IOP Conference Series: Earth and Environmental Science

PAPER • OPEN ACCESS

The effect of regulated deficit irrigation (RDI) on advance vegetative phase to the water stress and water productivity of Soybean (Glycine max [L.] Merr.) plant

To cite this article: RAB Rosadi *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **355** 012085

The effect of regulated deficit irrigation (RDI) on advance vegetative phase to the water stress and water productivity of Soybean (Glycine max [L.] Merr.) plant

RAB Rosadi, S Triyono, B Lanya and S Mahmud

Department of Agricultural Engineering, Faculty of Agriculture, University of Lampung, Jl. Sumantri Brojonegoro 1, Bandar Lampung, 35145 Indonesia

Email: bustomirosadi@yahoo.com

Abstract. The objective of this research was to investigate the effect of regulated deficit irrigation on advance vegetative phase to the water productivity of Soybean. This research was conducted under plastic house on the field laboratory of Lampung University from October 2018 to January 2019. The water stress treatments in regulated deficit irrigation levels were DI1 (0 – 100 %) of total available water as a control, DI2 (0 – 80 %),DI3 (0 – 60 %), DI4 (0 – 40 %) and DI5 (0 – 20 %) of total available water (TAW) arranged in a randomized block design with four replications. The results showed that the soybean plant started to experience stress from week IV, the soybean plant started to experience stress within 0-40 % 0f total available water and continuing to stress until the end of growth, even the RDI treatment was stop at week VI. It means that the soybean plant which experience to tress at vegetative advance can't be recovered even the soybean plant was irrigated to bring back the water to the field capacity. The (p) value was 0.6 and the Ks value were 0.84; 0.70; 0.68; 0.80, 0.86 and 0.88 at week IV, V, VI, VII, VIII and IX, respectively. The average Ks value was 0.79. There was no significant different between DI1 DI2, and DI3 in water productivity of soybean plant. The value of water productivity were 0.65, 0.49, 0.48, 0.40 and 0.42 at DI1, DI2, DI3,DI4, DI5, respectively. The optimum water management which the high crop water productivity (WP=0.48) was reach by RDI at DI3 treatment which maintain the available water between 0-60 % or the soybean plant must be irrigate by bring back the water to the 60 % of total available water. The optimum yield of soybean (Anjasmoro veriety) was 17.9 g/pot and crop water requirement was 36746.5 ml or equal to 566.08 mm.

1. Introduction

The soybean production in Indonesia has been fluctuating in the cropping area, 616, 614, 577, 356, and 680×10^3 ha, respectively from 2014 through 2018, and the total soybean yields were 955, 963, 860, 539, and 983 $\times 10^3$ tons for the respective cropping [8] or the average of soybean production in Indonesia was

860 x 10^3 ton in a year. These yields was too low compared to the demand for national consumption; therefore, Indonesia must be import the soybean.

In 2018, the total import of soybean was 2,58 million ton which consist of 2,52 million ton from US, 54,53 thousand ton from Canada and 10,41 thousand ton from Malaysia [5]. It is mean that, in 2018 Indonesia was import soybean to meet 72 % of the national consumption, and Indonesia become the highest soybean importing country in the world.

One of the reasons why the cropping area decreased was the limited water resources [4]. It is necessary to develop new irrigation scheduling approaches, not necessarily based on full crop water requirement, but ones designed to ensure the optimal water use of allocated water. Deficit (or regulated deficit) irrigation is one way of maximizing water use efficiency (WUE) for higher yields per unit of irrigation water applied: the crop is exposed to a certain level of water stress either during a particular period or throughout the whole growing season [9]. According to Chalmers et.al. in [2] Regulated deficit irrigation (RDI) for irrigation strategies based only on a reduction of irrigations amounts during certain plant cycle phases.

If water supply is limited, the rate of soilwater absorption by plants becomes less than the rate of evapotranspiration, and crop plants begin to be stressed when soil water falls below critical soil water content (θc). At or above θc, the rate of actual evapotranspiration (ETa) is the same as the rate of maximum evapotranspiration (ETm). But if soil water content is below θc, ETa < ETm or ETa/ETm < 1.0, the plant will be stressed [11].

