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Parameter Settings of the Control Unit for Automated Drip Irrigation for the use in the greenhouse using HYDRUS 2D/3D Numerical Simulations

Diploma Thesis

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Declaration

I declare that the Diploma Thesis "Parameter settings of the control unit for Automated Drip Irrigation for the use in the greenhouse using HYDRUS 2D/3D Numerical Simulations" is my own work and all the sources I cited in it are listed in Bibliography.

Prague, 26/04/2021 Signature ____________________________

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Parameter settings of the control unit for Automated Drip Irrigation for the use in the greenhouse using HYDRUS 2D/3D Numerical Simulation

Summary

As the population increase and the demand for water was getting higher, more focus was put on the agricultural sector to manage water efficiently while producing food. Drip irrigation technology offers the best control over the application of water. Drip irrigation technology demands for the optimization of the operational parameters such as duration of irrigation, frequency, and emitter discharge rate. Numerical simulation offers applicable approach to evaluate the efficiency of drip management practises. Numerical simulation was carried out with Hydrus 2D/3D to investigate the significant effect of moisture content, pressure head, volume of water applied, and soil hydraulic properties on different irrigation schemes. Good knowledge about the horizontal and vertical distances by which water spreads under a point source is important to the design efficient and effective surface drip irrigation. Two different irrigation schedules were made which were triggered irrigation and planned irrigation, Different irrigation schemes were simulated, one hour of irrigation and two hours of irrigation every day for 2 weeks was compared to evaluate the level of pressure head, moisture content and the effect of different hydraulic conductivity on the volume of water applied during irrigation. The simulation results show that the higher the hydraulic conductivity the higher the amount of water needed for the triggered irrigation, as water is transported fasted into the deeper parts of the profile. Planned irrigation scheme is not able to adjust to possible changes in saturated hydraulic conductivity within the vegetation season. Correlation between hydraulic conductivity value and the amount of water used was also observed for different irrigation duration and 2 hours irrigation every day for 2 weeks. Regular every day irrigation of 2 hours was found to be the best suitable considered greenhouse installations. Graphical and numerical outputs from the Hydrus simulation software offers a wide range of possible comparisons enabling comparisons of moisture contents and pressure head changes within the profile for given pre-set print times. As the evapotranspiration was considered in the simulations, considerable moisture content changes were observed on the surface. For installations with high potential evapotranspiration rates, subsurface drip irrigation would be the most water saving strategies reducing the evaporation and water requirements, because water can be delivered straight to the root zone.

Key words: surface drip irrigation, operational parameters, irrigation frequency, numerical simulation, Hydrus 2D/3D

Content

1 Introduction

This chapter of the thesis discusses literature relating to the subject under research. For the sake of clarification, the literature has been divided into sections and sub-sections. A thematic approach was adopted which helped dissect and analyse studies that were completed and linked to that specific topic. The topics to be discussed include irrigation and irrigation systems, irrigation design and management, greenhouse technology, irrigation and greenhouse use, irrigation water requirement determination, irrigation scheduling, greenhouse irrigation systems, Hydrus parameter settings and irrigation water requirement determination. Pictures, statistics, and scholar's study discussions will be used to help build a deeper understanding of the literature and the gaps therein. Due to changes in availability of water under climate change, security of food and agricultural activities as been affected and in the majority part of the world the climate change will increase the demand for irrigation due to insufficient rainfall and increase evapotranspiration caused by higher temperatures. Drip irrigation has been helpful improving water management by improving crop yield while making use of less water. However, there are models that simulate soil water dynamics beneath surface drip emitters which can also help in predicting the soil water movement. One of such models is Hydrus 2D/3D. Hydrus-2D/3D programs (Šimůnek et al., 2008) are finite element models for simulating one. two. and three-dimensional movement of water, heat, and multiple solutes in variable saturated media. The standard versions of Hydrus programs solve the Richards equation for variably saturated water flow numerically and the flow equation contain a submerged term which covers water uptake by plant roots. The heat transport equation observe movement by both conduction and convection with water flow.

Hydrus 2D/3D has proved to be sufficient to deal with water use efficiency in agriculture because the process involves irrigation scheduling and with the increase in competition for fresh water resources in urban area and also between industries and agriculture in semi-arid and arid environments, calls have been raised for the development of efficient water use strategies and this could happen by improving irrigation scheduling which is the timing and quality of water being applied over the growing season, However, implementing reliable irrigation plan is challenging due to many unsteady features that must be considered which includes climate, crop type, irrigation method, and system constraints (Howell, 1996).

There are two basic approaches to irrigation scheduling, and they can be classified as static and dynamic. The static approach involves giving the quantity of water for irrigation without stating how to dispense it during the growing season (Shani & Dudley 2001; Dudley & Shani 2003). While the dynamic approach includes distributing irrigation water at each time step or at each stages of the plant growth to ensure a perfect water content and maintain it throughout the growth period. Several approaches are employed to start and end irrigation. The most common approach is to start irrigation for a certain amount of time or with a certain volume of water when a fixed low water threshold is reached.

Hydrus 2D/3D (Šimůnek et al., 2008) is such a numerical code, which can be used to study optimal irrigation management and when used correctly, its predictions agree well with the field data (Skaggs et al., 2004).

2 Hypothesis and Objectives

The aim of this study is to simulate numerically and compare different irrigation schemes using Hydrus 2D/3D to investigate the best water saving strategy for drip irrigation and to also find the most effective and efficient irrigation duration under surface drip irrigation for a greenhouse.

- To simulate water infiltration and root water uptake using Hydrus 2D/3D
- To compare the numerical results of different irrigation schemes
- To study the effect of the soil moisture content
- To determine the best irrigation schemes for efficient water application.

The following hypothesis has been tested "Irrigation water behaviour in the greenhouse can be effectively described by numerical simulation which can lead to optimization and water saving of ongoing or planned irrigation systems".

3 Literature review

There is this popular adage, “the grass is greener where you water it”. This age-old adage depicts how relevant irrigation was then and is now. Today, the need for irrigation has been catapulted by the uncertain nature of the climate and this problem has been made worse by the high population increase. The world’s population which was around 7.594 billion in 2018 and it is projected to reach 8.5 billion by 2030, 9.7 billion by 2050 and exceed 11 billion in 2100 (UN News Centre, 2015). To be able to produce enough food to meet the demands of the growing population, irrigation must be applied to ensure that soil moisture is sufficient to meet crop water needs and thus reduce water deficit as a limiting factor in plant growth (van Averbeke et al., 2011). Irrigation agriculture has been predicted to be as a major global strategy to meet agricultural production targets, especially in developing economies. As early as 1996, the FAO had projected that an estimated 90% of agricultural land will be under irrigation by 2000 (Nagendran, 2011). Irrigation adds a major contribution towards agricultural production by making a whole range of crops usable in an otherwise irregular climate and helping to make certain against drought (Southorn, 1998).

3.1 Definition of Irrigation

Irrigation as a concept has been defined differently by academics around the world. Irrigation is defined as the deliberate application of water to crops, created to permit farming in arid regions and to offset drought in semiarid regions. This definition gives a clear picture of why irrigation is used in farming but not where irrigation could be employed, it was narrow by establishing that it was used to offset drought or used in areas where rain hardly fall, however, that is not always the case. This is because irrigation could be employed in areas where there is much water which does not support a particular kind of plant hence should be regulated. The primary objective of irrigation is to provide plants with enough water to obtain maximum yields and a high-quality harvested product.

Irrigation can also be defined as the pact of supplying additional water (beyond what is available from precipitation) to soil to enable or enhance plant growth and yield, and, in some cases, the quality of foliage or harvested plant parts (Sojka, Bjorneberg, & Entry, 2002). However, the definition of irrigation by Moncrieff (1905) is the most simplistic but complete definition.

Moncrieff defined irrigation as the artificial application of water to land for agriculture (Moncrieff, 1905). This definition disassociates itself from specifying where irrigation could be used and which environmental conditions make it favourable for one to employ irrigation to agriculture.

3.2 History of Irrigation

The earliest and simplest form of irrigation is affected by rising water from a lake, river or well, and pouring it over the land (Moncrieff, 1905). Irrigation as a practice can be traced as far back as the beginning of farming but since history does not deal with speculation but rather facts.

The earliest archaeological evidence of irrigation in farming dates to about 6000 B.C. in the Middle East's Jordan Valley. It is widely believed that irrigation was being practised in Egypt at about the same time and the earliest pictorial representation of irrigation is from Egypt around 3100 B.C (Sojka, Bjorneberg, & Entry, 2002). Irrigation is not a new technology or phenomena but age-old practice evidence of it can be seen in the Egyptian civilization (Grove, 1989). One of the earliest technologies used for irrigation is the shaduf. This device was used to fetch water from the river and poured into dug-out canals to be used to irrigate crops. Irrigation was used in most of the early civilizations in the world, and this could be attributed to the nature of their lands and resources.

According to Sojka, Bjorneberg, & Entry (2002), this irrigation technology later spread throughout Persia, the Middle East and westward along the Mediterranean, then to most Asian countries than to the Americas (Sojka, Bjorneberg, & Entry, 2002). The above does not mean all people were not aware of irrigation, it just to help man appreciate where evidence earliest use of irrigation exists. Irrigation then gained popularity in Europe and was used during the medieval age. This was used by large scale farmers to irrigate the plants. This technology was also employed by the Americas. The earliest discovery of irrigation in the United States can be traced back to 1200 BC in the desert and plains of modern-day Arizona, Colorado, and New Mexico.

The Las Capas site, located close to Tucson, Arizona, revealed America's earliest form of irrigation. A channel of waterway filtered into many small fields that extended to a territory of roughly 100 acres (Tianduowa et al., 2018).

3.3 Irrigation System

Every irrigation system is made of parts which come together to form a whole (system). The basic parts of an irrigation system include main intake structure and pumping station, conveyance and distribution system, field application systems, and a drainage system (Brouwer, Goffeau, & Heibloem, 1985). Depending on how the water is spread throughout the region, there are many different types of irrigation systems. A typical example of the irrigation system used in the field is shown in Figure 1.

