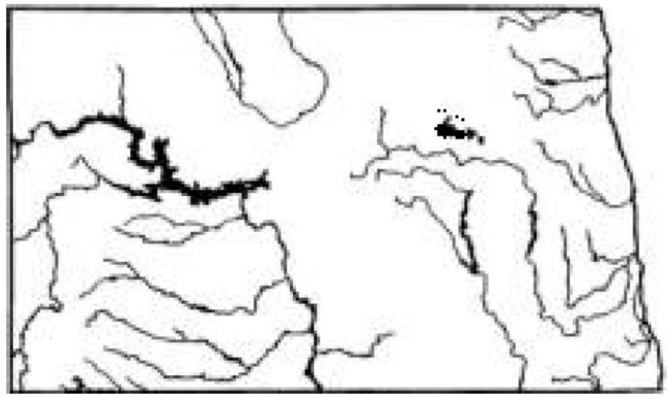

Technical Report No: ND19-01

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Responses of soybean (*Glycine* max) growth, yield, crop water use, and water use efficiency (WUE) along with root mass distribution to four constant water table depths (WTDs) of 30 (T_{30}), 50 (T_{50}), 70 (T_{70}), and 90 (T_{90}) cm were studied under a controlled environment using lysimeters. Additionally, irrigation treatment was included in the study as control experiments ($T_{control}$). A randomized complete block design was used with six replications in each treatment. The highest and lowest seed weight was found 7.00 and 3.91 g plant^{-1} at the 90 cm WTD (T_{90}) and irrigation treatment, respectively. Grain yield WUE values were 0.08, 0.22, 0.18, 0.25, and 0.31 and total biomass WUE values were 0.16, 0.53, 0.41, 0.53, and 0.61 for $T_{control}$, T_{30}, T_{50}, T_{70}, and T_{90} treatments, respectively. All these results showed that the highest WUE for grain yield and total biomass were found at 90 cm WTD treatment. Soybean was found to be tolerant to shallow groundwater conditions since the root mass distribution in the soil profile was significantly influenced by the presence of shallow WTDs. As a future study, a combined effect of groundwater depth and the impact of salinity could be studied. Additionally, field experiments using lysimeter could be conducted.

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BACKGROUND

Increases in the world population also increases the global demand for water use in urban, industrial, environmental, and agricultural areas. The world population is estimated to approach about 9 billion in 2050, which means water demand will be increased significantly during the upcoming decades (Ayars et al., 2006). Annual available water resource per capita is expected to decrease from 6,600 m^3 to 4,800 m^3 in 25 years due to the increasing global population. Since water resources are not evenly distributed in the world, around 3 billion people living in the arid and semi-arid regions greatly suffer from water scarcity and will have less than 1,700 m^3 annual water resource per capita (Cosgrove and Rijsberman, 2000).

The Food and Agricultural Organization reported that agriculture occupy 69% of the total water consumption, while industrial and municipal utilization cover 19 and 12% of water consumption, respectively in the world. It was projected that increases in world population cause an intensification of industrial development, hence water utilization in this sector could be increased accordingly. Therefore, water demand could affect the amount of water utilization in agricultural sectors since more water could be used in industrial area (Ayars et al., 2006; Hamdy et al., 2003). Thus, in agricultural sector, it is assumed that many arid and semi-arid regions will have difficulties to reach a sufficient and reliable water source (Hamdy et al., 2003; Steduto et al., 2017). To deal with this potential water crisis in agriculture, new water management approaches and strategies are required.

Improving water use efficiency (WUE) in agricultural sector is important and therefore, shallow water table contributions to crop growth have gained attention in recent years. Agricultural water management could be advanced by supplying sufficient amount of water from the groundwater in various water table depths (WTDs) (Ghamarnia et al., 2011). Highy yield and crop water use efficincy can be achieved with the optimum WTD. Therefore, determining a crop water requirements in different growth stages are important to calculate water requirement (Ayars et al., 2001; Franzen, 2013). Shallow groundwater is considered an alternative water resource for both dry and irrigated agriculture when the quality of groundwater is acceptable for sustainable crop production (Hutmacher et al., 1996). Optimum WTD is not only supplies a significant amount of water to crops but it eliminates waterlogging in the root zone (Kahlown and Ashraf, 2005).

Projected restrictions on availability of water for food production could be overcome by improving agricultural WUE, which is a strong indication of the improved agricultural water management. Improved WUE is possible through innovations in irrigation, technological development in drainage systems, improved crop tolerance, and productive land use (precision agriculture). Deficit irrigation applications combined with water use from shallow groundwater could be an approach to increase WUE in arid and semi-arid areas where water supply is limited (Franzen, 2013).

Several variations are affecting crop growth under shallow groundwater. Crop growth is a complex system under shallow groundwater levels due to limited information on the potential contribution of groundwater to plant water-use. Therefore, a lysimeter study was used to determine water table contributions to soybean (*Glycine max* L. Merrill) water demands and plant growth (Ghamarnia and Daichin, 2013; Talebnejad and Sepaskhah, 2015; Fidantemiz et al., 2019).