According to [7], the soil water content between field capacity (θFC) and θc is defined as readily available water (RAW) and in this range the crop yield and/or quality should be expected to be higher than in the range between θc and permanent wilting point (θPWP). Full irrigation is normally scheduled to maintain soil water content above θc.

The critical water content (θc) mentioned above according to [11] can be estimated by the following equation:

$$\theta\mathrm{c} = \theta\mathrm{FC} - p(\theta\mathrm{FC} - \theta\mathrm{PWP}) \quad (1)$$

where θFC is the water content at field capacity (m3/m3), θPWP is the water content at permanent wilting point (m3/m3), and θc is critical water content (m3/m3).

In the above equation, p is the fraction of total available water (TAW) that a crop can extract from soil water through the root zone without suffering water stress and can be estimated by the following equation:

$$p = \mathrm{RAW/TAW} \quad (2)$$

where RAW is the readily available water in root zone (m3/m3) defined as θFC−θc, and TAWis the total available water in root zone (m3/m3) defined as θFC−θPWP.

According to [1], [11], the evapotranspiration under water stress condition when soil water content falls below the critical water content, is referred as adjustment evapotranspiration (ETc adj), which can be calculated by the following equation:

$$\mathrm{ETc\,adj} = K\mathrm{s\,ETc} \quad (3)$$

where ETc adj is the crop evapotranspiration under water stress condition, ETc is the crop evapotranspiration under standard conditions defined as ETc=Kc ETo in which ETo is evapotranspiration of reference crop, Kc is crop coefficient, and Ks is water stress coefficient.

The value of Ks is very important for estimating ETc adj, so that the deficit irrigation scheduling can be made [11].

According to [10] the key word in evaluating the strategic of Deficit irrigation is crop water productivity (WP) which can be calculated by formula as follows:

$$\mathrm{WP} = \mathrm{Ya/ETa} \quad (4)$$

Where Ya = Mass of marketable yield, kg
ETa = Crop water requirement (Consumption), m^3

The objective of this research was to know the effect of regulated deficit irrigation (RDI) on advance vegetative phase to the water stress and water productivity of Soybean (Glycine max [L.] Merr.) plant.

2. Materials and Methods

This research was done in a plastic house of the University of Lampung from October 2018 to January 2019. Soybean cultivar *Anjasmoro* was grown in a *Ultisol.* This soil type is commonly found in Lampung covering about 48.5% of the total Lampung Province area. The bulk density was 1.086 g/cm3. Soil water content at field capacity, θFC (34.7 kPa) was 0.446 m3/m3 and wilting point, θPWP (1585 kPa) was 0.255 m^3/m^3. Total available water (TAW) was 0.191 m^3/m^3.

This research was conducted using a randomised complete block design with four replications. The water stress treatments in regulated deficit irrigation levels were DI1 (0 – 100 %) of total available water as a control, DI2 (0 – 80 %),DI3 (0 – 60 %), DI4 (0 – 40 %) and DI5 (0 – 20 %) of total available water (TAW) arranged in a randomized block design with four replications. For example, a water deficit level of DI2 (0–80%) means that water was applied to maintain the available water between 0 and 80% of TAW throughout the advance vegetative phase. When the AW deplete to some where before 0 % of TAW soon the water will bring back to a level of 80 % of TAW. (See figure 1 to 5)

Daily monitoring of soil water was done by gravimetric method. The soybean plant was irrigated by hand. The amount of irrigation is the same with the amount of evapotranspiration (ET) of the day before. ET (mm) was calculated as follows:

$$\text{ET} = [(Wi - 1 - Wi) \times 10]A \quad (5)$$

where Wi is the weight of container at day i (g), $Wi{-}1$ is the weight of container at day $i{-}1$ (g), and A is the container surface area (cm^2).

Agronomic variables evaluated in this research were plant height, leaf number, flower number, pod number, and seed yield. Also evaluated were evapotranspiration rate, crop water requirement (CWR), water productivity (WP). WP (kg/m3) was calculated as the ratio of yield (Y, kg) to CWR (m3).

Statistical analysis was done using F-test at 5% and 1% significant levels, followed by Least Significant Different (LSD) test at the same level.

