industrial crops and products 27 (2008) 75–85

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Safflower yield, chlorophyll content, photosynthesis, and water use efficiency response to nitrogen fertilization under rainfed conditions

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ARTICLE INFO

Article history:
Received 7 June 2007
Received in revised form
29 July 2007
Accepted 30 July 2007

Keywords:
Safflower
Assimilation rate
Nitrogen
Yield components

ABSTRACT

Safflower (*Carthamus tinctorius* L.) is a deep-rooted crop which can tolerate water stress and can be grown in rotation with other crop species. Nitrogen is very important for the growth and yield of safflower, however, the effect of N level on chlorophyll content, assimilation rate, transpiration rate, stomatal conductance, substomatal CO_2 concentration, and water use efficiency (WUE) have not been determined. A 2-year field study was conducted with the objective to determine the effect of N fertilization on yield, yield components, chlorophyll content, photosynthetic characteristics, and WUE of safflower grown under rainfed conditions. Three rates of N were used (0, 100, and 200 kg N ha^{-1}) and two hybrids (CW9048 and CW9050). N fertilization increased seed yield by an average of 19%, the seed weight per plant by 60%, the seed weight per head by 18%, the number of heads per plant by 32%, and the number of seeds per plant by 41% compared with the control. N level also affected chlorophyll content, N concentration at anthesis, protein, and oil yield. N application increased assimilation rate by an average of 51%, stomatal conductance of water vapour by an average of 27%, and WUE by an average of 60% over the 2 years of the study when compared to the control. The present study indicates that N fertilization can affect yield, yield components, photosynthetic efficiency, and physiology of safflower under rainfed conditions.

1. Introduction

Safflower is an oilseed crop which is grown throughout the semiarid region of the temperate climates in many areas of the world for use as vegetable and industrial oils, spices, and birdfeed (Weiss, 2000; Johnston et al., 2002). However, these regions are dominated by winter wheat (*Triticum aestivum* L. and *Triticum turgidum* sub. *durum*) and the acceptance and production of another crop requires that both have an important agronomic benefit to the cropping system and also improves the farmers' economic position (Johnston et al., 2002). Given that most oilseed crops have an indeterminate growth habit, adaptation is influenced by tolerance to high temperature and drought stress and by crop management such as nitrogen (N) fertilization to take advantage of optimum environmental conditions for flowering and seed fill (Kaffka and Kearney, 1998; Weiss, 2000).

The importance of oil crops such as safflower has increased in recent years, especially with the interest in the production of biofuels. Safflower is a crop species which is well adapted to dry land conditions (Kaffka and Kearney, 1998; Weiss, 2000). Moreover, safflower is a deep-rooted annual crop which has

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doi:10.1016/j.indcrop.2007.07.020

the ability to meet its water requirements by exploring a larger volume of soil than most crops (Knowles, 1958). N fertilization management is important to optimize production and oil content of safflower (Kaffka and Kearney, 1998; Bassil et al., 2002). However, research on the effect of N fertilization on safflower yield, and physiology under rainfed conditions is limited.

Nitrogen fertilization of safflower resulted in different responses as observed by Nasr et al. (1978). Those authors found that 75 kg N ha^{-1} was adequate for optimum seed, oil, and protein yield. While higher N rates (up to 600 kg N ha^{-1}) did not improve yield and yield components. Also, Gilbert and Tucker (1967) reported that up to 168 kg N ha^{-1} increased yield by increasing the number of heads per plant. Jones and Tucker (1968) found that high rates of N were effective in increasing seed yield when irrigation was included. Haby et al. (1982) found that 275 kg of N ha^{-1} from applied fertilizer, and expected mineralization from organic matter, was sufficient for higher yields of irrigated safflower. However, in other studies there was no yield increase with N fertilization (Strasil and Vorlicek, 2002). In California it is recommended 110–170 kg N ha^{-1} in irrigated safflower (Werkhoven et al., 1968; Kaffka and Kearney, 1998). The discrepancy found in the fertilizer N requirement for safflower may be related to the residual soil N, different cultivars that were used, different climatic conditions, and the effect of irrigation on crop growth and response to N fertilization. Varying N fertilizer recommendations have been proposed for irrigated safflower but data are unavailable for the N requirements of safflower for high yields under rainfed conditions.

