RESEARCH PAPER

Determining yield response factor (ky) of silage maize under different irrigation levels of pulsed and continuous irrigation management

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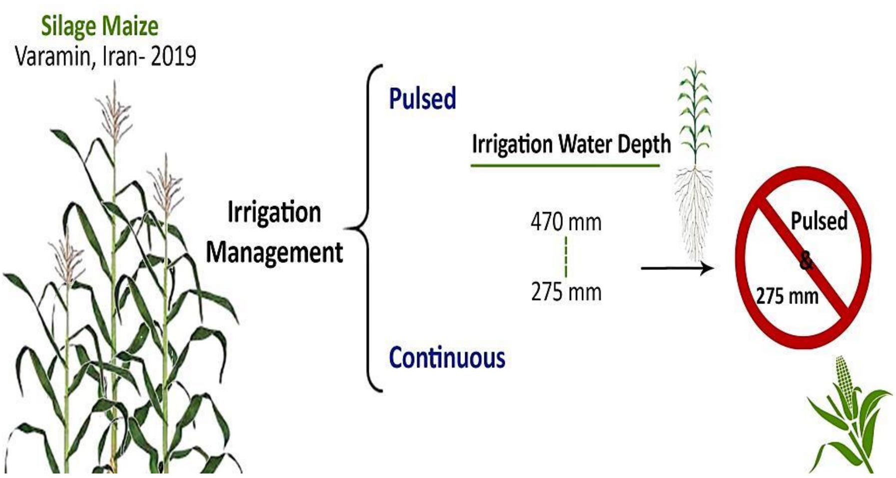
Highlights

- Pulsed irrigation refers to the practice of repeating irrigation on-off cycle until the entire irrigation depth is applied.
- Deficit irrigation creates water stress that can affect the growth and development of silage maize.
- The yield response factor (ky) indicates crop yield reduction as a function of evapotranspiration.
- The ky factor of silage maize in this study was equal to 2.13.

Graphical Abstract



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Abstract

The amount of irrigation water applied to the root zone of plants can greatly affect crop yield. The yield response factor (ky) indicates the reduction in crop yield as a function of evapotranspiration and can be an important tool for yield forecasting and irrigation management. The objective of this study was to determine the yield response factor (ky) of silage maize under different irrigation levels in the arid and semi-arid regions of Varamin, Iran. Actual crop evapotranspiration was determined by monitoring soil water content in the root zone of the plants. After harvest, the biological yield was determined and the yield response factor of silage maize was calculated. The results showed that the highest and lowest biological yield of silage maize were associated with treatments PI1 and PI4, respectively. The silage corn yield response factor (ky) in this study was 2.13, indicating a high sensitivity of silage corn yield to crop water use. As a result, it is recommended that pulsed management in drip irrigation systems with 60% deficit irrigation be avoided in areas with climatic conditions similar to those in the study area and limited water resources, as this reduces crop production efficiency.

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1. Introduction

Water is essential for crop growth, and its shortage has a negative effect on crop yield. Therefore, farmers tend to over-irrigate, an approach that hindersthe conservation of scarce water resources. Considering the global expansion of irrigated areas and the limited availability of irrigation water, there is a need to optimize water use efficiency (WUE) by maximizing crop yields under deficit irrigation conditions. When water deficit occurs during a specific period of growth stage, the yield response can vary depending on crop sensitivity to water stress at that specific growth stage. Therefore, the timing of the application of deficit irrigation appropriately is a tool for scheduling irrigation where a limited supply of water is available (Moutonnet, 2002). The irrigation scheduling based on deficit irrigation requires careful evaluation to maximize water use efficiency (Kirda, 2002). A standard formulation relates four parameters (Ya, Ym, ETa, and ETm) to a fifth: ky, the yield response factor, which relates relative yield decrease to relative evapotranspiration deficit. In other words, when the plant's water needs are not met, the actual crop evapotranspiration becomes less than the potential crop evapotranspiration and the crop is subjected to drought stress, leading to reduced yields. The response coefficient of the crop due to loss of irrigation is obtained at a specific stage of crop growth or the whole vegetative stages of the crop (Dixit, 2020). In one of the study, reported the yield response factor (ky) of corn equal to 1.04 based on 2 years data (Dağdelen et al., 2006). The ky values of silage maize to water deficit for a complete growing season were obtained 1.86 and 1.26 in 2005 and 2006, respectively (Kiziloglu et al., 2009). In the other study, stated that the yield response factor (ky) for the silage maize for two growing seasons averaged 1.12 (Bouazzama, 2012). Also, in the other research, reported different ky values that were observed in experimental years 2014 and 2015 (Ucak et al., 2016). They stated that irrigation treatments have a significant effect on ky values. Yield response factors (ky) for years of 2014 and 2015 were respectively calculated as 0.74 and 1.06. The main objective of this study was to determine Ky of silage maize under different irrigation levels in the arid and semi-arid region of Varamin, Iran.