Lysimeters are soil columns with a known volume and cross-sectional area and they are used to determine water-balance variables in agriculture. Plant root density distribution, root growth and development, and different stress factors include temperature, water, and drought stress can be studied in lysimeter system. Lysimeters can be equipped with soil water potential sensors, tensiometers, suction cups, oxygen probes, and temperature sensors. During the crop growing season, the level of water table is likely to change with the effect of input (precipitation and irrigation) and output (evaporation) parameters. Lysimeter studies will be a simple and secure way to obtain a better understanding of the relationship between these input-output balance and crop yield.

Soybean is extensively grown oilseed crop all around the world. Soybean, as a legumes plant, is well acknowledged for its good agronomical performance as well as for its importance in the sustainable agricultural systems. Production of soybean in North Dakota (ND) increased between the years of 1980 and 2018. Particularly, based on soybean yield (Mg/ha), five counties in ND were ranked in first 20 soybeans producing counties in the US in 2014 (ND Soybean Council, 2017). Groundwater variation and soil salinity are two important factors for the soybean crop in eastern ND. The temporary water table in these areas is relatively shallow during the rainy seasons and the water table rise become challenges that influence the growth and yield of soybean. Water table rise and salinity issues are interrelated and could be mitigated by conservation practices (Franzen, 2013; Niaghi and Jia, 2017).

North Dakota is located in the center of North America, and it has a continental climate that is a characteristic feature of the Great Plains and Midwest. The climate of North Dakota is characterized by high-air temperature variations, irregular rainfall, and low humidity. The water table in North Dakota is fluctuating based on the precipitation and snow melting, hence temporary shallow water table become challenges that influence in both positive and negative ways to the growth and yield of many agricultural products including soybean (Niaghi and Jia, 2017)

DESCRIPTION OF THE CRITICAL STATE OR REGIONAL WATER PROBLEM INVESTIGATED

Controlled drainage is an effective way of maintaining an optimum water-table depth in ND in order to increase the harvest yield. When optimal WTD is maintained, groundwater can be considered as an excellent water source for soybean to support the crop water requirement. Optimum WTD can prevent waterlogging and provide the necessary oxygen to the plants through roots. With ideal drainage system management, groundwater table level can be maintained to the bottom of rootzone during the plant growing season (Franzen, 2013). Thus, it has an outstanding approach to apply controlled drainage in ND to control the water table rise for soybean plant.

Lysimeter study in the greenhouse condition has an advantage to investigate water table contribution to plant water use to improve WUE in ND agriculture. Farmers will benefit with the given information about soybean tolerance on water depths since the results from this particular study will directly reduce the risk of yield reduction in the field. As of the author’s knowledge, there is not a study available to investigate drainage systems, groundwater level, salted groundwater, capillary rise, and groundwater potential for soybean plant by using lysimeters in the controlled environment. Investigating water table effect on soybean in a farm is time consuming, cost effective, and difficult to apply. However, a lysimeter test is the simplest and a more tenable way to achieve the goals stated in this proposal and the results obtained in this study can be transferred to large scales. With the comprehensive data that will be collected in this study, field scale tile drainage system with control structure will be able to design.

Capillary rise from water table will potentially reduce the amount of excess irrigation water. The contribution of capillary flux to crop water use can be quantified by using controlled water table levels in lysimeter experiments (Gao et al., 2017). Therefore, the data obtained in this study could be used to develop a model to simulate the water movement in the soil profile using some software, such as HYDRUS-1D model. Modeling techniques will help to simulate soil moisture and root uptake under different crop conditions to increase the soybean yield with optimum utilization of groundwater (Schaap et al., 2001; Šimůnek et al., 2013). The upward water movement from the water table and percolation to the water table can be simulated with the data obtained in this study. Additionally, modeling techniques help to determine the optimum WTDs and irrigation water amount on yield, crop evapotranspiration, water use efficiency, and irrigation water productivity of soybean.

Overall, this study was conducted in a greenhouse conditions and the results could provide introductory information for farmers and scientists about different depths of groundwater contribution to soybean plant. The producers and stakeholders in the areas where drainage problems exist could get benefit of the results of this research. This study has already presented in regional and national conferences and published as a peer reviewed journal article (Fidantemiz et al., 2019).

SCOPE AND OBJECTIVES

The main scope of this study is to determine an optimum shallow groundwater depth to achieve high yield soybean production. The specific objectives are as follows;

- To determine the optimum groundwater depth for soybean growth and yield parameters at water table depths of 30, 50, 70, and 90 cm without irrigation.
- To determine the amount of water consumption at different water table depths of 30, 50, 70, and 90 cm during the growing period of canola.
- To determine the root distribution of the soybean plant in the lysimeters at water table depths of 30, 50, 70, and 90 cm.

