencies; whereas higher rate of nitrogen showed negligible effect on safflower traits compared with 46 kg N ha$^{-1}$.


## 1. Introduction

Safflower is an oilseed crop which is grown in many areas of the world. It is especially well adapted to dry and temperate climate conditions (Kaffka and Kearney, 1998; Weiss, 2000) with low rainfall. In previous decades, safflower was popularly used for colouring and flavouring in foods, making dyes, paint and carpet-weaving industries; however, today it is grown mainly for edible oil, cooking oil and also pharmaceutical applications. On the other hand, safflower oil is rich in fatty acids (Oleic and Linoleic) which play important roles in reducing blood cholesterol levels and giving advantage to human health. In addition, safflower meal is a source of protein and fiber for livestock and poultry feed. Recently, the potential of safflower as biofuels and diesel fuel has been recognized which have introduced new economic source for farmers.

Sustainable use of water resources is mainly dependent to the agricultural sector as the major consumer of water supplies. In this situation, proper water management strategies are necessary. Deficit irrigation (DI) as a water saving strategy is commonly applied in arid and semi-arid regions to increase water productivity. The amount of irrigation reduction is crop-dependent and generally accompanied by no or minor yield loss that leads to increase in water productivity (Ahmadi et al., 2010; Sepaskhah and Ahmadi, 2010). A version of DI has introduced as partial root zone drying irrigation (PRD) in which two halves of plant root zones are exposed alternately to dry and wet cycles (Kang et al., 1997). The variable alternate furrow irrigation (VAFI) is an approach of this technique. The basic principle of the VAFI is to apply water to one of two adjacent furrows and change the irrigated furrow, alternatively. The application of this technique permits to irrigate only half

* Corresponding author.
*E-mail address:* sepas@shirazu.ac.ir (A.R. Sepaskhah).

http://dx.doi.org/10.1016/j.agwat.2016.04.010
0378-3774/

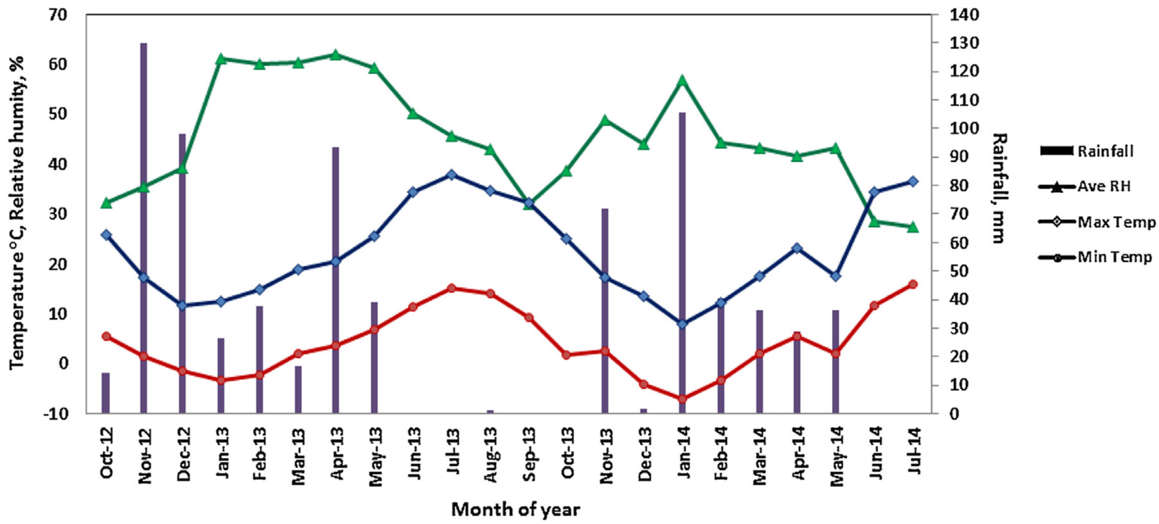


**Fig. 1.** The average of maximum and minimum air temperature and relative humidity with rainfall in years 2012–2014.

of the furrows in a set. PRD can stimulate root growth and maintain a constant absisic acid (ABA) signalling to regulate shoot physiology. In plants under DI, some of the roots in dry soils for long period may die and signalling may diminish and shoot water deficits may occur (Davies and Hartung, 2004). Whereas, plants under PRD performed better than under DI when the same amount of water was applied (Liu et al., 2006; Ahmadi et al., 2010).