Soybean seeds were planted in black plastic containers (10 l volume) which had been filled with 7 kg air-dried soil. The ET was calculated by gravimetric method. Five seeds were planted in each container, and after 1 week only two plants were maintained until the end of growth period. The soybean plants were sprayed with insecticide to protect them from insect attack at least twice a month. The growing period of soybean plant was 85 days, and irrigation was stopped 2 weeks before harvesting.

3. Results and Discussions

3.1. Plant growth

The effects of water deficit on plant growth indicators are shown in tables 1–3. It can be observed from the tables that DI1 and DI2 treatments had no significant differences with regard to plant growth indicators throughout the growing period. On the other hand, significant differences in growth indicators were observed for DI4, and DI5 treatments from week IV. With the exception of DI3 treatment that experienced stress at week V. DI4 and DI5 showed stress from week IV as far as the plant heights are concerned (see table 1.). The RDI treatment was applied at week III, IV and V (advance vegetative phase). That is why, the DI3 at week VI was no significant different compared to the DI1. DI3 treatment can be recovered because since week VI there is no deficit irrigation treatment and the available water of all plant were bring back to field capacity or the same with DI1 treatment.

Table 1. The effect of deficit irrigation (DI) on plant height (cm)

Deficit irrigation level (%)	Week IV			Week V			Week VI		
	Plant height (cm)			Plant height (cm)			Plant height (cm)		
DI1 (0-100% TAW)	51,81	a	a	75,38	a	a	94,88	a	a
DI2 (0-80% TAW)	50,88	a	a	73,50	ab	a	90,88	a	a
DI3 (0-60% TAW)	46,06	ab	a	63,38	bc	a	85,63	ab	a
DI4 (0-40% TAW)	44,25	bc	ab	61,38	c	ab	79,63	bc	ab
DI5 (0-20% TAW)	39,50	c	b	49,75	d	b	66,38	c	b
LSD		5%	1%		5%	1%		5%	1%

Numbers followed by the same letters vertically were not significantlydifferent

Table 2. The effect of deficit irrigation (DI) on leaf number

Deficit irrigation level (%)	Week IV			Week V			Week VI		
	Leaf number			Leaf number			Leaf number		
DI1 (0-100% TAW)	22,00	a	a	43,88	a	a	96,13	a	a
DI2 (0-80% TAW)	21,88	a	a	42,75	a	a	81,75	a	a
DI3 (0-60% TAW)	21,00	a	a	36,88	ab	a	78,00	ab	a
DI4 (0-40% TAW)	19,50	ab	a	33,13	b	ab	71,50	bc	ab
DI5 (0-20% TAW)	16,63	b	a	23,50	c	b	52,38	c	b
LSD		5%	1%		5%	1%		5%	1%

Numbers followed by the same letters vertically were not significantly different

In table 2, the plant leaves experienced stress from week IV for DI5, and since week V for DI4treatment as compared to DI1. It is mean that the growth performance indicators did not show water stress phenomenon at the same growth stage.

Based on table 3. The flower number experienced stress from week VI for DI5, and since week VII and VIII for DI4 treatment as compared to DI1. And Based on Table 4. The pod number experienced stress from week VII and VIII for DI5 treatment, and since week IX for DI4 treatment as compared to DI1.

3.2. Critical water content

Based on table 1-4, It is clear that the soybean plant, with the exception for DI3 treatment at week V, has been in stress condition since week IV for the DI4 treatment, and these stress condition was continue to the end of growth, even the deficit irrigation treatment was stop at week VI. It is meant that the soybean plat was in stress condition at DI4 (0-40 % TAW) treatment. These phenomenon was suite with evapotranspiration rate for DI4 compared to evapotranspiration rate for DI1 since week IV until week IX. (see table 6) So, the lower limit of available water of Soybean plant in stress condition was 40 % AW. It is mean that this limit point was critical water content (θc).