MATERIALS AND METHODS

Experimental design and preparation of lysimeters

The greenhouse experiments were conducted at North Dakota State University's greenhouses located in the university campus, Fargo, North Dakota. Total thirty lysimeters were used in this study. Six lysimeters were used as a control treatment with irrigation from the soil surface with no water table. In these controls, 50% of total available moisture was considered as a readily available moisture in the soil profile, and this point was used to give a decision point for applying irrigation. The remaining twenty-four lysimeters were used to test the groundwater contribution without any surface irrigation on crop production using four WTD treatments of 30, 50, 70 and 90 cm (measured from the top of the lysimeters) and all the treatments were replicated 6 times (6*4 = 24 lysimeters) (Figure 1).

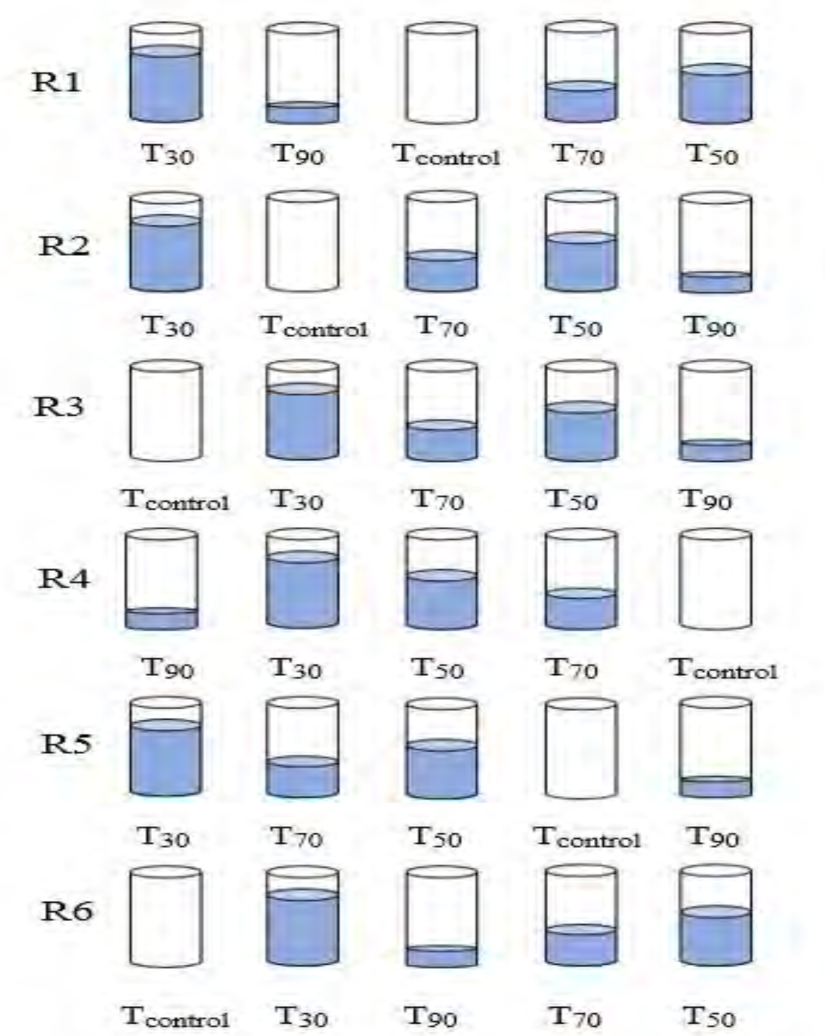

Figure 1. Schematics of randomized complete block design using 30 lysimeters. R1, R2, R3, R4, R5, and R6 are the replications for any particular treatment as shown $T_{control}$, T_{30}, T_{50}, T_{70}, and T_{90}.

First treatment was the irrigation treatment and was called as $T_{control}$ while other four treatments were non-irrigated treatments and they were called as T_{30}, T_{50}, T_{70}, and T_{90}. Non-irrigated treatments were continuously feed from the bottom of the lysimeters upward using Marriot bottle method to supply constant rate of flow to the lysimeters to maintain the designed WTD (30, 50, 70, and 90 cm). The volume of Mariotte bottles were 8 liters with a working volume of 6 liters and they were placed on adjustable shelves. A total of 24 Mariotte bottles were used and the height of each shelf was adjusted for the desired level based on the water depth in the lysimeters. The water volume in the Mariotte bottles were measured periodically (15 days) and the measured difference were considered as the portion of crop water use in the soil column. The water volume in the Marriott bottles were monitored and replaced back to the bottles to keep the system running continuously. The volume of water for each replenishment in the Marriott bottles was measured with graduated cylinders and recorded on a chart. Total losses from the Mariotte bottles were calculated to determine groundwater contribution to plant water use.

In this study, the bulk soil sample was collected from Fergus Falls, MN and uniformly packed into the lysimeters. The soil physical properties of the packed lysimeters are presented in in our publication (Fidantemiz et al., 2019). The soil texture was a loam based on the USDA classification system. Prior to packing, the soil samples were dried at the ambient temperature and sieved from 2 mm screen.

To prevent soil compaction in the lysimeters, the ratio of 300 g of sand and 1000 g of soil were mixed using electrical mixer. The bottom of the lysimeters filled with 12 cm gravel, and top of it filled with 12 cm sand and then 96 cm loam soil (Figure 2).