2. Materials and Methods

This study was conducted to determine the yield response factor (ky) of silage maize during the growing year of 2019 at the Saffari-Salehi livestock complex located in the Varamin (51° 41′ 42.8" E, 35° 19′ 51.9″ N 973 m altitude) region. Some meteorological data at the experimental site are indicated in Table 1. According to Table 1, the growing period of silage maize (July) is hot with the maximum temperatures that exceed 41.9 °C.

Table 1. Some meteorological data at the site of the experiment.

Variable	Months			
	July	**August**	**September**	**October**
Max. temperature (°C)	41.9	40.5	36.1	30.7
Min. temperature (°C)	24.1	22.3	18	13.6
Max. relative humidity (mm/month)	41.2	40	49.2	59.4
Min. relative humidity (mm/month)	13.2	13.9	21.4	20.3
Mean. wind velocity	2.6	1.8	1.6	1.3

Before the experiment started, soil samples were collected with an auger from soil layers 0-30, 30-60, and 60-90 cm for analyses. Some physical and chemical properties of the soil were determined (Table 2).

Table 2. Some physical properties of the experimental field soil.

Properties	Soil layer (cm)		
	0-30	**30-60**	**60-90**
Soil Texture	Loam	Loam	Loam
Bulk Density (ρa) (gr/cm^3)	1.49	1.51	1.51
Field Capacity (θ_{fc}, %) (m^3/m^3)	36	31	34
Wilting point (θ_{wp}, %) (cm^3/cm^3)	13.7	17.5	15.3

The experiment was conducted as a split-plot based on a randomized complete block design replicated three times. The treatments included four irrigation regimes in form of 60 (I4), 80 (I3), 100 (I2), and 120 (I1) percent of the irrigation depth of the full irrigation treatment as the main plots and two pulsed and continuous irrigation management sterategies as subplots. A length of 1 m space was considered between the treatment plots. Each treatment consisted of three two-row cultivation rowss, two rows one at each side of the oplots were considered as margins and the required data were collected from the center row. The length of the planting rows was 20 meters. The irrigation system used was a drip irrigation system equieped with drippers having a flow rate of 0.7 liter per hour and lateral pipes at a spacing of 20 cm. Tape lateral pipes were placed between the two planting rows. To determine the depth of irrigation water, a soil moisture monitoring method was used. Soil moisture was measured using a PR2/6 probe profile device, which was previously calibrated at field. The depth of irrigation water required was calculated based on the data read by the probe profile device before each irrigation event according to the equation (1) (Gupta et al., 2019):

$$\mathrm{SMD} = (\theta_{fc} - \theta_i) \times \mathrm{D}_{rz} \times f \quad (1)$$

Where, SMD is soil moisture deficit (mm), θ_{fc} and θ_i are respectively, soil moisture at field capacity and pre-irrigation moisture (volumetric percentage) and D_{rz} is crop root development depth (mm) and f is a coefficient for applying different levels of irrigation depth (coefficient f for treatments I_1, I_2, I_3, and I_4 was 1.2, 1, 0.8, and 0.6, respectively). In continuous irrigation management strategy, the calculated irrigation water depth was provided to the plant continuously at each irrigation event. In pulse management treatments, the amount of water required for each treatment was provided to the plant in three pulses with equal on and off duration times. In other words, if the irrigation time required for the treatment was three hours, the irrigation depth in the pulse treatments was applied as three one-hour pulses with one hour rest time between the irrigation pulses by closing and opening the irrigation valves. Irrigation of all treatments was done simultaneously. The volume of applied water was measured using calibrated volume meters. The soil water balance relationship (equation 2) was used to calculate the actual evapotranspiration of silage maize during the growing season (Allen et al., 1998).