Table 3. The effect of deficit irrigation (DI) on flower number

Deficit irrigation level (%)	Week		
	VI	VII	VIII

	flower number			flower number			flower number		
DI1 (0-100% TAW)	69.75	a	a	47.13	a	a	3.13	b	b
DI2 (0-80% TAW)	66.25	a	a	36.75	ab	a	4.00	b	b
DI3 (0-60% TAW)	71.88	a	a	28.25	b	ab	2.50	b	b
DI4 (0-40% TAW)	59.00	ab	a	30.25	b	b	3.25	b	b
DI5 (0-20% TAW)	47.38	b	a	23.00	b	b	11.00	a	a
LSD		5%	1%		5%	1%		5%	1%

Numbers followed by the same letters vertically were not significantly different

Table 4. The effect of deficit irrigation (DI) on pod number

Deficit irrigation level (%)	Week								
	VII			VIII			IX		
	pod number			pod number			pod number		
DI1 (0-100% TAW)	89.75	a	a	114.25	a	a	121.38	a	a
DI2 (0-80% TAW)	81.88	a	a	104.38	a	a	123.00	a	a
DI3 (0-60% TAW)	81.50	a	a	102.38	a	a	116.13	ab	a
DI4 (0-40% TAW)	78.63	a	a	95.88	ab	ab	105.38	bc	ab
DI5 (0-20% TAW)	37.13	b	b	77.00	b	b	99.88	c	b
LSD		5%	1%		5%	1%		5%	1%

Numbers followed by the same letters vertically were not significantly different

Using the eq. (2) the value of p (is the fraction of TAW that the crop can extract from the soil water through the root zone without suffering water stress) can be calculate as follow:

a. AWor TAW = θFC−θPWP and was judge as 100 % AW
b. RAW (readily available water) = θFC−θc.

With assume that θFC was 100 % of AW, and the point of θc was 40 %, so RAW = (100-40) % AW = 60 % AW. p = RAW/AW = 60/100 = 0.6

With using eq. (1) the θc can be calculate as follows:

$\theta c = \theta FC - p(\theta FC - \theta PWP)$= 0.446 m^3/m^3- 0.6 (0.446-0.255) m^3/m^3. θc = 0.331 m^3/m^3.

3.3. Water stress coefficients

Assuming that the evapotranspiration at DI1 (0–100%) occurred under the ideal condition for plant growth in which the soil water content is bring back to the field capacity daily, and there is no limitation for plant to meet the maximum evapotranspiration (ETm), the actual evapotranspiration (ETa) at DI1 treatment is crop evapotranspiration (ETc), which means the evapotranspiration of plant under standard conditions [1]. If evapotranspiration of plant is measured under water stress (ETc adj), the *K*s value can be calculated by using eq.(3).

From table 5, it can be seen that the *K*s values of soybean plant varied depending on the growth stage and the deficit irrigation level. The *K*s values are the same as the values of ETa/ETm when the plants were in stress condition. Table 5 shows that the Ks value were 0.84; 0.70; 0.68; 0.80, 0.86 and 0.88 at week IV, V, VI, VII, VIII and IX, respectively or 0.79 in average. And tended to increased week by week, even the treatment was stop at week VI.

Table 5. The ratio between the actual evapotranspiration and the maximum evapotranspiration (ETa/ETm), and water stress coefficient (Ks)

Deficit irrigation level (%)	**week**					
	IV	V	VI	VII	VIII	IX
DI1 (0-100% TAW)	1.00	1.00	1.00	1.00	1.00	1.00
DI2 (0-80% TAW)	0.98	0.95	0.92	0.98	0.96	0.96
DI3 (0-60% TAW)	0.93	0.90	0.86	0.97	0.97	0.90
DI4 (0-40% TAW)	0.84	0.70	0.68	0.80	0.86	0.88
DI5 (0-20% TAW)	0.61	0.53	0.50	0.70	0.77	0.84
ETm (mm)	36.9	70.5	102.7	120.9	117.7	124.1

The evapotranspiration of DI1 treatment was the maximum of evapotranspiration (ETm)
Ks is the value of ETa/ETm in stress condition or ETc adj/ETc. The cell with shading is in stress condition.