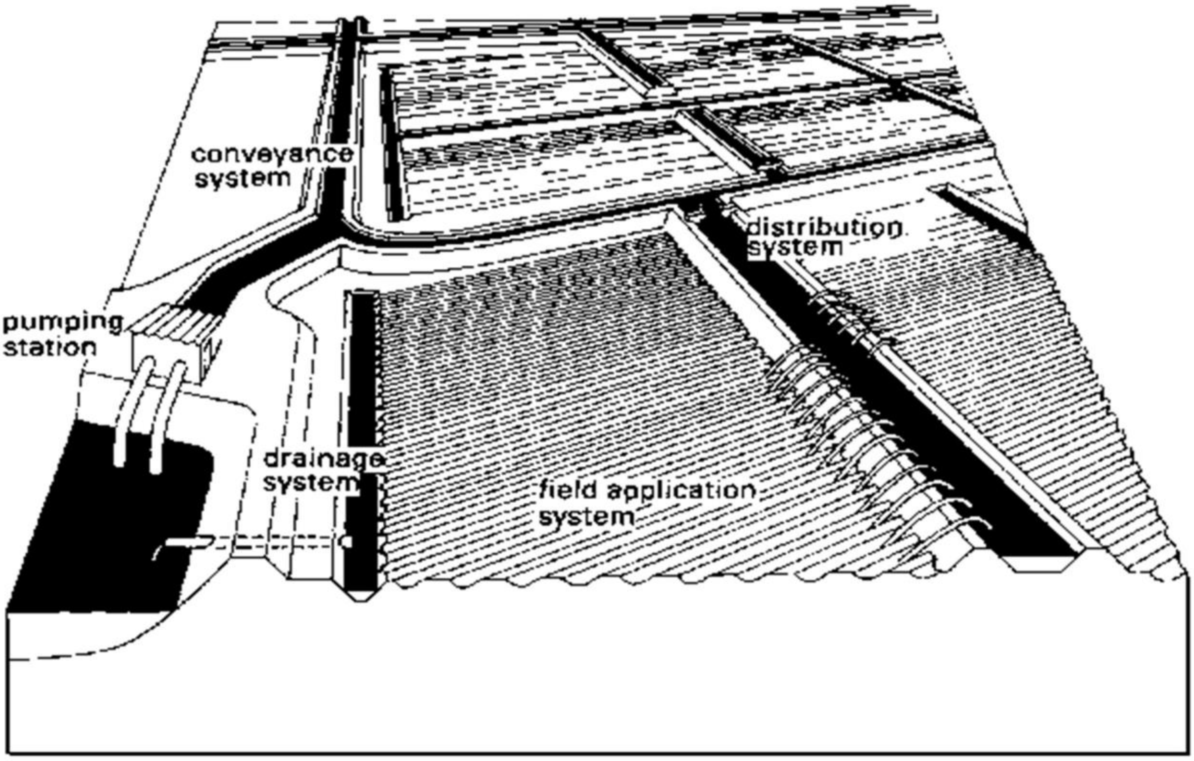

Figure 1. An example of an irrigation system. Retrieved from FAO.org

3.3.1 Parts of an Irrigation System

• Main intake structure:. It is the work of an intake structure to redirect from the channel at the valve the amounts of water necessary for any purpose with or without water being stored (Lauterjung & Schmidt, 1989). This intake structure shows the source of water used for irrigation and how it can be directed into the farm and hence cannot be negated.

• Pumping station: On commercial sites, pump, (or pumping) stations are used to raise the water pressure so that the machine has enough extra power to work the spray heads, nozzles, and rotors. Especially when there are many projects connected to the same water supply, pump stations are required, all of which require water pressure to operate.

In some cases, the irrigation water source can be found below the level of the irrigated fields. Then a pump must be used to deliver water to the irrigation system. There are several types of pumps, but the most commonly used in irrigation is the centrifugal pump shown on Figure 2 (Brouwer, Goffeau, & Heibloem, 1985).

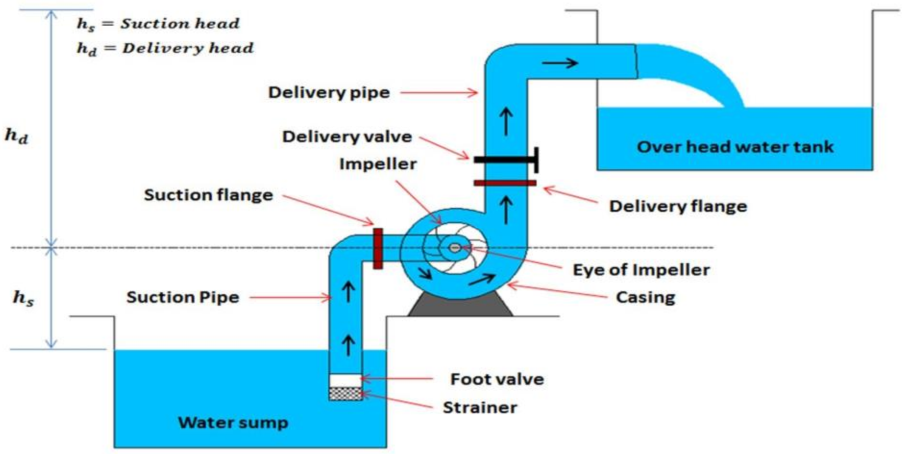

Figure 2. A working centrifugal pump. Retrieved from mechanicalbooster.com

• Conveyance and distribution system: They are canals that carry the water through the entire irrigation system. Channel structures are important for controlling and measuring water flow Conveyance and distribution systems are used to divide flow into two or more parts; they do not provide any water quality treatment or quantity control and should be designed by someone familiar with hydraulics (Ibid).

• Field application systems: There are several ways water can be applied to the ground. The easiest is to bring water from the supply source, such as a well, to each plant with a bucket. This is a very tedious method and it demands hard work. However, it can be used successfully to irrigate very small plots of land, such as vegetable gardens, that are in the close to a water source (Brouwer, Goffeau, & Heibloem 1985).

• Drainage system: A drainage system is necessary to remove excess water from the irrigated land. This excess water may be e.g. wastewater from irrigation or surface runoff from rainfall. It may also comprise of leakage or seepage water from the distribution system. (Brouwer, Goffeau, & Heibloem, 1985). It aids in the artificial removal of water from lands which have become saturated, to the detriment of agriculture (Moncrieff, 1905).

3.4 Methods of Irrigation Systems

According to the Food and Agriculture Organization of the United Nations, irrigation contributes to about 40% of the world's food production on 20% of the world's crop production land. Many methods are employed in irrigating crops around the world. The three main methods of irrigation are surface, sprinkler and drip/micro-irrigation (Bjorneberg, 2013 and Lehrsch, Bjorneberg, & Sojka, 2005). These methods are common and they are used around the world.

3.4.1 Surface Irrigation

Surface irrigation refers to methods of water application where a body of water, of some depth, is applied to one end of a bay or furrow (Southorn, 1998).

Surface irrigation systems types comprise of furrow, basin and border irrigation (Bjorneberg, 2013; Brouwer, Goffeau, & Heibloem, 1985; Alazba, 1997). For field crops, pastures and orchards, surface irrigation systems are usually used (Figure 3). The performance of surface irrigation systems varies immensely due to soil type variability, field uniformity, crop type, and management. Surface irrigation that is being used on descending areas includes graded furrows (small ditches aligned to crop rows) and border strips, and on relatively uniform areas that includes level or contour basins, terraces, and wild flooding (Lehrsch, Bjorneberg, & Sojka, 2005). This forming method of irrigation is preferred because smaller and more frequent irrigation applications can maintain a more consistent and lower soil matric potential that may reduce salinity hazards. Subsurface wastewater application can reduce pathogen drift and reduce human and animal contact with such waters (Lamm, 2002).

Figure 3. A typical example of surface from Wikipedia

<u>Types of Surface Irrigation</u>

a) **Furrow Irrigation**: Is a way of setting out the water channels in such a way that gravity plays the role of supplying enough water for the growth of appropriate plants. Furrow irrigation is an inherently erosive process. It is aggravated by the need for long fields to expand farming efficiency and for clean tillage to allow uniform and steady flow of water down the furrow (Lehrsch, Bjorneberg, & Sojka, 2005). It needed lower capital investment, less knowledge and high labour than most other irrigation systems. Fields can be irrigated without levelling or grading because the water flows in furrows. Furrow irrigation cannot be automatized because water flow rate must conform to each furrow for each irrigation (Bjorneberg, 2013).

a) **Border Irrigation**: In border irrigation, the field to be irrigated is divided into strips (also called borders or border strips) by parallel dykes or border ridges. Border irrigation is widely used to irrigate close-growing crops that are susceptible to stem and/or crown injuries when exposed to prolonged inundation (Zerihun et al., 2005). Border irrigation is suitable to all crops that are not destroyed by flood for short periods. It can be used with almost any crop if site conditions are such that the needed degree of water control can be obtained (Keller, 1983).

3.4.2 Sprinkler Irrigation

It is an irrigation method in which the water is sprayed from a point unto plants like a rainfall. In sprinkler irrigation, globs of water are dispensed through the air to the soil (Figure 4). Sprinkler irrigation includes (1) moving lateral systems, including centrepivot, lateral-move, and big-gun systems; and (2) stationary systems, including solid-set and side-roll systems (Lehrsch, Bjorneberg, & Sojka, 2005). Sprinkler irrigation is less wasteful but a power-concerted means to water crops. Spraying does offer a side benefit. The sprinklers, turned on during cold nights, do protect against mild frosts (Wojtkowski, 2008).

Also, the intensity of sprinkling can be well controlled; easy operation, possibility of automatization; easy setting; 20-30 % lower water demand compared to surface irrigation; the closed water carrying system impedes external chemical and physical contamination. Also, with this type of irrigation, it is easy to control the amount of water. Three main categories of sprinkler irrigation systems are solid-set, setmove and moving (Bjorneberg, 2013). It should be noted that the spray irrigation system, therefore, requires considerable attention to the performance specifications of each component and ensuring each component is integrated into the system (Southorn, 1998).

Figure 4. A sprinkler irrigation on a field. Retrieved from CivilDigital.com

3.4.3 Drip/micro irrigation

Drip irrigation is typically called trickle irrigation and requires oozing water onto the soil at very low rates from a system of small diameter plastic pipes conform into outlets called emitters or drippers (Figure 5). As previously mentioned, the most water-efficient is drip irrigation. For this, a system of hoses continually drips water onto the root zone of each plant (Brouwer, Goffeau, & Heibloem, 1985). Drip irrigation systems are ideal for flat as well as inclined lands, as they do not cause erosion. They are particularly useful in areas with a prolonged dry season which have a reliable source of water.

Figure 5. A picture depicting the drip irrigation method from Wikipedia

3.5 Irrigation Design and Management

The design and maintenance of good irrigation systems can both improve efficiency and minimize energy costs.

3.5.1 Irrigational Design

The design of irrigation systems is an important topic when it comes to ways of improving irrigation application, efficiency, and economical return in the production process (Pannunzio et al., 2004). The design of irrigation systems significantly affects the efficiency of applications and includes multiple variables and constraints whose main objective is to optimize benefits and reduce costs.

Irrigation systems have particular applications that are based on multiple factors, among which the most appropriate are the crop, type of the soil, topography, and availability of water and quality. The use efficiency of the different surface and pressurized irrigation methods ranges and is based on design, management, and operation (Holzapfel and Arumí, 2006). Undoubtedly, well-arranged and precisely used irrigation systems will have the highest productivity and water distribution levels, which will yield good production and high product quality (Holzapfel et al., 2000; 2004).

3.5.2 Irrigation Management

For a good management and implementation of the surface irrigation systems, a series of support elements have appeared, which includes simulation models and control and extraction systems.