Choosing a proper planting pattern can be another useful strategy to have more water saving in arid and semi arid regions. Several approaches are proposed in this way to reduce water consumption and increase water use efficiency (WUE) in crop production such as raised bed planting (Kukal et al., 2010) and in-furrow planting with or without mulched ridges (Buttar et al., 2006; Zhang et al., 2007). It is observed that better conditions for plant growth are provided by in-furrow planting due to higher soil water and temperature (Shabani et al., 2013; Yarami and Sepaskhah, 2015) and furrow planting pattern is a perfect method for regions with drought or saline stress risk (Mashreghi et al., 2014).

Nitrogen is one of the most important nutrients for crop production because it affects dry matter production by influencing leaf area development and maintenance as well as photosynthetic efficiency. In this respect, safflower response to N has known greater than other nutrients (Weiss, 2000). Growth is reduced when nitrogen amount in soil is not optimal (Sepaskhah and Barzegar, 2010; Tafteh and Sepaskhah, 2012). Under N deficiency, growth is inhibited and shoot–root ratio is decreased (Steer and Harrigan, 1986). Besides, N deficiency reduces the radiation interception, radiation use efficiency, dry matter partitioning to reproductive organs, leaf area index, and protein concentration of seeds (Marschner, 2012). Meanwhile, N deficiency delays both vegetative and reproductive phenological development, reduces leaf emergence rate, yield, and yield components such as the number of heads per plant, the number of seeds per head, the single seed weight, and the number of seeds per plant (Gilbert and Tucker, 1967; Jones and Tucker, 1968; Steer and Harrigan, 1986). Under low N level the lower photosynthesis is often attributed to the reduction in chlorophyll content (Evans and Terashima, 1987; Fredeen et al., 1991). On the other hand, the excessive use of nitrogen (N) can lead to pollution of underground water resources and threatening of ecosystem. Additionally, the commercial fertilization is another aspect to establish appropriate fertilizer N recommendations for economic crop yields (Ryan et al., 2009).

There are several researches which declared safflower is sensitive to water (Quiroga et al., 2001; Bassil and Kaffka, 2002a,b; Istanbulluoglu et al., 2009) and also responsive to nitrogen fertilizer (Dordas and Sioulas, 2008). In this regard, little or no information was found on simultaneous implementation of PRD irrigation (VAFI), planting method and nitrogen levels on the agronomic behaviour of safflower in the literature. Therefore, the objective of this study was to investigate the effects of variable alternate furrow irrigation, nitrogen application level and in-furrow planting method on yield of safflower, water and nitrogen use efficiencies.

## 2. Materials and methods

### 2.1. Experimental site and agricultural operations

This study was conducted in the Experimental Research Station of the Agricultural College, Shiraz University in Iran during the 2012–2013 and 2013–2014 growing seasons. The station was located in Badjgah valley at 29°56′N latitude, 52°02′E longitude and 1810 m above mean sea level in a semi-arid area. There was a weather station located near the site for daily recording of the climatic parameters (rainfall, maximum and minimum temperatures, maximum and minimum relative humidity, wind velocity, sunshine hours, pan evaporation). The mean monthly climatic data for the two years of experiment have reported in Fig. 1. Rainfall events were mostly occurred from November to May for both years of study as 433 and 276 mm for first and second year, respectively. Higher depths of precipitation were observed in November, December and April of 2012–2013 and November and January of 2013–2014. The average of minimum temperature was below zero from December to February of both years and they were in lower values in second year of experiment due to having snowfalls in comparison with the first year. A drop in temperature was occurred in May of 2013–2014. The mean relative humidity was about 45% during the experiment and it was lower in second year compared with the first year of study. The soil and applied water characteristics presented in Table 1 according to methods detailed in Sparks et al. (1996) and the physical properties of soil (Table 1) were taken from the study of Barzegari (2012).

Safflower seed (local Isfahan cultivar) was planted at 25 and 10 October of 2012 and 2013, respectively in 36 water balance lysimeters with barley as the preceding crop. Each lysimeter dimensions is 1.5 m × 1.5 m × 1.1 m. A layer of 0.05 m gravel was placed at the bottom of each unit and soil layer with height of 0.90 m was placed on top of the gravel layer. In each lysimeter a drain tube conducts the drainage water from the bottom to individual sumps