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Yield and yield components of saffron under different cropping systems

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ABSTRACT

This study was conducted to evaluate yield and yield components of saffron (*Crocus sativus* L.) in response to (i) production system (PS) (irrigated vs. non-irrigated); (ii) corm size (CS) (medium −2.25 to 3 cm diameter vs. small corms <2.25 cm diameter); (iii) planting depth (PD) (10 cm vs. 20 cm); and iv) planting density (PDEN) (51 corms m^{-2} vs. 69 corms m^{-2}).

This fully replicated multifactorial design was started in August 2000, and carried through November 2003, when the fourth saffron harvest took place. The total and average fresh weight of stigmas, and the number of flowers were measured at each harvest.

Results indicate that three of the four factors tested (PS, CS and PD) had a significant effect on the quantitative yield during the two most productive flowering years (2001 and 2002) and on the total flowering. Irrigated cultivation, medium size corms and 10 cm planting depth had the greatest effect in increasing the quantitative production of saffron.

Yield was also affected by planting density in contrasting ways. Whereas at high PDEN yield increased per unit of surface, at low PDEN, yield increased with respect to the initial number of corms planted.

The fresh weight of stigmas per flower yield component, an important aspect that determines the quality of the spice, was enhanced when corms were planted at 20 cm depth and when irrigation was applied to the crop.

1. Introduction

Saffron, one of the most costly of plant product, and the most expensive spice by far, is produced by drying the long orange-red stigmas of the saffron crocus (*Crocus sativus* L., *Iridaceae*) (Rees, 1988), an autumn-flowering geophyte extensively grown in the Near East and the Mediterranean basin since the Late Bronze Age (Zohary and Hopf, 1994; Negbi, 1999). This species is a sterile triploid that produced annual replacement corms and is propagated solely from these corms (Botella et al., 2002). The saffron plant is characterized by biological cycle with a long pause in the summer and an active growth period in the autumn (also the period during which the flowers blossom) (Botella et al., 2002; Molina et al., 2005). Corms are dormant (leafless) in summer although flower differentiation occurs at this time. Apex differentiation progresses further in May to July, during which time intensive laying down of generative organs occurs. The flowering of the maternal corm coincides with the formation of daughter corms during November; pale lilac flowers appear in autumn and may occur before, at the same time as, or after, leaf appearance (subhysteranthous behaviour). The flowers are made up of six petals from which a scarlet stigma, which subdivides into three branches, each of which terminates in a tube. The stigma is connected to the ovary by a long style. Vegetative growth of the leaves and roots of the maternal corm coincides with the slow development of the stem-apex of the daughter corm (December to February). On the order hand, the gradual senescence of leaves, roots and the maternal corm coincides with stem-apex transition to generative development (March). Intensive differentiation of flower organs occurs when daughter corms are "dormant" (June to August). Benschop (1993), Molina et al. (2005) and Gresta et al. (2009) noted that temperature is the most important environmental factor controlling growth and flowering in *Crocus* species. Traditionally, saffron fields are lifted when flower and spice production has declined, because of overcrowding and associated competition for water and nutrients, or increased disease problems (Sampathu et al., 1984; Rees, 1988). The lifespan of a saffron crocus crop, with good nutrition and management, is currently unknown, but in a Mediterranean environment indicated crops can produce well for at least 4 years (following lows yields in the year of establishment) (Tammaro, 1999).

Commercial saffron is a natural colouring and aromatic substances derived from fresh stigmas after appropriate drying. Crocin is responsible for the colour of saffron, whereas picrocrocin and safranal are responsible for its bitter taste and aroma. In early times, saffron had a wide variety of uses in Europe and the East, e.g. drug,

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textile dye, incense, cosmetics and food purposes (Ingram, 1969). The Roman believed it would ward off drunkenness if added to wine or worn as a chaplet on the head (Palmer, 1983). There is also a long tradition of saffron use in the traditional medicine of many cultures (Abdullaev, 1993; Ma et al., 2001). Therapeutic properties credited to the plant, are small doses, were sedative, expectorant, stimulant, aphrodisiac, antipasmodic and more, although there is no evidence of its efficacy and saffron no longer has any medicinal importance. Recently, there has been increasing interest in the biological effects of components of saffron and their potential medical applications, particularly those based on their cytotoxic, anticarcinogenic and antitumor properties (Abdullaev and Frenkel, 1999; Fernández Pérez and Escribano Martínez, 2000). Today in European kitchen, saffron is widely used as a condiment in a variety of food preparations such a rice dishes, pastas, soups, cakes, saffron bread and numerous sweets. Saffron is also used in the food industry to dye and perfume rice, pastas, candies, dairy products and alcoholic beverages, as well as pharmaceutical products (Pérez, 1995).

