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The Effect of Water Deficit at Individual Growth Stages on the Yield and Water Requirement of Soybean (*Glycine max [L.] Merr.*)

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Abstract: An experiment was conducted to determine the effect of available water deficit at different growth stages on the yield and crop water requirement of soybean. This research was conducted in a plastic greenhouse of Agricultural Faculty, the University of Lampung from August to November, 2001. A factorial experiment was arranged in randomized block design with three replications. The period of available water deficit (S) was the first factor with four different growth stages, namely: early vegetative phase (S1), advance vegetative phase (S2), flowering phase (S3), and pod filling to maturity phase (S4). Available water deficit (D) was the second factor with four levels including: D2(20-40%), D3(40-60%), D4(60-80%), and D5(80-100%). The results showed soybean to be sensitive to water stress especially at S3 and S4, and the critical water content of these stages was around 50% of available water deficit or 0.26 m^3/m^3(soil moisture suction was 120kPa). The values of water stress coeffisient (K_s) of the soybean at S2, S3, and S4 were 0.55, 0.57, and 0.27 respectivelly. The values of yield response factor (K_y) of S1, S2, S3, and S4 were 0.96, 0.42, 0.46, and 1.20 respectively. The water deficit at early vegetative (S1) and pod filling to early maturing (S4) was sensitive to the relative decrease of yield. The damage caused by water defict at early vegetative stage (S1) could recover by full irrigation (D1) after advance vegetative stage (S2). However, even small water deficit during pod filling to early maturing stage (S4) could strongly damage the yield of soybean. All the levels of water deficit (D1～D4) at pod filling to early maturing stage (S4) decreased yield efficiency extremely, which means that the deficit irrigation applied after the pod filling stage could not be tolerated.

Keywords: *Available water deficit, Water stress, Yield efficiency, Stress period*

1 Introduction

Soybean is a very important commodity in Indonesia, but until now Indonesia can not produce sufficient soybean to meet national consumption. According to Siswono (2004), Indonesia now imports 1.3 million tons of soybeans to meet 45% of national consumption, and has become the highest soybean importing country in the world.

Soybean production by Indonesia in 2003 was 6.8×10^5tons, with cropping land area of 5.3×10^5ha, or 1.278×10^3ton/ha. In the province of Lampung, soybean production in 2003 was 3.97×10^3ton from cropping area of 3.91×10^3ha, or 1.02ton/ha (Statistical Bureau, 2003). Usually, soybean is planted in paddy fields after the second harvesting of the paddy rice at the end of rainy season. Soybean is planted at the end of rainy season and grows through the dry season. Therefore, water availability becomes a limiting factor of production, so that the possibility of implementing deficit irrigation method is inevitable. Generally, farmers keep the land fallow after harvesting the paddy rice at the end of rainy season, because they are not sure whether there will be enough water for growing secondary crop. By applying deficit irrigation, there is a possibility to increase the cropping area of the fallow land.

James(1988) stated that deficit irrigation is accomplished by allowing planned plant stress during one or more periods of the growing season. Adequate water is supplied during critical growth stages to maximize water use efficiency (*i.e.*, maximizing crop production per unit of water applied). Also Kirda *et al.* (2002) stated that the main objective of deficit irrigation is to increase the water use efficiency (*WUE*) of a crop by eliminating irrigations that have little impact on yield. The resulting yield reduction may be small compared to the benefits gained through diverting the saved water to irrigate other crops.

