Industrial Crops and Products 94 (2016) 589–595

Contents lists available at ScienceDirect

Industrial Crops and Products

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

Fertilizer improves seed and oil yield of safflower under tropical conditions

Marinez Carpiski Sampaio[a,*], Reginaldo Ferreira Santos[a], Doglas Bassegio[b], Edmar Soares de Vasconselos[c], Marcelo de Almeida Silva[b], Deonir Secco[a], Tiago Roque Benetoli da Silva[d]

[a] Universidade Estadual do Oeste do Paraná, UNIOESTE, Pós-graduação em Energia na Agricultura, CEP 85819-130, Bairro Faculdade, Cascavel, PR, Brazil
[b] Universidade Júlio de Mesquita Filho, UNESP, Departamento de Produção e Melhoramento Vegetal, UNESP, CEP 18603-970, Botucatu, SP, Brazil
[c] Universidade Estadual do Oeste do Paraná, UNIOESTE, Campus de Marechal Cândido Rondon – Centro de Ciências Agrárias, CEP 85960-000, Marechal Cândido Rondon, PR, Brazil
[d] Universidade Estadual de Maringá, UEM, Campus Avançado de Umuarama, Departamento de Ciências Agronômicas, CEP 87020-900, Maringá, PR, Brazil

ARTICLE INFO

Article history:
Received 11 May 2016
Received in revised form 4 August 2016
Accepted 17 September 2016

Keywords:
Carthamus tinctorius
Oil content
Oil yield
Oilseed

ABSTRACT

Safflower (*Carthamus tinctorius* L.) has gained importance as an oilseed crop due to its hardiness and oil, which can be used in the production of biofuels. Studying proper crop management methods is highly important for the development of safflower in Brazil, since applying fertilizers correctly and using the appropriate time are efficient ways to achieve higher yield. Thus, the objective of this study was to evaluate safflower yield components, seed yield and oil content in two growing seasons. Two experiments under dryland conditions were conducted in 2014 in Cascavel, PR, Brazil. A randomised complete block design with three replications was used. Five rates of NPK fertilizer were used (0, 200, 400, 600 and 800 kg ha^{-1} of N-P_2O_5-K_2O formula 4-14-8) in two growing seasons (autumn and winter). Even in a Rhodic Acrudox with high concentrations of P and K, the application of NPK fertilizer in the furrow improved seed yield and oil yield in the autumnal growing season. Safflower seed yield averaged 2068 and 3820 kg ha^{-1} in autumn and winter, respectively. The application of NPK fertilizer to safflower in the autumnal growing season significantly increased oil content (23.9%). The linear plateau model predicted increased yield with NPK rates <652 kg and <610 NPK ha^{-1}, resulting in seed yield and oil yield of approximately 4374 kg ha^{-1} and 1048 kg ha^{-1}, respectively. Safflower seems promising as an alternative oilseed crop for Southern Brazil when seeded in autumn with basic fertilization.

1. Introduction

Due to the global demand for bio-energy species, safflower (*Carthamus tinctorius* L.) stands out in Brazil as an alternative in the production of food and energy (Santos and Silva, 2015; Santos et al., 2015). Due to its hardiness and favorable agronomic characteristics, safflower can be an alternative for arid areas, since it can be used in crop rotation for being tolerant to drought and having a deep root system (Merrill et al., 2002; Lovelli et al., 2007; Hussain et al., 2015).

One of the most efficient ways for safflower to develop in tropical conditions with high efficiency is by applying fertilizers correctly. However, one needs to know the proper amount of fertilizer to apply and also when and how to perform the application in a way that meets the growing needs of the environment. In tropical soils, farmers usually rely on the short-term positive effects of chemical fertilizers to maintain high crop yield.

In Brazil, safflower is an option for the second crop (off-season). Due to shortage of time and irregular rainfall, farmers prefer to use little or no fertilizer at sowing, which can hinder the performance of crops (Bicudo et al., 2009). Safflower has nutritional requirements that are similar to those of wheat, but it can access deeper layers of nutrients due to its root system (Haghighati, 2010). All nutrients are important for the crop, however, studies indicate that basic fertilization with nitrogen (N) (Dordas and Sioulas, 2008; Yau and Ryan, 2010; El-Mohsen and Mahmoud, 2013), phosphorus (P) (Abbadi and Gerendas, 2011; Golzarfar et al., 2012) and potassium (K) (Hussien and Wuhaib, 2010; Palizdar et al., 2011; Abbasieh et al., 2013) has been highly efficient on safflower growth throughout the world. The effects of fertilization on safflower development

* Corresponding author.
E-mail address: mari_marinez@hotmail.com (M.C. Sampaio).

