Agricultural Water Management 195 (2018) 114–119

Contents lists available at ScienceDirect

Agricultural Water Management

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

Research Paper

The role of superabsorbent hydrogel in bean crop cultivation under deficit irrigation conditions: A case-study in Southern Italy

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ARTICLE INFO

Article history:
Received 10 April 2017
Received in revised form 3 October 2017
Accepted 10 October 2017

Keywords:
Water deficit
Irrigation water use efficiency
Superabsorbent polymers
Time domain reflectometry monitoring
Bean crop

ABSTRACT

This study was planned for investigating the role of biodegradable cellulose-based superabsorbent polymers in the management of water irrigation systems in bean crop cultivations in areas affected by water scarcity. The paper focused the attention on the bean crop (*Phaseolus vulgaris* L.) cultivated in the Mediterranean region during the summer seasons characterised by optimal thermal conditions, but with a systematic absence of water for irrigation due to the low level of precipitations. We analysed the performance and the role of cellulose-based superabsorbent in the irrigation systems where it is necessary to ensure a continuous and adequate level of soil moisture. Based on crop evapotranspiration demand calculated from the analysis of weather data, deficits and full-drip irrigation strategies were applied. Full and deficit irrigation treatments received 100, 70 and 50% of evapotranspiration demand, respectively. In addition, given amounts of superabsorbent polymer granules (SAPs) were mixed with the soil, in particular, 0, 5 and 10 g were added to the soil for full and deficit irrigation treatments.This study highlights a significant difference between the treatments, the combination of deficit irrigation and soil amendment hydrogel leads to a maximization of the crop water productivity index. In fact, the highest water use efficiency indexes were obtained with soil amendment hydrogel strategies under water deficit irrigation conditions. Our findings could be useful to optimize the consume of water resources in bean crop cultivations in the Mediterranean regions.

1. Introduction

To date, the water scarcity has strongly required new strategies for designing efficient irrigation systems in agriculture. The water management cycle could be improved through measures to increase the soil moisture retention capacity and the water use efficiency (Iglesias and Garrote, 2015, 2009). For example in Consoli et al. (2017); Yazar et al. (2009), the effect of partial root zone drying (PRD) and deficit irrigation (DI) strategies on the yield and water use efficiency of the drip-irrigated orange trees and corn under the Mediterranean climatic conditions were highlighted. Nowadays drip irrigation is extremely widespread all over the world for its capability of providing small quantities of water, if compared to other irrigation systems (Bozkurt et al., 2006; Yaghi et al., 2013), directly and slowlyin the nearby of the plant roots.

Besides drip irrigation used as a strategy to increase irrigation efficiency (Biswas et al., 2015), the employment of superabsorbent polymers, which can retain water and thus increase the capacity of soil to store and release water under irrigation deficiency preserving the plant growth, should be taken into account.

The quality of irrigation plays an important role in the bean crop production in the Mediterranean area, the common bean (*Phaseolus vulgaris L.*) is the most important worldwide legume for human consumption because it is a source of proteins (Jones 1999; Builes et al., 2011). This cultivation requires a high temperature and appropriate soil moisture for a good harvest.

The thermal conditions favorable for plants occur in the summer season, when the rains are not abundant and able to guarantee a good level of soil moisture.

Drip irrigation technique provides water at a slow application rate only to the plant root zone, thus, smaller quantities of water are used to the utmost efficiency (Allen, 1998; Simsek et al., 2011). This is very important because water is not lost through drainage but after irrigation the superabsorbent granules, applied in the soil around the root zone, absorb the water by swelling and then release it slowly through a diffusive mechanism as the soil dries out (Cannazza et al., 2014; Demitri et al., 2013).

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https://doi.org/10.1016/j.agwat.2017.10.008
0378-3774/

The total available soil water in the root zone (TAW) is the amount of water that a crop can extract from its root zone, calculated from the equation:

$$TAW = AWC * Drz \quad (1)$$

where AWC is the available water capacity of the root zone (mm of water per mm of soil), and Drz is the depth of root zone that changes with development phases (mm).

In irrigation practice, a management allowed the depletion (MAD) of the TAW must be specified, because water stress occurs before soil water is depleted up to the welting point (PWP), thus only a percentage of TAW is allowed to be consumed. This TAW fraction is called readily available soil water in the root zone (RAW) and can be expressed in terms of depth of water (mm), using the following equation:

$$RAW = MAD * TAW \quad (2)$$

where MAD is the amount of water to be removed from plants before irrigation so that undesirable crop water stress does not occur. As reported by Allen, (1998), for dry bean crop the soil water depletion should not exceed 45 percent of the total soil water available. Almost the whole water uptake by the plants from the soil is lost as evapotranspiration (ET), and the measurement of the crop evapotranspiration (ETc) on a daily scale, and for the whole vegetative cycle, is equal to the water requirement of the given crop (Allen, 1998; Katerji and Rana, 2008). In this work, in order to assess the irrigation efficiency and effectiveness and exploit the rain potential to the full, an innovative class of biodegradable cellulose–based superabsorbent hydrogel was used as a water reservoir in the cultivation of bean crop in the Mediterranean area. In particular, the superabsorbent hydrogels used are a particular class of totally biodegradable and biocompatible macromolecular gels which can be mixed with the soil in the proximity of plant roots. These granules mixed with the soil in given amounts absorb water during irrigation, then, as the soil gets dry, they release water slowly and, in this way, water is not lost through drainage or evaporation because it is retained by superabsorbent hydrogel (Cannazza et al., 2014; Demitri et al., 2013; Sannino and Nicolais, 2005; Sannino et al., 2009). In arid areas during dry seasons, this function is extremely important as the hydrogel holds soil moisture to be returned when required by the plant root system. In addition, as reported in Cannazza et al. (2014), when the hydrogel granules swell, soil porosity increases providing the plant root zone with a better oxygenation. This paper deals with the influences of SAP in combination with drip irrigation in deficit irrigation conditions. To this purpose, SAP was employed in a cultivation of a local population of dry bean in order to evaluate the possibility to reduce water irrigation, but at the same time ensuring a sufficient water supply to the plant roots when needed. Therefore, as reported by Benlhabib et al. (2014), a proper agricultural management, with the selection of appropriate crops and varieties of crops as well as the use of technologies in water management can affect the productivity and sustainability of cropping systems in a positive way. In fact, the local population of dry bean used in this study, was little susceptible to water stress in a previous experimental test under water deficit conditions in the same area (Satriani et al., 2015), thus confirming that the decision to use local varieties can be a strategy towards a reduction in water consumption in agriculture

2. Materials and methods

2.1. Experimental details

A field experiment was conducted at the experimental agricultural Farm "Pantano of Pignola" (40°33′ 31.34″N and 15°45′ 31.66″E, and 400 m above sea level) of ALSIA (Agency for the Agricultural Development and Innovation of Lucania), Basilicata Region, Southern Italy (Fig. 1).

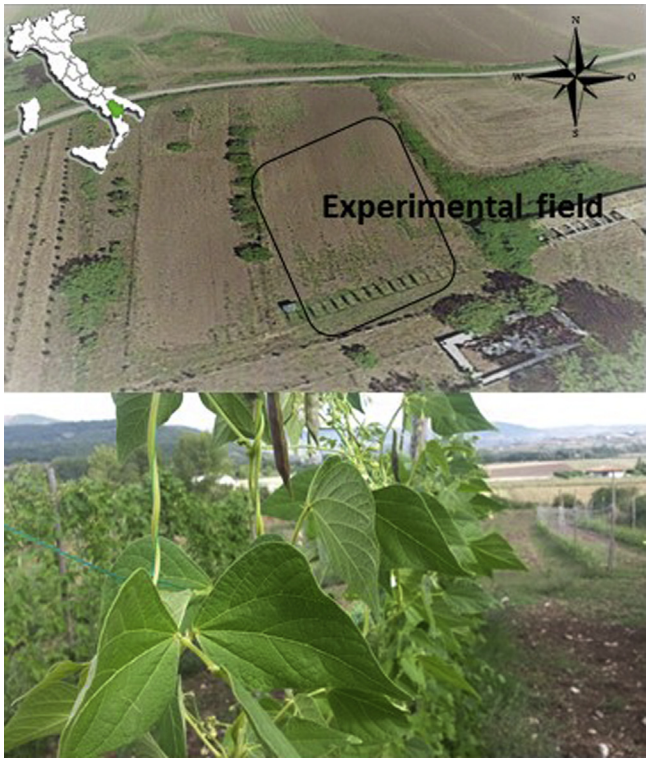

Fig. 1. Field experiment location (modified from GoogleHearth 2015).

Only a bean cultivar was chosen for field testing in order to eliminate differences in yield response between cultivars and assess the SAP treatment in optimal and stress irrigation conditions.

In fact, during the growing season between the months of June and September, the field study was carried out for a local population dry bean (*Phaseolus vulgaris* L) named "*fagiolo rosso scritto*". The bean crop in the research area, characterised by a Mediterranean climate with dry summers, is possible only with irrigation because the amount of rainfall is not often sufficient to satisfy the need for water supply for irrigation.

Wet sieving has been used to separate different particle size fractions into sediments in the soil samples collected within the first 60 cm of soil profile and by the granulometric analysis the soil was classified as silty–clay–loam (ASTM D422-63, 2007). Table 1 reports the soil physical characteristics.

The soil chemical analysis was carried out based on the methods of soil chemical and physical analysis as described in the Italian Official Gazette N. 248 of 21.10.1999.

For the first 60 cm of soil layer, soil organic matter was 34.9 g/kg, alkaline reaction with a pH of 7.6, total nitrogen was 2.1 g/kg, available P and K were 53.0 and 317.0 mg/kg, respectively.

For the experiment at hand, the seeds were hand sown on May 29, 2015 on rows 2 m long and 1.5 m apart. A drip irrigation system was installed before sowing and placed at each row with drippers spaced every 20 cm, one flow meter has recorded the amount of water applied in each irrigation event.

After sowing an irrigation water equal to 20 mm was given and after the emergence, plants were thinned to secure one plant every 20 cm within the rows (10 plants for row) and, in correspondence of each dripper a single bean plant was placed.

In order to optimize the use of irrigation water and especially reduce the consumption of water, after the emergence cellulose-