For a full evaluation of the effect of limited water supply on yield, consideration must be given to the effect of the limited water supply during the individual growth periods of crops. Where crops under consideration are very sensitive to water supply deficits, scheduling of the supply is based on meeting full crop water requirements. Where crops under consideration are less sensitive to water deficit and can be grown with acceptable yields without meeting full water requirements, scheduling of the supply is based on minimizing water deficits in the most sensitive growth periods. During periods of unpredictable water shortages within a season, adjustments of water scheduling must be made in relation to the difference in yield response to water deficits on the crops and their individual growth periods (Doorenboss and Kassam, 1979). According to Doorenboss and Kassam (1979), in order to quanti-

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fy the effect of water stress, it is necessary to derive the relationship between relative yield decrease and relative evapotranspiration deficit given by the following equation.

$$1-\frac{Y_a}{Y_m}=K_y\left[1-\frac{ET_a}{ET_m}\right] \quad (1)$$

where $1-Y_a/Y_m$ is relative yield decrease, Y_a is actual yield, Y_m is maximum yield (under no stress condition), $1-ET_a/ET_m$ is relative evapotranspiration decrease, K_y is yield response factor, ET_a is actual evapotranspiration, and ET_m is maximum evapotranspiration

The K_y of soybean at the different periods of stress were: 0.2, 0.8, and 1.0 under vegetative, flowering, and pod formation phases, respectively. The K_y of soybean for the whole growing period under water deficit was 0.85 (Doorenboss and Kassam, 1979). According to Kirda *et al.* (1999), the K_y of soybean at vegetative, flowering, and pod development and filling were 0.58, 1.13, and 1.76, respectively. And according to Moutonnet (2000), the K_y of soybean were 0.2, 0.8, 1.0, and 0.85 under initial, crop development, mid season, and over growing period of growth stages, respectively.

According to the Doorenboss and Kassam (1979), for the individual growth periods, the decrease in yield due to water deficit is relatively small for the vegetative and ripening period, and relatively large for the flowering and pod formation periods.

Based on the above description, the research was conducted with the objective to investigate the influence of deficit irrigation at individual growth stages on yield of soybean, so that the irrigation schedule for the indivudual growth stages can be made to ensure optimum growth and production of soybean.

2 Materials and Methods

This research was conducted in a plastic greenhouse located in the experimental field of Lampung University from August to October, 2001. The soybean cultivar used was *Willis*. Soybeans were planted in black plastic containers and soil surface was covered with plastic mulch. The soil type was *Ultisol*. This soil texture consisted of 0.25kg/kg of sand, 0.26kg/kg of silt, and 0.49kg/kg of clay; and was classified as clayey soil. The bulk density was 1.09g/cm^3. Soil water content at field capacity (34.7kPa) was 0.35m^3/m^3 and wilting point (1585kPa) was 0.17m^3/m^3. Total available water (*TAW*) was 0.18m^3/m^3.

This research was conducted using a factorial experiment in randomized complete block design with three replications. The first factor of treatment (*S*) consisted of four different growth stages:S1-early vegetative stage, S2-advance vegetative stage, S3-flowering stage, and S4-pod filling to early maturity stages. The available water deficit was the second factor (*D*) with five levels: D1(0-20%), D2(20-40%), D3 (40-60%), D4 (60-80%), and D5(80-100)%. For example, the water deficit level, D2 meant that water was given to maintain the available water depletion between 20 and 40% of *TAW* in the root zone. When the maximum allowable depletion of available water got closed to 40% of *TAW*, water was applied to bring back the available water depletion to the deficit level of 20% of *TAW*.

Agronomic variables evaluated in this research were yield (*Y*), and crop water requirement (*CWR*). Statistical analysis was done using F-test at 5% significant levels, followed by Least Significant Different (LSD) test at the same level.

Soybean seeds were planted in black plastic containers (10 liters volume), which had been filled with 10kg air-dried soil. The role of black plastic container is assumed to be similar to a weighing lysimeter that hydrologically isolates soil surface from lateral inflow /outflow. Five seeds were planted in each container, and after one week only 2 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 in a month. The period of water stress was two weeks, except S4, which period was 4 weeks. Total growth period of soybean was 85 days. And two weeks before harvesting, irrigation was stopped.