These appear to be an important aspect of irrigated agriculture and a key component due to the competition for water resources. In recent years, several irrigation systems have improved significantly the application efficiency at the farm level, improving irrigation water management. For example, in the main irrigation districts of Mexico, introducing new technologies and more effective combined with real-time irrigation scheduling, demonstrated water savings in the order of at least 20%, without any appreciable reduction in crop yields (Quiñones et al., 1999).

Ibragimov et al. (2007) compared to drip and furrow irrigation, obtaining that 18-42% of the irrigation water was saved with drip systems in comparison with furrow, and the IWUE increased by 35-103% compared with furrow irrigation. The similar comparisons were made by Maisiri et al. (2005) in a semi-arid agro-tropical climate of Zimbabwe; in this study, drip irrigation made use of about 35% of the water used by the surface irrigation systems, providing higher IWUE. The gross margin level for drip irrigation was higher than for surface irrigation. Both methods had similar results but surface drip had more advantages due to difficult challenges in replacement and higher cost for subsurface systems. Additionally, surface drip was recommended in early potato under Mediterranean conditions. Tognetti et al. (2003) determined that drip irrigation influenced positively many of the physiological processes and technological parameters in semi-arid conditions, as compared to low-pressure sprinkler irrigation.

Hanson and May (2004) obtained yield increases when the drip system was used compared to the sprinkler systems with similar amounts of applied water; additionally, drips systems reduced percolation below the root zone. Another study examined low-energy precision application (LEPA) and trickle irrigation for cotton in Turkey, with the conclusion that both irrigation systems could be successfully used under the arid climatic conditions of this country.

3.6 Greenhouse Technology

Greenhouse Technology is the system of giving a favourable environmental condition to the plants (Figure 6). It is rather used to shield the plants from unfavourable climatic conditions such as wind, cold, precipitation, excessive radiation, extreme temperature, insects and diseases (Pandey, & Pandey, 2015). A greenhouse (also called a glasshouse) is a building where plants are grown under controlled microenvironment. These structures have different sizes from small sheds to very large buildings. Sustainable agricultural development requires control of environmental conditions. Greenhouse technology, a branch of controlled environment agriculture, has undergone fast growth, mainly due to climate change and the clamour for quality fresh fruit, vegetables, herbs and flowers in developed countries (Thipe et al., 2017).

Greenhouse agriculture became known in the last three decades. Greenhouse controlled environment provides a good condition to grow crops out of season and upgrade the crops' productivity (Snyder, 2017). Greenhouse production systems reduce crop water requirements by as much as 20% to 40% compared to open field cultivation; however, farmers frequently apply more irrigation water than the estimated water consumption (Nikolaou et al., 2019). Greenhouse automation is the right tool to fully monitor and control the environment and has a dramatic social and economic impact. Greenhouses are made up of transparent glass or plastic construction for increasing crop growth (British Colombia Ministry of Agriculture and Lands, 2015).

They allow for more effective use of water and sunlight. Proper irrigation is key to improve the quality and productivity of crops grown in greenhouses (Simonne et al., 2010). The time, duration, type, and amount of irrigation are essential to optimize the use of water (Alimardani et al., 2009). Different irrigation systems can be used such as hand watering, overhead sprinkling system, movable irrigation boom, and flood floor, drip irrigation, capillary mat, and hydroponics (Kavianand et al., 2016). However, drip irrigation is the most suitable for greenhouses in terms of its efficient use of the available water. The soil moisture content ascertains the irrigation time; therefore, continuous monitoring is required to decide when to exactly start the irrigation.

Figure 6. A greenhouse design (Source: M. Miháliková, DWR)

3.7 Determination of irrigation water requirements

3.7.1 Water requirement determination

Water is very important for plant growth and food production. Estimating irrigation water requirements is vital for water program planning, management and maintaining crop evapotranspiration when precipitation is insufficient or not available (Arku et al., 2012). Irrigation water requirements are defined differently by, but these are a number of the popular definitions. First, irrigation water requirements may be defined as the quantity, or depth, of irrigation water additionally to precipitation required to provide the required crop yield and quality and to keep up a suitable salt balance in the root zone. This amount of water must be ascertained for such uses as irrigation scheduling for an appropriate field and seasonal water needs for planning, management, and development of irrigation projects (Martin, & Gilley, 1993).

Determining the factors for irrigation water requires a calculation or estimation of crop water usage rates. Estimates of daily and weekly crop water usage are required to plan irrigation applications and establish minimum system capacities. Seasonal or annual use of water is suitable for the dimensions of irrigation reservoirs and diversion facilities and for creating water rights.

The evaluation of the irrigation potential, based on soil and water resources, can only be done by concurrently evaluating the irrigation water requirements. Net irrigation water requirement (NIWR) is the amount of water required for crop growth. It is expressed in millimetres per year or m^3/ha per year (1 mm = 10 m^3/ha). It relies on the cropping pattern and the climate. Information on irrigation efficiency is important to be able to transform NIWR into gross irrigation water requirement (GIWR), which is the amount of water to be applied in reality, considering water losses. Multiplying GIWR by the area that is acceptable for irrigation indicate the total water requirement for that area. In this study, water requirements are expressed in km^3/year (Brouwer, Goffeau, & Heibloem, 1985).

The gross irrigation requirements of crops are the amounts of water needed to satisfy consumptive use, plus the amount required to take care of losses which happen during transportation and application. The losses include seepage and evaporation from canals and ditches, deep percolation, and surface run-off from the fields being irrigated (Tileston & Wolfe, 1951). Irrigated agriculture is facing new challenges that needs perfect management and innovative design. Formerly, emphasis centred on project design; however, current issues involve limited water supplies with several competing users, the threat of water quality degradation through excess irrigation, and narrow economic margins. Meeting these challenges requires improved prediction of irrigation water requirements (Martin & Gilley, 1993).

The quantity and timing of precipitation strongly affect irrigation water requirements. In arid areas, annual precipitation is commonly less than 10 inches and irrigation are important to successfully grow farm crops. In semiarid areas (those specifically receiving between 15 to 20 inches of annual precipitation), crops can be grown without irrigation, but are open to droughts that decrease crop yields and can result in crop failure in extreme drought condition. irrigated (Tileston & Wolfe, 1951).

The net irrigation water requirement is defined as the water needed by irrigation to ascertain crop evapotranspiration and supplementary water needs that are not supplied by water stored in the soil profile or precipitation. The net irrigation water requirement is defined as (all values are depths, in inches):

$$Fn = Etc + Aw - Pe - GW - \Delta SW \qquad (1)$$

where:

Fn = net irrigation requirement for period considered

ETc = crop evapotranspiration for period considered

Aw = auxiliary water—leaching, temperature modification, crop quality

Pe = effective precipitation during the period considered

GW = groundwater contribution

ΔSW = change in soil-water content for the period considered (Brouwer, Goffeau, & Heibloem, 1985)

The difference between the net irrigation requirement and the actual water applied constitute the amount of water lost during cultivation. This loss encompasses evaporation and seepage from ditches, deep infiltration, and run-off from the end of the field. The frequency of irrigation, and therefore, the required capacity of a system, sprinkler or surface, relies largely on how long the available water in the root zone will last when consumptive use is at a maximum (Tileston & Wolfe, 1951).

3.7.2 Evapotranspiration

It is the process which involves the loss of water from the soil to the atmosphere through evaporation and by transpiration from the leaves of the plants that grow on the soil. ET can be divided into two sub-processes which are evaporation and transpiration.

Evaporation takes place on the surface of water such as lakes, rivers, reservoirs and also from vegetation, ground surfaces and soil. Where else transpiration involves the evacuation of water from the soil by plant roots, distribution of the water through the plant into the leaf, and evaporation of the water from the inside of the leaf into the surface (Ward & Elliot, 1995).

Evaporation and Transpiration from soil and plants

According to FAO 56, evaporation and transpiration occur at the same time and there is no simple way of distinguishing between the two processes (Allen et al., 1998). The main factor of evaporation from a crop soil is mainly determined by the ratio of the solar radiation reaching the soil surface, temperature, wind velocity, and vapour pressure gradients. As crop start to grow, the ratio of solar radiation will decrease as the canopy covers the soil surface. Allen et al. (1998) explained that when the crop is small, water is primarily lost by soil evaporation, but once the crop is well matured and covered the soil, transpiration becomes the main process. Therefore, ET process rely on the crop growth stages where in the early stages, ET comes from evaporation, and when the crop develop, transpiration has more influence

Transpiration is defined by Kramer (1983) as the loss of water from plants in the form of vapour. The removal of water occurs through stomata which are the small openings on the plant leaf. Vaporization occurs when water and some nutrients is taken up by roots and transported through the plant to the intercellular spaces in the leaf. Here the vapour exchange with the atmosphere is controlled by the stomata aperture. Once some water is evaporated from the stomata, more water moves in the cellular spaces to replace the loss. The evaporation process initiates the pull of water from the roots through the xylem (plant tissue that transport water to leaf) and out from the leaves.

Like evaporation, transpiration also depends on the solar radiation, temperature, wind speed and vapour pressure gradient. The transpiration rate is also affected by crop characteristics, environmental location and cultivation practices. Different kinds of plants may have different transpiration rates.

Potential evapotranspiration

Potential evapotranspiration or PE is a measure of the capability of the atmosphere to extract water from the surface through the processes of evaporation and transpiration bearing no control on water supply. ET are complex processes because the rate of water vapour loss depends on many factors such as the amount of solar radiation reaching the surface, amount of wind, the aperture of the stomata, soil water content, soil type and the type of plant.

Reference evapotranspiration

Reference crop evapotranspiration, ETo is the ET rate from reference surface of a hypothetical grass reference crop with specific characteristics. The crop is assumed to be well watered with a full canopy cover. Moreover, ETo is a climatic parameter expressing the evaporation power of the atmosphere. The Penman-Monteith (equation1) method is recommended to calculate ETo.

Actual evapotranspiration

Actual evapotranspiration, AE is the quantity of water that is actually removed from a surface due to the process of evaporation and transpiration . AE is also known as crop evapotranspiration, ETc. In FAO 56 , ETc is the ET from the normal well planted crops. The water loss from ET is the quantity of water that is required of the crop. ETc can be calculated by multiplying ETo with crop coefficients (Kc). Kc is crop specific ET values which incorporates crop characteristics and averaged effects of evaporation from the soil .

3.8 Irrigation scheduling

Irrigation scheduling is the mechanism used to determine the proper frequency and period of watering by irrigation system managers. The following factors can be considered: the drippers discharge rate, how rapidly the water is applied, Irrigation scheduling should aim at achieving the evapotranspiration rate targeted by the manager, for which it is critical to know crop evapotranspiration. The radiation method is regarded by some authors the best way of scheduling irrigation in greenhouses. A solar integrator triggers a starting signal to a water supply system after a previously set level of radiation is reached (De Graaf, 1988). An irrigation system controlled by a solar radiation method can significantly supply the nutrient requirement to plants without unnecessary water and nutrient emissions (Roh & Lee, 1996). The irrigation scheduling aim is to decide the exact amount of water to be applied to the field and the exact timing for application. The amount of water that is applied is determined by using a measure to check the need for irrigation and a technique to state how much water is needed in any case

Irrigation scheduling is one of the components that control the agronomic and economic viability of greenhouse. It is important for both water use efficiency and optimum crop yields.

