

GROUNDWATER TABLE EFFECTS ON YIELD, GROWTH AND WATER USE OF
CANOLA (*BRASSICA NAPUS* L.) PLANT

A Thesis
Submitted to the Graduate Faculty
of the
North Dakota State University
of Agriculture and Applied Science

By
Hakan Kadioglu

In Partial Fulfillment of the Requirements
for the Degree of
MASTER OF SCIENCE

Major Program:
Natural Resource Management

May 2019

Fargo, North Dakota

North Dakota State University
Graduate School

Title

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MASTER OF SCIENCE

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ABSTRACT

Lysimeter experimental studies were conducted in a greenhouse to investigate canola (*Brassica Napus*) plant water use, growth and yield parameters under three different water table depths of 30, 60, and 90 cm. Additionally, control experiments were conducted and only irrigation was applied to these lysimeters without water table limitation. Canola plant's tolerance level to shallow groundwater was determined. Results showed that groundwater contributions to canola plant were 97, 71, and 68%, while the average grain yields of canola were 4.5, 5.3, and 6.3 gr for the treatments of 30, 60, and 90 cm water table depths, respectively. These results demonstrated that 90 cm water table depth is the optimum depth for canola plant to produce high yield with the least amount of water utilization.

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my thesis advisor Dr. Halis Simsek from Agricultural & Biosystem Engineering Department at North Dakota State University. Thanks to his continuous support, patience, motivation, enthusiasm and immense knowledge that helped me to complete my master's degree. Besides to my advisor, I would like to thank the rest of my thesis committee members: Dr. Xuefeng Chu, Dr. Chiwon Lee and Dr. Md. Saidul Borhan for their encouragement, insightful and patient.

My sincere thanks also go to Dr. Dr. Harlene Hatterman-Valen and Dr. Aaron Daigh for their permission to use their facilities and sources. I would like to thank Dr. Mukhlesur Rahman to encourage and support me during the planting time. I am grateful to Yavuz Fatih Fidantemiz for sharing his knowledge and experience with me generously. I would like to thank Ekrem Ergun for his endless effort and friendship during my entire study.

Last but not the least, I would like to thank my father, Prof. Izzet Kadioglu, for his encouragement, support and motivation. Whenever challenges of my research decreased my motivation, he patiently listened and gave advice to me. My thanks and appreciations also go to my mother, Sakine Kadioglu for her love and spiritual support throughout my life.

Funding for this research was provided by the North Central Region Canola Research Program, North Dakota Water Resource Research Institute and North Dakota Agricultural Experiment Station. These funding supports are thankfully acknowledged. Without funding, we could not start and complete this research.

Finally, I gratefully acknowledge the financial support provided by the Turkish Government (YLSY program), Ministry of Education and DSI (General Directorate of State Hydraulic Works) for my master's degree scholarship.

DEDICATION

I dedicate this thesis to my family;

my wife, **Ozgun Kadioglu,**

my son, **Mehmet Alp Kadioglu**

and

my daughter, **Aybuke Kadioglu.**

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LIST OF ABBREVIATIONS

ET₀	Reference evapotranspiration
ET_c	Evapotranspiration (crop water use)
RCBD	Randomized complete block design
RAM	Readily available moisture
WUE	Water use efficiency
WTD	Water table depth.
TAM	Total available moisture

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1. INTRODUCTION

Growth in the world population increases the agricultural production to meet demand for more varied diets and causes of water scarcity in agricultural, environmental, and municipal water consumption. It was projected that, world population will be about 9 billion in 2050 and this high population will cause extreme water scarcity in many countries (Hamdy et al., 2003; U.N. 2004; Ghamarnia et al., 2012). Thus, the necessary solutions must be investigated to control excessive amount of irrigation water utilization. One solution could be encouraging the farmers to use shallow groundwater. Approximately 80% of available water resource in the world is being used in the agricultural applications. The gap between the availability of adequate water versus water needs will increase and hence, the management of groundwater utilization in agriculture will be accepted as an alternative strategy to deal with the potential water crisis. Therefore, shallow surface and groundwater resources have become important for water demand (Condon et al., 2004; Kahlowan and Ashraf, 2005; Ayars and Schoneman, 1986).

Improved and well-managed water use efficiency (WUE) is one of the most important purposes of agricultural water management systems and it increases the productivity and reliability of crop yield. Consumption of groundwater is an extremely significant part of WUE. Describing WUE for irrigation is complicated (Howell, 2001). It was defined that WUE is a grain crop yield or total crop biomass per unit of water use (Sinclair et al., 1984; ASABE standards, 2008).

A good quality of groundwater can be accepted as supplemental irrigation water source that supplies crops' water demands depending on crop species. Some crops such as canola (*Brassica napus L.*), soybean (*Glycine max*), and safflower (*Carthamus tinctorius*) are able to use saline groundwater and hence those crops will help to increase the utilization of groundwater and

to decrease the utilization of surface irrigation water. Because shallow groundwater can reduce both drainage and irrigation requirements, it needs to be managed correctly (Hamdy et al., 2003; Yang et al., 2007; Ghamarnia et al., 2012). In addition, there are obvious relationships between water table management (WTM), crop productivity and environmental pollution. The environmental and economic benefits of WTM decrease environmental pollution and increase crop productivity and irrigation intervals. To supply sufficient soil moisture content to the crops, WTM should be well performed (Mejia et al., 2000).

Consumption of shallow groundwater as a crop water supply depends on several factors such as groundwater table depths, groundwater availability and quality, crop species, distribution of plant root system, weather conditions, and soil type (Ghamarnia et al., 2012; Huo et al., 2012). The amount and quality of groundwater is also affected by the irrigation method and management practices because applying an excessive amount of irrigation water can increase the amount of groundwater utilization. It is not possible to control all these parameters in the field conditions because groundwater contributions are highly variable and difficult to estimate. Therefore, lysimeters are often used to conduct the experiment that simulates only a single parameter at a time (Luo and Sophocleous, 2010).

Lysimeters in the greenhouse conditions allow to conduct more complex field studies in the controlled environment. Lysimeter studies have been carried out to estimate groundwater depth and contribution and determine the effects of different water table levels on crop grain yields. Lysimeters can be also used to predict the amount of crop water use from the groundwater table (Mejia et al., 2000; Ayars et al., 2006; Putz et al., 2018).

1.1. Statement of Objective

The main scope of this study is to determine an optimum shallow groundwater depth to achieve high yield of canola plant. The specific objectives and the hypotheses of the study are as follows:

- To determine the optimum groundwater depth for canola growth and yield parameters at water table depths of 30, 60 and 90 cm without irrigation.

Hypothesis: The depth of groundwater table could affect canola plant growth and yield parameters.

- To determine the amount of water consumption at different water table depths of 30, 60 and 90 cm during the growing period of canola.

Hypothesis: Water use from groundwater could be different depending on the canola growth stage at water table levels of 30, 60, and 90 cm.

- To determine the root distribution of the canola plant in the lysimeters at water table depths of 30, 60, and 90 cm.

Hypothesis: The root distribution of the canola plant varies depending on the water table depth.

2. LITERATURE REVIEW

2.1. Importance of the Study

As the global population grows, the demand for fresh water in many regions is increasing dramatically. This population increase causes more water stress for agriculture, production of energy, industrial uses, and human consumption. Even though many countries have never faced the lack of water yet, water can no longer be accepted as an infinite source. Population increases will gradually decrease the amount of water needs for each person. Thus, it is required to find additional strategies to decrease the impact of water crises across the globe (Hamdy et al., 2003; Condon et al., 2004; Ripoll et al., 2014;).

In addition to the population growth, water availability, quality, and quantity for domestic and industrial demand are affected by water pollution, agricultural utilization, and technological developments. Water resources have been irrefutably decreasing throughout the world. One of the most important factors to increase pressure on freshwater resources is urbanization along with population growth. Many developed countries suffer from migration from the rural area to urban area because of estimated changes in water use efficiency (Vorosmarty et al., 2000; Okello et al., 2015).

Farmers who have limited water for crops, must consider deficit irrigation method or using an alternative crop that may have low irrigation demand. However, unprogressive deficit irrigation applications can cause water stress that reduces crop productivity (Payero et al., 2006; Payero et al., 2009). To deal with this problem, improved and well managed WUE should be preferred. Consuming water from groundwater can combined deficit irrigation to increase WUE in arid and semi-arid areas (Howell, 2001; Franzen, 2013).

2.2. North Dakota Canola Production

Canola is a potential oil-seed and alternative biofuel crop mostly grown in Northern High Plains of the USA. It can be grown under inadequate irrigation and weather conditions and therefore it is highly adapted in cold weather conditions with insufficient water availability. A comparison between soybean and canola showed that, while a typical Midwest soybean farm can manufacture about 60 gallons of soybean oil per acre, standard canola can produce 111 gallons of oil per acre (Johnston et al., 2002; CAST, 2008; Herget et al., 2016).

High temperature may cause abiotic stress on canola plant and influences its growth. Canola's sensitivity for high temperature is higher in the flowering period than podding period. During the blooming season of canola plant, heat stress may shorten the flowering period. Thus, farmers might have a vast amount of dry matter instead of canola seeds at the end of the harvest period (Johnston et al, 2002; Kutcher et al, 2010).

North Dakota (ND) state is located in the midwestern and northern regions of the United States. It has a continental climate condition which has the important difference between low and high temperatures. The lowest and highest average temperatures in ND for 2018 are determined as 0 and 82°F in the months of January and July, respectively. In addition to the high air temperature variations, irregular rainfall, low humidity, and shallow groundwater are the important difficulties that impact on crop growth and yield in ND. However, two common types of canola, winter (*B. rapa*) and spring (*B. napus*) canola can be grown in ND. Although winter canola can be produced in ND and northwestern Minnesota, ND farmers mainly preferred to plant spring canola since spring canola can survive under the hard winter condition and its yield growth is higher than winter canola. (Kandel, 2010; NOAA, 2018)

According to the ND Agricultural Statistics report, canola planted area has been increased from 0.910 million acres to 1.590 million acres between 2008 and 2017 in ND. In addition, the second highest area in ND, 1.560 million acres, was harvested in 2017 (USDA, 2018).

2.3. Effect of Water Table Depth on Plant Water Use and Crop Yields

Groundwater quality becomes very important for crop water use and yield parameters. If the plant roots can reach the water table level, the amount of irrigation water should be recalculated because inefficient plant water use reduces the crop yields. It is not possible to accept all groundwater resource as a water supply. Groundwater quality needs to be considered before recalculation of amount of irrigation water. Additionally, irrigation method and management, soil hydraulic properties, and hydraulic conductivity affect crop water use efficiencies from shallow water table (Kahlow and Ashraf, 2005; Luo and Sophocleous, 2010).

2.4. Previous Researches and Results

As of the author's knowledge, there is not a study available to explain the relationship between groundwater depth and canola plant growth using lysimeters. Therefore, other studies were evaluated to understand the lysimeter systems. Hutmacher et al. (1996) conducted three years of lysimeter experiments for cotton using clay loam soil to determine the effect of different shallow groundwater salinity levels on water table contribution. Four different groundwater salinity levels include 0.3 (non-saline), 12, 20, and 24 dS m⁻¹ were tested in the first year of the study. In the second and third years, five different groundwater salinity levels include 0.3, 7.7, 15.4, 23.1, and 30.8 dS m⁻¹ were tested. The percentages of cotton water use from shallow water table varied from 28 to 42% of total crop water use for 0.3, 20, and 20 dS m⁻¹ salinity treatments. Less than 10% of cotton total water use from shallow groundwater was observed at more than 20

dS m⁻¹ salinity treatments. It has been found that growers need to consider both influence of shallow groundwater uptake and salinity tolerance of crop for sustained productivity.

Mejia et al. (2000) conducted a two-years field experiment to determine the effect of two different water table depths of 50 and 75 cm on both corn and soybean crops to determine the grain yields. A free drainage system was conducted 100 cm below the soil surface for both treatments. Corn harvesting results in the first year were compared with and without free irrigation system. Free drainage treatment of corn grain yield weight was found 13.8% higher than no drainage treatment at 50 cm water table depth. However, only 2.8% corn yield increase was observed at 75 cm water table depth. In the second year, corn yield decreased from 13.8 to 6.6% at the 50 cm water table depth while it increased from 2.8 to 6.9% at 75 cm water table depth. Similar results were observed for soybean in the first and second years. Soybean grain yield increases at 50 cm water table depth for first and second years were found as 8.5 and 37.3%, respectively. Similarly, the highest grain yield results were obtained from free drainage treatments for both at 50 and 75 cm water table depths. According to the result, 75 cm water table depth with free drainage system was recommended for corn and soybean (Mejia et al., 2000).

The influence of different shallow groundwater table depths on water use and grain yield parameters of the six different crops were determined using eighteen lysimeters. As a result of the study, the groundwater contribution of crops varied in terms of water table depths. Wheat water use from 50 cm groundwater depth is 100% of crop water requirement while groundwater contribution of sunflower was 80% of crop water use. The harvesting result of maize and sorghum showed that these two crops were not tolerant to higher water table depths. Thus, the lowest grain yield weight was found below the 200 cm water table depths for maize and sorghum. The optimum water table depth was found 150-200 cm for six crops. Under no

irrigation condition, crops could be harvested without any grain yield losses. If quantity and quality of groundwater is sufficient for crops, the amount of applied irrigation water should be remodified based on groundwater salinity level (Kahlowan and Ashraf, 2005).

Luo and Sophocleous (2010) studied influence of groundwater evaporation contribution to winter wheat crop water use using lysimeters. Different water table depths, climate and irrigation conditions were performed to determine the amount of crop water use from desired groundwater table levels. Relationship between wheat crop water use and depth of water table were found to be varied. Winter wheat was supplied 75% of crop water-use from 100 cm groundwater depth without irrigation application, while 3% of crop water use was supplied from 300 cm groundwater level with 3 times irrigation applications. The results also showed that the amount of water table contribution was affected not only water table depth but also soil profile, rainfall, irrigation, and climatic variations.

To determine groundwater contribution to safflower, Ghamarnia and Golamian (2012) carried out an experiment using lysimeters. Silty loam soil was packed in twenty lysimeters and randomized block design was used with four replications. Treatments were performed and classified based on groundwater salinity levels. Constant water table depth of 80 cm and five different salinity levels of 1, 2, 5, 8, and 10 dS/m were performed in their study. The inverse relationship was observed between groundwater salinity level and crop water use from groundwater. Groundwater contribution to safflower crop was found as 59, 51, 38, 32, and 19% for 1, 2, 5, 8, and 10 dS/m concentration of salinity treatments, respectively. High groundwater salinity also decreased weight of safflower grain yield; 66.43 and 75.68% reductions were determined for seed and oil, respectively. To reach optimum amount of water use from

groundwater and met better harvesting results, fewer level of groundwater was recommended at 80 cm water table depth.

