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Determination of Optimal Irrigation Scheduling for Soybean (*Glycine max L.*) Yield and Water Productivity at Jimma, South West Ethiopia

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Abstract

The knowledge of crop water requirement is an important practical consideration to improve water use efficiency in irrigated agriculture. Water use efficiency can be improved by proper irrigation scheduling, which is essentially governed by crop evapotranspiration (ETc). Therefore, this activity is aimed to evaluate the responses of soybean to irrigation regime (when and how much to irrigate). Field experiment was conducted during 2016 up to 2018 to determine the optimal irrigation regime of soybean (*Glycine max* L.) at Jimma Agricultural Research center under five irrigation treatments (Irrigation at 60% ASMDL, 80% ASMDL, ASMDL, 120% ASMDL and 140% ASMDL). For irrigation treatment at allowable soil moisture depletion (ASMDL), irrigation was scheduled when 50% of the total water available was depleted. The three years combined result indicated that there were a highly significant ($P<0.01$) variation among treatments for grain yield and water productivity. The grain yield of soybean was significantly ($P<0.01$) affected due to moisture stress imposed at different growth stages. Accordingly, the highest grain yield and water productivity was obtained from FAO recommended allowable soil moisture depletion level (ASMDL) treatment. As a moisture depletion level goes up or down from the FAO recommended soil moisture depletion level the grain yield and water productivity declined. Therefore, for better water productivity without a yield loss, it is recommended to use FAO recommended allowable soil moisture depletion (0.5) for soybean production in Jimma area on sandy loam soil.

Keywords: ASMDL; Irrigation regime; Soybean; Water productivity

Abbreviations: ETc: Crop Evapotranspiration; ASMDL: Allowable Soil Moisture Depletion Level; RCBD: Randomized Complete Block Design; MRR: Marginal Rate of Return

Introduction

Water is the elixir of life. Water is a scarce resource with competing demands drinking, irrigation, industrial and recreational uses. Irrigation is by far the largest demand of water among the competing uses in many semi-arid agricultural regions [1]. Against these backdrops and in the context of dwindling fresh water reserves, it is imperative that the agricultural sector use its irrigation water more efficiently. Exploring and identifying strategies to achieve a substantially more efficient and productive use of water in irrigation can be done through field experimentation [2].

Irrigation implies the application of water to crops in right amount at the right time [3]. Salient features of any improved method of irrigation is the controlled application of the required amount of water at desired time, which leads to minimization of range of variation of the moisture content in the root zone, thus reducing stress on the plants. Due to water shortage, crop plants undergo severe water-stress which might affect yields. Irrigation scheduling is a viable solution technique for systematically determining the time and quantity of irrigation in individual fields where there is water shortage [1,4].

Soybean (*Glycine max L.*) is the world's most important grain legume crop in terms of total production, consumption and international trade. It is an important grain legume because of its high protein (35%), and nitrogen fixing ability (17-127kg N ha^{-1} $year^{-1}$) [5]. Soybean is inherently more stress tolerant [6] than other legume crops but it still suffers considerable damage due to drought stresses in different regions. Allen et al. [7] has expressed the moisture depletion level for soybean should be 0.5. However, the recommendations are needed to be verified on the operational environment since the crop water requirement is dependent on the type of crop and climatic condition. For effective use of available water resource, it is relevant to determine the actual crop water need and the right time of water application (irrigation scheduling). However, limited information is available in the technical literature on optimum level of irrigation water in the study area. This study investigated the effects of different levels of water supply and application frequency on the water use efficiency.

Materials and Methods

Description of the Experimental Area

The experiment was conducted at Jimma Agricultural research center in south west Ethiopia for the consecutive three years. The Jimma Agricultural research center is located at 7046' N latitude, 3600' E longitude, and at an altitude of 1753m above sea level. The center receives an average annual rainfall of about 1530mm with monthly mean maximum and minimum temperatures of 25.9 °C and 11.3 °C, respectively. The soil texture has been classified as sandy loam soil and the available water holding capacity per unit meter of the soil profile in the root zone is 121mm (Figure 1).