$$\mathrm{ET_a} = \mathrm{I}_{rrg} + \mathrm{P}_e + \mathrm{CR} - \mathrm{RO} - \mathrm{DP} \pm \Delta\mathrm{S} \quad (2)$$

Where ET_a is the actual evapotranspiration (mm), I_{rrg} is irrigation depth (mm), P_e is effective rainfall (mm), CR is capillary rise (mm), DP is deep percolation, ΔS is the soil water content variation (mm) and RO is runoff (mm). The capillary rise was considered negligible because the water table was at a depth of 30 m below the soil surface. Due to the good soil permeability and the low drippers flow rate, no surface runoff was observed in the experimental plots during the growing season. Also, according to the data recorded at the nearby weather station, effective rainfall during the growing season was zero. The relationship between relative evapotranspiration reduction ($1 - ET_a/ET_m$) and relative yield reduction ($1 - Y_a/Y_m$) was determined using the method given by Doorenbos and Kassam (1979) as follows (Doorenbos and Kassam, 1979):

$$\left(1 - \frac{Y_a}{Y_m}\right) = k_y \left(1 - \frac{ET_a}{ET_m}\right) \quad \text{or} \quad Y_d = k_y \times ET_d \quad (3)$$

Where Y_a is actual yield, Y_m is maximum harvested yield, ET_a is actual evapotranspiration, ET_m is maximum evapotranspiration, Y_d is relative yield reduction, ET_d is relative evapotranspiration reduction and ky is a crop yield response factor that varies depending on species, variety, irrigation method and management, and growth stage when deficit evapotranspiration is imposed. The crop yield response factor indicates whether the crop is tolerant of water stress. A response factor greater than unity indicates that the expected relative yield decrease for a given evapotranspiration deficit is proportionately greater than the relative decrease in evapotranspiration (Kirda et al., 1995) The maximum yield of silage maize under two treatments of pulsed and continuous irrigation was considered as Y_m and its corresponding evapotranspiration was also considered as ET_m. Doorenbos and Kassam (1979) stated that when $K_y < 1$, yield loss is less significant than evapotranspiration deficit; when $K_y > 1$, yield loss is more significant than evapotranspiration deficit (for maize, $K_y = 1.25$ for the whole growing period); and when $K_y = 1$, yield loss is equal to evapotranspiration deficit (line 1:1). In this study, the relative yield drop and production efficiency in terms of percentage were calculated using equations (4) and (5), respectively (Doorenbos and Kassam, 1979).

$$\text{relative yield reduction } = k_y\left(1-\frac{ET_a}{ET_m}\right)\times 100 \quad (4)$$

$$\text{production efficiency} = \frac{y_a}{y_m} = [1-(\text{relative yield reduction })] \quad (5)$$

3. Results and Discussion

Table 3, shows the depths of irrigation water for each one of the treatments under both pulsed and continuous irrigation management. The same amount of irrigation water was applied to both managements.

Table 3. Irrigation water depth for different irrigation levels.

Irrigation Management	Treatments	Irrigation Water Depth (mm)
Pulsed (P)	I_1	470
	I_2	405
	I_3	340
	I_4	275
Continuous (C)	I_1	470
	I_2	405
	I_3	340
	I_4	275

Figs. 1 And 2, show the trend of changes in the biological yield (the weight of the dry matter of the plant shoots) per water consumption and actual evapotranspiration of silage maize under both pulsed and continuous irrigation managements. In continuous irrigation management (Fig. 1), with increasing irrigation depth, the highest yield was obtained in over-irrigation treatment (CI_1) and the lowest biological yield was related to under-irrigation treatment at 60% level (CI_4). In pulse irrigation management, with increasing the depth of irrigation water, the highest and lowest biological yields were obtained from PI_1 and PI_4 treatments, respectively. Despite the same irrigation depth applied at the PI_2 and CI_2 treatments, pulse management increased biological yield by 25% compared to continuous irrigation management, which could be due to the better soil moisture distribution within the plant root zone. Pulse irrigation management reduced the performance of PI_4 treatment by 9% compared to CI_4 treatment, which can be explained by the fact that the application of this management intensified the stress in this treatment (Sarker et al., 2020).

