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Effects of Irrigation at Different Growth Stages on Yield Components and Yield of Soybean (*Glycine max* (L.) Merr.) Grown in the Low Country Dry Zone of Sri Lanka

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ABSTRACT. Irrigation is essential to achieve high soybean yields in the dry zone of Sri Lanka. When water supply is limited, manipulation of the timing of irrigation is one way of maximizing yield per unit of water applied. Therefore, the objective of this study was to quantify the yield response to irrigation at different phenological stages of soybean (var. PB-1) and to elucidate its physiological basis. Three phenological stages, namely, vegetative, flowering and pod-filling were identified. Treatments were defined as irrigation/non-irrigation during all possible combinations of the above stages.

Seed yields were sensitive to amount and timing of irrigation. Higher yields were achieved when a greater number of stages were irrigated. When two stages were irrigated the yield was not sensitive to the particular combination of stages irrigated whereas it was highly sensitive to the irrigated stage when only one stage received irrigation. Irrigation during flowering produced the highest yield gains whereas the lowest gains were achieved by irrigation during pod-filling. Variation of both total dry weight and harvest index contributed to differences in seed yield. Irrigation during flowering was essential for a high harvest index indicating the importance of retention of initiated flowers and young pods. This was confirmed by the high correlation between seed yield and the number of pods/m^2. The absence of negative correlations between yield components indicated that genetic improvement of soybean yields can be achieved by breeding for individual yield components. However, it also meant that yield component compensation was not possible in soybean.

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INTRODUCTION

Soybean is one of the main grain legumes grown in the dry zone of Sri Lanka during the drier *Yala* season (Dharmasena, 1987), particularly where water availability is not sufficient to grow a second rice crop (Arulnandhy, 1987). Due to the limited rainfall during *Yala*, soybean crops are often subjected to water stress. Therefore, alleviation of water stress through supplementary irrigation could produce significant yield increases in soybean.

In the dry zone of Sri Lanka, the predominant method of irrigating upland crops is surface irrigation. Because of the higher water requirement in surface irrigation as compared to other methods (Michael, 1978) and the general scarcity of irrigation water in the dry zone during *Yala*, ways of maximizing soybean yield gains in response to irrigation should be sought. Controlling the amount of water applied is difficult for the farmers. However, the timing of water application is one aspect of irrigation which can be manipulated by the farmers to achieve maximum yield increases from limited irrigation. The present study examines this aspect of irrigation response in soybean.

The physiological basis of maximizing yield gains through variation of timing of irrigation is the differential sensitivity of different growth stages of soybean to water stress (Sionit and Kramer, 1977; Silvius *et al.*, 1977). As the final seed yield is the product of final biomass and harvest index, any yield gains should occur through increases of one or both of the above two components. Therefore, achieving an adequate biomass through vegetative growth is an essential prerequisite for high yield. In addition, initiation of a higher number of flowers and pods and their subsequent filling through adequate photosynthesis would ensure a high harvest index and a high seed yield. Therefore, it can be hypothesized that all growth stages of soybean are sensitive to water stress and that final seed yields would respond positively to irrigation at any growth stage. Hence, the objectives of the present study were to quantify the yield response to irrigation at different growth stages of soybean and to elucidate the physiological basis of the above response.

MATERIALS AND METHODS

The experiment was conducted at Maha-Illuppaliama in the dry zone (DL_1) of Sri Lanka on Reddish Brown Earth (Rhodustalfs) soil during *Yala*, 1995. Soybean (var. PB-1) crops were established by seed at a spacing of 40 cm x 5 cm in 3 m x 3 m plots on 5th May, 1995. In order to apply different irrigation treatments, the plots were prepared as sunken beds. There was a distance of 1 m between plots on all sides.

Treatments and experimental design

Eight treatments were defined by different combinations of irrigation at 3 different growth stages. For this purpose, the life cycle of soybean was divided into 3 stages, namely vegetative, flowering and pod-filling. The vegetative stage was defined as the period between germination and observation of the first flower. According to the classification of developmental stages of soybean (Fehr *et al.*, 1971), the vegetative stage corresponded to the duration from the V_1 stage (*i.e.* just after germination) to the beginning of R_1 stage. The flowering stage was defined as the period between the observation of first flower (R_1 stage) and 75% pod initiation (R_4 stage). The period from 75% pod initiation (R_4) to maturity (R_8) was defined as the pod-filling stage. Respective durations of the 3 stages were 30, 28 and 29 days.

The experimental treatments consisted of all possible combinations of irrigation at the three different growth stages defined above (Table 1). As recommended by the Department of Agriculture (Anonymous, 1990), irrigation (I) was done twice weekly during the first 40 days after sowing (DAS) and thereafter once-a-week until harvest at 87 DAS. Therefore, the number of irrigations during vegetative (0-30 DAS), flowering (31-58 DAS) and pod-filling (59-87 DAS) stages were 8, 5 and 4, respectively (Table 1).