2.4.1. Root System

Crop root distribution is important to understand soil and plant response to water utilization. Although root is the most important vegetative part of the crop (Lesczynski and Tanner, 1976), root contribution is the least measured parameter in the literature (Ayars et al., 2006). Shallow groundwater can be accepted as a crop water supply, if crop root reach shallow groundwater level. Crop roots need to be well developed to reach deeper groundwater levels (Soppe and Ayars, 2003). The development of root is depending on several factors such as soil density, pH, and fertility. If soil has; low bulk density, high fertility, and pH the crop root can be well developed at the lower water table levels (Borg and Grimes, 1986).

Crops' roots need efficient amount of oxygen to complete growing period. Saturated root zone supplies lower amount of oxygen to crops. Since soil texture in ND includes saturated root zone, crop cannot reach potential harvesting results. Dry area in the root zone is the most important part of crop planting. More root contribution is generally observed at the end of growing period. Since crops have well developed root system during the last period of crop growth, the highest amount of water use from groundwater occurs in this cycle (Ayars et al., 2006; Franzen, 2013).

2.4.2. Soil Hydraulic Properties

Soil hydraulic functions need to be determined to calculate evapotranspiration for water table in lysimeter studies (Schindler et al., 2010). The level of water table, soil salinity, climate, and hydraulic conductivity influence evaporation rate. The amount of water in the root zone depends on hydraulic properties of unsaturated soil zone. Soil type is a significant factor in terms

of influence of water use from water table since unsaturated soil hydraulic conductivity is the property of the soil type. To save water in agriculture and improve water use efficiency, soil hydraulic properties need to be determined. (Zhang et al., 1999; Ayars et al., 2006)

2.4.3. Management of Drainage and Irrigation System

The influence of excessive amount of water in the field is significant for crop grain yields and field operations. To provide optimum amount of water for crops, drainage systems are mostly preferred to be installed into the subsoil. Drainage systems discharge excessive amount of water from soil and provide optimal water table level and soil moisture content in the root zone. For easy plantation and obtaining reliable results from below ground parameters (root, root-soot ratio and etc.), drainage systems could be applied in the field experiments (Skaggs and Schilfgaard, 1999; Rijal et al., 2012).

Drainage system management need to be well performed since non-functional drainage management methods may cause to discharge necessary water for crop in the root zone. Because of inefficient drainage system, plant root cannot take sufficient amount of water from groundwater, and deficient amount of irrigation water can cause water stress. Thus, crop grain yield loses can be occurred because of crop water stress. Another effect of insufficient drainage management is that water table level can increase to unexpected level. Excessive amount of water in the root zone causes undeveloped crop root zone and grain yield losses (Kahlowan and Ashraf, 2005; Ayars et al., 2006).

2.4.4. The Method Used to Determine Groundwater Contribution to Crops

Water balance equations are used to describe the water fluxes in the soil profile. In addition, to calculate crop water use from groundwater and soil water content changes in desired

period of time, different modified water balance equations were performed in several experiments. Hillel (1998) used Eq.2.1 to calculate water content changes in the root zone.

$$(\Delta S) = (P + I + Cr) - (R + Dp + ET) \quad (\text{Eq.2.1})$$

where, Cr is capillary rise, P is precipitation, I is irrigation, R is runoff, Dp is deep percolation, ET is evapotranspiration, ΔS is the change in soil water content (Hillel, 1998).

To calculate water use from groundwater, a field experiment can be conducted. The parameters that need to be measure in a field experiments are groundwater table depth, groundwater availability and quality, crop species, distribution of plant root system, weather condition, and soil type. It is not possible to control all these parameters in the specific time interval under the field conditions. Thus, groundwater contributions are highly variable and difficult to estimate for field experiments. For this reason, lysimeters were mostly utilized as reliable research tools to measure the amount of water loses by evaporation and transpiration. The actual groundwater contribution to crops can be determined by monitoring the amount of water changes in the lysimeters (Jia et al., 2006; Luo and Sophocleous, 2010).

3. EFFECT OF WATER TABLE LEVEL ON CANOLA WATER USE, WATER USE EFFICIENCY AND ROOT DISTRIBUTION

3.1. Introduction

Crop water use from groundwater has already broadening last twenty years in the United States. Furthermore, shallow groundwater could be used more as a crop water supply since flooding and drought events could be increased because of unpredictable weather conditions. Thus, shallow groundwater contributions to crops became important agricultural application for water resources management (Tebaldi et al., 2006; Scanlon et al., 2010).

To determine relationship between crop water use from groundwater and different water table depths, many studies were performed using different parameters (Ayars et al., 2006). Torres and Hanks (1989) was conducted an experiment to determine groundwater contribution to wheat crop using two different soil textures, silty clay loam and fine sandy loam. Different water table levels of 50, 100, 150 cm, and irrigation (no groundwater) were performed for both soil textures. The results showed that relationship between groundwater contribution and soil texture was not found at 50 cm water table depth. However, the highest proportion of groundwater contribution to crop water use, 90%, was obtained from both silty clay loam and fine sandy loam soil textures for 50 cm groundwater treatments. When water table depth decreased from 50 to 100 cm, groundwater contribution reduced from 90 to 40% for silty clay loam and 90 to 31% for fine sandy loam soils. Similar decreases were observed for 150 cm groundwater treatments in both soil textures. Kruse et al. (1993) found similar relationship between water table depth and crop water use from groundwater. While groundwater contribution was 76% at 60 cm water table level, lower contribution, 27 %, was obtained at the 105 cm groundwater treatments.

3.2. Materials and Methods

3.2.1. Experimental Design and Preparation of Lysimeters

This study has been conducted in a greenhouse located at ND State University campus, Fargo, ND. Thirty-two lysimeters were used in the study with four treatments, which were three different water table treatments include 30, 60, and 90 cm water table depths with no irrigation application and a control treatment (no water table) with surface irrigation application (Figure 3.1). Each treatment had 8 replications so that 24 lysimeters (8 replications x 3 different water table depths = 24) were used for water table experiments and 8 lysimeters were used for control experiments. For the control treatment, 50% of the total available moisture (TAM) was considered as readily available moisture (RAM) in the soil profile. In this study, tap water was used for both groundwater and irrigation water sources.

All the lysimeters in the greenhouse were distributed using a randomized complete block design (RCBD) method. Water table treatments for 30, 60, and 90 cm were called as T_{30} , T_{60} , and T_{90} , respectively. The control treatment was called as T_{control} . Twenty-four Mariotte bottles were connected to those 24 lysimeters used for treatment 1, 2, and 3. Amber color Mariotte bottles were preferred to use to prevent algal growth in the Mariotte bottles. The volume of Mariotte bottles were 4 liters, and 4 adjustable shelves were used to adjust desired height of the Mariotte bottles. The variation of water volume in the Mariotte bottles was measured to determine the water consumption of canola.

The Mariotte bottles were connected to the lysimeters from the bottom and continuously fed the lysimeters with a constant flow rate. The water reduction on the Mariotte bottles was monitored and the difference was considered as canola water consumption that supplied from

groundwater. Graduated cylinders were used for replenishment in the Mariotte bottles to obtain reliable measured water use.

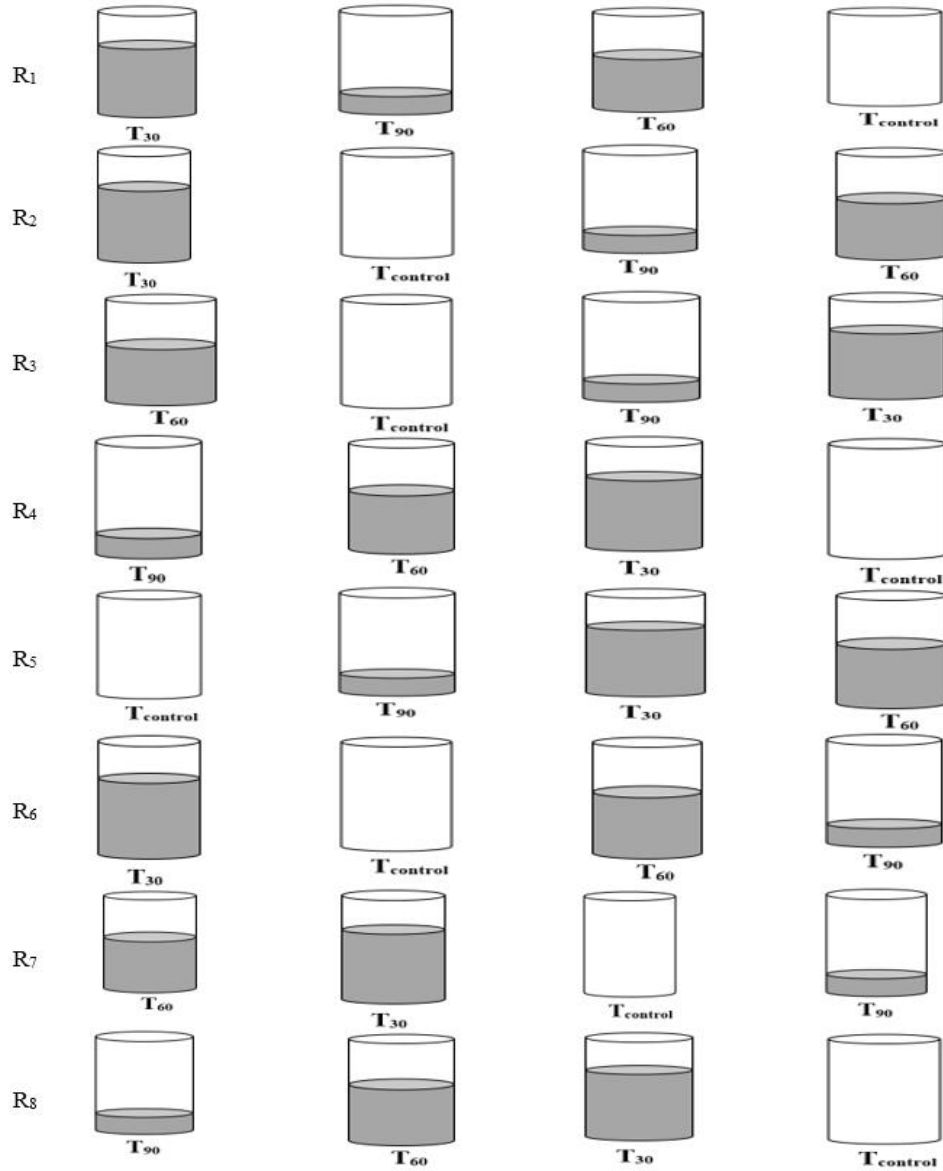


Figure 3.1. Schematics of randomized complete block design using 32 lysimeters. R1, R2, R3, R4, R5, R6, R7, and R8 are the replications and T30, T60, T90, and T_{control} are the treatments.

The loam soil texture was used to pack all the lysimeters. Bulk soil samples were collected from an agricultural field in Fergus Falls, MN. Air-dried soil was grounded to less than 2 mm packing of the lysimeters. The textural characteristics of the soil were changed by adding 300 g of sand to each 1 kg of soil to deal with soil compaction problem. All the detailed soil

physical properties of packed lysimeters are determined in Figure 3.2. Gravel (8 cm) was packed at the bottom of the lysimeters, sand (8 cm) was packed at top on the gravel, and finally loam soil (100 cm) was placed at the very top of the lysimeters to fill lysimeters (Figure 3.2). All the lysimeters were packed uniformly in the same conditions.

Each lysimeter's diameter, wall thickness and height were 125.8 mm (6 inches), 5 mm (0.002 inches) and 126 cm (49.6 inches), respectively. The lysimeters were made of Schedule-40 PVC material. The bottom of the lysimeters was closed with a cap and glued to prevent leaking.

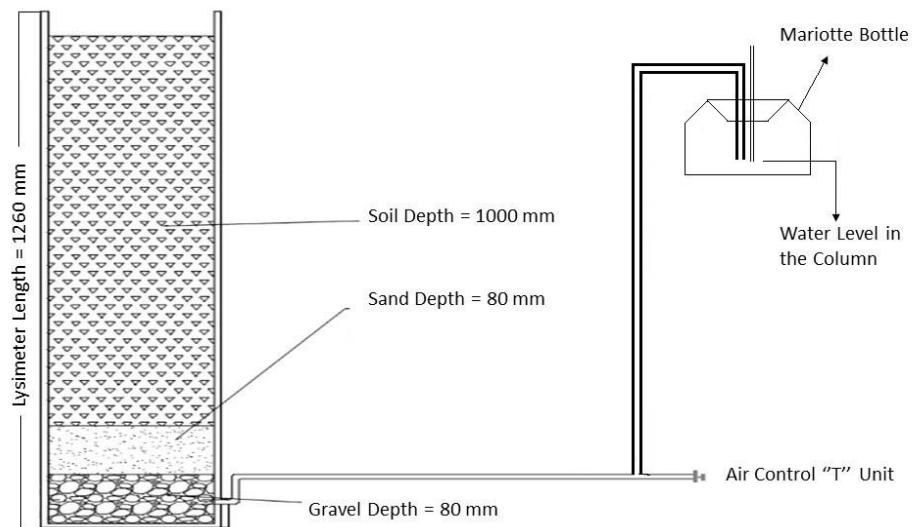


Figure 3.2. Schematic diagram of a lysimeter and Mariotte bottle system.

In the control treatment lysimeters (T_{control}) three soil water potential sensors (TEROS-21, METER Group, Inc.) were used to determine the irrigation timing and the amount of water needs for the irrigation. Each three water potential sensors were placed at different depths of 15, 45, and 75 cm in a lysimeter. For the remaining treatments (T_{30} , T_{60} , and T_{90}) total six soil water potential sensors were used and placed in the appropriate depths. One soil water potential sensor was placed in the 15 cm from the top of the soil surface in T_{30} lysimeter. Two soil water potential

sensors were placed in the 15 and 45 cm depths in T₆₀ lysimeter. Three soil water potential sensors were placed in the 15, 45, and 75 cm depths in T₉₀ lysimeter. To ensure hydraulic contact between sensors and moisture in the soil, all the sensors were placed horizontally in the lysimeters. All 9 water potential sensors were plugged in two Em50G (Decagon Inc) datalogger at 10-minute intervals.

Two ETgage model E atmometers (C&M Meteorological Supply, Colorado Springs, CO, USA) were used to measure evapotranspiration in the greenhouse. The measured data was collected in HOBO Pendant Event Data Loggers. Between November 4, 2018 (planting) and February 4, 2019 (harvesting), daily ET₀ data were collected and recorded. Air temperature, barometric pressure, relative humidity, and vapor pressure were measured by using Atmos 14 sensor (Decagon Devices, Inc., Pullman, WA). The device was connected to Em50G datalogger to transfer the data to a computer.

3.2.2. Canola Planting

NDOLA-01 type of canola seeds were planted on November 4, 2018 and the plants were harvested on different dates from February 4 to February 10, 2019. It was observed that some canola plants reached fully harvesting stage at different times (Table 3.1). Total 96 canola plants completed germination stage in eight days. The germination rate of canola seeds was measured and reported in Figure 3.3.