The irrigation water is applied to the cultivation according to fixed plan based upon the observation of the soil water status; the crop water requirements (Phocaides, 2007).
Irrigation scheduling enhances water resources management efficiently, which is hypercritical in arid and semiarid conditions. Regulated DI scheduling, controlling the moment and the level of water stress, is more efficient in conditions of water scarcity than sustained DI (Torrecillas et al., 2018).

3.9 Irrigation systems for greenhouse applications

Greenhouse crops are irrigated by adding water through drip tubes or tapes to the surface of the media, by hand using hoses, overhead sprinklers and booms, or by sub-irrigating water through the bottom of the container, or by using a combination of these delivery systems. Different irrigation systems can be utilized such as hand watering, overhead sprinkling system, drip irrigation, capillary mat, and hydroponics. However, drip irrigation is the most appropriate for greenhouses in term of its well-planned use of the available water (Elaydi, 2017). The required time and volume of irrigation are most likely the important factors for effective irrigation management and water saving, and these also enhance the productivity and quality of crops grown in the greenhouse (Nikolaou et al., 2019). It is clear from the above the available literature on irrigation and greenhouse. It opens up on some of the methods available and best practices and also highlights the advantages and disadvantages of each method and its application.

3.9.1 Surface Drip Irrigation (SD)

Surface Drip Irrigation systems are said to be used for irrigation of perennial crops that are widely spaced but these days, the method can also be applied to Annual row crops too. Some of the main components of surface drip irrigation systems are filters, control and system valves, injection systems, underground pipelines and many more.

<u>Advantages and Disadvantages SD</u>

As described by Lamm et al. (2007) and Keller and Bliesner (1990) surface drip irrigation, when compared to other systems of irrigation, has many advantages, such as increment in water use efficiency, water management improvement and it is also good for orchards and vineyards because the emitters can apply water directly to the root zone of the young trees). It has a high crop yield and quality because the system only wet some part of the soil. Weed control is also easier with surface drip irrigation systems than the other irrigation systems.

But the system also has some disadvantages which are high system costs, but the actual cost relies on the system design, filtration equipment and so on. Drip emitters of surface drip irrigations also have narrow flow passageways than in microsprinkler irrigation systems and this causes the blockage of the passageways.

3.9.2 Subsurface Drip Irrigation (SDI)

Subsurface drip irrigation (SDI) is a system of drip irrigation that applies water directly to the crop root zone with the aid of a buried polyethylene pipe, it can also be called dripline or drip tape. These driplines come in different sizes and thickness in order to maintain acceptable consistency for different field lengths. Small size driplines can be utilized when short lateral lengths are required. And as this length increases, it must be replaced with a larger diameter dripline to maintain constant adequate irrigation. The thickness of the dripline wall can also be linked to its durability. Driplines that has light thickness are mainly used for temporary installations, which will be removed after a short time. Driplines that are very thick are preferred for a permanent installation because they can withstand higher operating pressures.

Emitters are usually separated every 8 to 24 inches along the length of the dripline. In the event of irrigation, pressure will force the water out of the emitters drip by drip and once the water gets into the soil profile, its movement and wetting pattern will rely on the physical characteristics of the soil.

<u>Advantages and disadvantages of the SDI</u>

One of the advantages SDI has over other irrigation methods is the water application efficiency, since the driplines are usually buried in the soil between each crop row, the system only wets some part of the soil volume and after the system has been installed, it can be automated and this will considerably reduce labor. It also saves Energy because it operates at relatively low pressure and deliver small flow rates. SDI also increases crop yield as it can be automated to allow frequent application of water and also fertilizers, pesticides and other chemicals can be added to the irrigation water to increase the yield.

SDI also have some disadvantages and one of them is the investment cost, the cost of installation is expensive compared with other irrigation methods, installing an SDI system also requires a specialized equipment which is labor intensive, the management time for SDI can be more than the other irrigation systems and this is because operating an SDI system requires frequent maintenance such as chlorination, application of fertilizers and other chemicals also require some special knowledge.

4 Materials and methods

4.1 Experimental site description

The green house with installed drip and sprinkler irrigation systems in the campus of the Czech university of Life Sciences Prague. The soil is sandy loam with the basic characteristics listed in Table 1.

Table 1. Basic physical characteristics of the soil

Soil Type	Sand %	Silt %	Clay %	Bulk density (g/cm^3)	Water content at saturation (cm^3/cm^3)
Sandy Loam	71	17.2	11.8	1.3	0.438

4.2 Simulation program description and settings

A study of water infiltration and root water uptake in a surface drip irrigation system was observed using HYDRUS 2D/3D software package. It was developed by Šimůnek et al. (2006) and is designed for simulating water, heat, and solute movement in two and three-dimensional variably saturated media. In order to find the solution, the program numerically solves the Richards equation for variably saturated flow. Richards equation has been derived by incorporation of Darcy's law into the continuity equation, which represents the conservation of mass during fluid flow through a unit volume of the porous media (equation 2). Hydrus also enables to account the water uptake by plants thanks to its incorporated sink term. Its graphical interface enables to delineate boundaries of the simulation domain, insertion of the observation nodes and setting of the initial and boundary conditions for given simulation. As a physically based program, with measured input parameters it generally does not require a specific calibration. However, further investigations are planned in the future on the basis of the outcomes of this thesis to compare the predicted and real behaviour of water from the drip irrigation system in the experimental greenhouse.

$$qi = K(h)\left(K_{ij}^{A}\frac{\partial h}{\partial xj} + K_{iz}^{A}\right) \qquad (2)$$

Where $K(h)$ is the unsaturated hydraulic conductivity fuction (L/T), h is the soil water pressure head (L), x_i ($i=1,2$ for two dimensional model and $i=1,2,3$ for three dimensional model) are spatial coordinates (L), K_{ij}^{A} and K_{iz}^{A} are components of a dimensionless anisotropy tensor K^A (which reduces to the unit matrix when the medium is isotropic).

Recent updates of the software incorporated a special boundary conditions module with dynamic evaluation of wetted area for surface drip irrigation. Use of this special boundary condition considers the natural situation expressed by larger infiltration flux for early times with continuous increase of wetted area with proceeding irrigation event. That is why an axisymetrical 2D situation below a single dripper was evaluated, and this dynamic wetting started at the left upper corner and spread towards the centre of the domain. The maximum of 12.5 cm of wetted surface area has been determined for the applied dripper with the discharge of 2.3 l/h.

Water flow parameters were determined by Rosetta application for determination of the Mualem – van Genuchten water flow parameters. This estimate is based on the silt, aand and clay content, dry bulk density and moisture contents at 33 and 1500 kPa (all these parameters have been determined during the previous research of the DWR, Project CZ.07.1.02/0.0/0.0/16_023/0000111). Saturated hydraulic conductivity has also been measured in situ, but due to its high spatial variability, three different values (levels) were used in the simulations; lowest one, averaged value, the highest of the measured values 112 cm/days; 272 cm/day, and 657 cm/day.

Two different approaches were assessed in this study. Triggered irrigation (TI) and Planned irrigation (PI).

Triggered irrigation enables to specify the pressure head value at which the irrigation should start at specified irrigation rate and duration. The following pressure head (cm) for triggering the irrigation was tested: -336.4 cm (field capacity in US – moisture content at 33 kPa. Boundary flux applied at the dripper was calculated on the basis of the discharge rate of the dripper through its surface area with consideration of the axisymetrical flow to reach the value of 498 cm/day. Two irrigation durations of 1 and 2 hours were evaluated.

The following scenarios with different duration and frequency were tested within the Planned irrigation approach: 0.5 hours, 1 hour and 2 hours of irrigation every day and 2 hours and 4 hours of irrigation every second day.
Detailed settings of the individual parameters are discussed and explained in the following sections dealing with the Hydrus settings.

4.2.1 Domain type and units

The principle of the 2D axisymetrical flow is nicely explained by the drawing in Figure 7. Initial work space for definition of the domain was set with min (0.00) and max (1000.00) on x axis and min (0.00) and max (200) on z axis. All the length units were set to be inserted in cm.

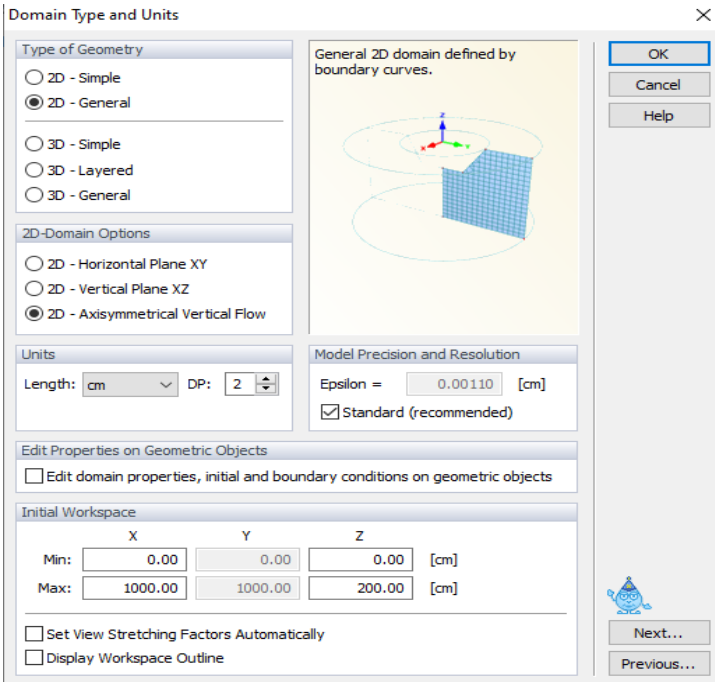

Figure 7. HYDRUS 2D/3D settings; domain type and units

4.2.2 Time information

The time unit was selected to be days and the final time was set to be 14 days, since all irrigation schemes were simulated for 2 weeks. Figure 8**Error! Reference source not found.** shows number of tie-variable boundary records for planned irrigation scheme showing two records (one showing the value for irrigation flux and the second as 0 for given time period). For 2 weeks this set of boundary conditions records were repeated 14-times.