Transpiration (*T*, mm/d), which determined crop water requirement, was measured by gravimetric method. Daily transpiration (*T*) was calculated by the following formula:

$$T=10\times\frac{WD_{i-1}-WD_i}{A_c} \quad (2)$$

where WD_i is the weight of container at day (*i*)(g), WD_{i-1} is the weight of container at day (*i*-1)(g), and A_c is the area of the container (=487cm^2).

Daily irrigation was done to maintain the soil moisture at certain level of deficit irrigation as shown in Table 1. The soil water condition for the whole growing season was maintained at 0-20% of *AW* deficit (D1) or water content between 0.31-0.35m^3/m^3, except for the water stress period at certain growth stage as shown in Tables 1 and 2. In the water stress period of S1 to S4, the water deficit treatments of D2 to D5 were applied.

Table 1: The range of deficit irrigation treatment

Water Deficit level (% of *TAW*)	water content (m^3/m^3)
D1 (0 - 20%)	0.350 - 0.314
D2 (20 - 40%)	0.314 - 0.278
D3 (40 - 60%)	0.278 - 0.242
D4 (60 - 80%)	0.242 - 0.206
D5 (80 -100%)	0.206 - 0.170

3 Results and Discussions

3.1 Crop Water Requirement

The influence of water deficit levels at individual growth stages on the total crop water requirement (*CWR*) is shown in Table 3. Numbers followed by the same letter were not significantly different using LSD-test at 5% significant level. Since plastic mulch was used to protect

Table 2: The scheme of the water management according to soybean's growth stages

week		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
growth stage		early vegetative		advance vegetative		flowering		pod filling		maturing			
available water deficit	S1	**D2～D5**		D1								no irrigation	
	S2	D1		**D2～D5**		D1							
	S3	D1				**D2～D5**		D1					
	S4	D1						**D2～D5**					

evaporation, the crop water requirement (*CWR*) in this experiment was equal to the total transpiration for the whole growing period. *CWR* is an indicator of water stress experienced by the plants leading to poor performance.

It can be observed from this table that there was no significant difference in *CWR* under the available water deficit of D2 for all the growth stages, since the soil moisture was more than the critical water content. However, there were significant differences in *CWR* for the rest of the treatments especially at S3 and S4 under D3, D4 and D5. Under the water deficit D3, soybean started to experince the water stress severely during the S2, S3 and S4 growth stages. Soybean was sensitive to water stress especially at S3 and S4, and the critical water content of these stages was around 50% of available water deficit or computed as $0.35-0.5\times(0.35-0.17)=0.26\mathrm{m}^3/\mathrm{m}^3$ (120kPa). It means that at S3 (flowering phase) and S4 (pod filling to maturing phase), irrigation to maintain soil moisture content at 50% of available water deficit is tolerable, but below this point will have an effect on the growth of soybean. At S2, the fraction of water depletion "*p*" was around 0.9 of available water deficit and the critical water content was computed as $0.35-0.9\times(0.35-0.17)=0.19\mathrm{m}^3/\mathrm{m}^3$ (616kPa).

Table 3: The effect of available water deficit at different growth stages on total the total *CWR* (mm)

AW Deficit level (%)	Growth stage S1	S2	S3	S4
D2	434.9	471.5	447.2	429.9
(20-40%)	abcd	a	ab	abcd
D3	439.7	390.7	392.7	352.6
(40-60%)	abc	def	def	f
D4	409.7	431.7	359.5	269.6
(60-80%)	bcd	abcd	ef	g
D5	401.0	407.5	269.0	217.8
(80-100%)	cde	bcd	h	i

3.2 Transpiration

Evaporation from soil surface was prevented by the mulching, hence the water loss from the pots was assumed to be only the transpiration of soybean. Therefore, the ET_a and ET_m in (1) could be substituted for T_a and T_m, respectively.