During each irrigation, the soil of the relevant plots were brought to field capacity. There was not a single rainfall during the whole period of the experiment (*i.e.* 87 days). Therefore, except for stored soil moisture, irrigations were the only source of water for the experimental crops.

The experimental design was a randomized complete block design with 3 replicates. Apart from the different irrigation regimes, all crops were managed similarly , according to recommendations of the Department of Agriculture (Anonymous, 1990).

Measurements

Total dry weight and leaf area index throughout the season were measured by destructive sampling of 10 randomly-selected plants on 14, 27, 40,

Table 1. Definition of experimental treatments.

Treatment	Growth stages and irrigations				
	Vegetative	Flowering	Pod filling	No. of stages irrigated	Total no. of irrigations received
T1	N	N	N	0	0
T2	I	I	I	3	17
T3	I	N	N	1	8
T4	I	I	N	2	13
T5	I	N	I	2	12
T6	N	I	I	2	9
T7	N	N	I	1	4
T8	N	I	N	1	5

N - Non-irrigated I - Irrigated

55, 69 and 87 DAS. Yield was measured by harvesting a pre-designated 1 m^2 area from the middle of the plot at 87 DAS. Yield components, *i.e.* number of pods per m^2, no. of seeds per pod and mean seed weight, were measured on 10 randomly-selected and pre-designated plants within the main harvest area.

Data analysis

Analysis of variance (ANOVA) of the measured data was carried out using the SAS statistical package. Pre-planned pairwise comparisons of treatment means were made using the least significant difference (LSD) at $p = 0.05$.

RESULTS AND DISCUSSION

Leaf area index (LAI) and total dry weight (TDW)

Significant ($p<0.05$) treatment differences in TDW and LAI were observed at all samplings (Figure 1). The treatment differences in TDW increased and became clear from 40 days after sowing (DAS). Final TDWs can be put into 4 clear groups on the basis of the number of growth stages irrigated, indicating that soybean growth responded to both timing and amount of irrigation. T2 had the highest TDW followed successively by T6, T4 and T5 which received irrigation during 2 growth stages. There was no significant difference in TDW within the above group. The group comprising of T8, T3 and T7 which received irrigation during only one growth stage followed next in that descending order. There were significant differences in TDW within this group. The unirrigated T1 treatment had the lowest final TDW. LAI s at 69 DAS also followed the same pattern as above with the exception T2 whose LAI was not significantly different from T4, T5 and T6.

Seed yield, yield components and harvest index

Seed yields among the different irrigation treatments (Table 2) were similar to the variation of final TDW with clear divisions into the four groups depending on the number of stages irrigated. Irrigation during all 3 growth stages caused a significant yield increase over all other regimes. Failure to irrigate during any stage caused reduced yields by 50 g/m^2. Irrigation at all 3 stages produced a 10-fold yield increase over the rainfed treatment. The group of treatments which received irrigation during two stages while showing a significant yield advantage over the group which received irrigation during only one stage, did not show significant yield differences among themselves. In contrast, there were significant yield differences within the group which received irrigation during only one stage.

The lowest yield reduction was shown when the single irrigation was provided during the flowering stage indicating that in rainfed cultivation of soybean, the most critical period in need of irrigation is the flowering stage. However, providing irrigation during one stage achieved significant yield increases over the rainfed crop. The above pattern showed that soybean yields are sensitive to both the timing and the total amount of irrigation.

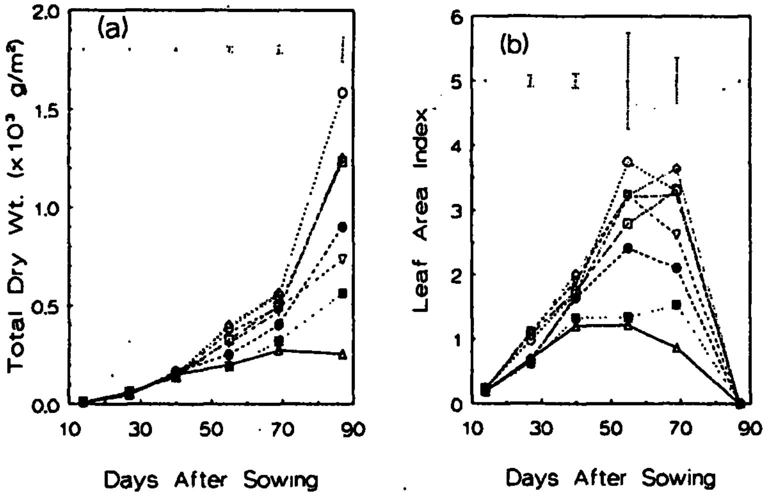

Figure 1. **Seasonal variation of total dry weight (a) and leaf area index (b) under different irrigation regimes. Vertical bars indicate LSD at p=0.05. ▵-T1; o-T2; ▿-T3; ◇-T4; □-T5; +-T6; ■-T7; ●-T8.**