To provide same water curved conditions to all lysimeters, proper planting bed was prepared. At the beginning of the experiments, all the lysimeters were filled with water to the soil surface in the lysimeters. Then, the valves at the bottom of the lysimeters were opened and water in the lysimeters was drained. About 30 hours later, the valves were closed to keep the adequate moisture in the lysimeters to use for germination process. Mariotte bottles were connected and

adjusted for desired level for each lysimeters. Ten seeds were sowed from 1 to 3 cm soil depths. During the germination process, three healthier canola plants were kept in each lysimeter.

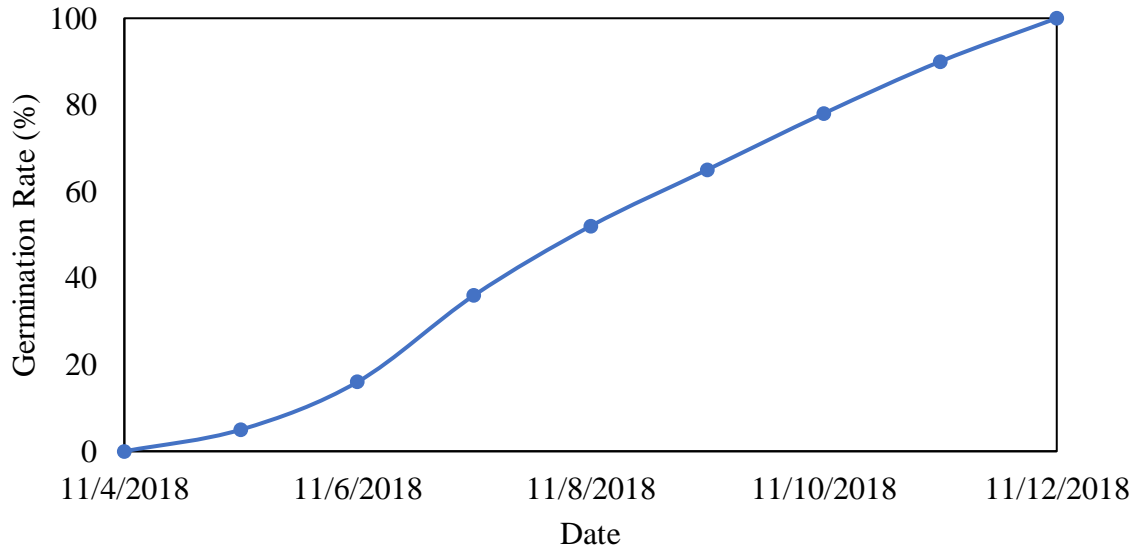


Figure 3.3. Germination rate of canola

Table 3.1. Canola harvesting dates

Treatments	Replications							
	1	2	3	4	5	6	7	8
T _{control}	5- Feb	5- Feb	6- Feb	6- Feb	5- Feb	5- Feb	5- Feb	5- Feb
T ₃₀	9- Feb	10- Feb	10- Feb	9- Feb	10- Feb	9- Feb	9- Feb	10- Feb
T ₆₀	7- Feb	6- Feb	6- Feb	7- Feb	6- Feb	7- Feb	7- Feb	7- Feb
T ₉₀	5-Feb	4- Feb	5- Feb	4- Feb	5- Feb	4- Feb	4- Feb	4- Feb

Although iron deficiency was observed at the beginning of experiment, beneficial nematodes, supplements and chemicals have never applied during the whole experiment.

3.2.3. Plant Root Measurements and Crop Water Use Determination

After harvesting the canola, 16 lysimeters from four randomly selected treatments were cut vertically to determine canola plant root dry mass in each treatment. In order to analyze whole canola root distribution in each treatment, lysimeters were cut from top through bottom

using electric saw. During the soil extraction process, three plant root depth intervals (0-30, 30-60, and 60-90 cm) were selected based on three water table depths. Soil in the lysimeters were washed and the roots were separated gently from the soil. The wet roots were air dried and weighed accordingly to determine the root distribution and dry mass in each treatment examined in each depth interval. Evapotranspiration in each lysimeter were calculated using Eq.3.1.

$$(\Delta S) = (P + I + Cr) - (R + Dp + ET) \quad (\text{Eq.3.1})$$

where, Cr is capillary rise, P is precipitation, I is irrigation, R is runoff, Dp is deep percolation, ET is evapotranspiration, ΔS is the change in soil water content.

Irrigation, precipitation, runoff, and deep percolation were not applied in this study since the experiments was performed in controlled greenhouse. After evaluation of the controlled environment condition, the soil water balance equation was used to determine ET for each treatment (Eq. 3.2).

$$ET = Cr + S_1 - S_2 \quad (\text{Eq.3.2})$$

S_1 demonstrates initial soil moisture condition and S_2 shows final soil moisture condition in the lysimeters

Water reduction in the Mariotte bottles was measured every 15 days to determine capillary rise in the lysimeters. The amount of water use of canola was calculated using soil water balance equation (Eq. 3.1) (Hillel, 1998).

To determine the initial moisture conditions of the lysimeters at the beginning of the experiment, the soil water potential sensors were used. After cutting sixteen lysimeters, soil water content was measured, and the final moisture conditions of the sixteen lysimeters were determined for both irrigated and non-irrigated treatments.

3.2.4. Irrigation Scheduling

As mentioned earlier, the soil water release curve (Figure 3.4) was used to consider 50% of the total available moisture as the readily available moisture in the soil profile of control treatment. The irrigation depths for each lysimeters were calculated by using Equation 3.3 (Majumdar, 2001).

$$d = \sum_{i=1}^n \frac{F_{ci} - M_{bi}}{100} \times A_{si} \times D_i \quad \text{Eq. 3.3}$$

where, d is the equivalent depth of water in cm, F_{ci} is field capacity of the layer in percent by weight, M_{bi} is current water content of the layer in percent by weight, A_{si} is apparent specific gravity (Bulk density), D_i is the depth of each layer, n is the number of layers.

Table 3.2. The summary of soil physical properties

soil fractions				physical properties of soil			
sand (%)	silt (%)	clay (%)	soil texture	field capacity (cm^3/cm^3)	readily available moisture (50%) (cm^3/cm^3)	permanent wilting point (cm^3/cm^3)	bulk density (g/cm^3)
43	35	22	Loam	0.32	0.27	0.21	1.41

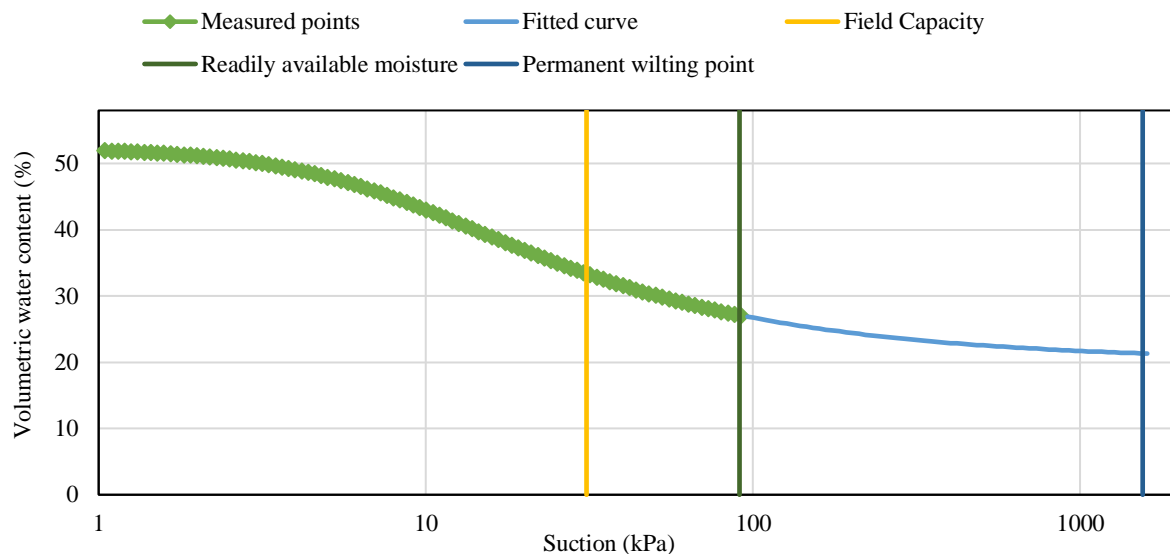


Figure 3.4. The soil moisture release curve

The summary of physical properties of soil-sand mixture was determined based on laboratory test results (Table 3.2). To determine the soil water retention curve, water in the lysimeters was drained out from the lysimeters through valve at the bottom of the lysimeter until the readily available moisture content in the lysimeter become 50%. For the control experiments, necessary amount of irrigation was applied at the surface of the lysimeters to maintain the soil field capacity as $0.32 \text{ cm}^3/\text{cm}^3$.

3.2.5. Statistical Analysis

Randomized complete block design model with eight replications and four treatments were applied in this study (Figure 3.1). The effect of different groundwater levels on canola growth and yield parameters (crop water use, plant height, seed weight, pod weight, total biomass, root-shoot ratio and root distribution) were analyzed by using one-way analysis of variance (ANOVA) with $P \leq 0.05$ level of significance (R Studio, R Core Team 2017).

Statistical Package for the Social Sciences version 25 (SPSS) and Duncan homogeneous test comparisons with the $P = 0.05$ probability level were used to conduct mean separation tests on four different treatments. Main fold analysis was performed to obtain mean graphics.

3.3. Results and Discussions

3.3.1. ET_0 and Air Temperature in the Greenhouse

To determine relationship between evapotranspiration and temperature in the greenhouse and interpret the temperature and ET_0 changes during the different canola growing stages (germination, growing, and harvesting), daily average ET_0 rates and temperature data were collected between November 4, 2018 (planting) and February 4, 2019 (harvesting). According to the result obtained from ETgages, the lowest and highest temperature in the greenhouse were determined as 15.5°C and 29.5°C , respectively. The lowest temperature was observed first 10

days of canola growing period because of extreme ambient cold temperatures. Temperatures in the greenhouse were 25 ± 5 °C from November 14, 2018 to February 4, 2019 (Figure 3.5).

The lowest daily ET_0 was measured as 3.80 mm during the germination stage of canola. After first 10 days of canola growing period, ET_0 rates were fluctuated, and the highest ET_0 was measured as 7.80 mm. Cumulative ET_0 was calculated as 577 mm during total experiment process (92 days). Figure 3.5. explains correlation relationship between evapotranspiration and temperature. When the greenhouse temperature reduced in any time, ET_0 also decreased comparatively.

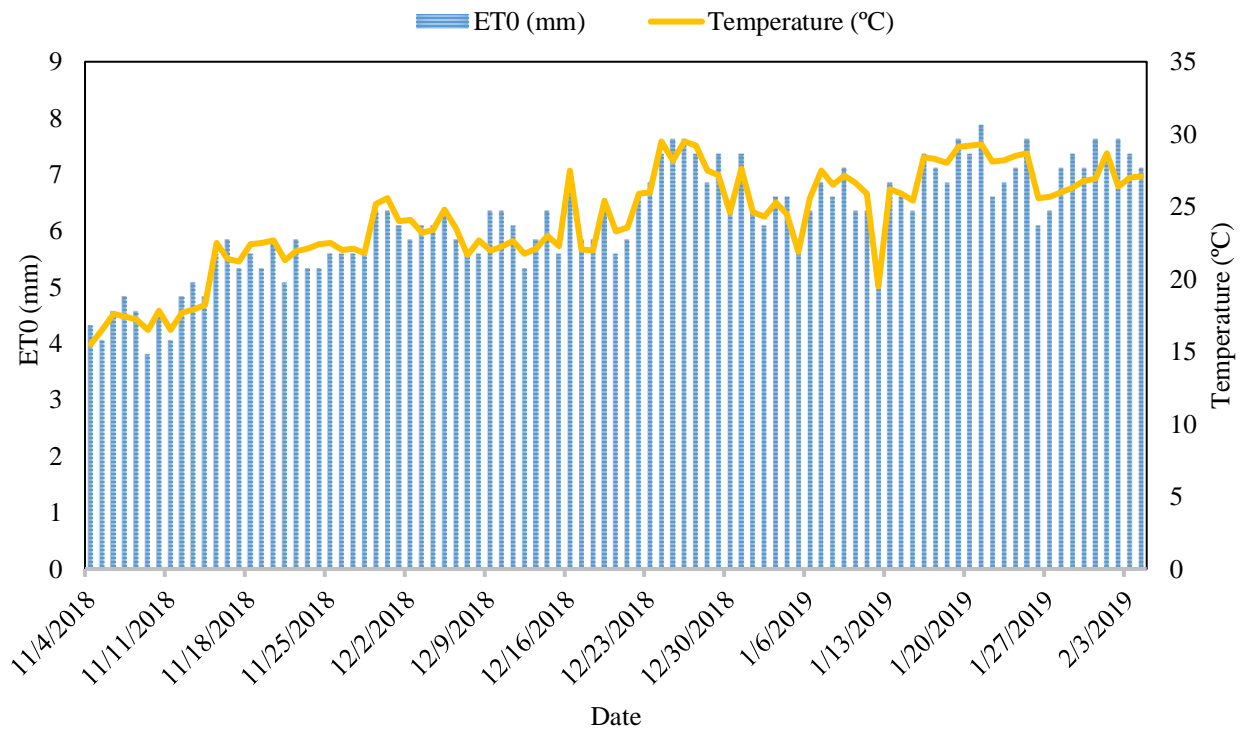


Figure 3.5. Measured daily air temperature (°C) and ET_0 values in the greenhouse.

3.3.2. Crop Water Use

To prevent water stress and applied excessive amount of irrigation water, water content was kept between field capacity ($0.32 \text{ cm}^3/\text{cm}^3$) and critical point ($0.27 \text{ cm}^3/\text{cm}^3$) for control treatments. Three different plant root depths were considered for water requirement calculations.

Canola root depth was projected 30 cm between November 4 and December 4 in 2018 for calculation of crop water requirements. Between December 4 and January 4, 2019, plant was irrigated until 60 cm root depth. After January 4, 2019 crop water requirement was calculated for 90 cm root depth.