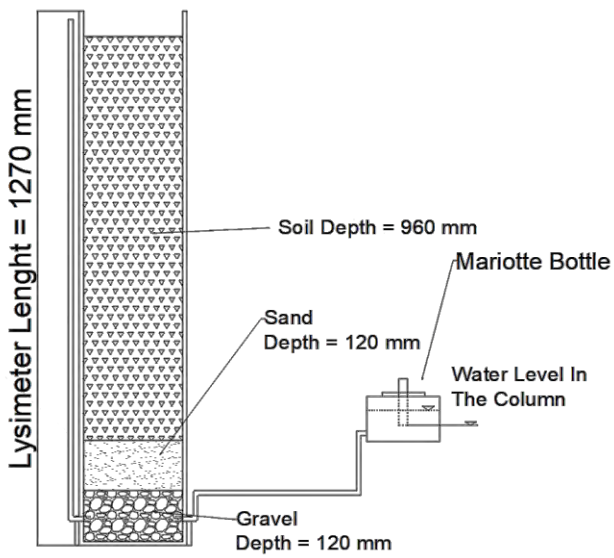

Figure 2. Schematic diagram of a lysimeter and Mariotte bottle system (Fidantemiz et al., 2019).

The lysimeters were made of Schedule-40 PVC with a diameter of 152.8 mm (6 inches), the wall thickness of 5 mm (0.02 inch), and the height of 127 cm (50 inches). One end of the lysimeters were enclosed by a cap and sealed to prevent water and soil release from the lysimeters. Decagon VP-4 sensors (Decagon Inc., Pullman, WA) were used to determine humidity and air-temperature in the greenhouse. ETgage model E atmometers (C and M Meteorological Supply, Colorado Springs, CO, USA) were used to measure evapotranspiration. The ET_0 data were collected daily during the experiments start from March 1st to July 4th. Dataloggers were used to record the data automatically.

The irrigation timing for the control treatments during the experiments were determined using soil water potential sensors (TEROS-21, METER Group, Inc. Pullman, WA). The sensors were placed in the lysimeters horizontally at the depths of 15, 45, and 75 cm start from the top of the soil surface. The moisture data were collected using Em50G dataloggers in every 10 minutes intervals. A soil-water release curve was determined by using a HYPROP® (Version 10/2011, UMS GmbH München) instrument.

As a soybean variety, ND Bison soybean (RFP-279), which is a conventional type crop released by the North Dakota Agricultural Experiment Station in 2016 was used. Soybean seeds were sowed in the lysimeters on March 1st and harvested on different dates between July 5th and July 22nd. Plants were harvested once they reached full maturity stage (Kandel 2010).

At the beginning of the experiments, all 30 lysimeters were filled with tap water and the cap at the bottom of the lysimeters were opened after 36 hours to drain waters with the gravity from the lysimeters. Since all the waters did not release from the columns in 36 hours, the remaining moistures were enough for seedling. Total eight seeds were planted at the beginning in 1.5 inches depth (Kandel 2010). Once all the seeds emerged, three best looking plants were kept in the lysimeters. Weekly chemicals were applied in the greenhouse for the thrips control. Additionally, Botanigard Maxx (on April 5th), Azatin (on April 16th), and Mainspring (May 7th) were applied to prevent growth of aphids, thrips and spider mites.

A randomized complete block design with six blocks was used to design the distribution of the lysimeters in the greenhouse. (Figure 1). One-way analysis of variance (ANOVA) with P ≤0.05 was applied to explain water table effect on soybean growth and yield parameters. Mean separation tests on treatments were applied using Tukey HSD (honestly significant difference) test comparisons at the P ≤0.05 probability level.

