Soil irrigation management: the effect on production and water productivity in the marigold[1]

Manejo de irrigação via solo: efeito na produção e produtividade da água da calêndula

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ABSTRACT - The management of water resources in irrigated agriculture is a basic method of guaranteeing water use efficiency in agricultural crops. The aim of this study was to evaluate production and water productivity in the marigold under different soil-water matric potentials and at different stages of development. The experiment was conducted in pots in a protected environment. The experimental design was of randomised blocks with six treatments (-10, -15, -30, -40, -50 and -60 kPa) and 4 replications, giving a total of 24 experimental units for each individual trial, which were represented by the development stage of the marigold. Tensiometers were used to monitor the matric potential of the soil, with readings taken daily. The production and dry weight of the floral capitula were evaluated together with water productivity. The data were submitted to regression analysis. It was found that the variations in irrigation depth throughout the growth cycle and during the reproductive phase of the marigold gave significant results for the variables under analysis. For the complete cycle, the production of floral capitula was seen to be greater at a matric potential of -10 kPa, a higher value than the pressure at field capacity (-30 kPa). However, the greatest water productivity was obtained at a matric potential of -32.74 kPa.

Keywords: Medicinal plant. *Marigold officinalis* L.. Water requirement. Water deficit. Water productivity.

RESUMO - A gestão de recursos hídricos na agricultura irrigada é uma alternativa fundamental para garantir a eficiência do uso água para as culturas agrícolas. O objetivo do trabalho foi avaliar a produção da calêndula e a produtividade da água sob diferentes potenciais matriciais de água no solo em diferentes fases de desenvolvimento. O experimento foi conduzido em ambiente protegido e em vasos. O delineamento experimental foi em blocos ao acaso com 6 tratamentos (-10, -15, -30, -40, -50 e -60 kPa) e 4 repetições, totalizando 24 unidades experimentais para cada ensaio isolado, representado pela fase de desenvolvimento da calêndula. Para monitorar o potencial matricial de água no solo foram utilizados tensiômetros e as leituras foram efetuadas diariamente. Foi avaliado a produção e massa seca de capítulos florais, e a produtividade da água. Os dados foram submetidos a análise de regressão. Observou-se que a variação da lâmina de irrigação durante todo ciclo de cultivo e na fase reprodutiva da calêndula resultou em resultados significativos para as variáveis analisadas. Para o ciclo completo verificou-se que a produção de capítulos florais foi maior para o potencial matricial de -10 kPa, valor superior à tensão n capacidade de campo (-30 kPa). No entanto, a maior produtividade da água foi obtida para o potencial matricial de -32,74 kPa.

Palavras-chave: Planta medicinal. *Calendula officinalis* L.. Demanda hídrica. Déficit hídrico. Produtividade da água.

INTRODUCTION

Agriculture is an activity that results in the greatest demand for available water resources, around 70% of world consumption. In this global context, it becomes important not only to increase production, but also to optimise agricultural areas and use the water resources efficiently. An increase in water productivity, defined as the ratio between the production and supply of water during the growth cycle (VAN ITTERSUM *et al*., 2013), is highly necessary for the sustainability of agricultural systems, especially in the face of global climate change.

Faced with climate change and with irregular rainfall distribution in many regions of Brazil, it is important to develop techniques to reduce the impact on agricultural development (BELTRÃO JÚNIOR *et al*., 2017; CUNHA; COELHO; FÉRES, 2014). In order to optimise the use of water in irrigated agriculture, it is essential to promote techniques of efficient irrigation management, which would maximise production, favour lesser input and improve the sustainability of the water resources (BORGHETTI *et al*., 2017; BUTARRO *et al*., 2015).