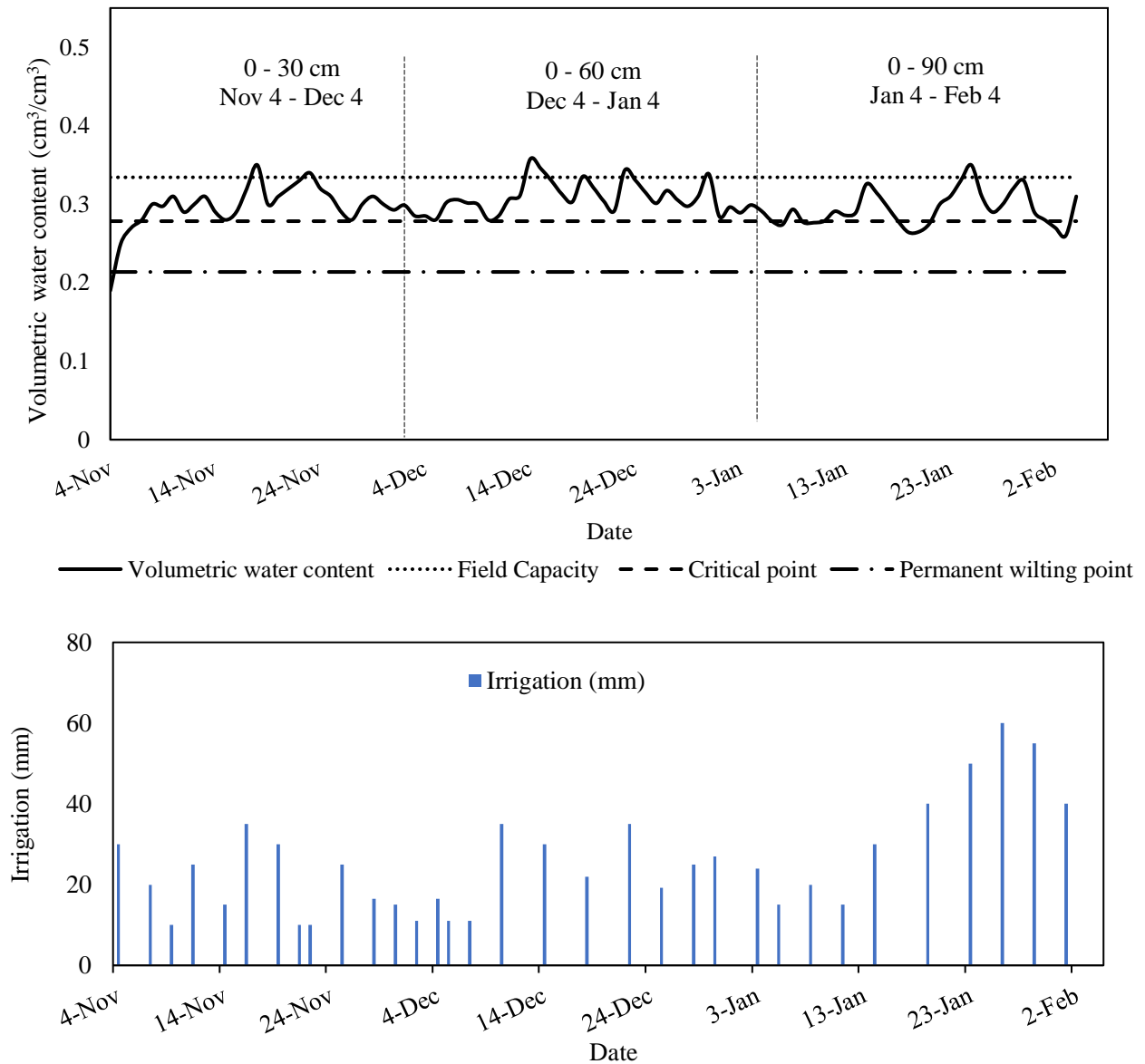


Figure 3.6. Soil moisture content measurements of control treatment at the desired depth of soil profile, and the amount of irrigation water applied to the lysimeters.

Figure 3.6 demonstrates volumetric water content with specified root depths and amount of applied irrigation water during the experiment. Other properties such as field capacity critical

points (RAM and 50% of TAM) and permanent wilting point were represented in Figure 3.6. Volumetric water content was always maintained between field capacity and RAM. Available soil moisture in the root zone was fluctuated and it exceeded 50% of total available soil moisture level twice.

Four control treatment lysimeters were cut to calculate total evapotranspiration. As explained earlier, the same amount of irrigation water applied to all control treatment lysimeters. Based on the data obtained from the sensors, the amount of cumulative irrigation water was found as 752 mm for each lysimeters. Calculated cumulative canola plant water use were varied from 733 to 749 mm. Thus, average ET_c was calculated as 740 mm for treatment lysimeters (Table 3.3).

Table 3.3. Total canola water-use of control treatments.

lysimeter number	initial condition	cumulative irrigation water	final condition	cumulative ET_c	Mean ET_c
#	mm	mm	mm	mm	mm
R3- $T_{control}$	162	752	181	733	740
R4- $T_{control}$	162	752	174	740	
R6- $T_{control}$	162	752	165	749	
R7- $T_{control}$	162	752	176	738	

Total canola plant water use and groundwater contribution for remaining 12 lysimeters are presented in table 3.4. Data collected from water potential sensors used to calculate soil water content. According to the results from sensors, initial soil water content was 350 mm in the 90 cm soil profile. Since all lysimeters were packed at the same conditions, the minor water content differences among the other lysimeters were eliminated.

Similar to control treatments, canola evapotranspiration in the lysimeters was measured. Each root depths had different ET_c results because evapotranspiration was influenced to

determined WTD. According to the comparison ET_c values from different WTD, 30 cm soil profile had the highest ET_c , 717 mm. The significant difference was observed between 30 and 90 cm soil profile based on ET_c values.

Table 3.4. Total canola water use from groundwater depths (mm).

lysimeter number	depth	initial condition	water use from GW	final condition	ET_c	mean ET_c	mean ET_c
#	cm	mm	mm	mm	mm	mm	% $T_{control}$
R3	30	350	632	241	741	717	97
R4	30	350	615	268	697		
R6	30	350	643	245	748		
R7	30	350	607	275	682		
R3	60	350	485	279	556	527	71
R4	60	350	426	289	487		
R6	60	350	433	271	512		
R7	60	350	454	251	553		
R3	90	350	402	235	517	501	68
R4	90	350	355	225	480		
R6	90	350	379	214	515		
R7	90	350	341	198	493		

These results showed that, there are inverse relationship between WTD and evapotranspiration. Additionally, same inverse relationship was obtained between WTD and groundwater contribution. When water table level increased from 90 to 30 cm, the amount of water use from groundwater increased (Figure 3.7).

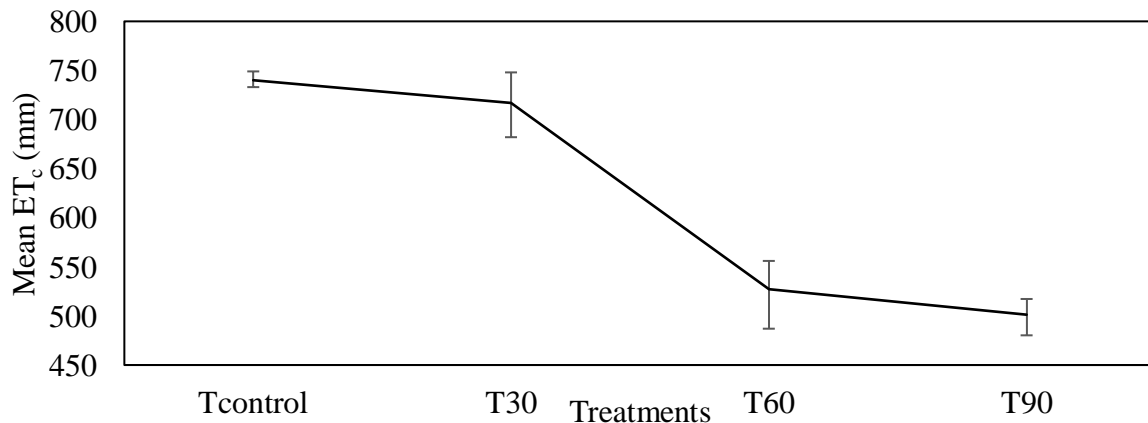


Figure 3.7. Canola plant water use with sixteen lysimeters.

3.3.3. Growth and Yield Parameters

According to the statistical results for growth and yield parameters, differences among T_{control} , T_{30} and T_{60} for mean plant height was not significant, but T_{90} was significantly higher than other treatments. The highest mean canola plant height was 134.6 cm at T_{90} treatment and the lowest mean plant height was 113.3 cm at T_{30} treatment. Similar inverse relationship between WTD and groundwater contribution was observed between plant height and WTD. When WTD level increased from 90 to 60 cm in the lysimeters, canola plant height decreased from 134.6 to 113.3 cm.

Obvious significant differences between each treatment were obtained for mean total biomass, pod weight and seed weight per plant. The highest mean total biomass, pod weight and seed weight were calculated as 22.1, 12.6, and 6.3 gr at T_{90} treatment, respectively. The lowest mean total biomass, pod weight, and seed weight results were calculated as 15.1, 9.5, and 4.8 gr at T_{30} treatment, respectively. These results showed that, higher water table depths decreased canola harvesting results. Overall, statistical results proved that there is a negative correlation between the canola plant growth and yield parameters and WTD.

The water use results between water table treatments and control treatment showed that, T_{control} lysimeters consumed the highest amount of water (Table 3.3 and Table 3.4). After harvesting, plant height, total biomass, pod and seed weights results showed that T_{90} treatment produced the highest yield values compare to other treatments. T_{control} treatment had the second highest yield (Table 3.5). As explained earlier, T_{control} used optimum amount of irrigation water, 740 mm, and T_{90} consumed 501 mm water from groundwater. However, better growth and yield result were obtained in T_{90} treatment.

Table 3.5. Statistical analysis of canola growth and yield parameters.

Treatment	Plant Height cm/plant	Total biomass g/plant	Pod weight g/plant	Seed weight g/plant
T _{control}	118.0 ^a	19.4 ^c	11.7 ^c	5.8 ^c
T ₃₀	113.2 ^a	15.1 ^a	9.5 ^a	4.7 ^a
T ₆₀	113.8 ^a	17.8 ^b	10.8 ^b	5.3 ^b
T ₉₀	134.6 ^b	22.0 ^d	12.5 ^d	6.3 ^d

Note: Statistical results for mean canola growth and yield parameters are indicated with letters.

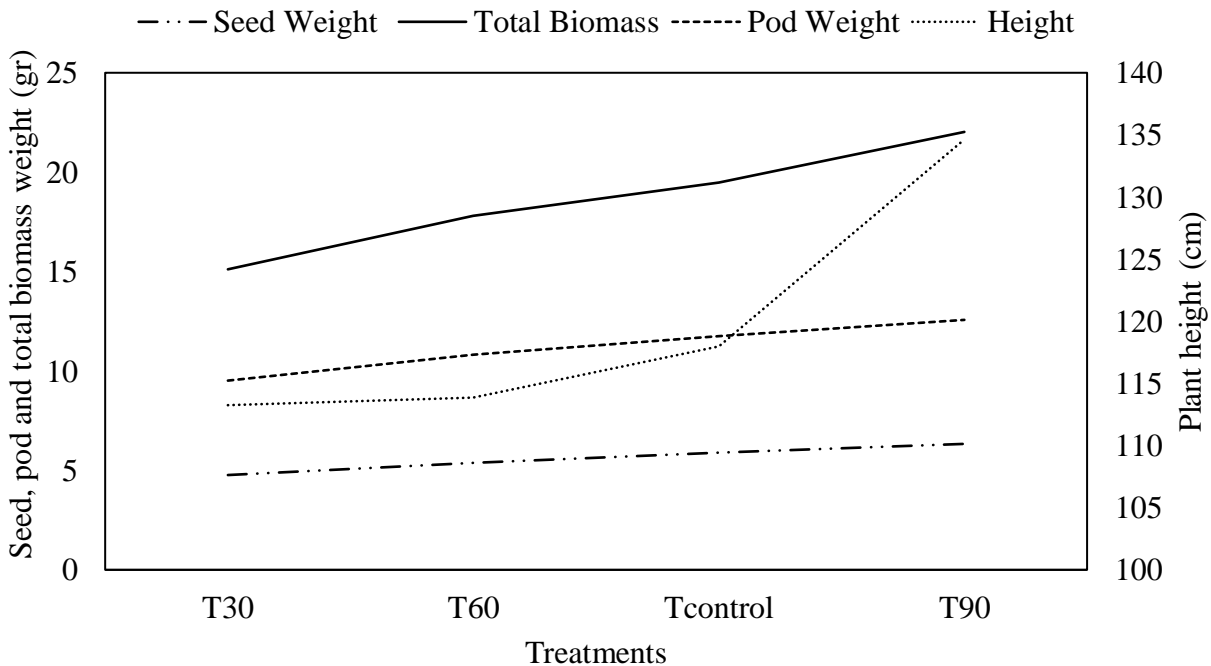


Figure 3.8. Canola harvest results, pod weight, total biomass, height and seed weight.

3.3.4. Water Use Efficiency (WUE)

WUE was calculated for both grain yield (harvested seed weight) and total biomass (harvested total dry matter). Since sixteen lysimeters were cut, average grain yield and total biomass values of sixteen lysimeters were used for grain yield and biomass WUE calculations. The same statistical difference grain yield and total biomass results of thirty-two lysimeters was extrapolated using sixteen lysimeters data in response to WTD (Table 3.6).

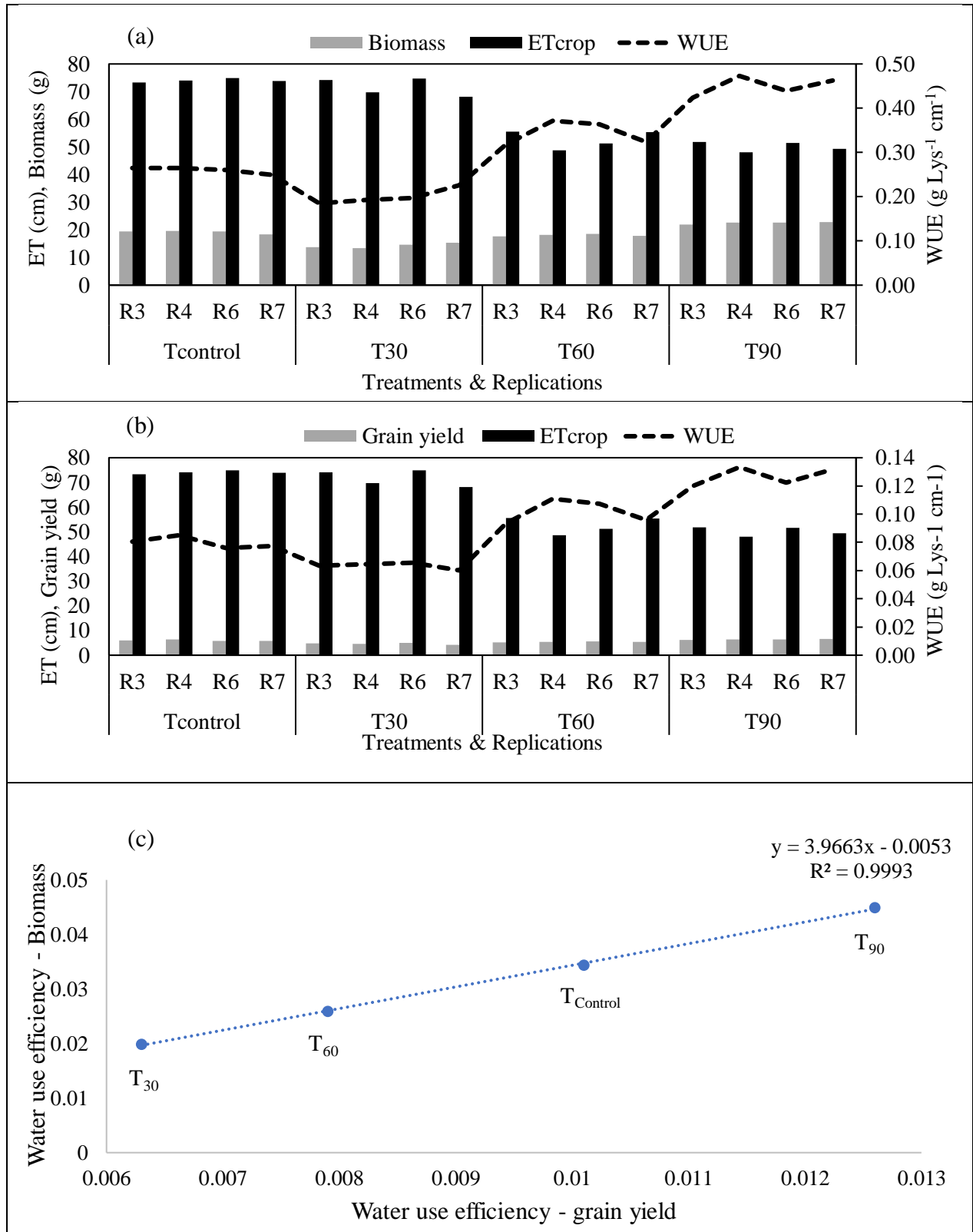


Figure 3.9. Canola water use efficiency with treatments: (a) grain yield WUE (b) total biomass WUE (c) correlation between grain yield and total biomass.