Saffron is currently being cultivated in Marocco, Spain, India, Pakistan, Turkey, Italy, Switzerland, Greece and Central Asia. While the world's total annual saffron production is estimated at 205 tons per year, Iran with more than 47,000 ha of land under saffron cultivation, is said to produce 80% of this total (Ehsanzadoh et al., 2004). Khorasan province alone accounts for 46,000 ha and 137 tons per year of the above-mentioned total. There was a marked reduction in saffron production during the last decades in some of the traditional producing countries, as Spain, Italy and Greece (European Saffron White Book, 2006). This reduction in production has been most marked in Spain, a country rightly, considered in the near past as the leading producing country in the world, where the land area devoted to saffron cultivation fell from 13,000 ha in 1914 to under 6000 ha in 1972, and to 116 ha in 2006 (Camarena and San Juán, 2008). This cultivated surface area reduced was accompanied by a parallel reduction in production from over 124 tons in 1914 to 60 tons in 1972, and to 1.33 tons in 2006. However, Spanish trade balance had a significant surplus, around 5 million euros, and reached at 8.7 million in 2005. In 2006, over 58 tons saffron valued at 15 million dollars were imported, mainly from Iran, and around 55 tons saffron valued at 22.6 million dollars were exported (Datacomex, 2008).

Saffron trade is regulated by several quality standards, which take into account several parameters, such as the stigmas colouring power, style length and flower remains (NCCEA, 1999; ISO, 2003). The quality of the saffron from Castilla-La Mancha is worldwide recognized and, it is currently protected and sponsored by the official source name "Azafrán de la Mancha" (DOCM, 1998).

Castilla-La Mancha produces 93% of the Spanish saffron, being 94% the national cultivated saffron area contained in the region. The province of Albacete is the most important saffron producer within this region, producing 83% of the total cultivated surface area and about 82% of Castilla-La Mancha's total saffron production (MAPA, 2007). Overall, the cultivation of saffron in Spain is no longer a fruitful economic enterprise; on the contrary, it is maintained just by a few family farming operations.

There are several problems related to the lack of skilled labour: the aging of local population, the continuous and generalized town abandonment and the strong demand for labour highly concentrated in time due to harvesting by hand for 2–3 weeks (0.25–3.5 million flowers per hectare, depending on the planting productivity) (de Juan et al., 2003). Moreover, the technology of saffron production has not changed from the ancient times (de Juan et al., 2003). Increasing labour costs have turned saffron production unprofitable despite its high market price.

Due to all the reasons stated above, updating saffron farming practices becomes an imperative (Pérez, 1995; Rubio, 1997; European Saffron White Book, 2006). Adequate farming techniques will allow producers, using a high quality plant material, to benefit from enhanced yields, to reduce labour costs and to increase profits.

The aim of this study is to investigate agricultural practices in an improved saffron yield by determining the optimum levels of the following agronomic factors: production system (irrigated vs. non-irrigated), corm size, planting depth, and planting density.

2. Materials and methods

The trial was carried out at the experimental fields of the School of Agricultural Engineering of Albacete, Spain (01°52′45″W long; 38°57′30″N lat; altitude 700 m), from 7 August 2000, when the corms were planted, to 19 November 2003, once the fourth saffron harvest had finished. The climate of the area is classified as Warm Mediterranean, with a "Cool Oats" winter, a "Maize" summer, thermal regime "Warm Temperate" and humidity regime "Dry Mediterranean" (Papadakis, 1961). The soil of the plots, where the trial was conducted, is catalogued as Aridisols, Calcids, Haplocalcids, Xeric Haplocalcids (USDA, 1999).

The experiment was laid out in balanced factorial design with five replications. The following factors and levels were tested: (i) production system (PS), i.e. non-irrigated and irrigated cultivation; (ii) corm size at planting (CS), i.e. medium corms (2.25–3 cm diameter) and small corms (<2.25 cm diameter); (iii) planting depth (PD), i.e. 10 and 20 cm; (iv) and planting density (PDEN), i.e. 51 and 69 corms m^{-2}. Elemental replications area was 1 m^2, with three rows 0.33 m apart.

With regard to the irrigated production system, water was applied following two criteria. Firstly, no water was applied between leaf withering and approximately a month before the first buds of the replacement corms had grown. Secondly, irrigation was scheduled both in August and September, to favor the emergence of dormancy of corms, and in March and April, in order to improve the replacement corm formation. Table 1 shows the monthly accumulated rainfall values and the irrigation regime scheduled for this production system.

Flowers were harvested daily from each replication during the flowering period. Afterwards, they were taken to the laboratory, where stigmas were separated from the flowers by hand. Then, in order to obtain the quantitative yield of the crop and its components, the number of flowers (NF) harvested and the total fresh weight of collected stigmas (FWS) were recorded. Thus, NF and FWS both per planted corm, and per square meter, and the fresh weight of stigmas per flower in 2001, 2002, 2003, and in the whole period (2001–2003), were estimated. The analysis of the fresh weight of stigmas per flower helps us conclude whether or not the studied factors have an influence on the average size of the stigmas and, therefore, the qualitative yield of this spice.

Data has been treated by analysis of variance, which was performed using the SPSS version 7.5.2S statistical software package (SPSS Inc., Chicago, IL, USA). It has been set 5% to be the maximum acceptable limit to be considered a significant result.

3. Results

3.1. Quantitative yield and yield component related to the number of flowers

The quantitative production of flowers in 2000 was very scarce, that is the reason its mean values are not shown in Figs. 1–6. Still, CS and PDEN and the interaction of PD × PDEN are statistically significant for the number of flowers per square meter and the number of flowers per planted corms, i.e. the variables that had to do with the number of flowers. However, the total fresh weight of stigmas per