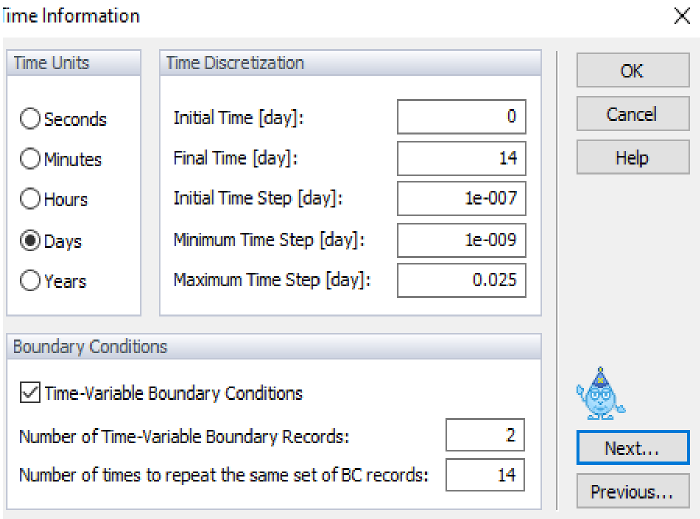

Figure 8. HYDRUS 2D/3D settings; time information

4.2.3 Soil hydraulic model

The soil hydraulic properties (van Genuchten-Maulem parameters) were obtained by using Rosetta Lite module incorporated in Hydrus (Figure 9).

The water flow parameters were estimated by neural network prediction based on the particle size distribution data, dry bulk density and the water content at 33 and 1500 kPa. The estimated parameters were adapted, only the value of saturated hydraulic conductivity was set to experimentally obtained values Table 2.

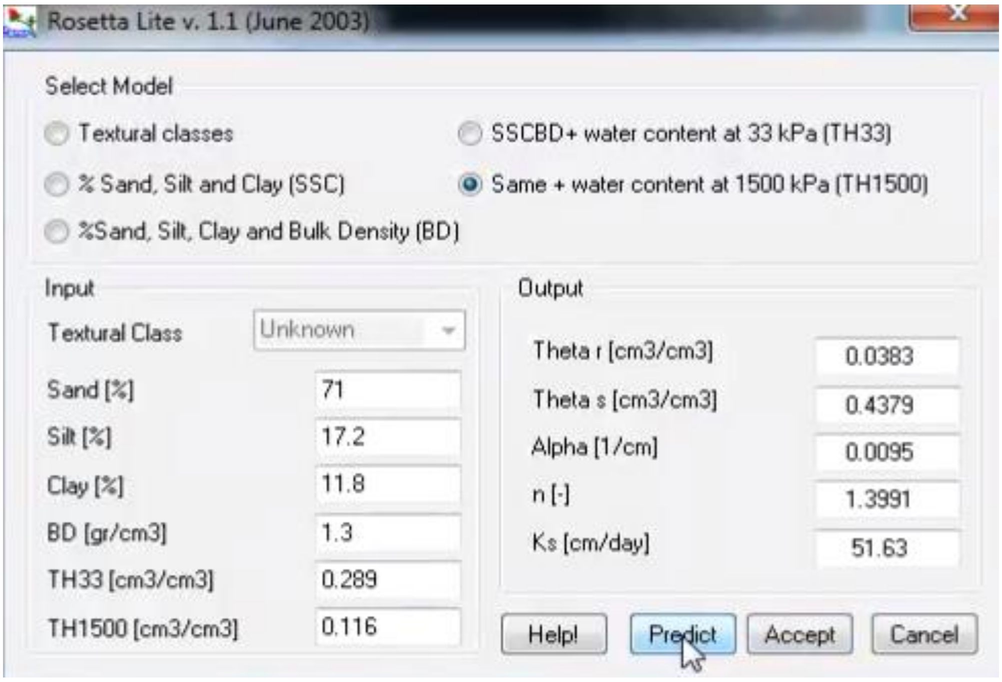

Figure 9. HYDRUS 2D/3D settings; Rosetta Lite settings for the estimation of the water flow parameters

Table 2. HYDRUS 2D/3D settings; parameters of the van Genuchten model

Mat	Name	θr(-)	θs(-)	α (1/cm)	n (-)	Ks (cm/day)	l (-)
1	Sandy Loam	0.0383	0.4379	0.0095	1.3991	112 272 657	0.5

4.2.4 Root Water and solute uptake model

Feddes parameters were selected with "No solute stress" on the solute stress model Figure 10. This is the sink module, which enables to incorporate the plant water uptake; its potential and actual value based on which the water availability to the plant can be evaluated for the different irrigation scenarios.

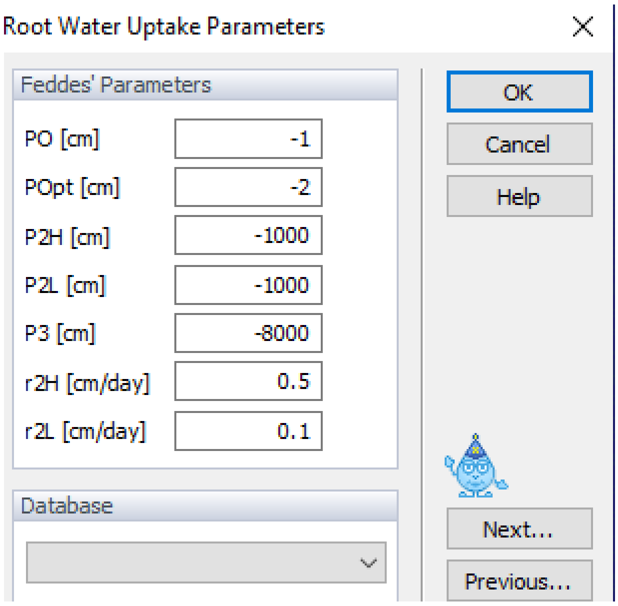

Figure 10. HYDRUS 2D/3D settings; root water uptake parameters

4.2.5 Time variable boundary conditions

The time for the simulations was selected to 14 days. No precipitation (as the irrigation was simulated for greenhouse application), but evaporation, transpiration and variable flux (irrigation) were considered. The value for evaporation and transpiration were calculated by multiplying the crop coefficient and reference evapotranspiration, the value for crop coefficient and reference evapotranspiration was taken from FAO 56 (Table 3, Table 4). There was no data for the plants in the greenhouse, but similar plant was selected. ET value was separated into evaporation and transpiration using the surface cover fraction.

Table 3. Average ETo for different agroclimatic region in mm/day (FAO, 1998)

Regions		**Mean daily temperature (°C)**		
		Cool	**Moderate**	**Warm**
		~10°C	**20°C**	**> 30°C**
Tropics and subtropics				
	Humid and sub-humid	2-3	3-5	5-7
	Arid and semi-arid	2-4	4-6	6-8
Temperate Region				
	Humid and sub-humid	1-2	2-4	4-7
	Arid and sub-arid	1-3	4-7	6-9

Humid and sub-humid value from temperature region was used as the Average ETo to calculate evapotranspiration.

Table 4. Single (time averaged) crop coefficient Kc and mean maximum height (FAO, 1998)

Crop		$K_{c\,ini}$[1]	$K_{c\,mid}$	$K_{c\,end}$	**Maximum Crop Height (h) (m)**
a. Small Vegetables		**0.7**	**1.05**	**0.95**	
Broccoli			1.05	0.95	0.3
Brussel Sprouts			1.05	0.95	0.4
Cabbage			1.05	0.95	0.4
Carrots			1.05	0.95	0.3
Cauliflower			1.05	0.95	0.4
Celery			1.05	1	0.6
Garlic			1	0.7	0.3
Lettuce			1	0.95	0.3
Onions					
	- dry		1.05	0.75	0.4
	-green		1	1	0.3
	-seed		1.05	0.8	0.5
Spinach			1	0.95	0.3

The crop coefficient for midseason for lettuce was taken from the above table as lettuce is similar to the plant we have at the green house.

Evapotranspiration = ETo*Kc = 2

The leaf Area Index was estimated to be 0.75 m for the initial growth.

Soil surface cover fraction = 1-LAI (leaf Area Index)

= 1-0.75 = 0.25

Transpiration = Evapotranspiration * SCF

= 2*0.25= 0.5mm

Evaporation = Evapotranspiration * (1-SCF) = 2* 0.75 = 1.5 mm

4.2.6 FE mesh parameters

Initially, the program has generated an automatic finite element mesh with a size of 5.5 cm. Refinement function has been used to decrease the size of element close to the area of the dripper and also in the root zone. In total, the mesh is created by 3083 2D elements on the basis of 1617 nodes (Figure 11).

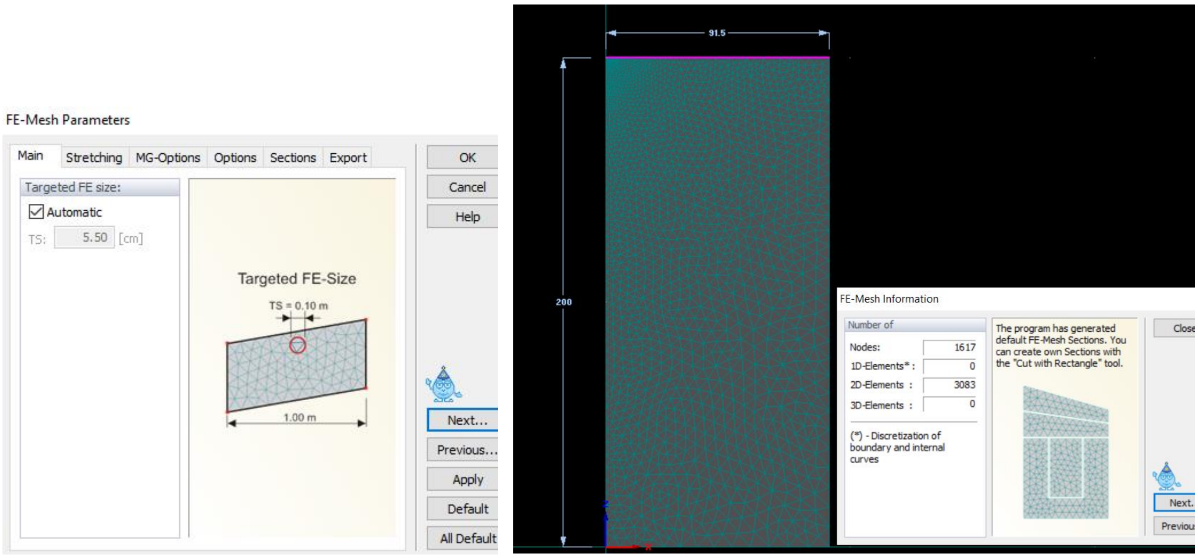

Figure 11. HYDRUS 2D/3D settings; FE-Mesh Parameters (left), FE-mesh design (right)

4.2.7 Domain properties

Based on the measured particle size distribution data, sandy loam soil was chosen as the material for the whole simulated domain with dimensions of 91 cm (width) and 200 cm (depth). 12 observation nodes were inserted on the domain and most of the nodes were inserted close to the surface of the domain, just to properly observe the drip irrigation effects. Location of the observation nodes is indicated in Figure 12.