Monitoring soil water is a technique that allows the need for irrigation to be assessed, and that can promote efficient use of the water resources. The soil water status can be obtained by determining the water storage capacity and the matric potential of the soil (NOLZ *et al*., 2016). The matric potential is generally determined with the use of tensiometers. This equipment is inexpensive, easy to handle, is not dependent on the texture or density of the soil, and allows the water conditions to be monitored (CONTRERAS *et al*., 2017). Although it has many advantages, taking readings under the conditions of a water deficit is limited, as the operating range of the tensiometer is between 0 and -75 kPa.

Given this scenario and the management of irrigated agriculture, the cultivation of medicinal plants becomes important. Although there are few agronomical studies on the water requirements and nutritional demand of these plants, their productive potential in small agricultural areas must be considered (RIBEIRO *et al*., 2014).

With the production of medicinal plants, Brazil generates around USD 400 million on the herbal medicine market, equivalent to 6.7% of the sale of medicines in the country (CORRÊA JUNIOR; SCHEFFER, 2013; RODRIGUES, 2016). Borba, Harter-Marques and Citadini-Zanette (2012) point out that the production of medicinal plants has become a promising alternative for family farming, one that is expanding, and that has high economic potential due to the demand for herbal medicines.

Considering the typical economics of using medicinal plants in the country, the marigold stands out as a species with high potential for the herbal and cosmetic industry (ALEMAN; MARQUES, 2016). Yadegari and Shakerian (2014) point out that the economically important part of the marigold is the floral capitula, which have flavonoids, carotenoids and essential oils as active compounds.

Marques, Bortolo and Santos (2011) concluded that deficit irrigation management and the use of supplementary irrigation during pre-flowering allowed maximum productivity of the floral capitula, the main economic part of the marigold. Elhindi (2012) found that the use of a drip irrigation system can favour growth, production and quality in the marigold. Controlled deficit irrigation can be an alternative for increasing the production of floral capitula and the synthesis of economically important secondary metabolites. Therefore, considering the need to advance agronomic research on the irrigated cultivation of medicinal plants, the aim of this study was to evaluate marigold production and water productivity under irrigation management at different soil-water matric potentials.

MATERIAL AND METHODS

The experiment was conducted in pots containing 8.5 kg of soil, in a protected environment at the Department of Biosystems Engineering of the Luiz de Queiroz College of Agriculture at the University of São Paulo (ESALQ/USP) in the district of Piracicaba. According to the Köppen international classification, the climate in the region is type Aw, tropical with dry winters (ALVARES *et al*., 2013), a mean temperature of less than 18 °C during the coldest month, and humid summers with mean temperatures greater than 22 °C during the hottest month. The average temperature in the protected environment was 21.1 °C.

To obtain the marigold seedlings (*Marigold officinalis* L.), commercial seeds of the Bonina Sortida da Isla® cultivar were used. The seedlings were produced in expanded polystyrene trays of 200 cells containing Plantamax® commercial substrate. Seedling formation lasted until 34 days after sowing (DAS).

Three individual experiments were carried out in a randomised block design. The three experiments were characterised by the development stage of the marigold: the vegetative phase (61 days after transplanting the seedlings), the budding/flowering phase (a period of 57 days after the start of flowering), and the complete cycle (118 days from transplanting the seedlings). The treatments under test were based on the following soil water matric potentials: -10, -15, -30, -40, -50 and 60

Table 1 - Total irrigation depth applied for each matric potential under test at different stages of development in the marigold

Matric potential (kPa)	Total irrigation depth (mm)		
	Complete cycle	Vegetative phase	Reproductive phase
-10	252.11	186.71	150.33
-15	219.18	150.70	137.09
-30	186.45	98.32	135.05
-40	163.54	79.21	124.12
-50	153.62	53.05	122.97
-60	140.63	41.71	112.04

kPa. For the experiments at the vegetative and budding/flowering phase, the soil was maintained at a potential of -30 kPa whenever there was no variation in the treatment. Each experiment comprised six treatments with four replications, giving a total of 24 experimental units.

Puncture tensiometers were used to measure the matric potential of the soil. These were installed at a depth of 20 cm in at least one replication of each treatment in each experiment. Readings were taken daily at the beginning of the day.