Table 6. The effect of deficit irrigation (DI) on ET

Deficit irrigation level (%)	**IV**		**V**		**VI**		**VII**		**VIII**		**IX**	
	ET		ET		ET		ET		ET		ET	
DI1 (0-100% TAW)	37	a	71	a	103	a	121	a	118	a	124	a
DI2 (0-80% TAW)	36	a	67	a	95	a	118	a	113	a	119	ab
DI3 (0-60% TAW)	33	ab	61	a	85	a	112	a	110	ab	108	b
DI4 (0-40% TAW)	30	b	48	b	68	b	95	b	99	bc	108	c
DI5 (0-20% TAW)	23	c	38	c	52	c	85	b	91	c	105	c
LSD		5%		5%		5%		5%		5%		5%

Numbers followed by the same letters vertically were not significantly different

Table 7. The effect of deficit irrigation (DI) on yield, CWR and WP

	Yield (g/pot)			CWR (ml)			WP (kg/m^3)		
DI1 (0-100 % TAW)	25,41	a	a	38875.50	a	a	0,65	a	a
DI2 (0-80 % TAW)	18,48	a	a	37543.25	ab	a	0,49	a	a
DI3 (0-60 % TAW)	17,90	ab	ab	36746.50	b	ab	0,48	ab	a
DI4 (0-40 % TAW)	13,14	b	b	32884.00	bc	bc	0,40	b	a
DI5 (0-20 % TAW)	11,93	b	b	28484.00	c	c	0,42	b	a
LSD		5%	1%		5%	1%			

Numbers followed by the same letters vertically were not significantly different.

3.4. Crop water productivity (WP)

Table 7. show that, the yield of DI4 and DI5 was highly significant difference compared to DI1 and there is no significant difference between DI3 and DI1. Even the DI3 treatment was significantly different compared to DI1 in CWR, but the crop water productivity (CWR) DI3 treatment was no significant difference compare to DI1. It is meant that DI3 treatment, that is the deficit irrigation which bring back water to the 60 % 0f TAW was the optimum water management on Soybean.

4. Conclusions

1. The soybean plant started to experience stress at week IV until week IX with p = 0.60, and θc = 33.1m^3/m^3, if soil water was maintained at 0–40% AW (DI4), even the stress treatment just 3 weeks, that is at vegetative advance phase.
2. The various Ks values at p=0.6 are 0.84, 0.70, 0.68, 0.80, 0.86 and 0.88 from week IV to week IX, respectively or 0.79 in average.
3. The value of water productivity were 0.65, 0.49, 0.48, 0.40 and 0.42 at DI1, DI2, DI3,DI4, DI5, respectively.
4. The optimum yield of soybean plant with the high crop water productivity (WP) was reached by deficit irrigation that maintained the soil water condition at the level of 0–60% of AW with WP = 0.48 kg/m^3.
5. The optimum yield of soybean plant was 17.9 g/pot and crop water requirement was 36746.5 ml or equal to 566.08 mm.

5. References

[1] Allen R G, Pereira L S, Raes D and Smith M 1998 Crop evapotranspiration, guidelines for computing crop water requirements *Irrigation and Drainage Paper* **56** (Rome: FAO) 301
[2] Capra C, Simona C and Baldasare S 2008 Water Management Strategies Under Deficit Irrigation *J.of Ag. Eng.-Riv.di Ing. Agr.* **4** 27-34
[3] Doorenbos J and Kassam A H 1979 *Yield response to water* (Roma: FAO) p 1–57
[4] Fagi A M and Tangkuman F 1985 *Water management for soybean* (Sukamandi: Food Crops Research Institute) p 135–138
[5] **https://finance.detik.com/berita-ekonomi-bisnis/d-4387112/25-juta-ton-kedelai-as-masuk-ri-sepanjang-2018.** 2,5 Juta Ton Kedelai AS Masuk RI Sepanjang 2018.
[6] Indonesian Statistical Bureau 1998 Indonesian Statistic (Jakarta,Indonesia)
[7] James L G 1988 *Principle of farm irrigation system design* (New York: Wiley) p 1–40
[8] Kementerian Pertanian Republik Indonesia 2018
[9] Kirda C 2000 *Deficit Irrigation Practise, Water Reports 22* (Rome: FAO)
[10] Rosadi R A B 2012 *Irigasi Defisit* (Lampung: Lembaga Penelitian Universitas Lampung)
[11] Rosadi R A B, Afandi, Senge M, Ito K and Adomako J T 2005 *J. Paddy Water Environtment*. (DOI)