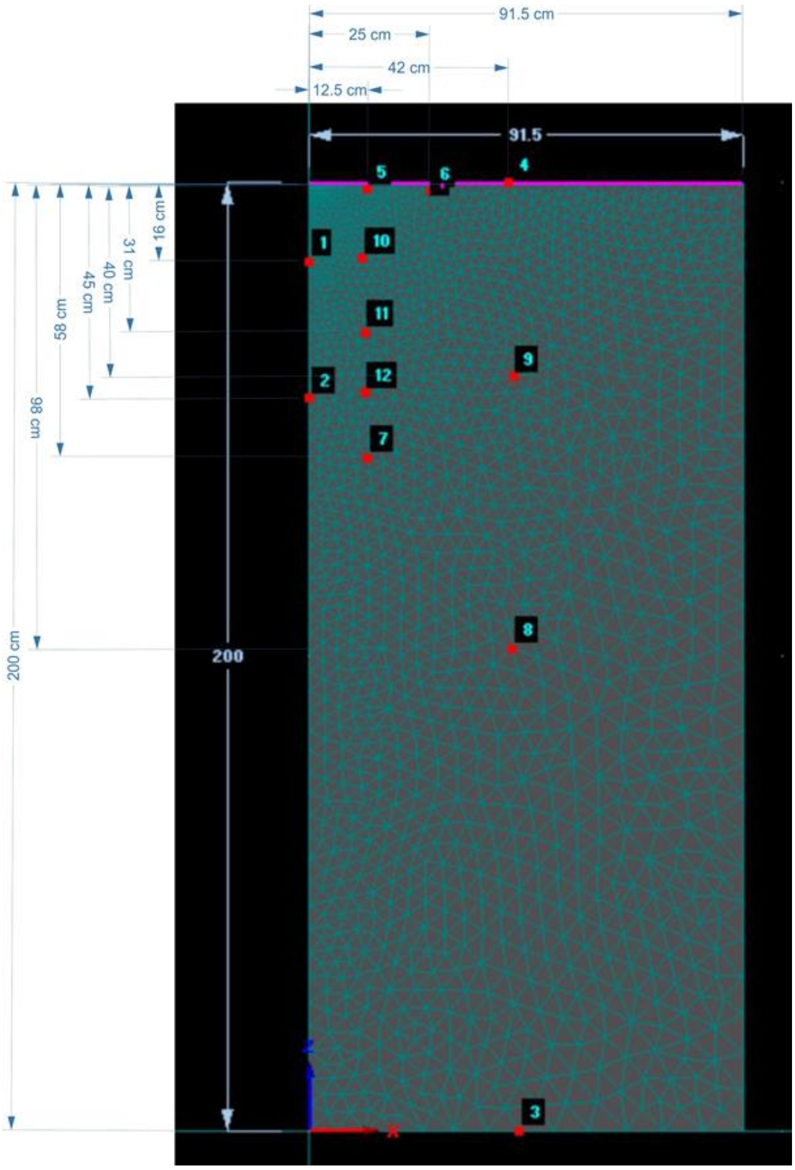

Figure 12. HYDRUS 2D/3D settings; domain dimensions and observation nodes localization

4.2.8 Initial conditions

The initial condition for the domain was set to be based on pressure head, the set value was -250 cm uniformly for the whole profile.

4.2.9 Boundary conditions

The selected boundary condition is system dependent. The variable flux was assigned to the dripper which was placed on the left side of the surface of the domain. The boundary over the length of 12.5 cm next to the dripper was assigned as the special boundary condition enabling dynamic evaluation of the wetted area (purple colour). The rest of the surface is open to the atmosphere (atmospheric boundary – light green colour). On both sides of the domain was selected a no-flow boundary (white colour) and at the bottom a free drainage was set (dark green colour). Boundary conditions (left), uniform material distribution (middle) and initial pressure head value of – 250 cm (right) are displayed in Figure 13. Dynamic wetting specification is presented in Figure 14.

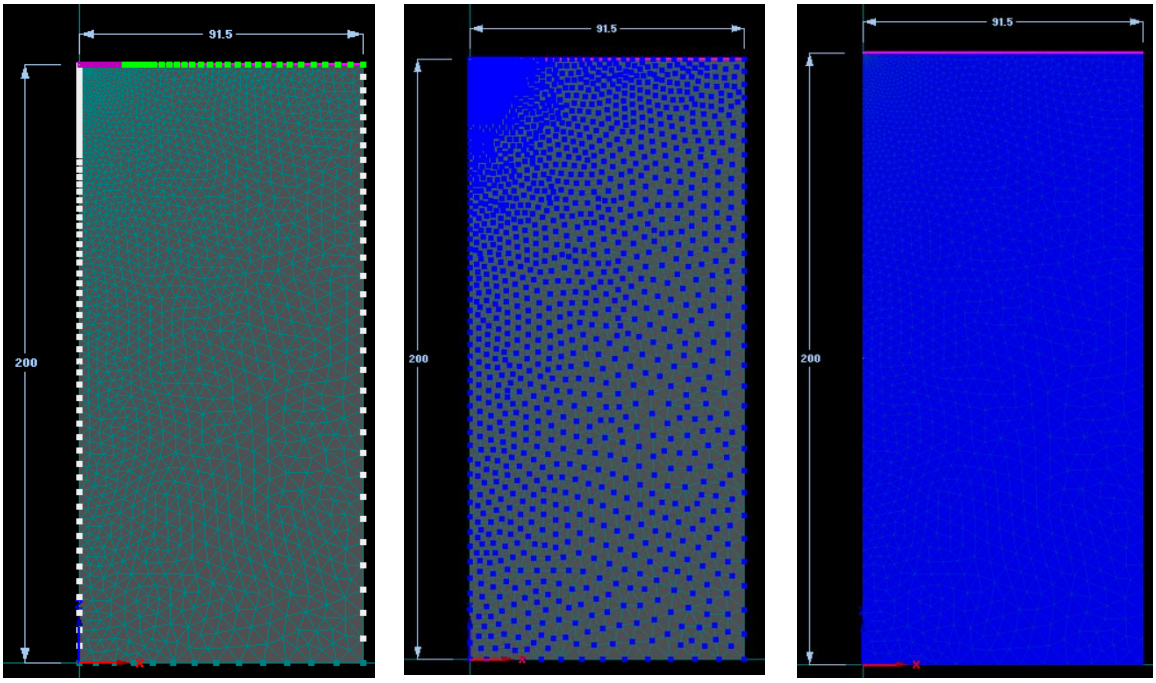

Figure 13. HYDRUS 2D/3D settings; boundary conditions (left), material distribution (middle), initial conditions (right)

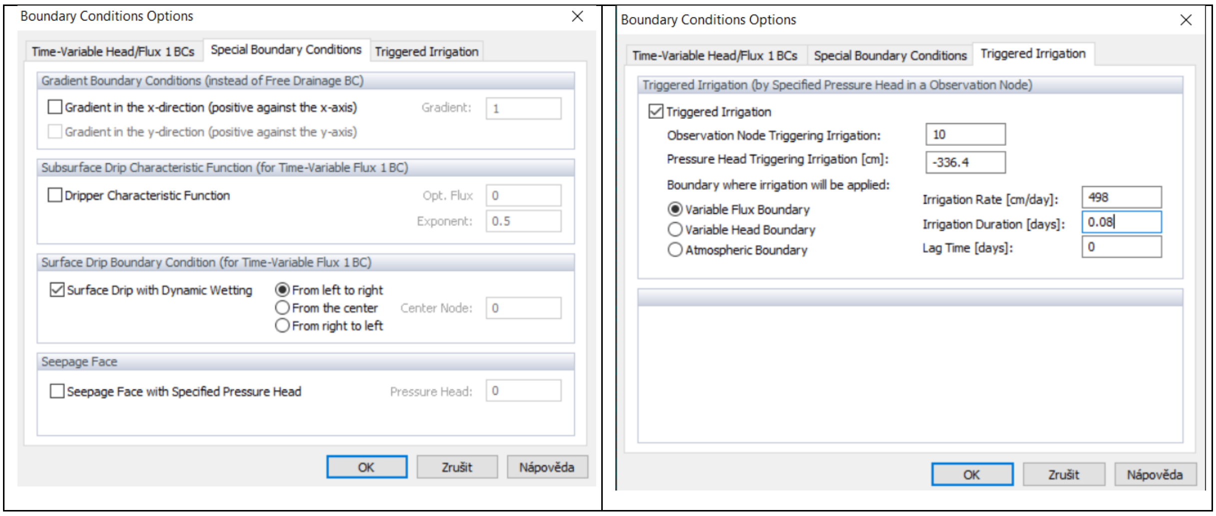

Figure 14. HYDRUS 2D/3D settings; dynamic wetting specification (left) and triggered irrigation specification (right)

With all input parameters, boundary and initial condition data, the software simulated the water movement within the soil profile under the dripper and provided graphical outputs for selected print times.

5 Results

Hydrus 2D/3D provides numerical and graphical outputs enabling animation of volumetric water content changes or pressure head changes within the whole domain for the given experimental period. Only pictures from selected times will be displayed here for demonstration. All output data were exported to MS Excel, where numbers and graph comparisons between the simulations were evaluated. Additionally, amounts of water used by the particular irrigation scenario by a single dripper were calculated and compared.

5.1 Triggered irrigation

The calculated volumes of applied water (l) by a single dripper for each simulated irrigation scenario for 1 and 2 hours of irrigation duration are presented in Table 5 and Table 6.

Table 5. Irrigation settings for one hour irrigation duration

Irrigation Duration (hour)	Irrigation Interval	Dripper Discharge (l/h)	Saturated Hydraulic Conductivity (cm/day)	Number of Irrigation Events	Pressure Head Triggering Irrigation (cm)	Volume of applied water by a single dripper within 2 weeks (l)
1	ON 10	2.3	112	4	-336.4	9.2
1	ON 10	2.3	272	15	-336.4	34.5
1	ON 10	2.3	657	49	-336.4	112.7

Table 6. Irrigation settings for two hour irrigation duration

Irrigation Duration (hour)	Irrigation Interval	Dripper Discharge (l/h)	Saturated Hydraulic Conductivity (cm/day)	Number of Irrigation Events	Pressure Head Triggering Irrigation (cm)	Volume of applied water by a single dripper within 2 weeks (l)
2	ON 10	2.3	112	3	-336.4	13.8
2	ON 10	2.3	272	9	-336.4	41.4
2	ON 10	2.3	657	24	-336.4	110.4

Volumetric water content within the root zone and triggering point (at observation node 10 in depth of 16 cm) was evaluated together with the total amount of water used within the set irrigation scheme. Effect of hydraulic conductivity on amount of applied water is graphically displayed in Figure 15. Linear relationship between these characteristics is displayed in Figure 16 and Figure 17. The volumetric water contents at ON10 with clear indication of triggered irrigation events is presented in Figure 18.