Figure 1 shows the relation between T_a/T_m and the fraction of water depletion "*p*". The value of T_a/T_m is the ratio of the actual transpiration (T_a) under available water deficit to the maximum transpiration (T_m) at each growth stage, which is an indicator that the plant is in stress condition. The value of T_a/T_m is corresponding to the water stress coefficient proposed by Allen *et al.* (1998).

Acording to Allen (1998); ET_{cadj} is the crop evapotranspiration under non standard condition (*i.e.* water stress condition) and can be calculated by the formula: $ET_{cadj}=K_s\times ET_c$, where K_s is water stress coefficient, and ET_c is evapotranspiration under standard condition.

In this case, ET_{cadj} was substituted by T_a and ET_c by T_m. The K_s value at S2 at D5 was $T_a/T_m=18.6/33.8=0.55$ (see Table 5). S3 and S4 was in stress condition at D3. By the same formula, the K_s values at S3 and S4 were calculated as 0.57 and 0.27 respectivelly.

The value of "*p*" is the ratio of available water stored in root zone to *TAW*, which is an indicator of water deficit level. For example, the value of "*p*" under the water management of D3(40-60%) treatment is 0.5.

Figure 1 shows that T_a/T_m values decreased with increasing "*p*", with S3 and S4 declining sharply. S1 decreased until p=0.3 and increased to p=0.5 and then decreased slightly afterwards. On the other hand, S2 showed a wave-like movement with a peak at p=0.3 and lowest at p=0.5. It means that the water stress condition at flowering (S3) and pod filling to maturity (S4) stages were too strong to be tolerated due to the effect of high transpiration rate.

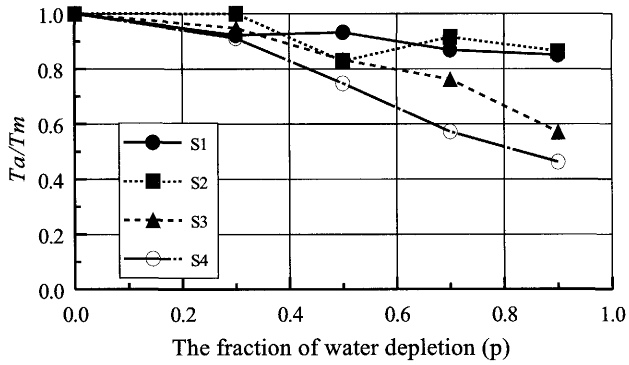

Figure 1: The effect of available water deficit at various growth stages

3.3 Yield

The effect of available water deficit (D) at the various growth stages (S) on yield is shown in Table 4. It could be seen that there is no significant deference in yield of S1 treatment for all the water deficit levels (D2～D5). Furthermore, the water deficit levels less than D5 during S2 showed no significant difference in yield. The yield under the water deficit of D2 and D3 during S3 and S4 showed no significant difference but experienced water stress under D4 and D5. It means that water stress at D3, having available water depletion fraction or p=0.5, a moisture was maintained at 40-60% of available water deficit through the whole period, was favorable and there had no effect to the yield.

Figure 2 shows the relation between (Y_a/Y_m) and the fraction of water depletion "p". The value of (Y_a/Y_m) is the ratio of the actual yield (Y_a) gained under available water deficit level of "p" to the maximum yield (Y_m) under no water stress condition, which is also an indicator that the plant is in stress condition.

Beyond the water depletion p=0.5, the values of Y_a/Y_m for the various growth stages decrease in the order S4<S3<S2<S1. It is clearly evident from these results that water deficit level applied during pod filling to early maturing phase affected the yield of soybean greatly.