The relationship between WUE of canola total biomass and grain yield was found. The correlation of both WUE values were determined (Figure 3.9). The effects of different WTD levels on both grain yield and total biomass WUE were observed. The significant differences between the treatments were found in terms of grain yield and total biomass WUE values. The highest grain yield and biomass WUEs for T₉₀ were calculated as 0.0126 and 0.0449 g lys⁻¹ mm⁻¹. The lowest values for both parameters were calculated at T₃₀ treatment (Table 3.6).

Table 3.6. Statistical analysis of canola mean grain yield, total biomass, water use, and water use efficiency results. These results belong to sixteen lysimeters.

Treatments	Mean grain yield (g/lysimeter)	mean total biomass (g/lysimeter)	Mean crop water use (mm)	Mean grain yield WUE (g/lysimeter*mm)	Mean total biomass WUE (g/lysimeter*mm)
T _{control}	5.9 ^c	19.2 ^c	740.0 ^b	0.0079 ^b	0.0259 ^b
T ₃₀	4.5 ^a	14.3 ^a	717.0 ^b	0.0063 ^a	0.0199 ^a
T ₆₀	5.3 ^b	18.0 ^b	527.0 ^a	0.0101 ^c	0.0344 ^c
T ₉₀	6.3 ^d	22.5 ^d	501.2 ^a	0.0126 ^d	0.0449 ^d

Note: Statistical results of WUE are indicated with letters in table Table 3.6.

3.3.5. Dry Root Mass

After cutting 16 lysimeters as mentioned earlier, soil profile was divided in three different layers as 0-30, 30-60 and 60-90 cm (measured from the top) to determine percentage of root mass distribution in terms of WTD (Table 3.7). Overall, the highest root-mass was found in T_{control} at 0-30 cm (4.52 g and 54.6%). There is a linear relationship between WTD and root mass for T_{control}. When WTD increased from 90 to 30 cm, root weight increased from 0.73 to 4.52 g. Since T_{control} did not have WTD, lower amount of root was found in deeper soil layers. The significant differences were observed in 0-30 cm layers between T₉₀ and other treatments and more root mass was observed in 60-90 cm in treatment T₉₀. The highest average root weight

found 7.97 g in 3rd layer of T₉₀ among other treatments and layers (Table 3.7). Opposite the linear relationship between WTD and root mass for T_{control}, the inverse correlation was observed between WTD and root mass for T₉₀.

Table 3.7. Average root mass and proportions of roots.

Layers	Depth	Average root mass and percentage							
		T _{control}		T ₃₀		T ₆₀		T ₉₀	
	cm	g	%	g	%	g	%	g	%
1 th	0-30	4,52 ^b	54,6	4,4 ^b	47,8	4,60 ^b	42,9	3,13 ^a	19,1
2 nd	30-60	3,02 ^a	36,7	2,95 ^a	31,9	4,02 ^b	37,6	5,22 ^c	32,1
3 rd	60-90	0,73 ^a	8,7	1,87 ^b	20,3	2,08 ^b	19,5	7,97 ^c	48,8
Total		8,27 ^a	100	9,22 ^a	100	10,7 ^b	100	16,32 ^c	100

There is no significant difference between T₃₀ and T_{control} for total root weight distribution. However, the lowest mean of total root weight was determined as 8.27 g for T_{control}. The mean total root mass of T₉₀ was always two-fold of T_{control} (Figure 3.10 and Figure A.1).

Comparatively, lower dry root mass was measured at the 2nd and 3rd layers of the T_{control}, T₃₀, and T₆₀ but higher dry root mass was found at the 2nd and 3rd layers of the T₉₀. Similar to other results (grain yield, plant height, total biomass, pod weight, and WUE), the best root mass results were obtained from T₉₀ (Table 3.7).

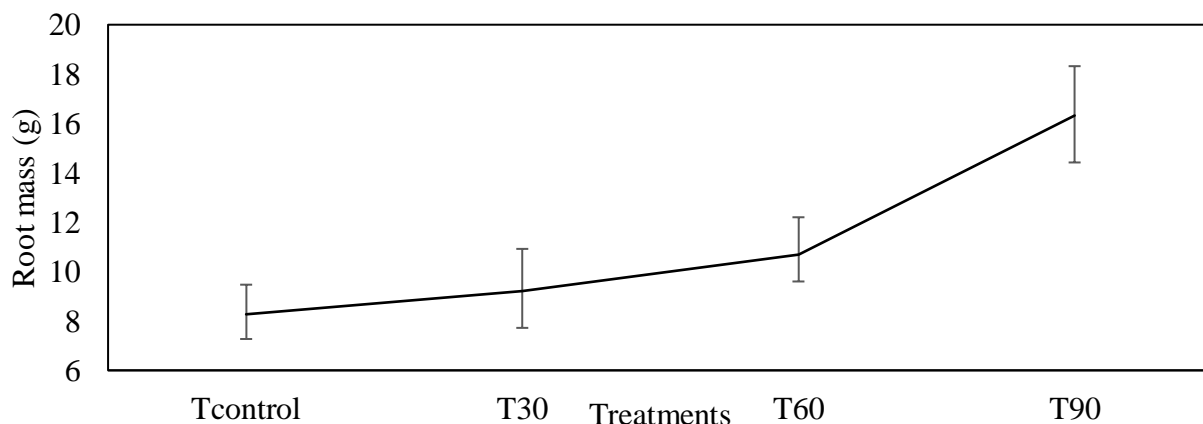


Figure 3.10. Summary of total root distribution.

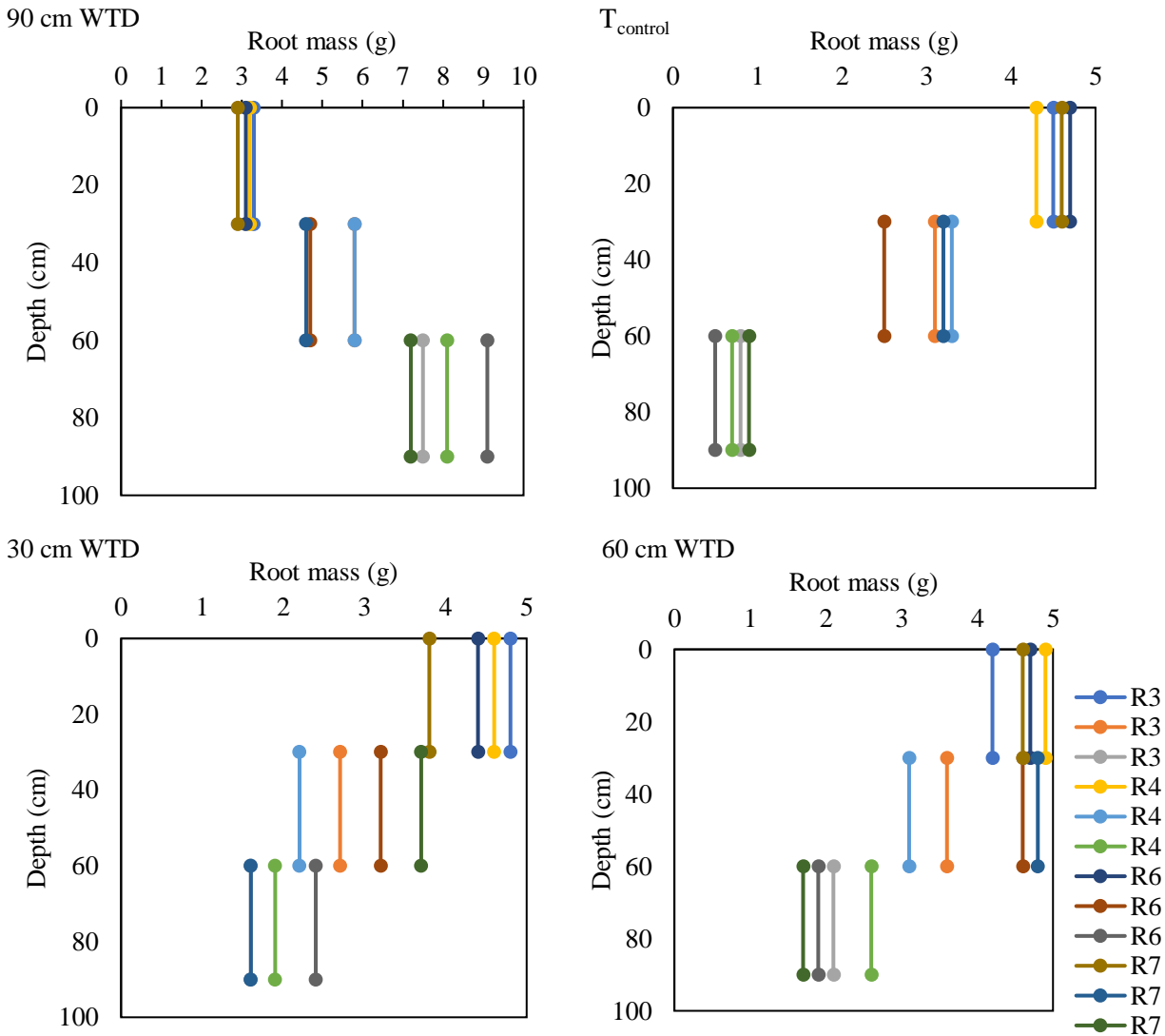


Figure 3.11. Root mass distribution of canola with different layers (0-30, 30-60, and 60-90 cm).

3.3.6. Root-Shoot Ratio

To analyze the relationship between total biomass and roots mass, root-shoot ratio was calculated for sixteen lysimeters. Total root weight was divided by total biomass to calculate root-shoot ratio. The result of root, total biomass and root-shoot ratio data are presented in Figure 3.12.

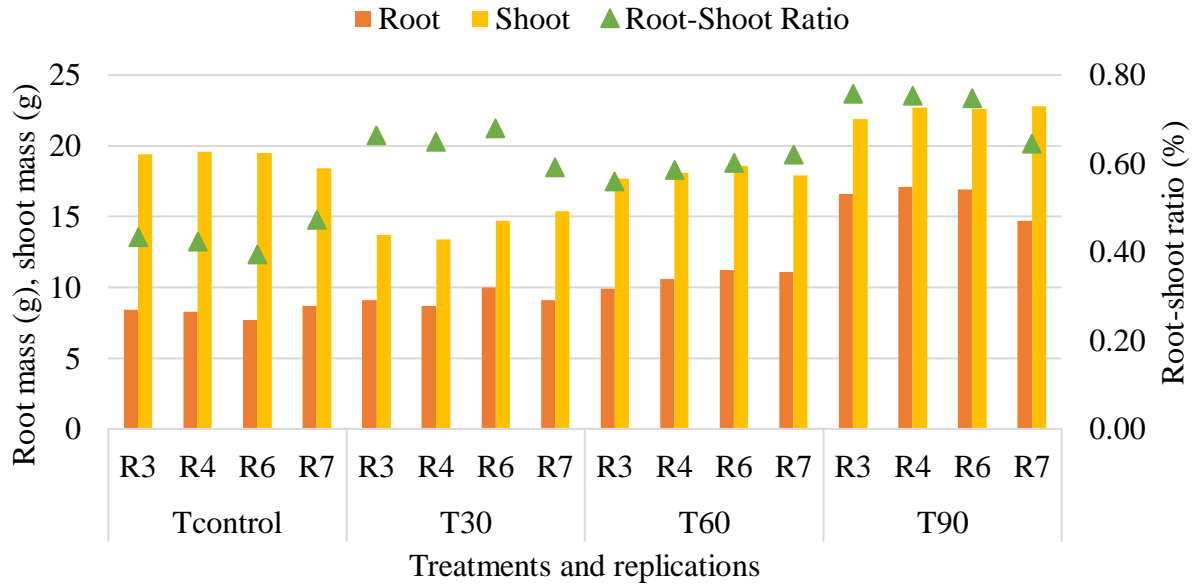


Figure 3.12. Root-shoot ratio with different WTD.

The lowest root-shoot ratio was found in T_{control} lysimeter, 0.39. Root-shoot ratio of T_{90} was 0.76, which was the highest root-shoot ratio. Even though total biomass of canola plant in T_{control} was more than T_{30} and T_{60} , root-shoot ratio of T_{control} was lower than other treatments. According to results, T_{90} was chosen as a best plant for root-shoot ratio. Canola plant root in T_{90} was stronger and heavier than other treatments since plant in T_{90} treatment improved their roots to reach groundwater. Similarly, since canola plant in T_{control} easily reached irrigation water, lower root data was observed in T_{control} .

4. SUMMARY AND FUTURE WORK RECOMMENDATION

4.1. Summary

In this study, canola plant height, water use from different groundwater levels, optimum amount of irrigation water, total biomass WUE, grain yield WUE, root mass, root-shoot ratio and harvesting results (total biomass, pod and seed weight) were determined and compared with three different water tables and optimum amount of irrigation under the adjustable weather conditions in the greenhouse. Investigated NDOLA-01 type of canola plant results showed that the plant was affected by different water table levels since inverse and linear relationship were found in results depends on different WTD. Significant statistical difference was observed among the treatments. Determination of above and below ground parameters include total biomass and root weight showed that 90 cm water table depth of lysimeters produced the best results. Similarly, the lowest crop water use from water table was found at the T₉₀ treatments. The highest crop water use was calculated at the irrigated lysimeters, and it was significantly higher than 90 cm lysimeters.