RESULTS AND DISCUSSION

ET_0 and air temperature in the greenhouse

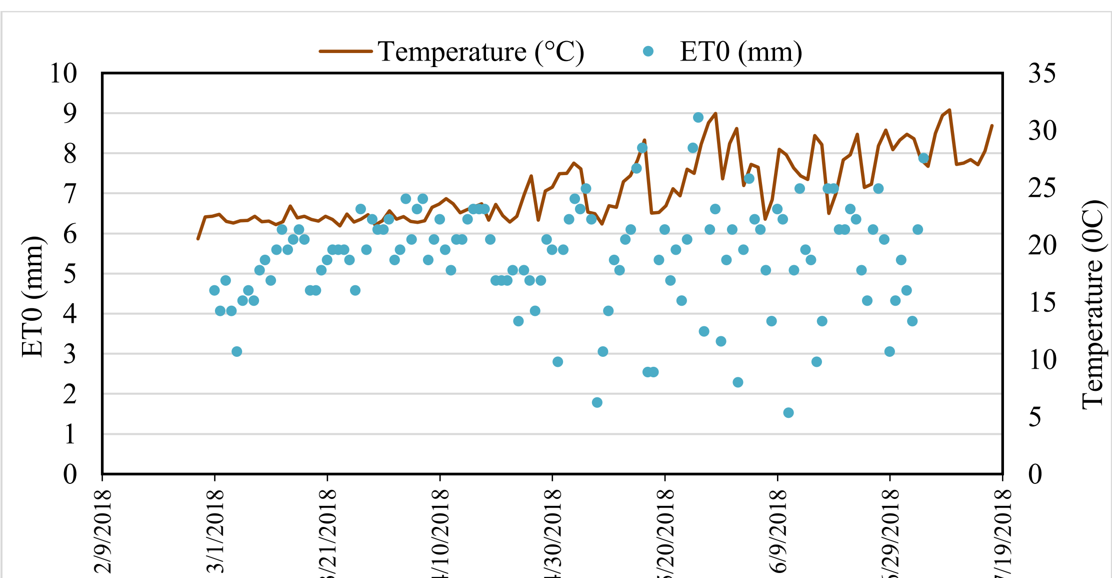

Figure 3. Measured daily air temperature (°C) and ET_0 values in the greenhouse (Fidantemiz et al., 2019).

Daily average air temperature and ET_0 rates were measured continuously during the soybean growing period. The average daily greenhouse temperatures were measured as 25±5 °C in March and April and fluctuated through July because of high ambient temperatures (Figure 3). Average (cumulative) ET_0 values during the experiments were measured as 687 mm in between March 1st and July 4th. The results showed that the room temperature and ET_0 was changed proportionally in the greenhouse (Fidantemiz et al., 2019)

Crop Water Use

$T_{control}$ experiments were designed in the way that available soil moisture content in the soybean plant root zone was always kept in between field capacity and readily available moisture, and it never exceeded 50% total available soil moisture level until May 20th (Karam et al., 2005). However, it was determined that the soil moisture level exceeded 50% of total available soil moisture content range in between 60-90 cm soil profile. Therefore, the irrigation scheduling was adjusted based on the sensors' readings. After May 30th, the soil water content varied between readily available moisture and permanent wilting point.

Crop water requirements were determined as 30 cm in between March 1st and April 5th and it increased to 60 cm on April 5th. Data for soil moisture distribution throughout the growing period and time and amount of irrigation applied in irrigated treatment (Fidantemiz et at., 2019). Total evapotranspiration values in irrigated treatment (R2-$T_{control}$) were calculated and found that the sum of the soybean crop water use varied from 856 to 886 mm, with a mean value of 873 mm in irrigated lysimeters. The same amount of water was applied in all the control treatments (Table 1).

Table 1. Summary of total crop water use of irrigated treatment.

Lysimeters	initial water use	cumulative irrigation water	final water use	cumulative ETc	mean ETc
	mm	mm	mm	mm	mm
R2-$T_{control}$	175	891	190	876	
R3-$T_{control}$	175	891	180	886	873
R4-$T_{control}$	175	891	211	856	

Note: R and T denote to replication and treatment, respectively. Initial conditions were assumed to be identical for all lysimeters.

Soil water content in the lysimeters was calculated using the data obtained from the soil water potential sensors and found to be 360 mm in the 90 cm soil profile. Since the initial conditions of these lysimeters were the same, the small differences of water content among the lysimeters were eliminated.

Soybean growth and yield parameters

Differences between treatments, in response to varying WTD were not significant for plant height, pod weight and total biomass, however, for seed weight T_{90} was significantly higher than $T_{control}$ (Table 2). The highest mean plant height was 50.1 cm for $T_{control}$ (irrigated) treatments, while the lowest mean plant height was 48.8 cm at T_{90} treatments. There is a negative correlation between the mean plant height and WTD. Although plant height was not statistically significant, some replications clearly showed that higher plant height was observed with the irrigated treatments.

The highest and lowest seed weight was found at the 90 cm WTD (T_{90}) and irrigated ($T_{control}$) treatment as 7.00 and 3.91 g/plant, respectively. Seed weight for T_{50} increased by 6% compared to T_{30}; by 6% for T_{70} compared to T_{50}, and; by 12% for T_{90} compared to T_{70}. One reason for low grain yield in irrigated lysimeters could be the water stress in the late reproductive stage. Karam et al. (2005) stated that seed filling, along with seed enlargement stage, are known to be the most susceptible periods of soybean growth. Thus, the author reported that moisture stress in R5 stage resulted for 30% soybean seed yield decrease. Similar results were obtained for pod weights since correlation between grain yield and pod weight was 98% (Fidantemiz et al., 2019).

Table 2. Soybean growth and yield parameters (Fidantemiz et al., 2019).

treatment	height	total biomass	pod weight	seed weight per plant
#	cm	g/plant	g/plant	g/plant
$T_{control}$	50.1 [a]	9.2 [a]	5.9 [a]	3.91 [a]
T_{30}	49.2 [a]	13.4 [a]	7.9 [a]	5.53 [ab]
T_{50}	48.9 [a]	14.8 [a]	8.5 [a]	5.88 [ab]
T_{70}	49.4 [a]	14.6 [a]	8.7 [a]	6.25 [ab]
T_{90}	48.8 [a]	14.5 [a]	9.7 [a]	7.00 [b]

Note: The letters of a and b explains the statistical results among the treatments.