Table 4: The effect of available water deficit at varous growth stages on yield (g/pot)

AW Deficit level (%)	Growth stage			
	S1	S2	S3	S4
D2	37.0	38.7	37.6	29.1
(20-40%)	abc	a	ab	bcdef
D3	35.7	30.9	31.0	23.1
(40-60%)	abc	abcde	abcde	efg
D4	33.9	32.1	27.8	14.0
(60-80%)	abcd	abcde	cdef	gh
D5	31.5	25.8	19.6	10.3
(80-100%)	abcde	def	fgh	h

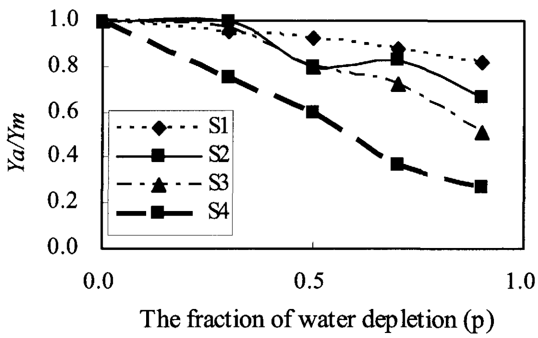

Figure 2: The effect of available water deficit at various growth stages to the Y_a/Y_m

3.4 Yield response factor

The values of the yield response factor (K_y) at individual growth stages (S1～S4) that were calculated using equation (1) are shown in Table 5. The K_y values are almost the same for the individual growth stage, and the average K_y values are 0.96 at early vegetative (S1), 0.42 at advance vegetative (S2), 0.46 at flowering (S3), and 1.20 at pod filling and early maturing (S4).

Figure 3 shows that the relationship between relative yield decrease ($1-Y_a/Y_m$) and relative transpiration deficit ($1-T_a/T_m$) is linear as assumed by Doorenboss and Kassam (1979), and the gradient of yield factor line is corresponding to the average K_y values.

According to this result, the effect of water deficit at S2 and S3 stages on the relative decrease of yield is small, since K_y values at S2 and S3 are smaller than 1, which are 0.42 and 0.46, respectively. However, the water deficit at early vegetative (S1) and pod filling to early maturing (S4) was sensitive to the relative decrease of yield due to high value of K_y, which is around 1.

3.5 Yield efficiency

Figure 4 shows the effect of available water deficit (D) at individual growth stage (S) to the yield efficiency. Yield efficiency (*YE*) is defined as the ratio of yield (g) of soybean to the crop water requirement (g).

It can be observed that there is no significant difference in YE values of S1. This implies that the damage caused by water defict at early vegetative stage (S1) could recover by full irrigation (D1) after advance vegetative

Table 5: The yield response factor of soybean

WD stage	Yield (g)	T (mm)	$1-Y_a/Y_m$	$1-T_a/T_m$	K_y
S1	37.0	6.2	0.04	0.05	0.88
	35.7	6.1	0.08	0.07	1.11
	33.9	5.7	0.12	0.14	0.89
	31.5	5.3	0.19	0.19	0.98
		6.6*			0.96**
S2	38.7	33.9	0.00	0.30	—
	30.0	25.2	0.20	0.48	0.42
	32.1	21.6	0.17	0.56	0.31
	25.8	18.6	0.33	0.62	0.54
		33.9*			0.42**
S3	37.6	87.6	0.03	0.11	0.26
	31.0	56.8	0.20	0.42	0.47
	27.8	39.8	0.28	0.59	0.47
	19.6	19.7	0.49	0.80	0.62
		98.2*			0.46**
S4	29.1	335.2	0.25	0.16	1.58
	23.1	262.4	0.40	0.34	1.18
	14.0	165.3	0.64	0.58	1.09
	10.3	100.9	0.73	0.75	0.96
		397.7*			1.20**

Remark:
* The value of maximun transpiration of all the treatments
** The average K_y value at each growth stage of water stress