Considering harvesting results, canola plant showed significant statistical differences among the treatments. The highest measured pod weight, total biomass, and seed weight were found at the 90 cm lysimeters although 90 cm treatments consumed lowest amount of water from the groundwater. The highest harvesting results with the lowest amount of consumed water showed the highest total biomass and grain yield WUE. On the other hand, the lowest harvesting results and the highest crop water use were obtained from 30 cm lysimeters. It was assumed that canola crop tend to use continuously water from groundwater when roots reached the groundwater. As a consequence of that high WTD level (30 cm) made negative impact on canola.

Below ground parameters such as root distribution in each specified soil depth (0-30, 30-60, and 60-90 cm) were examined clearly. The significant statistical difference was not found between root distribution and layers. However, stronger and heavier roots were found near the water table level. Opposite the root weight in each layer, total root weight was affected by WTD, and the significant statistical differences occurred among the treatments. Total root weight at the 90 cm lysimeter was significantly higher than other treatments. Irrigated treatment had lowest total root weight. It was projected that canola root at the drier lysimeter developed root structure since canola plant was in tendency to reach water.

In terms of crop total biomass WUE and grain yield WUE, grain yield parameters, harvesting results, root mass distribution and root-shoot ratio; it was observed that 90 cm was the best water table depth for canola in this lysimeter experiment.

4.2. Recommendations for Future Work

- All these experiments could be conducted in the real farm conditions using lysimeter techniques.
- In this study, three water table depths between 30 and 90 cm were tested. Beyond 90 cm depth could be studied to determine canola plant's behavior.
- Using the same soil packing and weather conditions, 90 cm WTD with optimum amount of irrigation water could be performed.
- Other crops that grown in ND could be studied.
- Tap water with no salinity was used in this experiment. Saline water in different concentrations could be added in the experiments as a future study.

REFERENCES

- ASABE Standards. 2008. S526.4: Soil and Water Terminology-Forages. St. Joseph, MI: ASABE.
- Ayars, E. J., and A. R. Schoneman. 1986. Use of saline water from a shallow water table by cotton. *Transactions of the ASAE* 29(6):1674-1678.
- Ayars, E. J., W. E. Christen, W. R. Soppe, and S. W. Meyer. 2006. The resource potential of in-situ shallow groundwater use in irrigated agriculture: a review. *Irrigation Science* 24(3):147-160.
- Borg, H. and W. D. Grimes. 1986. Depth development of roots with time: An empirical description. *Transactions of the ASAE* 29(1):194-0197.
- Climate of North Dakota. (n.d.). Retrieved November 17, 2018 (NOAA), from https://www.ncdc.noaa.gov/climatenormals/clim60/states/Clim_ND_01.pdf
- Condon, A.G., R.A. Richards, G.J. Rebetzke, and G.D. Farquhar. 2004. Breeding for high water use efficiency. *J. Exp. Bot.* 55:2447-2460.
- Council for Agricultural Science and Technology (CAST). 2008. Convergence of Agriculture and Energy: III. Considerations in Biodiesel Production, CAST Commentary.
- Franzen, D. 2013. Managing saline soils in North Dakota. NDSU Extension Service, Fargo, ND.
- Ghamarnia, H., M. Golamian, S. Sepehri, I. Arji, and V. Rezvani. 2012. Groundwater contribution by safflower (*Carthamus tinctorius* L.) under high salinity, different water table levels, with and without irrigation. *Journal of Irrigation and Drainage Engineering* 138(2):156-165.
- Hamdy, A., R. Ragab, and E. Scarascia-Mugnozza. 2003. Coping with water scarcity: water saving and increasing water productivity. *Irrigation and drainage* 52(1):3-20.

- Herget, G.W., J.F. Margheim, A.D. Pavlista, D.L. Martin, R.J. Supalla, and T.A. Isbell. 2016. Yield, irrigation response, and water productivity of deficit to fully irrigated spring canola. *Agricultural Water Management* 168:96-103.
- Hillel, D. 1998. *Environmental soil physics: Fundamentals, applications, and environmental considerations*. Elsevier.
- Howell, T. A. 2001. Enhancing water use efficiency in irrigated agriculture. *Journal of Agronomy* 93(2):281-289.
- Huo, Z., S. Feng, G. Huang, Y. Zheng, Y. Wang, and P. Guo. 2012. Effect of groundwater level depth and irrigation amount on water fluxes at the groundwater table and water use of wheat. *Irrigation and drainage* 61(3):348-356.
- Hutmacher, B. R., E. J. Ayars, S. S. Vail, D. A. Bravo, D. Dettinger, and A. R. Schoneman. 1996. Uptake of shallow groundwater by cotton: growth stage, groundwater salinity effects in column lysimeters. *Agricultural Water Management* 31(3):205-223.
- Jia, M., M.D. Dukes, J.M. Jacobs, and S. Irmak. 2006. Weighing lysimeters for evapotranspiration research in a humid environment. *American Society of Agricultural and Biological Engineers (ASABE)* 49(2):401-412.
- Johnston, A.M., D.L. Tanaka, P.R. Miller, S.A. Brandt, D.C. Nielsen, G.P. Lafond, and N.R. Riveland. 2002. Oilseed crops for semiarid cropping systems in the Northern Great Plains. *Journal of Agron* 94: 231-240.
- Kahlow, M. A. and M. Ashraf. 2005. Effect of shallow groundwater table on crop water requirements and crop yields. *Agricultural Water Management* 76(1):24-35.
- Kandel, H. 2010. Soybean production field guide for North Dakota and Northwestern Minnesota.

- Kruse, G. E., F. D. Champion, L. D. Cuevas, R. E. Yoder, and D. Young. 1993. Crop water use from shallow, saline water tables. *Transactions of the ASAE* 36(3):697-707.
- Kutcher, H.R., J.S. Warland, and S.A. Brandt. 2010. Temperature and precipitation effects on canola yields in saskatchewan, Canada. *Agricultural and Forest Meteorology*. 150:161-165.
- Lesczynski, D. B., and C. B. Tanner. 1976. Seasonal variation of root distribution of irrigated, field-grown Russet Burbank potato. *American Potato Journal* 53(2):69-78.
- Luo, Y. and M. Sophocleous. 2010. Seasonal groundwater contribution to crop-water use assessed with lysimeter observations and model simulations. *Journal of Hydrology* 389(3-4):325-335.
- Majumdar, K. D. 2001. *Irrigation water management: principles and practice*. PHI Learning Pvt. Ltd.
- Mejia, N. M., A. C. Madramootoo, and S. R. Broughton. 2000. Influence of water table management on corn and soybean yields. *Agricultural Water Management* 46(1):73-89.
- Okello, C., B. Tomasello, N. Greggio, N. Wambiji, and M. Antonellini. 2015. Impact of population growth and climate change on the freshwater resources of Lamu Island, Kenya. *Journal of Water* 7:1264-1290.
- Payero, O. J., R. S. Melvin, and S. Irmak. 2006. Response of soybean to deficit irrigation in the semi-arid environment of west-central Nebraska. *Transactions of the ASAE* 48(6):2189-2203.
- Payero, J.O., D.D. Tarkalson, S. Irmak, D. Davison, and J.L. Petersen. 2009. Effect of timing of a deficit-irrigation allocation on corn evapotranspiration yield, water use efficiency and dry mass. *Agricultural Water Management* 96:1387-1397.

- Putz, T., J. Fank, and M. Flury. 2018. Lysimeters for vadose zone research. *Vadose Zone* 17:180035.
- Rijal, I., X. Jia, X. Zhang, D. D. Steele, T. F. Scherer, and A. Akyuz. 2012. Effects of subsurface drainage on evapotranspiration for corn and soybean in southeastern North Dakota. *Irrigation and Drainage Engineering* 138(12):1060-1067.
- Ripoll, J., L. Urban, M. Staudt, F. Lopez-Lauri, L.P.R. Bidel, and N. Bertin. 2014. Water shortage and quality of fleshy fruits-making the most of the unavoidable. *Journal of Experimental Botany* 65(15):4097-4117.
- Scanlon, B.R., R.C. Reedy, and J.B. Gates. 2010. Effects of irrigated agroecosystems: 1. Quantity of soil water and groundwater in the southern High Plains, Texas. *Water Resources Research* 46(9).
- Schindler, U., D. Wolfgang, G.V. Unold, L. Muller, and R. Wieland. 2010. Extending the measurement range of soil hydraulic properties using the air-entry pressure of the ceramic cup. *Plant Nutrition and Soil Science* 173:563-572.
- Sinclair, T.R., C.B. Tanner, and J.M. Bennett. 1984. Water-use efficiency in crop production. *BioScience* 34:36-40.
- Skaggs, R.W., and J. van Schilfgaarde. 1999. *Agricultural Drainage*. Agronomy Monograph 38, Madison, WI: American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America.
- Soppe, O. W. R. and E. J. Ayars. 2003. Characterizing groundwater use by safflower using weighing lysimeters. *Agricultural water management* 60(1):59-71.
- Tebaldi, C., K. Hayhoe, M. J. Arblaster, and A. G. Meehl. 2006. Going to the extremes. *Climate Change* 79(3-4):185-211.

- Torres, S. J. and J. R. Hanks. 1989. Modeling water table contribution to crop evapotranspiration. *Irrigation Science* 10(4):265-279.
- United Nations. 2004. Global E-Government readiness report.
<https://publicadministration.un.org/egovkb/en-us/Reports/UN-E-Government-Survey-2004>
- United States Department of Agriculture (USDA). 2018. North Dakota Agricultural Statistics.
- Vorosmarty, C.J., P. Green, J. Salisbury, and R.B. Lammers. 2000. Global water resources: Vulnerability from climate change and population growth. *Journal of Science*, 289:284-288.
- Yang, J.F., S. Wan, W. Deng, and G. Zhang. 2007. Water fluxes at a fluctuating water table and groundwater contributions to wheat water use in the lower Yellow River flood plain, China. *Hydrological Processes* 21(6):717-724.
- Zhang, H., X. Wang, M. You, and C. Liu. 1999. Water-yield relations and water-use efficiency of winter wheat in the North China Plain. *Irrigation Science* 19:37-45.

APPENDIX

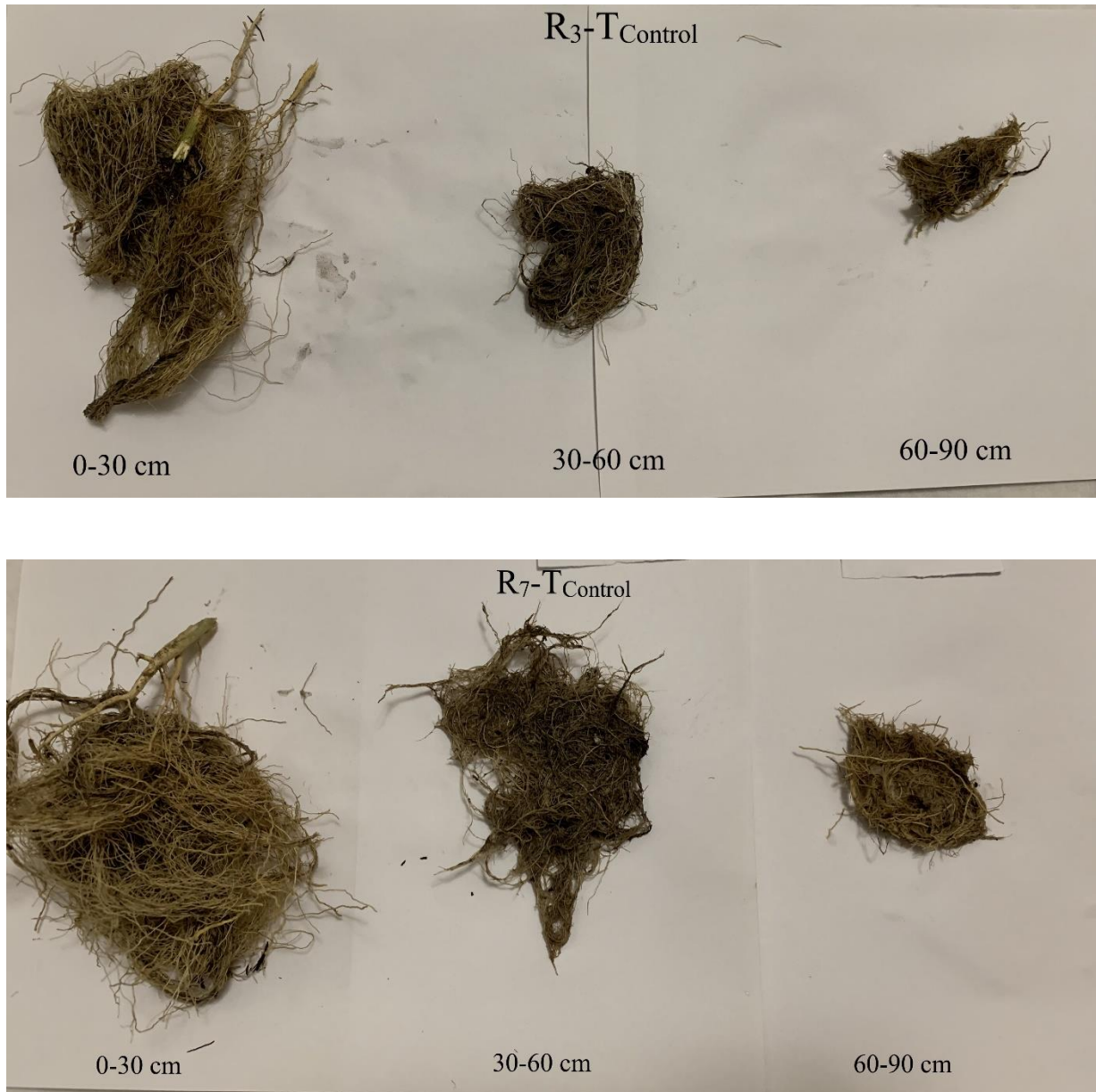


Figure A.1. Extracted roots from three different layers (0-30, 30-60, 60-90 cm) - R3-T_{control} and R7-T_{control} treatments.