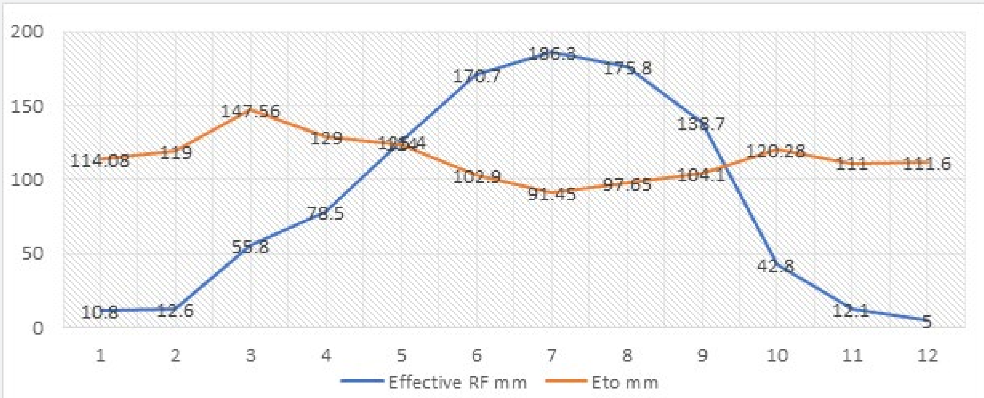

Figure 1: Monthly rainfall as compared with reference evapo-transpiration.

Experimental Materials, Design and Management

A field experiment was carried out in three seasons of 2016 and 2018. Randomized Complete Block Design (RCBD) with three replications was used following the procedure of Gomez and Gomez [8]. Five treatments of different soil moisture depletion level were assigned and randomized in plots. The treatments are 60, 80, 120 and 140% ASMDL (FAO recommended allowable soil moisture depletion level) and FAO recommended ASMDL assigned as a check. The optimal irrigation schedule (ETc) was computed with Cropwat model.

Each individual plot had area of 3.0m X 3.0m = 9.0m^2, which consists of 5 rows. Clark 63K soybean variety (*Glycine max L.*) was used as seed source. The recommended spacing of 75 and 5cm between row and plant was employed. Each experimental treatment was fertilized with recommended fertilizer application, that was 100kg/ha and 100kg/ha of DAP and Urea, respectively. All cultural practices were done to all treatments in accordance to the recommendation made for the area. Irrigation water was applied as per the treatment to refill the crop root zone depth close to field capacity.

Data Collected

Yield and growth parameter were recorded, and the treatments were compared based on grain yield and growth parameter, which includes plant height, above ground biomass and grain yield. Also, water productivity of the crop was estimated. Grain yield was calculated by harvesting the total number of plants in the net plot (3.75m^2) and grain yield per plot was measured using electronic balance and then adjusted to 10.0% moisture and converted to hectare basis. Above ground biomass was determined by harvesting all the plants from the net plot area at physiological maturity and weighed after sun drying to a constant weight and converted to hectare basis. The water productivity was calculated by the ratio of harvested yield per total water used.

$$W\rho = \frac{Harvested\ grain\ yield}{Total\ water\ used} \ldots\ldots\ldots(1)$$

The data were statistically analyzed combined for all years by SAS software. SAS software version 9.2 for windows was used for analysis [9]. Whenever the treatment effects were found significant, GLM test at 1 and 5% was performed to assess significant difference among treatments means.

Economic Evaluation

To assess the costs and benefits associated with different treatments the partial budget technique as described by CIMMYT [10] was applied on the yield results. Economic analysis was done using the prevailing market prices during experimentation and at the time the crop was harvested. All costs and benefits were calculated on hectare basis in Ethiopian Birr (ETB/ha). The different costs of the experiment that includes cost for irrigation water and labor cost to irrigate were the variable costs among the different treatments. The adjusted yield was obtained by reducing the average yield by 10% as indicated in CIMMYT [10]. The average cost the local people were paying for daily labor was 26.00 Birr per day. The farm gate price of Soybean during the harvesting time was 15 Birr/kg and the price of irrigation water was taken 1.00 Birr per 10m^3 of water (own assumption). Some of the concepts used in the partial budget analysis are gross benefit, total variable cost and net benefit. The gross benefit was obtained as the product of the real price and the adjusted grain yield of common bean for each treatment. The Dominant analysis procedure as detailed in CIMMYT [10] was used to select potentially profitable treatments

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from the range that was tested. The selected and discarded treatments using this technique are referred to as undominated and dominated treatments, respectively. The undominated treatments were ranked from the lowest to the highest variable cost. For each pair of ranked treatments, a percentage marginal rate of return (MRR) was estimated.