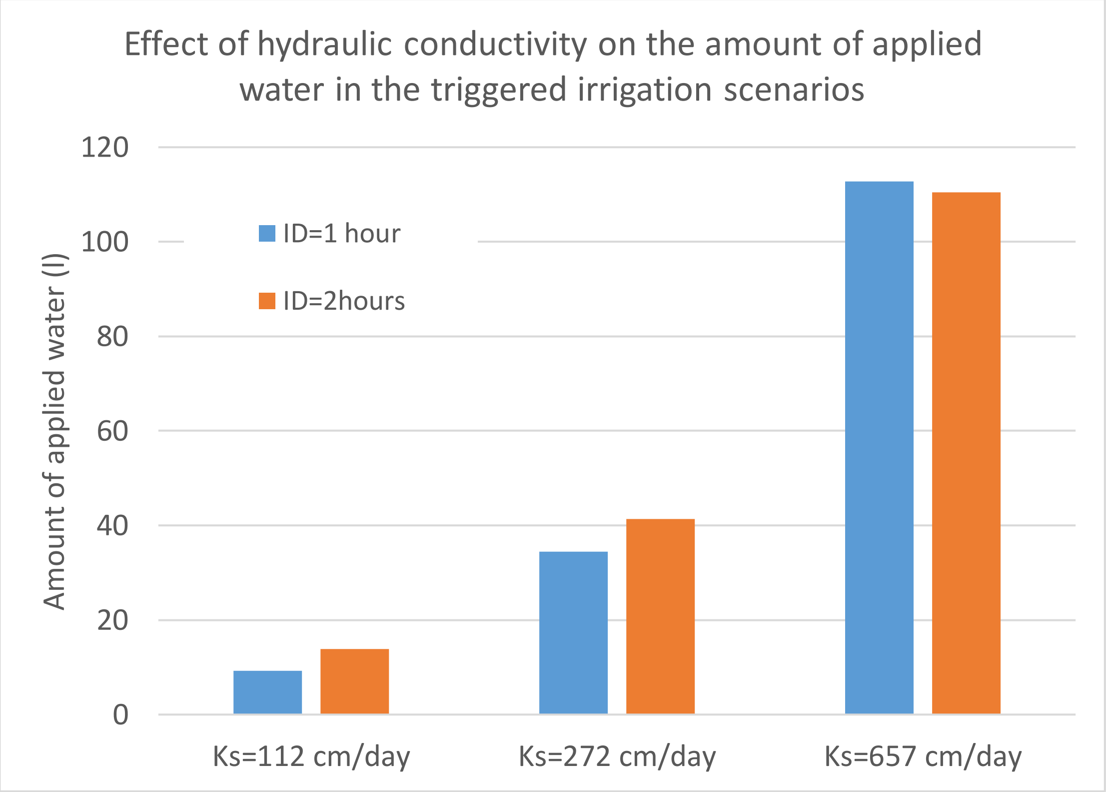

Figure 15. Effect of hydraulic conductivity on amount of applied water based on the triggered irrigation

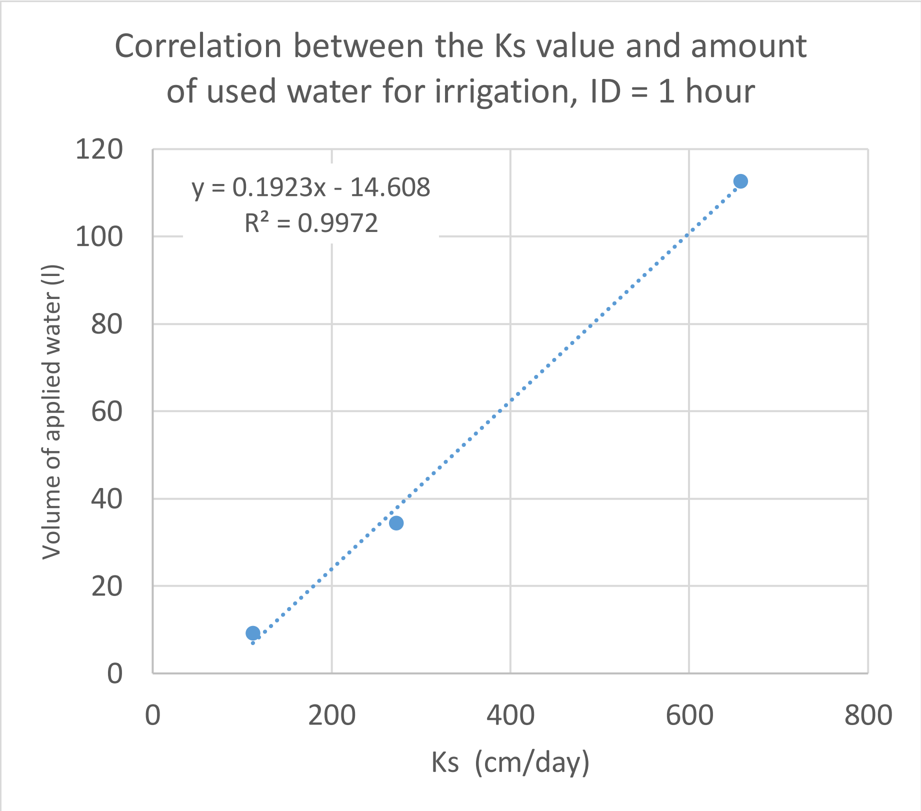

Figure 16. Correlation between the Ks value and amount of used water for irrigation

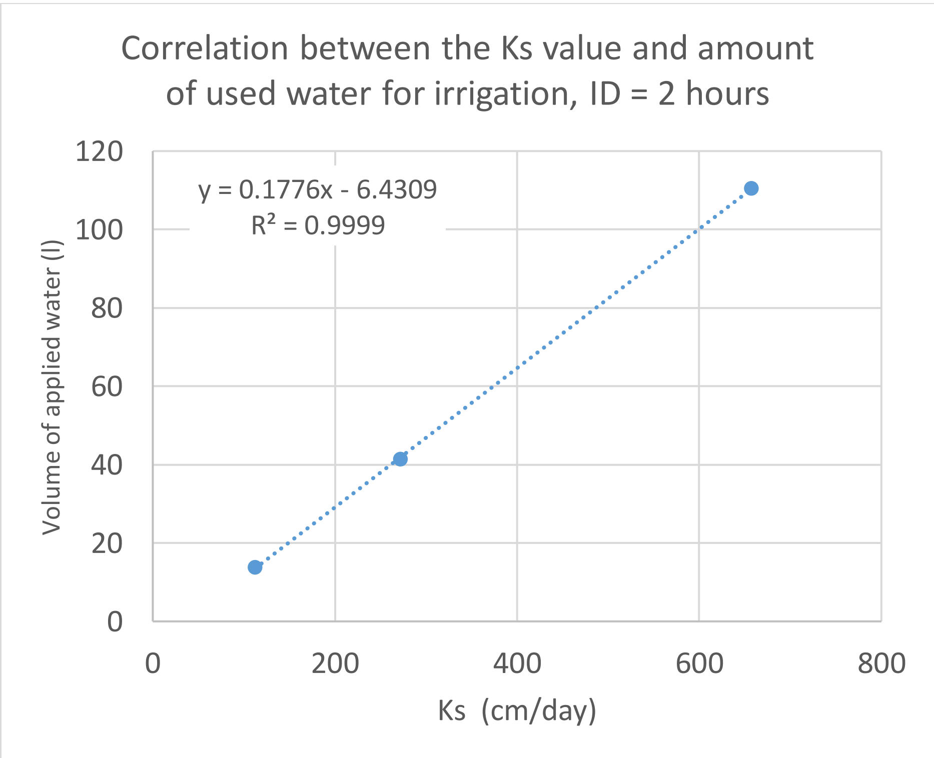

Figure 17. Correlation between the Ks value and amount of water used.

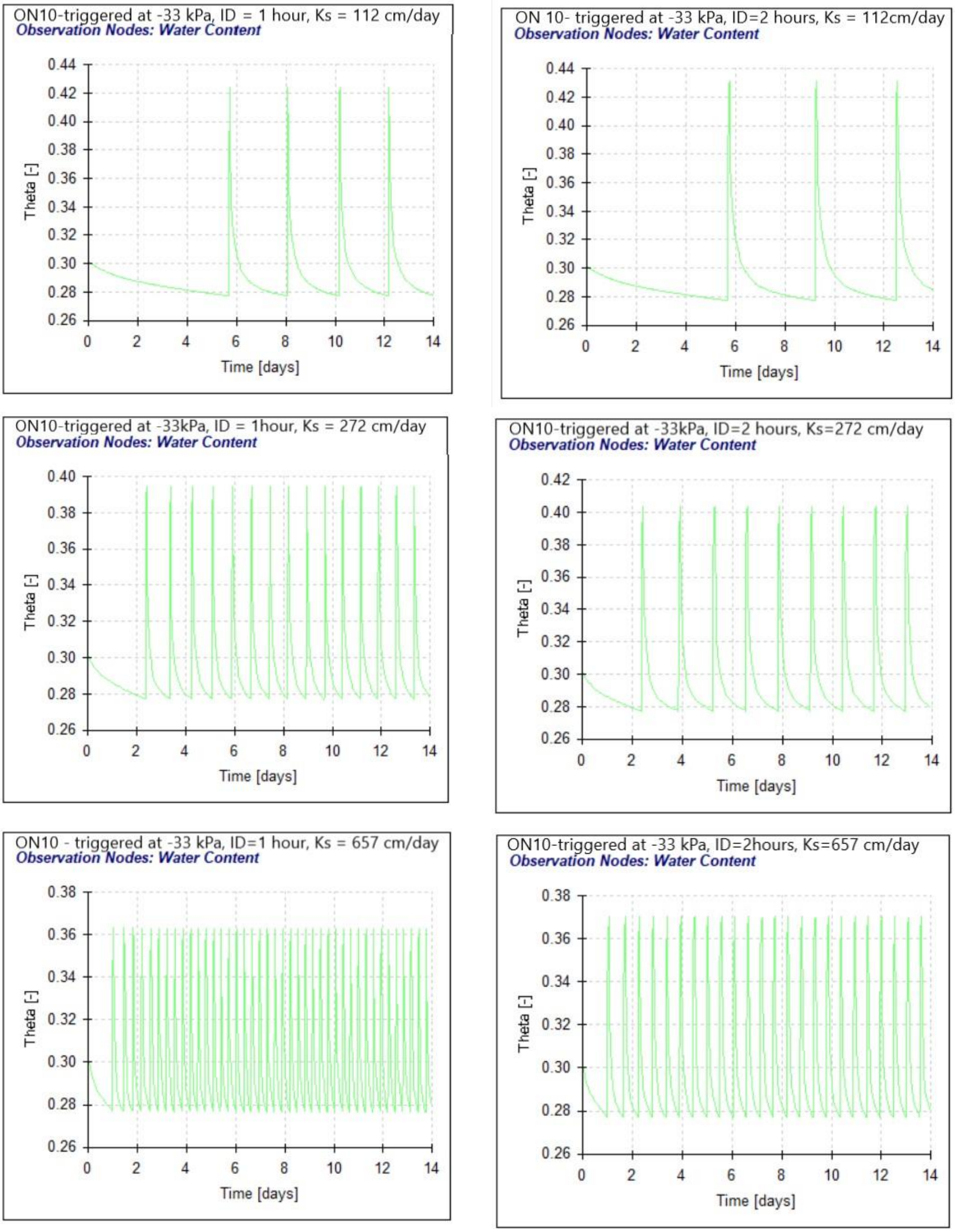

Figure 18. Showing moisture content of 1 hour and 2 hours irrigation duration with different hydraulic conductivity

5.2 Planned irrigation

The planned irrigation settings and results are shown in Table 7, Table 8, and Table 9.