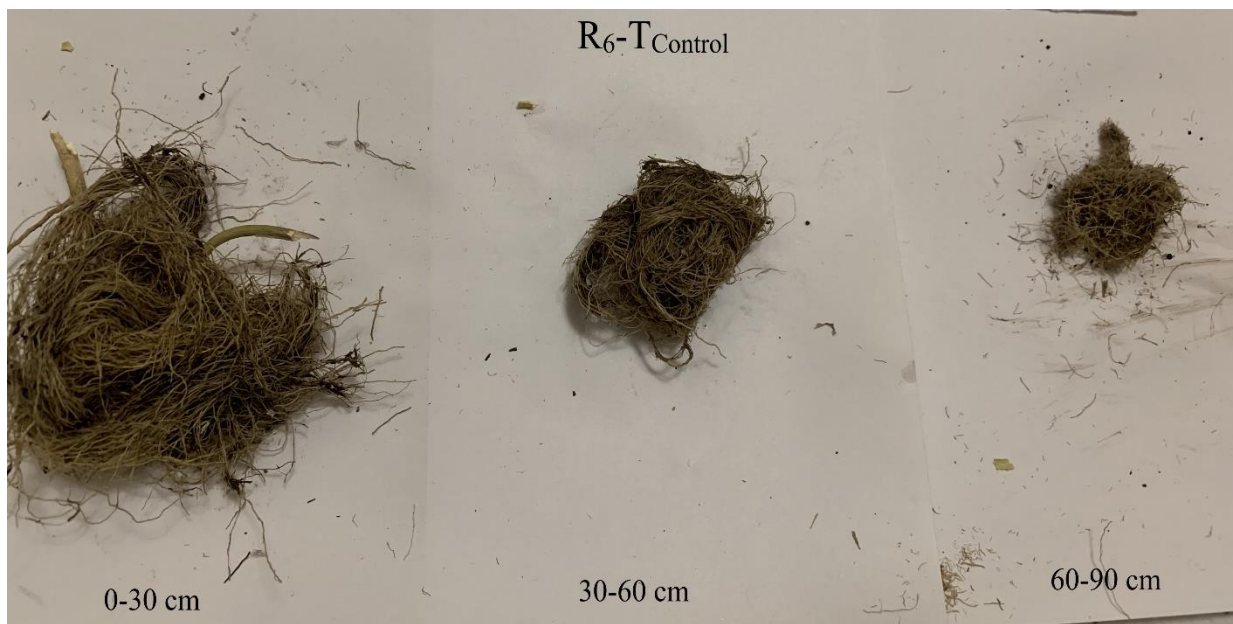
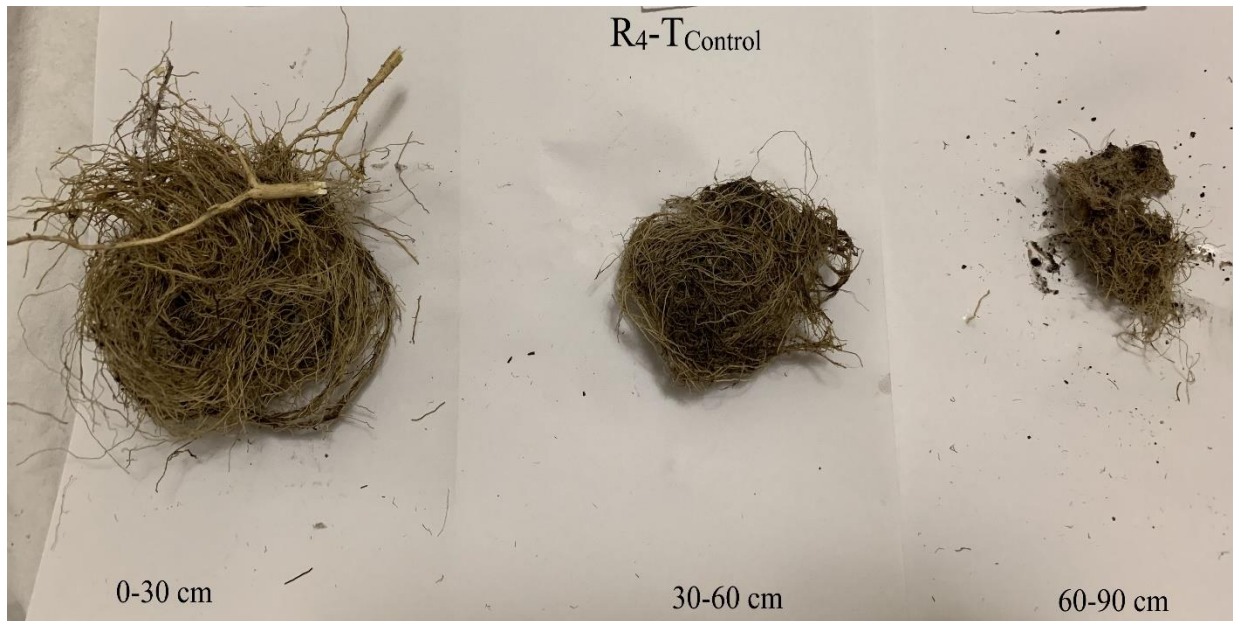


Figure A.2. Extracted roots from three different layers (0-30, 30-60, 60-90 cm) – R4-T_{control} and R6-T_{control} treatments.

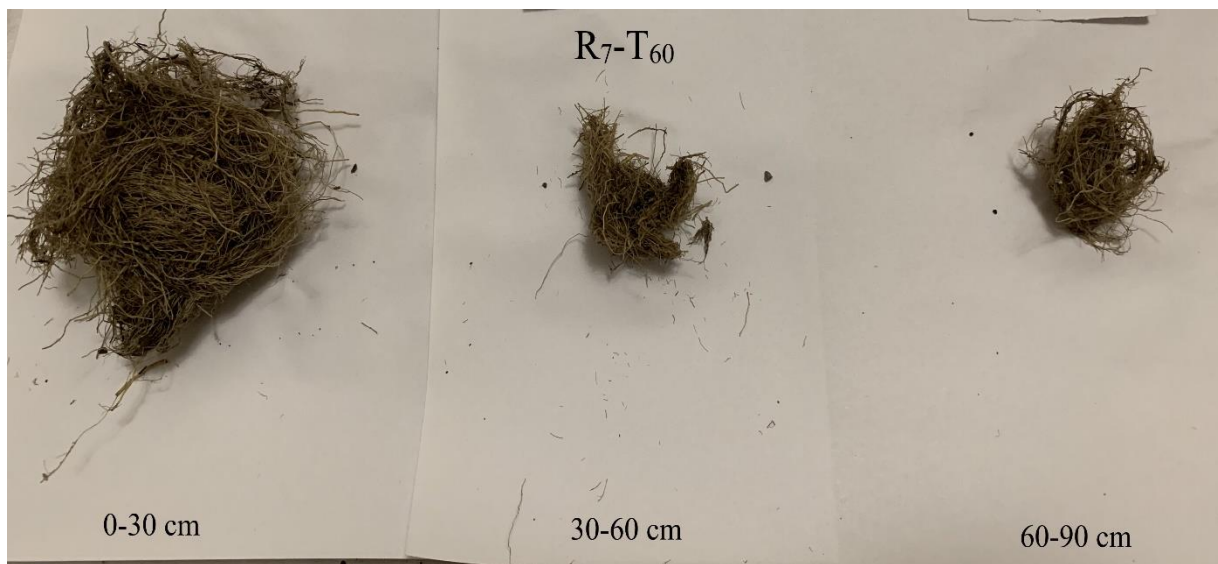
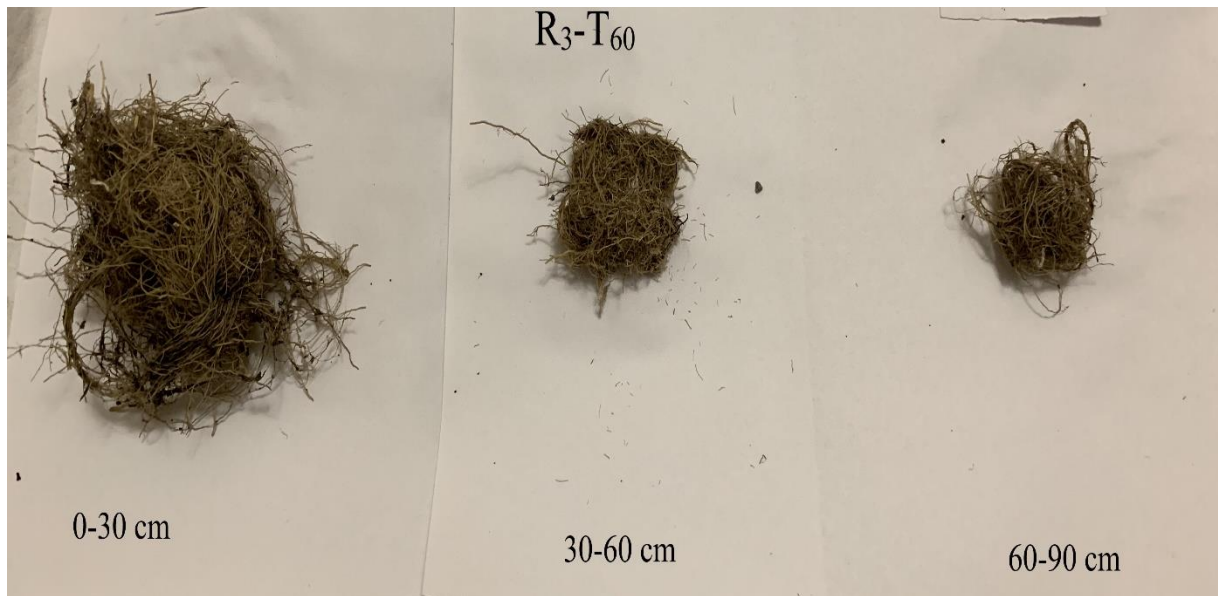


Figure A.3. Extracted roots from three different layers (0-30, 30-60, 60-90 cm) - R₃-T₆₀ and R₇-T₆₀ treatments.

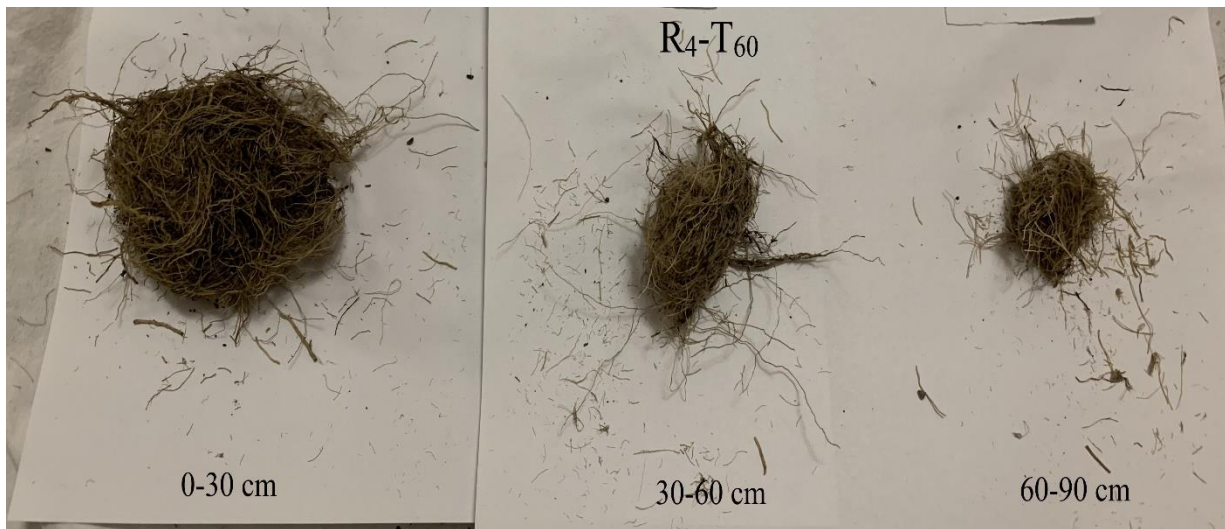
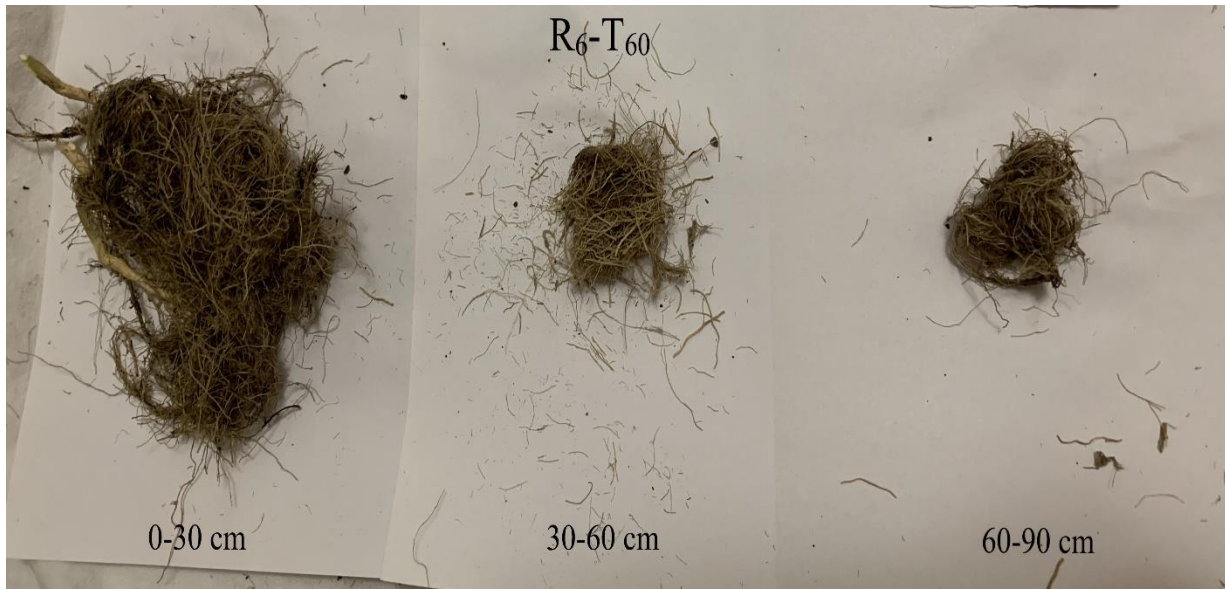


Figure A.4. Extracted roots from three different layers (0-30, 30-60, 60-90 cm) – R6-60 and R4-T60 treatments.

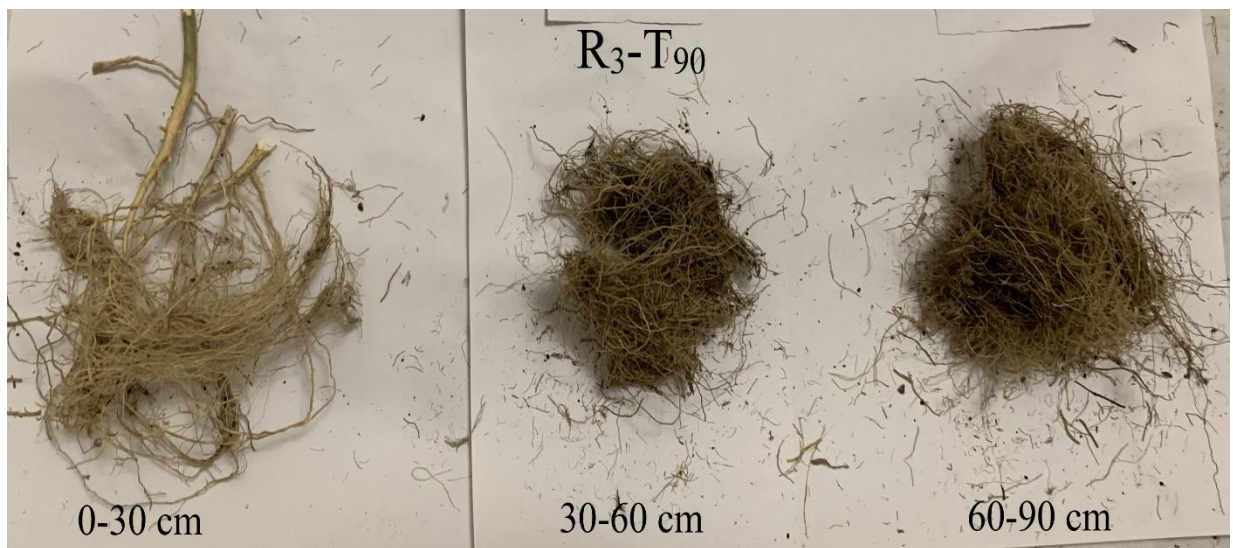


Figure A.5. Extracted roots from three different layers (0-30, 30-60, 60-90 cm) – R4-T90 and R3-T90 treatments.