According to Fig. 2, the highest actual evapotranspiration at different levels of irrigation under both pulsed and continuous irrigation management was related to treatment PI1 and the lowest was related to treatment PI4 With the increase of actual evapotranspiration, biological yield also increased in both irrigation managements, but this increase was greater in pulse management. A linear relationship was observed between the actual evapotranspiration of silage maize and the biological yield under both pulsed and continuous irrigation management. Other researchers have reported a linear relationship between actual evapotranspiration and yield (Cakir, 2004; Dağdelen et al., 2006; Gençoğlan et al., 1999; Kırnak et al., 2003; Payero et al., 2006).

To determine the yield response factor of silage maize, a linear relationship was established between the values of the relative decrease in biological yield versus relative decrease in evapotranspiration with zero Y-intercept (Fig. 3). The yield response factor for the whole growing season in this study was 2.13. Gencoglan and Yazar (1999), obtained ky values between 1.08 to 1.61 (Gençoğlan and Yazar, 1999); Kipkorir et al., (2002) and Popova et al., (2006), obtained ky values of 1.21 and 1.28, respectively (Kipkorir et al., 2002; Popova et al., 2006);

Bozkurt et al., (2011), stated that the seasonal yield response factor (ky) was 1.98 (Bozkurt et al., 2011); as 1.04 (Dağdelen et al., 2006); as between 0.88-0.93 (Öktem, 2006); Bouazzama et al., (2012) and Irmak et al., (2016), found ky values of 1.12 and 1.14, respectively (Bouazzama et al., 2012; Irmak et al., 2016); Ertek and Kanber (2001), reported ky value as 0.70 and indicated that a unit water deficit may result in a 0.70 unit reduction in yield (Ertek and Kanber, 2001). The present ky values of silage maize obtained in the present study are higher than the values reported by other researchers, which indicates a greater sensitivity of biological yield to water consumed by the crop. Of course, several factors such as cultivar type, planting time, planting density, and climatic conditions that are directly related to crop yield have also played a role in the variability of this factor.

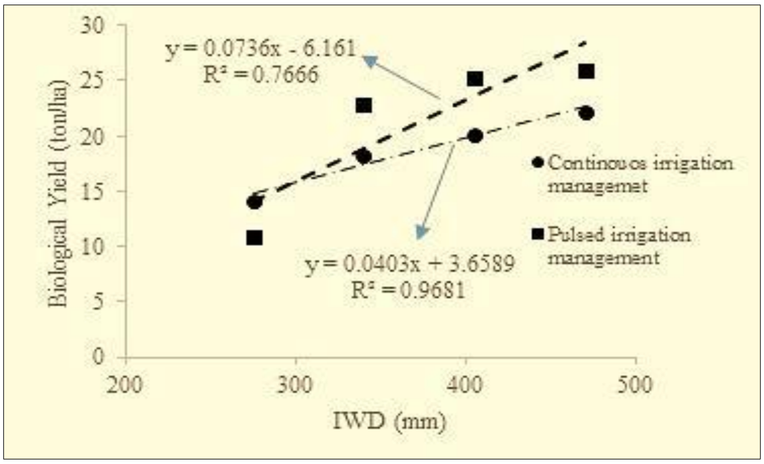

Figure 1. The relationship between Biological Yield and IWD.