The volumetric humidity equivalent to the tensiometer reading was obtained considering the depth of installation (Equation 1) and the soil water retention curve (Equation 2) adjusted by the Van Genuchten model (1980). The soil used in the experiment was a Typic Eutrophic Red Latosol with a field capacity of 0.243 cm^3 cm^{-3} (-30 kPa) and a permanent wilting point of 0.101 cm^3 cm^{-3} (-7935 kPa).

$$\psi m = |L| + 0.098 \tag{1}$$

$$\theta = 0.078 + \frac{0.430 - 0.078}{\left[1 + \left(0.036|\psi m|^{1.56}\right)\right]^{036}} \tag{2}$$

where: Ψm is the matric potential (kPa), L is the tensiometer reading, c is the installation depth of the tensiometer considering the water column (cm), and θ is the volumetric humidity in cm^3 cm^{-3}.

The irrigation depth corresponding to each treatment was applied using a drip irrigation system. One dripper with a flow of 4 L h^{-1} was employed for each vessel. The system was evaluated under working conditions. The irrigation efficiency (Ei) was 84.6%.

The irrigation depths were calculated (Equation 3) based on the actual moisture content of the soil (θa) and the equivalent humidity for each treatment (θt). The effective depth of the root system of the marigold was considered to be 20 cm.

$$Li = \frac{(\theta t - \theta a)z.10}{Ei} \tag{3}$$

where: Li is the irrigation depth (mm), θt is the equivalent moisture for the treatment (cm^3 cm^{-3}), θa is the actual humidity (cm^3 cm^{-3}), z is the effective depth of the root system (cm), and Ei is the irrigation efficiency (%).

Irrigation based on the matric potential was carried out daily throughout the experiment. The total irrigation depth (Table 3) for each stage of development and matric potential was determined at the end of the experiment, considering each irrigation depth for the 15 days after transplanting (DAT) the seedlings.

The following parameters were evaluated during the experiments: production of floral capitula (PFC) for the entire period of flowering, dry weight of the floral capitula (DWFC) by the end of the harvest, and water productivity (WP). WP (Equation 4) was determined from the dry weight of the floral capitula and the total irrigation depth applied by the end of the harvest. It was decided to evaluate the production of floral capitula as these are economically important in phytotherapy.

$$WP = \frac{DWFC}{Ir} \tag{4}$$

where: WP is the water productivity (kg mm^{-1}), $DWFC$ is the dry weight of the floral capitula (kg) and Ir is the irrigation depth (mm).

The data were submitted to the Komogorov-Smirnov test for normality, followed by the F-test at a level of 5%. The mean values of each treatment were compared using the Scott-Knott test, and any parameters showing a difference between the mean values were submitted to regression analysis.

RESULT AND DISCUSSION

Figure 1 showed that the production of floral capitula per pot was only significant when the irrigation

depth varied throughout the development cycle of the marigold. There was a linear adjustment, where the production of floral capitula decreased by 53.8% for a reduction in water availability based on the lowest soil matric potential of -60 kPa.

Figure 1 - Production of floral capitula in the marigold for the matric potentials under test at different stages of development
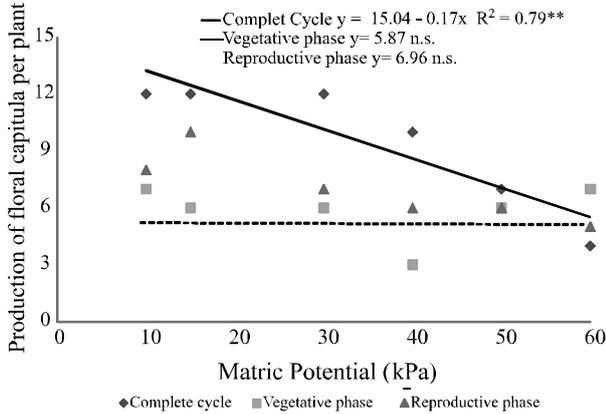
Létourneau et al. (2015), point out that a decrease in the soil matric potential reduced strawberry production in the field. This response depended on the length of time the crop was exposed to the water deficit, as well as the stage of development; whereas in the present study with the marigold, there was no statistical difference for the production of floral capitula during either the vegetative or reproductive phases. Apparently, acclimatising the marigold to a water surplus or water restriction did not interfere in the vegetative development or flowering of the plants.