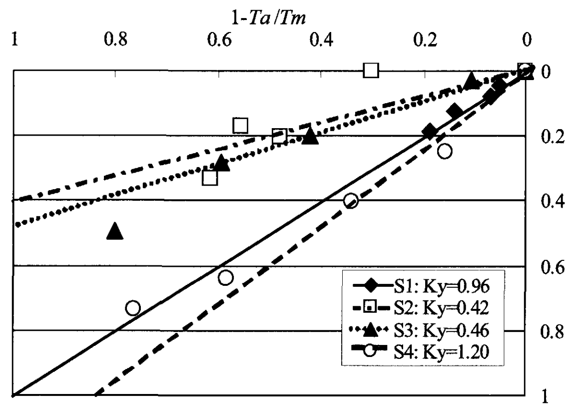

Figure 3: Yield response to water deficit at the different growth stages

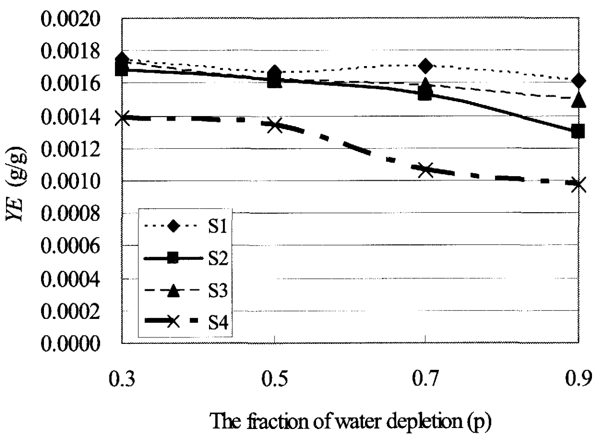

Figure 4: The relationship between the available water deficit(p) and yield efficiency (g/g)

stage (S2). However, all the levels of water deficit (D1～D4) at pod filling to early maturing stage (S4) decreased YE extremely, indicating that the deficit irrigation applied after the pod filling stage was not effective.

4 Conclusion

1. Soybean is sensitive to water stress especially at flowering to early maturing stage (S3～S4), and the critical water content at these stages was around 50% of available water deficit or 0.26 m^3/m^3. The critical water content at advance vegetative stage (S2) was 0.19 m^3/m^3.
2. Since the water deficit level during pod filling to early maturing stage (S4) was low, it affected the yield of soybean strongly.
3. The values of yield response factor (K_y) of S1, S2, S3, and S4 were 0.96, 0.42, 0.46 and 1.20 respectively.
4. The water deficit at early vegetative (S1) and pod filling to early maturing (S4) influenced the relative decrease of yield.
5. The damage caused by water defict at early vegetative stage (S1) could be recovered by full irrigation (D1) after advance vegetative stage (S2).
6. All the levels of water deficit (D1～D4) at pod filling to early maturing stage (S4) decreased yield efficiency extremely, which means that the deficit irrigation applied after the pod filling stage could not be tolerated.

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References

[1] Allen, R.G., LS. Pereira, d. Raes, and M. Smith (1998): Crop Evapotranspiration, Guidelines for computing crop water requirements, Irrigation and Drainage Paper no. 56, FAO, Rome, Italy. p.301.
[2] Doorenbos, J. and A.H. Kassam (1979): Yield Response to Water. FAO, Roma, pp.1-57.
[3] Fagi, A.M., and F. Tangkuman (1985): Water Management for Soybean, Food Crops Research Institute. Sukamandi, pp.135-138.
[4] Indonesian Statistic (1998): Indonesian Statistical Bureau, Indonesia, Jakarta.
[5] James, L.G. (1988): *Principle of Farm Irrigation System Design,* John Wiley & Sons. New York, pp.1-40.
[6] Kirda, C., P. Moutonnet, C. Hera, D.R. Nielsen. (1999): *Crop Yield Response to Deficit Irrigation,* Kluwer Academic Publisher, Dordrecht, the Netherlands, pp.21-38.
[7] Moutonnet, P. (2000): Deficit Irrigation Practise, Water Reports no. 22, FAO. Rome, Italy.
[8] Siswono. Y. (2004): The development in agricultural sector kept on decling (in Indonesia), Campus News Paper. 8 January 2004. p.1.

Discussion open until June 30, 2006