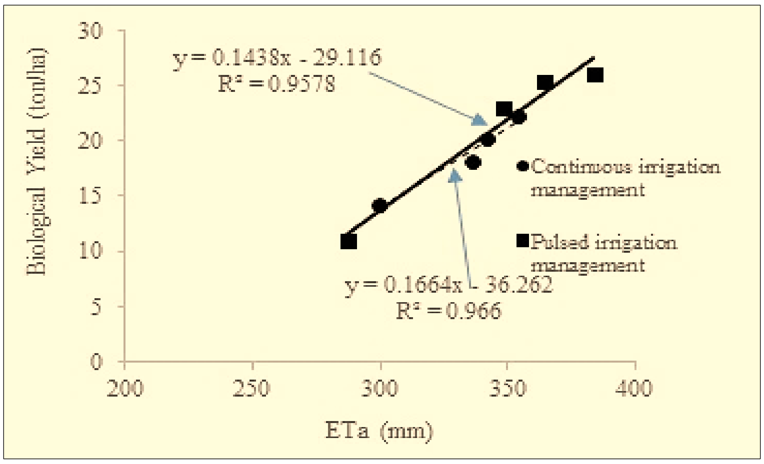

Figure 2. The relationship between Biological Yield and ET_a.

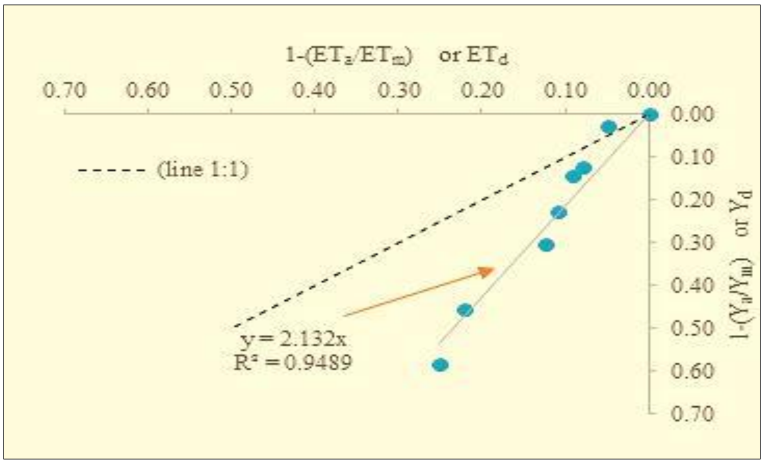

Figure 3. The relationship between evapotranspiration reduction (ET_d) and relative yield reduction (Y_d).

The relative yield drop and production efficiency (%) for pulsed and continuous irrigation management are indicated in Table 4.

Table 4. Relative yield drop and production efficiency at different levels of irrigation.

Treatments	$(1-\frac{ET_a}{ET_m})$	$(1-\frac{Y_a}{Y_m})$	$k_y(1-\frac{ET_a}{ET_m})\times 100$	$\frac{y}{y_m}$
PI_1	0	0	0	100
CI_1	0.09	0.14	20	80
PI_2	0.05	0.03	11	89
CI_2	0.11	0.23	23	77
PI_3	0.12	0.12	17	83
CI_3	0.08	0.30	26	74
PI_4	0.25	0.58	54	46
CI_4	0.22	0.46	47	53

According to Table 4, the highest and lowest production efficiencies were related to and treatments, respectively. On the other hand, the highest and lowest relative drop in performance occurred in treatments and respectively. The reason for the relative decrease in yield in the treatment compared to other treatments can be expressed as follows, considering that in the PI4 deficit irrigation treatment, about 40% less water volume was provided to the crop than the full irrigation treatment (I1), which The installment was given to the crop in three stages (three pulses). Therefore, in the pulse management treatment, one-third of the volume of water calculated for the 60% irrigation shortage treatment is given to the crop in one pulse, which due to its small volume, water is not expected to have penetrated to the depths of the soil, but in The surface layers of the soil are exposed and are more exposed to the phenomenon of evaporation from the soil surface. As a result, the combination of these factors causes less water to be provided to the plant than continuous management, which ultimately intensifies water stress in this treatment and reduces yield.

4. Conclusion

The results showed that the highest and lowest biological yields were obtained under two irrigation managements among different levels of irrigation and treatments. On the other hand, the highest actual evapotranspiration was related to treatment and the lowest was related to treatment. The yield coefficient of forage maize was obtained through a linear relationship between the relative values of biological yield versus the relative decrease of evapotranspiration with a width of zero origins, and its value was calculated to be 2.13 for the whole growth period. This value indicates the high sensitivity of the performance to water consumption. It is also suggested that in areas with similar characteristics of the present study faced with limited water resources, pulse management should not be used with deficit irrigation at the level of 60% because it will reduce production efficiency.

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