In the trial for the complete cycle, the plants were exposed for 118 days to variations in field capacity and to the matric potentials of -10, -15, -30, -40, -50 and -60 kPa, almost twice the time of the trials of either the vegetative or reproductive phase. The intensity and duration of abiotic stress has a direct influence on plant response. Soil water availability is one of the main abiotic factors that influence physiological processes, including primary and secondary metabolism, and plant production. When the water deficit is imposed for a time, and then full irrigation is resumed, the plants may not suffer any negative impacts on production.

Contreras et al. (2017), found that as the soil water content decreases, determined from the soil matric potential, the irrigation interval fluctuates considerably, this can produce water stress in the crop, with a consequent fall in production.

Geerts and Raes (2009) found that deficit irrigation is one method for optimising irrigation management during plant development. In regions where the type of soil, water availability and climate conditions are limiting factors in production, maximising water productivity could be an alternative way of maintaining or maximising the production of agricultural crops. Irrigation at a matric potential of less than field capacity might be considered a condition of water deficit; as such, three matric potentials of less than field capacity were tested in the present experiment. For the marigold, these potentials had a negative effect on the production of floral capitula.

Rios et al. (2014), concluded that in cultivating the castor bean in Lavras, Minas Gerais, a matric potential of -15 kPa resulted in the greatest productivity (1994.14 kg ha^{-1}), while a matric potential of -75 kPa resulted in the lowest productivity (773.91 kg ha^{-1}). Pereira et al. (2009), studying the matric potentials of -15, -25, -40 and -60 kPa when cultivating the gladiolus (Gladiolus L.), found that a reduction in matric potential had a significant effect on floral production, and that a potential of -15 kPa gave the best results for the number of flowers.

The dry weight of the floral capitula (Figure 2) decreased on average by 7.2% throughout the cycle for each level of matric potential. It should be noted that the production of floral capitula in the present study was directly proportional to the dry weight of the floral capitula over the entire growth cycle of the marigold.

Figure 2 - Dry weight of floral capitula in the marigold for the matric potentials under test at different stages of development
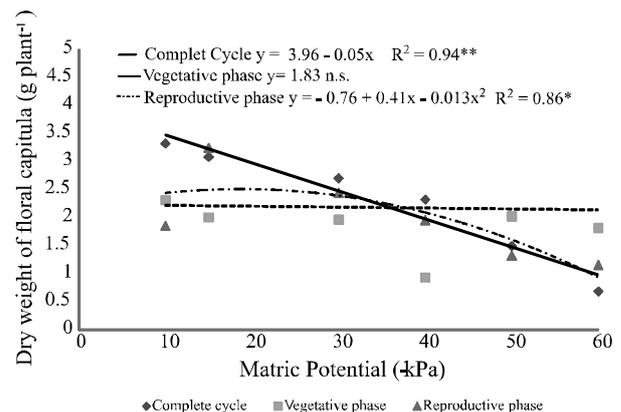
During the reproductive phase, the dry weight of the floral capitula reached the highest value of 3.25 g plant^{-1} at a matric potential of -15 kPa. These results corroborate those obtained by Laribi et al. (2009), who found a reduction

of 20.68% in dry-weight production in cumin (*Carum carvi*) due to water restriction.

According to Lima *et al.* (2013), a reduction in the soil water potential from -20 to -120 kPa applied during the vegetative and reproductive phases in Cayenne pepper resulted in a decrease in crop productivity, with a reduction in shoot weight in response to the disturbance in plant development.