A linear correlation between biomass and seed weight was observed. Total biomass was the highest at the T_{50} (14.8 g) and the lowest at the $T_{control}$ (9.8 g). Low soybean total biomass at the $T_{control}$ was probably caused by the moisture stress through end of the growing period. A linear correlation between mean soybean grain yield and 30, 60, 70, and 90 cm WTD treatments was observed with R^2 value of 0.95 (data not shown). These results showed that grain yield increased with the WTD.

Water Use Efficiency (WUE)

WUE values for total grain yield and total biomass were calculated by dividing total grain yield and total biomass parameters to ET_c values. Grain yield values were 6.9, 15.1, 10.5, 14.1, and 17.2 g/lys and total biomass values were 13.8, 33.9, 30, 33.8, and 33.9 g/lys for $T_{control}$, T_{30}, T_{50}, T_{70}, and T_{90} treatments, respectively. Similarly, grain yield WUE values were 0.08, 0.22, 0.18, 0.25, and 0.31 and total biomass WUE values were 0.16, 0.53, 0.41, 0.53, and 0.61 for $T_{control}$, T_{30}, T_{50}, T_{70}, and T_{90} treatments, respectively. All these results showed that the highest WUE for grain yield and total biomass were found at 90 cm WTD treatment (Fidantemiz et al., 2019).

Dry Root Mass

Dry root mass distribution in response to WTD is presented in Table 3. Total 15 lysimeters (3 lysimeters from each treatment) were cut and soil profiles were extracted to analyze the root mass distribution. The results showed that $T_{control}$ treatment was high, 4.37 g, in 0-20 cm depth compare to 20-40 and 40-75 cm depths. Mostly 0-60 cm of soil depth was wetted by irrigation, and available water existed in the 0-20 and 20-40 cm depth soil so that roots were mostly developed in the top 40 cm depth. When the proportion of root mass of irrigation treatment was considered, it was found that around 71% of root mass occurred in the top 20 cm, and 90% of root mass was in the top 40 cm. The mean total mass of $T_{control}$ in the soil profile was determined as 6.17 g, which was the lowest among all treatments and significantly lower than T_{70} and T_{90} treatments (Fidantemiz et al., 2019).

Table 3. Average root mass and proportions of roots (Fidantemiz et al., 2019).

Layers	Depth	Average root mass and percentage									
		$T_{control}$		T_{30}		T_{50}		T_{70}		T_{90}	
	cm	g	%	g	%	g	%	g	%	g	%
1th	0-20	4.37^{A}	71	3.53^{A}	41	2.40^{B}	27	2.30^{B}	20	3.10^{B}	24
2nd	20-40	1.17^{B}	19	2.23^{A}	26	1.73^{B}	19	1.10^{B}	10	1.30^{B}	10
3rd	40-75	0.63^{B}	10	2.90^{A}	33	4.80^{A}	54	8.00^{A}	70	8.43^{A}	66
TOTAL		6.17^{b}	100	8.67^{ab}	100	8.93^{ab}	100	11.40^{a}	100	12.83^{a}	100

Note: Uppercase letters indicate statistically significant differences ($P \leq_{0.05}$) between depths within a given treatment, and lowercase letters indicate statistically significant differences between treatments.

Similarly, at the 30 cm WTD treatment (T_{30}), the highest root mass values were found in the 1st layer as 3.53 g (Table 3). Soybean root mass lessened to an average of 2.23 g in the 2nd layer. However, root mass that was observed at 40-75 cm depth increased to 2.9 g. Proportional root mass in three soil layers (0-20, 20-40, and 40-75 cm) of 30 cm WTD accounted for 41, 26, and 33%, respectively. Mean total root mass of T_{30} in the soil profile was found as 8.67 g, which was higher than average for the control treatment. However, there was no significant difference between $T_{control}$ and T_{30} treatments in terms of their mean total root mass (Fidantemiz et al., 2019).

In contrast to irrigation and the 30 cm WTD treatments, a significant part of the root mass for the 50 cm WTD treatment was concentrated in the 3rd layer (40-75 cm soil depth) where it meets the water table. Mean root mass of 1st, 2nd, and 3rd layers were averages of 2.4, 1.7 and 4.7 g, respectively. Proportional root mass in three soil layers accounted for 27, 19, and 54%, respectively. In comparison with 1st and 2nd layers, the 3rd layer was significantly higher, and likewise, in terms of their total mass, there was no significant difference between $T_{control}$, T_{30}, and T_{50} treatments (Fidantemiz et al., 2019).