Result and Discussion

Plant Height

The over years analysis of variance revealed that there is no a significant difference ($p<0.05$) among treatments on soybean plant height (Table 1). Even though, the maximum plant height was obtained from 60% ASMDL (sixty percent of the allowable soil moisture depletion level) followed by 80% ASMDL and ASMDL (FAO recommended soil moisture depletion level). Whereas, the minimum was obtained from 140% ASMDL. From the present study, as a moisture depletion level reduced the plant height of the crop increased but not statistically significant. Similar research conducted by Admasu et al. [11] reported that plant height is not significantly affected by the different depletion levels but, the plant height improved as a moisture depletion level reduce which agrees with the current findings. The current result agrees with the finding of Gadissa et al. [12] on Vernonia (*Vernonia galamensis L.*). They reported that the plant height affected by the different level of soil moisture depletion level and as the soil moisture depletion level increase from 30% to 100%, plant height was reduced by 20.8%.

Table 1: Effect of different soil moisture depletion level on yield, yield components and water productivity result and discussion.

Treatments	Plant Height (cm)	Dry Bio Mass Yield (t ha^{-1})	Grain Yield (K.g ha^{-1})	Water Productivity (K.g m^{-3})
60% ASMDL	69.63	5.81	2747.3ab	0.74bc
80% ASMDL	68.74	5.21	2764.8ab	0.77ab
ASMDL	68	5.18	2924.5a	0.81a
120% ASMDL	64.21	4.58	2580.7bc	0.54bc
140% ASMDL	63.9	4.07	2439.2c	0.51c
LSD at 0.05	ns	ns	242.51	0.05
CV %	9.02	13.45	7.45	8.82

Means followed by the same letters within columns do not differ significantly at $p<0.05$ probability level according to LSD. ASMDL- allowable soil moisture depletion level, ns- not significantly different.

Above ground dry biomass yield

The over years analysis of variance revealed that there is no a significant difference ($p<0.05$) among treatments on soybean above ground dry biomass yield (Table 1). The maximum soybean above ground biomass yield obtained from 60% ASMDL (sixty percent of the allowable soil moisture depletion level) whereas, the minimum was obtained 140% ASMDL (Table 1). From the current study, as the irrigation scheduling become frequent, the above ground biomass production improved linearly. However, this result is contradicted with the finding of Tesfaye et al. [13] on lemongrass.

Grain yield

Different soil moisture depletion level had a significantly ($P<0.05$) influenced grain yield. The maximum grain yield (2924.5kg ha^{-1}) was recorded in FAO recommended ASMDL treatment (Table 1). However, this result was not statistically higher than 80% ASMDL and 60% ASMDL. On the other hand, the minimum grain yield (2439.2kg ha^{-1}) was obtained at 140% ASMDL (Table 1). This was statistically similar with 120% ASMDL treatment. As soil moisture depletion level increase and decrease away from FAO recommended ASMDL, seed yield was slowly decreased. Increasing soil moisture depletion level from FAO recommended ASMDL to 140% ASMDL leads to a decrease of 7% grain yield. Whereas declining of soil moisture depletion level from FAO recommended ASMDL to 40% ASMDL leads to a reduction of 13% in grain yield (Table 1). Gadissa et al. [12] on Vernonia (*Vernonia galamensis L.*) reported that from the maximum soil moisture depletion level goes down or up reduced the grain yield which agrees with the current finding. Similar result also reported on lemongrass [13], maize [14] and potato [11]. Basu and Singh [15] reported decreased seed yield under drought conditions Better yield at 60% soil moisture depletion level might be due to normal moisture supply which helped in root enhancement, capsule setting, and higher 1000seed weight. Nielsen [16] reported that chickpea exhibited the greatest rate of increase in yield with an increase in water use. Over-irrigation decreased seed yield by 24.3% when irrigated at 30% soil moisture depletion level. It might be due to the fact that frequent irrigation leads to shallow root and enhance vegetative growth rather than seed yield. These findings are confirmed by the results of Hassan and Sarkar [17] who concluded that application of further irrigation in chickpea gradually decreased yield and water use efficiency, causing the wastage of irrigation water.