http://dx.doi.org/10.1016/j.indcrop.2016.09.041
0926-6690/

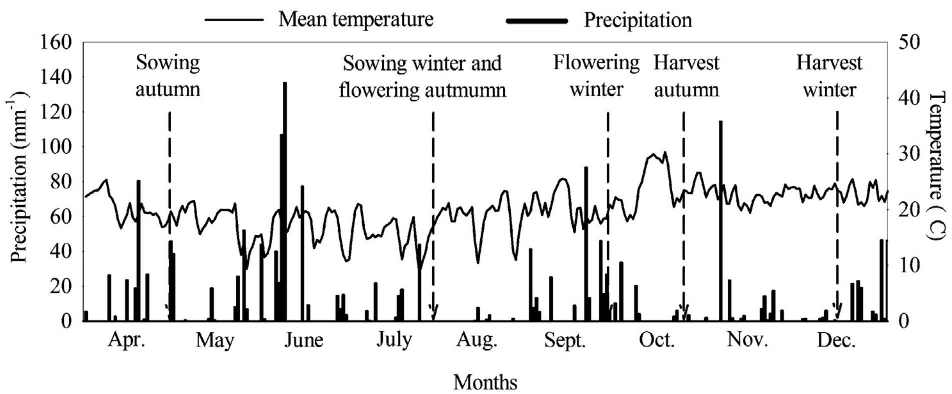

Fig. 1. Behavior of meteorological variables of precipitation and mean temperature during safflower cultivation seasons in Cascavel, PR, Brazil, in 2014.

Table 1
Soil chemical attributes (0–2 dm) in two growing seasons.

Soil	P (Mehlich 1) (mg dm^{-3})	pH ($CaCl_2$)	K	Ca	Mg	H + Al	CTC	V (%)
			cmol$_c$ dm^{-3}					
Autumn season	12.8	5.2	1.3	4.6	2.2	5.7	14.3	59
Winter season	19.4	5.4	0.8	4.5	2.8	5.2	13.3	61

have not been extensively studied, especially in Brazil, and existing studies are limited to controlled conditions that do not focus on oil production (Bonfim-Silva et al., 2015; Anicésio et al., 2015).

In addition to fertilization, time of sowing and the period of nutrient uptake directly interfere in safflower crop productivity (Mündel, 2004), since the plants can complete their growth cycle before the beginning of the dry months due to increased metabolic activity and rapid growth, which can change their phenotype to escape drought conditions (Sherrard and Maherali, 2006).

Safflower yield and oil components may be affected by many factors, such as genotype, ecology, morphology, physiology and fertilization (Cosge et al., 2007). The time of sowing has great impact on safflower oil properties (Senkal et al., 2016).

Several studies report that sowing safflower in autumn may lead to a significant increase in seed yield (Koutroubas et al., 2004; Yau, 2007; Golzarfar et al., 2012). Thus, due to the low fertility of tropical soils, low volume of scientific information on the subject and the hypothesis that safflower response to basic fertilization is dependent on sowing seasons, the aim of this study was to evaluate the effects of different fertilizer rates on yield components, seed yield and safflower oil content in two growing seasons.

2. Materials and methods

2.1. Location and climatic conditions

Two experiments were conducted in 2014 in Cascavel, Paraná State, Brazil, whose geographic coordinates are 24°56′40″S and 53°30′31″W with an average altitude of 715 m. The behavior of the meteorological variables of the experiment is shown in Fig. 1.

The soil of the experimental area was classified as Rhodic Acrudox (Soil Survey Staff, 2014). The experimental area had been managed in a no-tillage system for over 20 years, with corn or soybean crops in the summer and oats or wheat crops in the fall/winter seasons. Soil properties are presented in Table 1.

2.2. Experimental set-up

The first growing season started with sowing on April 30, 2014 (autumn), and the second one on July 30, 2014 (winter). In the first season, safflower was sown after soybean. Sowing in winter at low temperatures may cause negative effects on plant growth and on the seed filling stage.

The safflower genotype IAPAR was sown manually, leaving 10 plants per meter after thinning (222 thousand plants per ha).

2.3. Treatments and experimental design

A randomised complete block design with three replications was used. Each block was divided into five plots, to which five rates of N-P_2O_5-K_2O (4-14-8) fertilizer were applied (0, 200, 400, 600 and 800 kg ha^{-1}). Each plot consisted of four rows measuring 4 m long, with spacing of 0.45 m between rows.

2.4. Traits evaluated

When the flowering stage reached 50%, at 80 and 60 days after emergence in the autumn season and winter season, respectively, plant height was determined by measuring the distance between the soil level and the plant apex with a graduated tape. Six random plants were measured within each plot. The number of branches and capitula per plant was also determined when flowering reached 50% from six random plants from each plot. Stem diameter was also determined, by measuring the basal region of the stem with a digital caliper. The safflower plants were separated into stem, branches, roots and capitula in the flowering stage and dry matter was determined by drying at 65 °C until constant weight was obtained.

Harvest took place after 160 and 140 days after emergence in the autumn and winter seasons, respectively, and seed yield was determined. Plants were collected from a linear meter of each plot and manual threshing and cleaning of the seeds were performed. Values were expressed in kg ha^{-1}. The 1000-seed weight was determined by counting sub-samples of 100 seeds per plot. The samples were weighed on a precision scale to two decimal places. Moisture content was determined gravimetrically by drying a subsample for 24 h at 105 °C and corrected to 12%. The 1000-seed weight was determined in accordance with the Rules for Seed Analysis (Brasil, 2009).

Oil content was determined by TD-NMR in an SLK-SG-200 spectrometer (Spin Lock Magnetic Resonance Solutions, Malagueño,