Although the variation of final TDW followed the same pattern as that of seed yield, significant inter-treatment variations in harvest index (HI) (Table 2) were also responsible for the above-described variation. Treatments which received irrigation during 2 stages had significantly higher HI. The treatment which received irrigation only during the flowering stage also had a HI which was similar to the above group which received irrigation during 2 stages. This meant that adequate partitioning of assimilates into reproductive structures would occur if the crop is not water-stressed during the flowering stage. More importantly, irrigation during the flowering stage would ensure adequate retention of reproductive sinks to be filled during the subsequent period (Fageria *et al.*, 1991; Frederick and Hesketh, 1994). This is confirmed by the variation pattern of the number of pods/m^2 (Table 2).

The number of pods/m^2 and the number of seeds per pod showed significant variation between treatments (Table 2) while mean seed weight was relatively stable across the irrigation regimes. Numbers of pods/m^2 and seeds per pod showed highly significant positive correlations with seed yield (Table 3).

Table 2. Seed yield, yield components and harvest index under different irrigation regimes.

Trt.	Seed yield (kg/ha)	No. of pods/m^2	No. of seeds per pod	Mean seed weight (g)	Harvest index (%)
T1	252 F	393 E	0.85 F	0.101 B	27.79 D
T2	2505 A	1820 A	1.64 AB	0.105 B	55.92 A
T3	1119 D	947 D	1.38 CD	0.114 AB	49.2 B
T4	1982 B	1351 BC	1.79 A	0.109 AB	56.97 A
T5	2004 B	1449 BC	1.62 AB	0.113 AB	55.42 A
T6	2017 B	1519 B	1.56 BC	0.112 AB	56.21 A
T7	798 E	781 D	1.11 E	0.122 A	38.27 C
T8	1419 C	1269 C	1.34 D	0.114 AB	55.95 A
CV(%)	8.99	10.7	8.62	7.02	6.76

Note: Means in a column followed by the same letter are not significantly different at $p = 0.05$.

The number of pods/m^2 was the major determinant of final seed yield. Therefore, ensuring initiation and retention of an adequate number of reproductive sinks is the physiological basis of maximizing yield gains in soybean through irrigation. While irrigation during all 3 stages would be the best option to achieve the above requirement, in a situation where water is limited, irrigation during the flowering stage can be recommended. In addition, the significant correlation between seed yield and the number of seeds per pod meant that adequate seed set is also required to achieve high soybean yields. Irrigation of two growth stages produced the highest seed set. Treatment comparisons showed that seed set is more sensitive to water stress during vegetative and flowering stages than during the pod-filling stage. Most probably, the abortion of ovules and fertilized embryos due to water stress

Table 3. Correlation matrix between seed yield and yield components.

	No. of pods/m^2	No. of seeds/pod	Mean seed weight
Seed yield	0.965***	0.867***	0.006^{ns}
No. of pods/m^2	-	0.753***	0.017^{ns}
No. of seeds/pod	-	-	-0.028^{ns}

*** - significant at p=0.0001   ns - non-significant at p=0.05

(Frederick and Hesketh, 1994) at the above two stages determined the number of seeds per pod.

There were no negative correlations between yield components (Table 3) indicating that soybean yield improvement could be achieved through breeding for higher individual yield components. The absence of negative correlations also meant that there was no 'yield component compensation' in soybean. Therefore, if a yield component is reduced due to some factor (eg. water stress), the reduction of yield would not be compensated by an increase in a subsequent yield component.

CONCLUSION

The present study showed that significant yield gains in soybean can be achieved by manipulating the timing of irrigation. When irrigation water is limited, irrigating any two growth stages would produce significant yield gains as compared to irrigating only one stage or maintaining the crops under rainfed conditions. When it is possible to irrigate two stages, the resulting yield does not depend on the combination of stages irrigated. On the other hand, if irrigation can be provided for only one growth stage, the yield gain would be highly dependent on the stage of irrigation. The highest gain would be achieved by irrigation at the flowering stage while the lowest at the pod-filling stage. Practical recommendations to farmers can be based on the above observations.

Soybean yield gains in response to irrigation are achieved through increases in both TDW and HI, indicating the importance of both photosynthesis and partitioning of assimilates. In addition, retention of a greater number of reproductive sinks by having a higher number of pods/m^2 and ensuring a higher seed set through a greater number of seeds per pod are prerequisites to maximize yield gains by manipulation of the timing of irrigation. Yield losses due to decreases in the above two yield components cannot be compensated through increases in mean seed weight which remained largely insensitive to irrigation.

It should be noted that the above conclusions are based on only one season's results. Therefore, the experiment is being repeated in *Yala*, 1996 to confirm the results and conclusions of the present work.

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