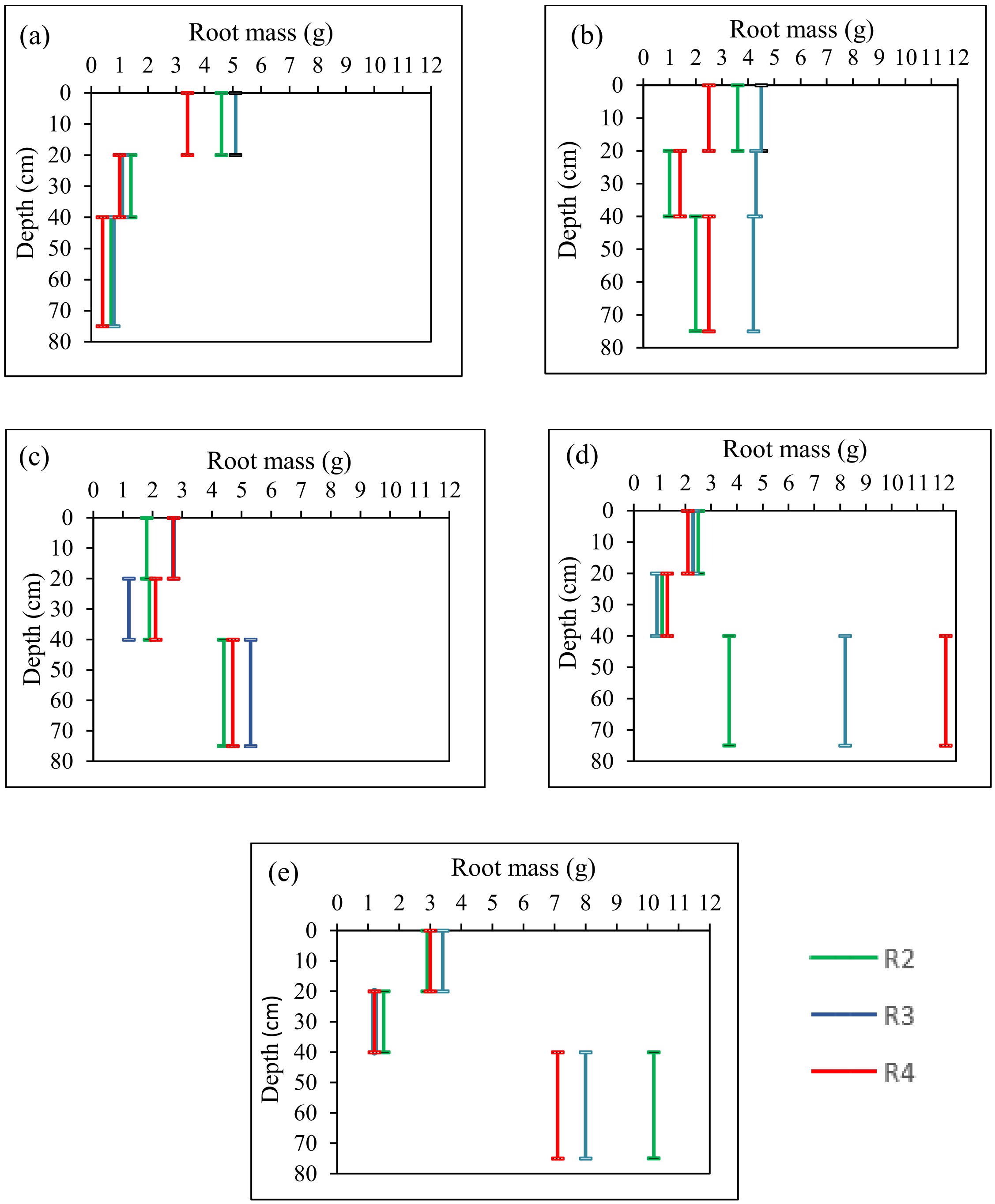

Figure 4. Root mass distribution of soybean as influenced by water table depth (WTD). (a) irrigated, (b) 30 cm WTD, (c) 50 cm WTD, (d) 70 cm WTD, (e) 90 cm WTD. Data at 20 cm represent root mass from 0 to 20 cm depth interval; 40 cm represents 20-40 cm; and 75 cm represents 40-75 cm.

A similarity across the replications of T_{70} and T_{90} treatments was observed in root mass development. (Figure 4). Mean total root mass of T_{90} treatment was found the highest among all treatments with 12.83 g, and T_{70} was found to be 11.40 g. Comparing proportional root mass distribution of T_{70} and T_{90} treatments in 1st, 2nd, and 3rd layers, percentages of root mass in each layer was quite similar. However, T_{90} was consistently higher than T_{70} in all the layers. Compared to T_{70}, T_{90} had 12% higher total root mass. However, T_{90} did not differ significantly from T_{70} ($p<0.05$). It was clear that stress occurred in the upper layers, stimulating roots to develop at deeper layers, and resulted in root development near the water table.

Comparatively, very low dry root mass was found at the 1st, and 2nd layers of the T_{70} and T_{90} treatments, most probably because the plants roots did not spend energy to increase root density in the upper two layers. Similar findings were found by Imada et al. (2008) that they observed higher fine-root length just above the deeper WTD versus the upper layers.

Total mean root mass and root mass per layer varied with WTD. The total mean dry root mass for irrigation treatments was lowest compared to all other treatments. Increasing root development was observed in deeper layers in response to increasing WTD, and proportion of root mass in the layers varied significantly. While 90 and 67% of the root mass was present at the 1st and 2nd layer of the $T_{control}$ and T_{30} treatments, roots in the 3rd layer for T_{90} accounts for approximately 66%.