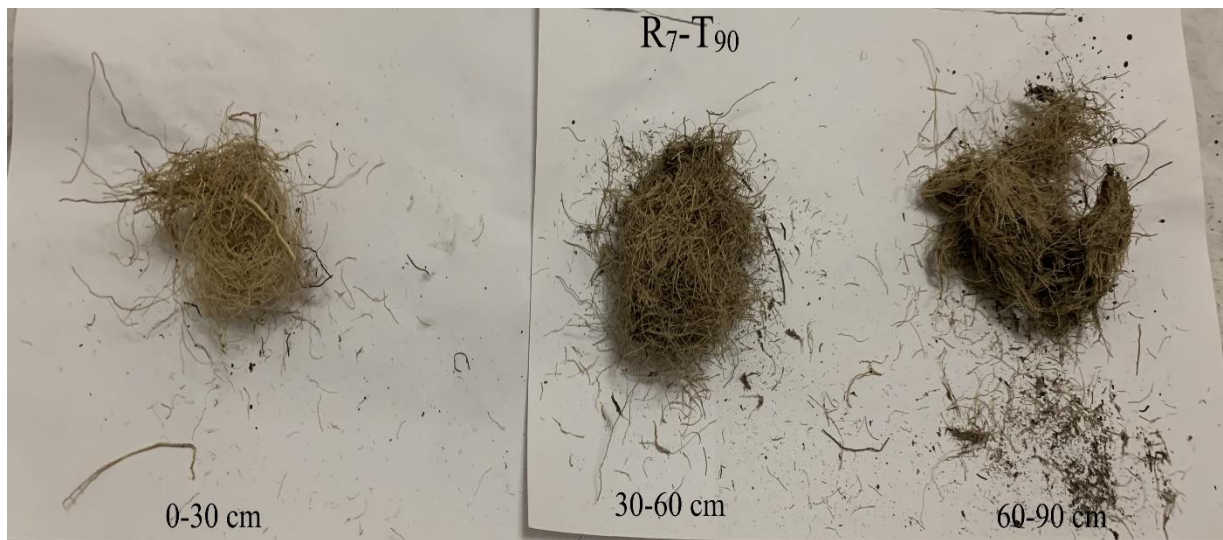
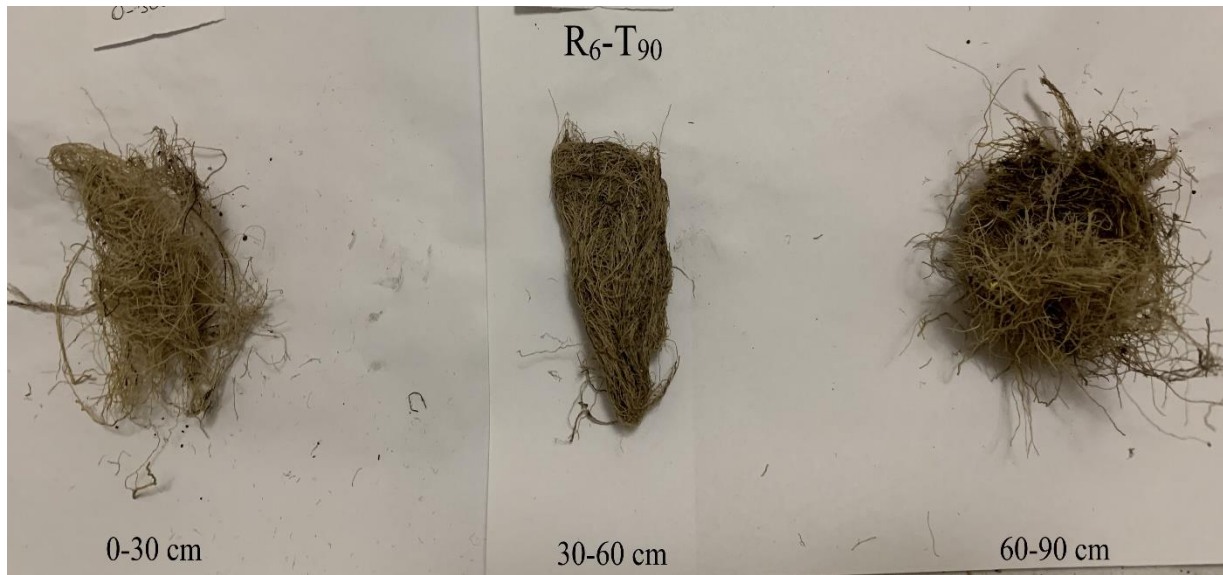


Figure A.6. Extracted roots from three different layers (0-30, 30-60, 60-90 cm) – R6-T90 and R7-T90 treatments.

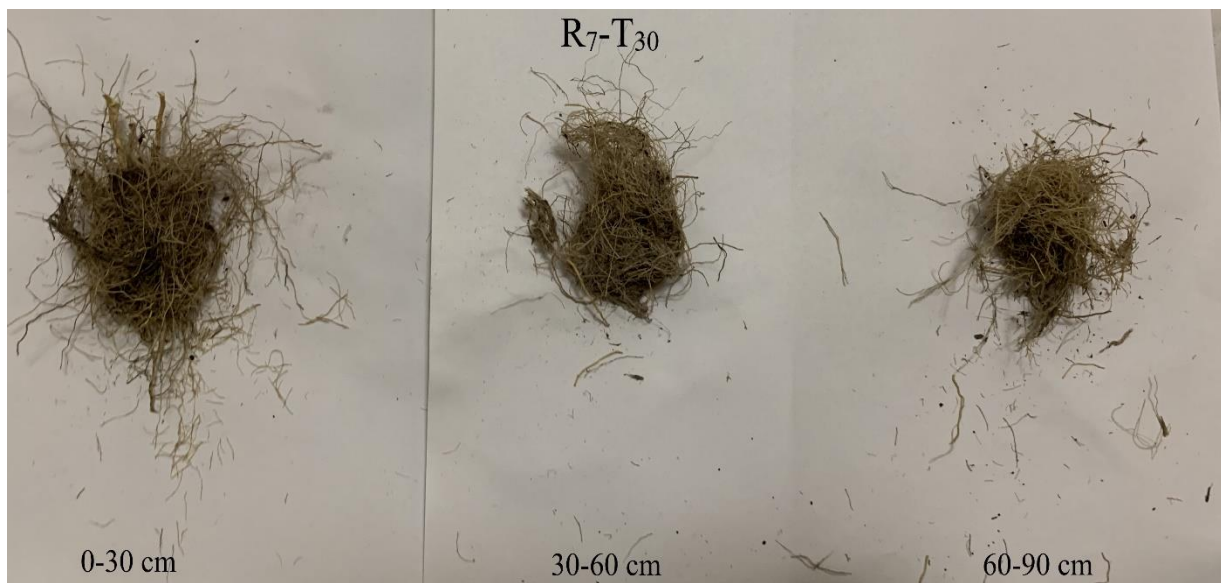
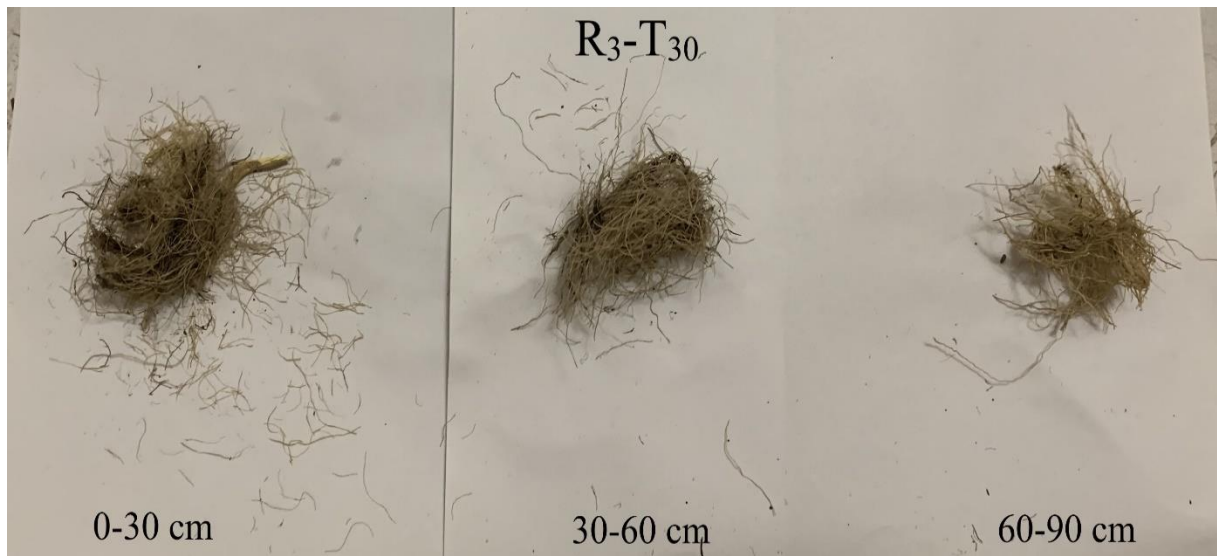


Figure A.7. Extracted roots from three different layers (0-30, 30-60, 60-90 cm) – R₃-T₃₀ and R₇-T₃₀ treatments.

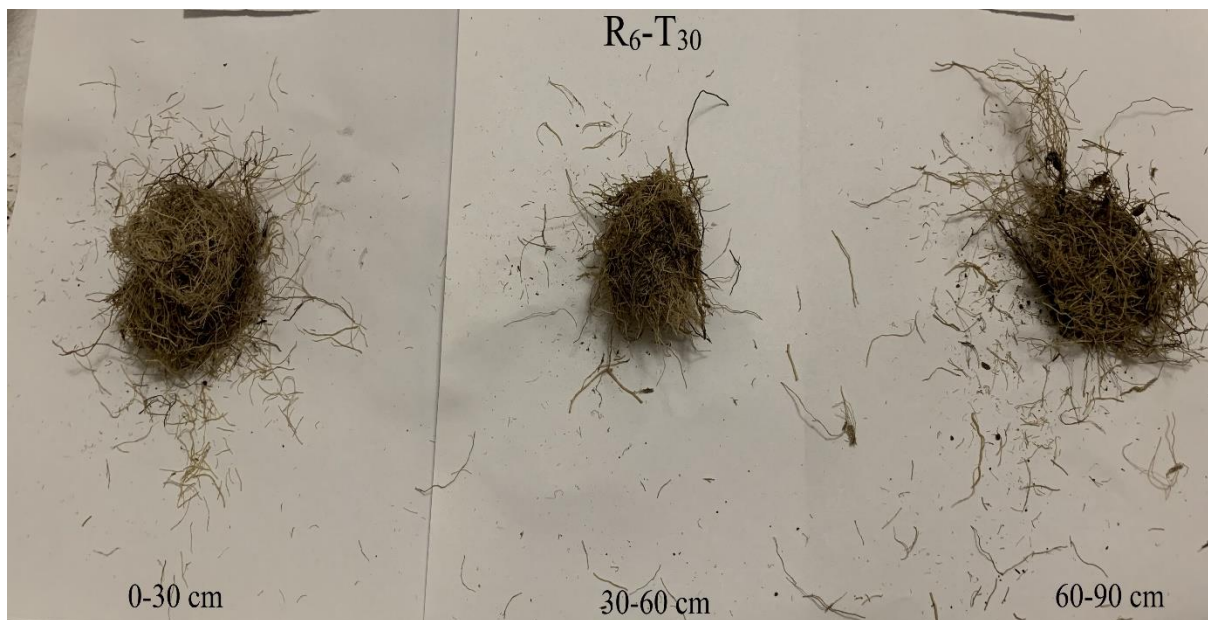
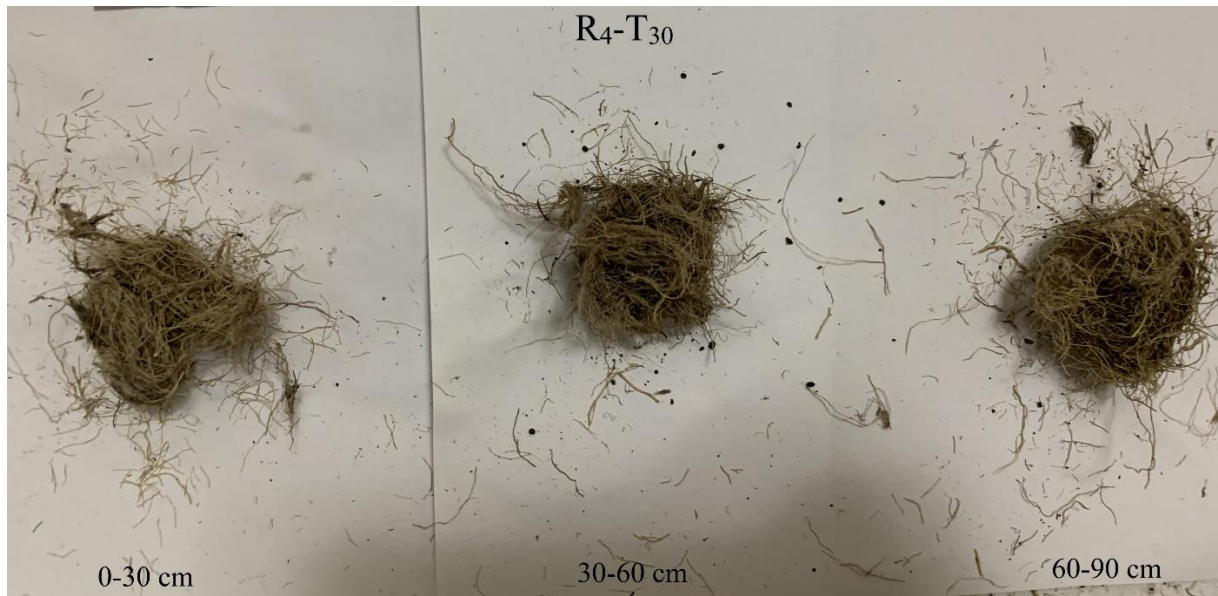


Figure A.8. Extracted roots from three different layers (0-30, 30-60, 60-90 cm) – R4-T30 and R6-T30 treatments.