Farahani *et al.* (2009), and Rahimi *et al.* (2016), point out that water stress in medicinal and aromatic plants reflects in reduced production, due to mechanisms of primary metabolism being activated under conditions of stress. One of these mechanisms might be a reduction in photosynthetic activity, which can cause a decrease in dry weight and productivity, affecting the harvest index.

Water productivity (Figure 3) is defined as the amount of water used to produce a given crop. It was found from Figure 3 that for the complete cycle, a potential of -32.74 kPa resulted in greater water productivity, taking the dry weight of the capitula to be around 0.03 g mm^{-1}. This means that when using a potential close to field capacity, savings of 17.5% to 35.2% of the irrigation depth may be possible, compared to the irrigation depths of greater matric potential under test.

Figure 3 - Water productivity in the marigold for the matric potentials under test at different stages of development

◆Complete cycle ■Vegetative phase ▲Reproductive phase
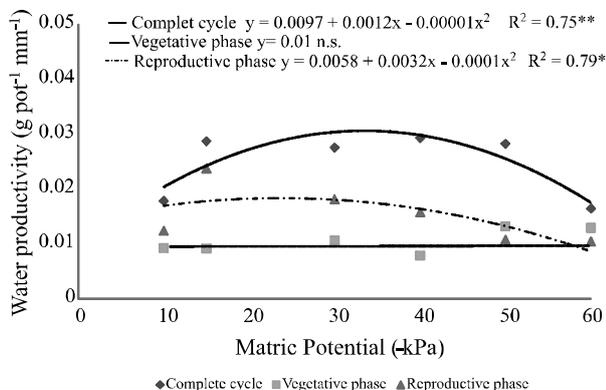
During the reproductive phase, considering a polynomial regression for the obtained data, the matric potential of -15.95 kPa showed greater water productivity, around 0.017 g pot^{-1} mm^{-1}. For other species of medicinal plants, the results were different. Delatorre-Herrera *et al.* (2010), concluded that a reduction in soil water availability can promote an increase in water use efficiency and water productivity in aloe vera grown in arid regions in the north of Chile. It is important to remember that the production and water requirement of medicinal and aromatic plants depend largely on abiotic conditions and the particularities of each species.

Contreras *et al.* (2017), found that for the courgette, the highest values for water productivity were obtained at matric potentials of -25 kPa and -40 kPa. A matric potential of -25 kPa was recommended to achieve the highest commercial productivity for the crop, considering the agronomic and environmental factors. It should be noted that this potential was equivalent to an irrigation depth of 300 mm over a period of 138 days after transplanting (DAT), and was close to that obtained for maximum water productivity in the marigold, of 202 mm over a period of 118 DAT.

Marques, Bortolo and Santos (2011), and Aleman and Marques (2016), point out that the reduction in water productivity may result from a decrease in soil water availability in line with the lowest matric potentials. Depending on the time of exposure, amount of water deficit and stage of crop development, physiological processes such as photosynthesis, stomatal opening, the production of abscisic acid, leaf abscission and osmotic adjustment can have a negative impact on production.

There was no significant difference for the production or dry weight of the floral capitula, or for water productivity, during the vegetative phase. This may have been due to the marigold being less responsive to the reduction in soil water availability during vegetative development. Ripoll *et al.* (2016), found that in the tomato, each stage of development was sensitive to moderate water stress, however the reproductive phase and the fruit-production phase proved to be the most sensitive.

CONCLUSION

1. The production and dry weight of floral capitula is negatively influenced by the reduction in soil water availability represented by matric potentials of less than -30 kPa;

2. Over the complete cycle, the irrigation depth of 202 mm (-32.74 kPa) resulted in greater water productivity, i.e. sustainable production of the potted marigold;

3. During the reproductive phase, maximum water productivity was obtained at a matric potential of -29 kPa.

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