Water productivity

The over years analysis of the result revealed that water productivity was significantly ($p<0.05$) influenced by different soil moisture depletion levels. The highest water productivity was obtained from (0.81kg/m^3) was obtained at FAO recommended ASMDL followed by 80% ASMDL (0.77kg/m^3) which are statistically the same (Table 1). Whereas, the minimum was obtained from 140% ASMDL (0.51kg/m-3) followed by 120% ASMDL (0.54 kg/m^{-3}) (Table 1). From the present study, the highest water productivity was got from the treatment which have the maximum grain yield. The reason behind is the amount

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of water consumed by all treatments approximately equal due to that the maximum water productivity was obtained from the treatment who have a maximum nominator (i.e. grain yield). The study clearly showed that grain yield was increased until the soil moisture depletion level increased to FAO recommended ASMDL. However, beyond this level, grain yield was reduced gradually. Also, the water productivity was gradually increased until the soil moisture depletion level increased to FAO recommended ASMDL. This result is consistence with the finding of Yaziz & Tefera [14] on maize. The current finding is in line with the findings of Tesfaye et al. [13] and Singh [18] who reported maximum water use efficiency of lemongrass recorded around mid of the tested irrigation water levels.

Economic Comparison of Stage Specific Moisture Stress

Table 2: Economic analysis result and discussion.

Treatments	Mean Yield (K.g/ha)	Adjusted Yield (K.g/ha)	Gross Benefit (ETB/ha)	Cost of Irrigation Water (ETB/ha)	Labor Cost (ETB/ha)	Gross Cost (ETB/ha)	Net Benefit (ETB/ha)	MRR (%)
60% ASMDL	2747.3	2472.57	37088.6	422.6	11510.4	11933	25155.5	D
80% ASMDL	2764.8	2488.32	37324.8	427.7	11171.9	11599.6	25725.2	D
ASMDL	2924.5	2632.05	39480.8	460.2	10156.3	10616.5	28864.3	1059.34
120% ASMDL	2580.7	2322.63	34839.5	466.1	9750	10216.1	24623.3	201.26
140% ASMDL	2439.2	2195.28	32929.2	441.4	9140.6	9582	23347.2	-
Sensitivity Analysis								
Treatments	Mean Yield (K.g/ha)	Adjusted Yield (K.g/ha)	Gross Benefit (ETB/ha)	Cost of Irrigation Water (ETB/ha)	Labor Cost (ETB/ha)	Gross Cost (+10%) (ETB/ha)	Net Benefit (-10%) (ETB/ha)	MRR (%)
60% ASMDL	2747.3	2472.57	37088.6	422.6	11510.4	13126.3	22639.98	D
80% ASMDL	2764.8	2488.32	37324.8	427.7	11171.9	12759.5	23152.71	D
ASMDL	2924.5	2632.05	39480.8	460.2	10156.3	11678.1	25977.87	866.73
120% ASMDL	2580.7	2322.63	34839.5	466.1	9750	11237.7	22161.01	164.67
140% ASMDL	2439.2	2195.28	32929.2	441.4	9140.6	10540.2	21012.46	-

Remark; ASMDL- allowable soil moisture depletion level.

The results of economic analysis revealed that, the highest net benefit of 28,864.3 ETB/ha obtained from the recommended allowable soil moisture depletion level i.e. 50% (0.5) with a marginal rate of return (MRR) of 1059.34% (Table 2). Sensitivity analysis of irrigation method relative to 10% increase in the cost of water and labor as well as 10% loss due to different post-harvest problem, transportation and storage the MRR remains above the acceptable range. This depict relative advantage and stability of economic benefits due to the irrigation method in the production of Soybean in Jimma and other similar area.

Conclusion and Recommendation

Agricultural water scarcity is the most critical constraint for the development of agriculture in arid and semi-arid climates. Hence, effective use of available water with appropriate irrigation scheduling has a significant implication on irrigated agriculture. Based on this, the experiment was conducted to determine the optimal depletion level. From the result obtained, there is a significant difference among treatments on soybean grain yield and water productivity. The maximum yield and water productivity were obtained from the FAO recommended soil moisture depletion level. Although the minimum was obtained from 140% of FAO recommended allowable soil moisture depletion level. From the current study we can observe that as a moisture depletion level goes down to 20% ASMDL it produces a yield loss 7% and also, when it goes up until 140% ASMDL the yield loss reached 13%. Also, the economic analysis revealed that irrigate the crop when the soil moisture level reached 50% of the total available water gave maximum net benefit with highest MRR. Therefore, irrigation of soybean (Glycine max L.) at recommended soil moisture depletion level (i.e. 50% total available water in the root zone) is an optimum depletion level based on the current finding based on grain yield, biomass yield, plant height and water productivity.

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