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. Under N deficiency, growth is inhibited and shoot–root ratio is decreased (Steer and Harrigan, 1986). In addition, N deficiency reduces the radiation interception, radiation use efficiency, dry matter partitioning to reproductive organs, leaf area index, protein content of the plant, and the seed (Marschner, 1995). Moreover, 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).

Nitrogen level affects the physiology of crop plants, however, there are no reports, to our knowledge, on the effect of N on photosynthesis of safflower. High N fertilization can increase photosynthesis and plant growth on several crops (Evans, 1989; Huber et al., 1989; Cechin and Fumis, 2004). Up to 75% of leaf N is found in chloroplasts and most of it is part of ribulose bisphosphate carboxylase (Rubisco) alone. Under low N level the lower photosynthesis is often attributed to the reduction in chlorophyll content and Rubisco activity (Evans and Terashima, 1987; Fredeen et al., 1991). In some species (wheat (*Triticum aestivum* L.), beans (*Phaseulus vulgaris* L.)) stomatal conductance (g_s) is increased with N (Shimshi, 1970; Shangguan, 1997). In others such as cotton (*Gossypium hirsutum* L.) there was a negative response (Radin et al., 1988). Sugiharto et al. (1990) found positive correlation between the photosynthetic capacity of leaves and leaf nitrogen concentration.

Water use efficiency (WUE) indicates the performance of a crop which is grown under any environmental constraint (Howell, 2001). Crop management practices such as N fertilization can influence both the amount of water extracted by a crop and crop growth, and consequently can affect WUE. Optimal N enhances rooting depth as well as total root mass, hence, alleviating drought effects where deep sub-soil moisture is present provided there is water deficiency in the soil and there are no physical constraints to rooting. However, the effects of N on crop water use are expected to vary with the availability of soil moisture. In addition, it is not known how N fertilization can affect WUE by safflower under rainfed conditions. Under rainfed and dry conditions N fertilization is not as effective in increasing crop yields as in irrigated crops because the plants cannot take up N from the soil (Marschner, 1995; Fageria and Baligar, 2005).

The effect of N fertilization on safflower has not been extensively studied especially under rainfed conditions. In addition, there is not enough information about the effect of the application of different levels of N on yield, yield components, seed quality characteristics, chlorophyll content, gas exchange characteristics, and instantaneous water use efficiency (WUE). The main hypothesis that was tested was whether N fertilization can affect yield, yield components, chlorophyll content, gas exchange characteristics, and instantaneous WUE of safflower under rainfed conditions.

2. Materials and methods

2.1. *Experimental site and experimental design*

The experiment was carried out at the experimental farm of the Aristotle University of Thessaloniki, Greece during the 2003–2004 and 2004–2005 growing seasons. The farm is located in Northern Greece (22°59′6.17″E, 40°32′9.32″N). Two different hybrids were used CW9048 and CW9050, which are high yielding hybrids with high oil content. The soil type where the experiment took place was a calcareous sandy loam (Entisols, Orthents, Typic Xerorthent) with wheat (*Triticum turgidum* subsp. *durum* L.) as the preceding crop (Table 1). The soil characteristics were determined according to methods detailed in Sparks et al. (1996). Weather data (rainfall, maximum and minimum temperatures) were recorded daily and are reported as mean monthly data for the 2 years that the study was conducted (Table 2).

The experimental design was split plot with the hybrids as the main plots and as the subplots the fertilizer treatments with three different N levels and five replications. The experimental plots were 3 m × 5 m and consisted of five rows 0.5 m apart. The treatments were 0, 100, and 200 kg N ha^{-1} applied preplant in the form of $(NH_4)_2SO_4$ (20.5–0–0). Also P and K were applied at a rate of 60 kg P_2O_5 ha^{-1} and 100 kg K_2O ha^{-1} preplant in the form of superphosphate and K_2SO_4, respectively, and were incorporated in the soil before sowing. Seeds were hand-planted on 18 December 2003 and 10 Decem-