Root-Shoot Ratio

To determine plant response to WTD, the relationship between total biomass and roots were analyzed. Root-shoot ratios (total root mass per total plant biomass in each lysimeter) were calculated for 15 lysimeters. Root mass, shoot mass, and root-shoot ratio data are shown in Figure 5.

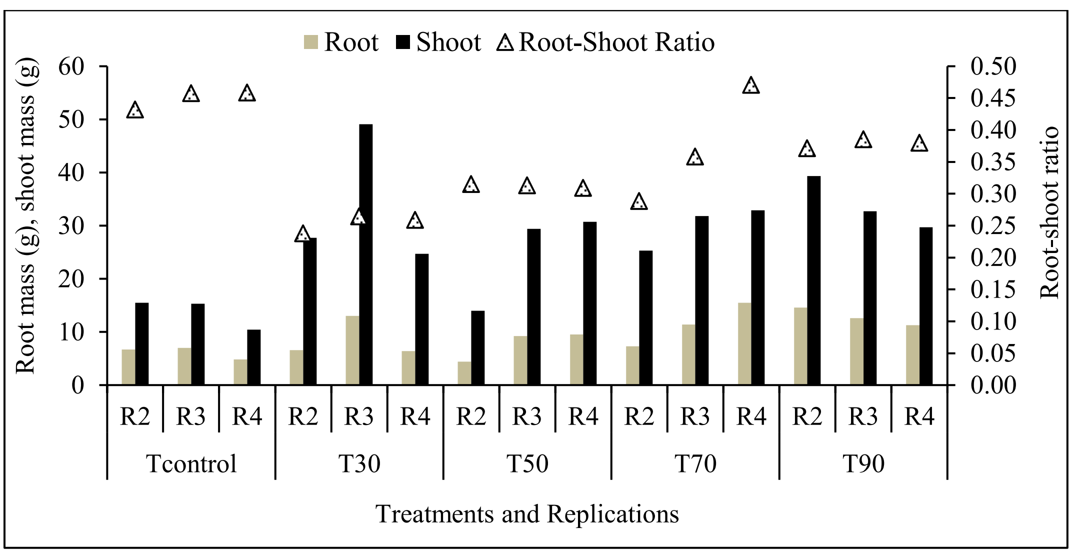

Figure 5. Root-shoot ratio in response to shallow groundwater table.

The average highest and lowest root-shoot ratio were observed in the irrigated ($T_{control}$) and 30 cm WTD (T_{30}) treatments. $T_{control}$ and T_{30} showed the ratio of roots to shoots ranged from 0.43 to 0.46 for $T_{control}$ and 0.24 to 0.26 for T_{30}. Similarly, an ANOVA test showed significant differences between the treatments. Further analysis with the Tukey HSD test indicated that mean root-shoot ratio of 30 cm WTD was significantly lower than all treatments except for the 50 cm WTD treatment. Furthermore, the mean root-shoot ratio for the irrigated treatment was shown to be significantly higher than all other treatments with the exception of the 90 cm WTD treatment. Although the highest root-shoot ratio was found in the irrigated treatment, considering the root and shoot mass, T_{70} and T_{90} treatments reached the highest values.

CONCLUSIONS

Parameters of soybean growth, yield, crop water use, and WUE along with root mass distribution in response to different WTD were investigated using lysimeter technique in greenhouse conditions. ND Bison Soybean (RFP-279) variety was found to be tolerant to shallow water table in a vegetative growth period since there was no statistical difference observed among the treatments at the measured above ground parameters such as plant height. Similarly, yield parameters such as total biomass and seed weight did not show any significant difference among the treatments. The lowest groundwater contribution to crop water use was found at the T_{90} treatment. These results showed that the depth of water table is the main factor for crop water use. Although significant differences did not occur for the total biomass and seed weight in all the WTD treatments, higher WUE values were observed at deeper WTD because of the lower crop water use at the deeper WTD treatments.

The roots response to different WTD strongly indicated an effect between root development and WTD. Roots were developed near the water table to be compatible in using groundwater. Significant root developments were found in the 40-75 cm depth of the T_{70} and T_{90} treatments. When roots reach to the water table, they become capable of providing water to plants so that higher water uptake by roots from the groundwater can be possible with the plants root system. Considering root mass distributions, it was clearly shown that root mass of T_{70} and T_{90} treatments was higher than shallower water table treatments (T_{30} and T_{50}) and also significantly higher than irrigated treatment ($T_{control}$). It is most probable that developed roots in deeper layers enabled plants to use water from groundwater. In terms of root-shoot ratio, total water use, and WUE; it was found that 70-90 cm WTD was found to be optimum depth interval for soybean in this lysimeter study.

Shallow groundwater quality is one of the critical factors affecting crop water use. The combined effect of groundwater depth and the impact of salinity is needed for future studies. In this study, the highest yield parameters, root distribution and WUE values were obtained from 90 cm WTD. Deeper WTD treatments could be studied for future studies. With the light of this study, field lysimeter application to determine water table effect on soybean crop could be studied.

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