Table 7. Irrigation settings planned, Ks =112 cm/day

Irrigation Duration (days)	Irrigation Interval	Dripper Discharge (l/h)	Saturated Hydraulic Conductivity (cm/day)	Number of Irrigation Events		Volume of applied water by a single dripper within 2 weeks (L)
0.02	Everyday	2.3	112	14		16.1
0.04	Everyday	2.3	112	14		32.2
0.08	Everyday	2.3	112	14		64.4
0.08	Every 2 Days	2.3	112	7		32.2
0.16	Every 2 Day	2.3	112	7		64.4

Table 8. Irrigation settings planned, Ks=272 cm/day

Irrigation Duration (days)	Irrigation Interval	Dripper Discharge (l/h)	Saturated Hydraulic Conductivity (cm/day)	Number of Irrigation Events		Volume of applied water by a single dripper within 2 weeks (l)
0.02	Everyday	2.3	272	14		16.1
0.04	Everyday	2.3	272	14		32.2
0.08	Everyday	2.3	272	14		64.4
0.08	Every 2 Days	2.3	272	7		32.2
0.16	Every 2 Days	2.3	272	7		64.4

Table 9. Irrigation settings planned, Ks= 657 cm/day

Irrigation Duration (days)	Irrigation Interval	Dripper Discharge (l/h)	Saturated Hydraulic Conductivity (cm/day)	Number of Irrigation Events		Volume of applied water by a single dripper within 2 weeks (l)
0.02	Everyday	2.3	657	14		16.1
0.04	Everyday	2.3	657	14		32.2
0.08	Everyday	2.3	657	14		64.4
0.08	Every 2 Days	2.3	657	7		32.2
0.16	Every 2 Days	2.3	657	7		64.4

Although the triggered irrigation is a very adaptive and convenient, the current greenhouse irrigation scheme is based on the planned irrigation. That is why the evaluation is made into more details. Five different irrigation duration/frequency scenarios were simulated for three different levels of saturated hydraulic conductivity (112, 272, and 657 cm/days). 30 minutes of irrigation every day, 1 hour of irrigation every day, 2 hours of irrigation every day and every second day and 2 hours of irrigation every second day. Since the irrigation is based on a given schedule, the effect of saturated hydraulic conductivity is not reflected and identical values for all three levels were obtained (Figure 19). However, differences in volumetric water contents at ON10 can be observed, e.g. for one and two hour of irrigation duration shown on Figure 19

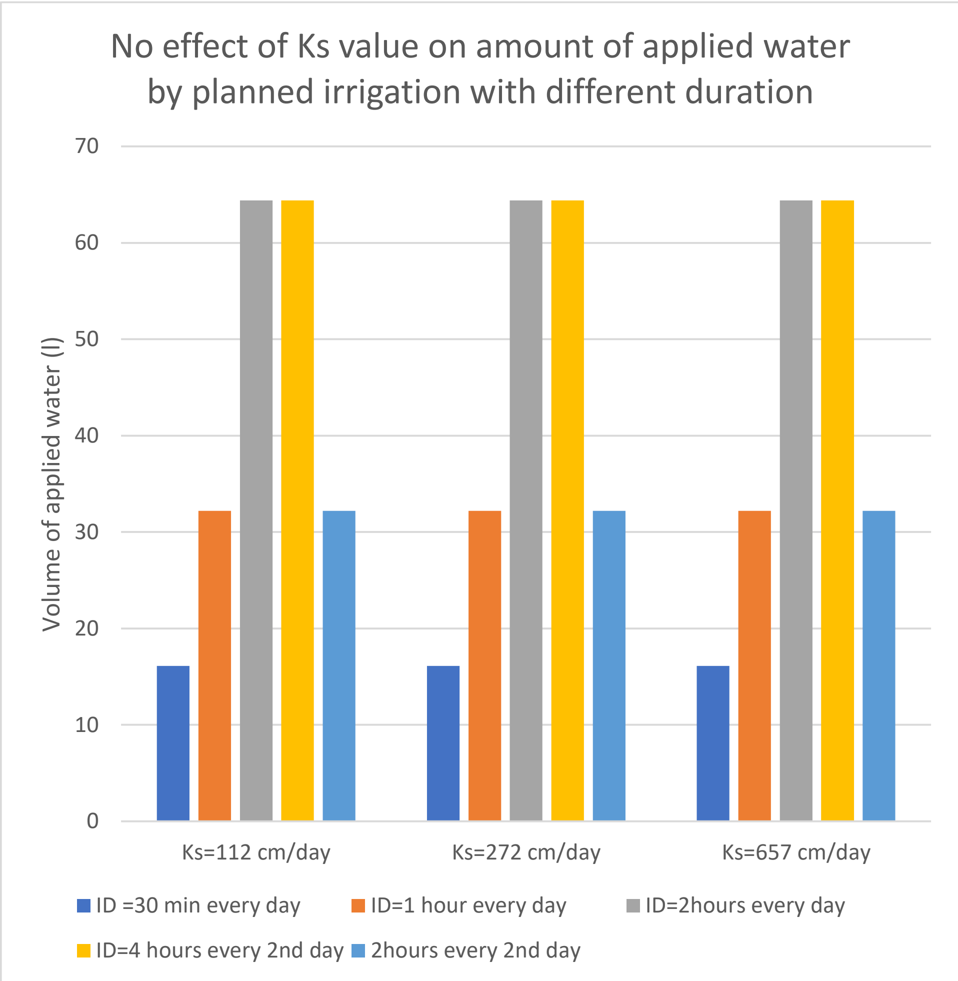

Figure 19. No effect of Ks value on amount of applied water by planned irrigation with different duration for 2 weeks simulation period

Volumetric water contents and pressure head changes for both irrigation duration times are presented in Figure 20 and Figure 21.

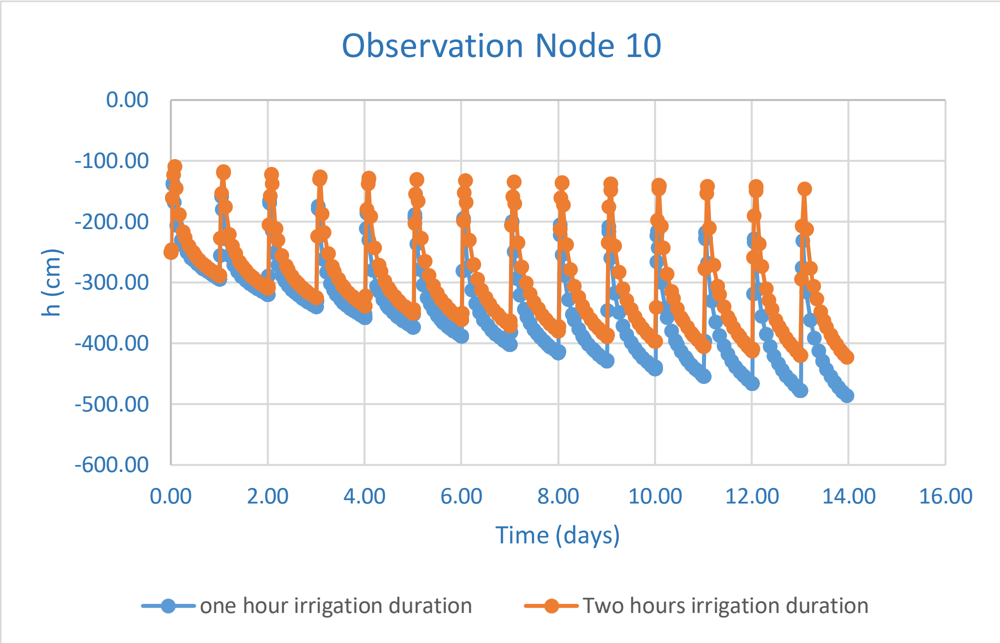

Figure 20. Comparison of one- and two-hours irrigation duration in terms of pressure head

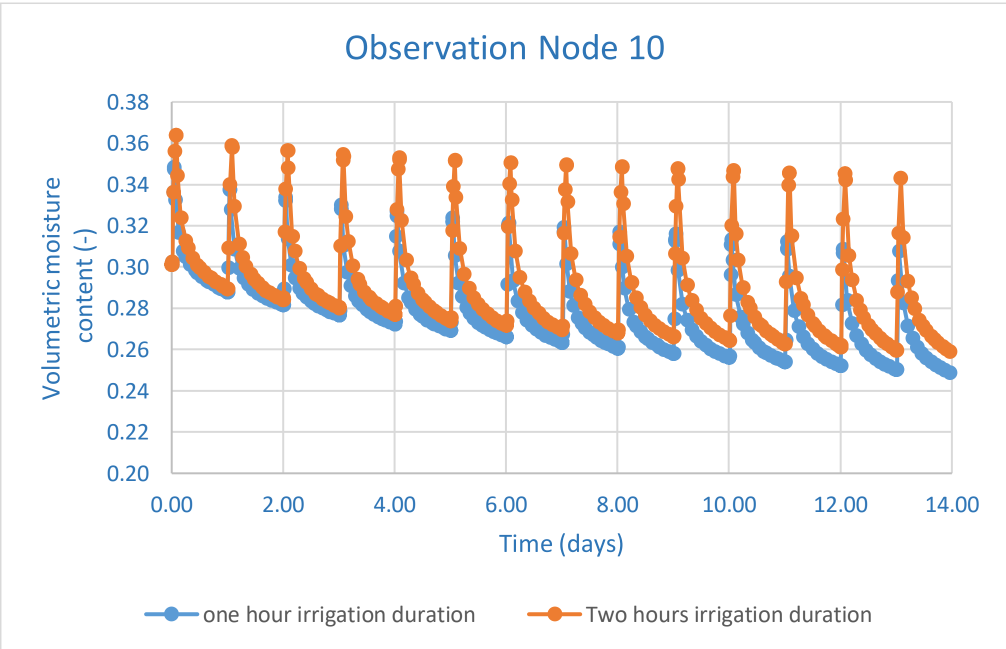

Figure 21. Comparison of one- and two-hours irrigation duration in terms of moisture content

Effect of hydraulic conductivity on the number of irrigation events together with the effect of the irrigation durations is shown in Figure 22, Figure 23, Figure 24, and Figure 25.

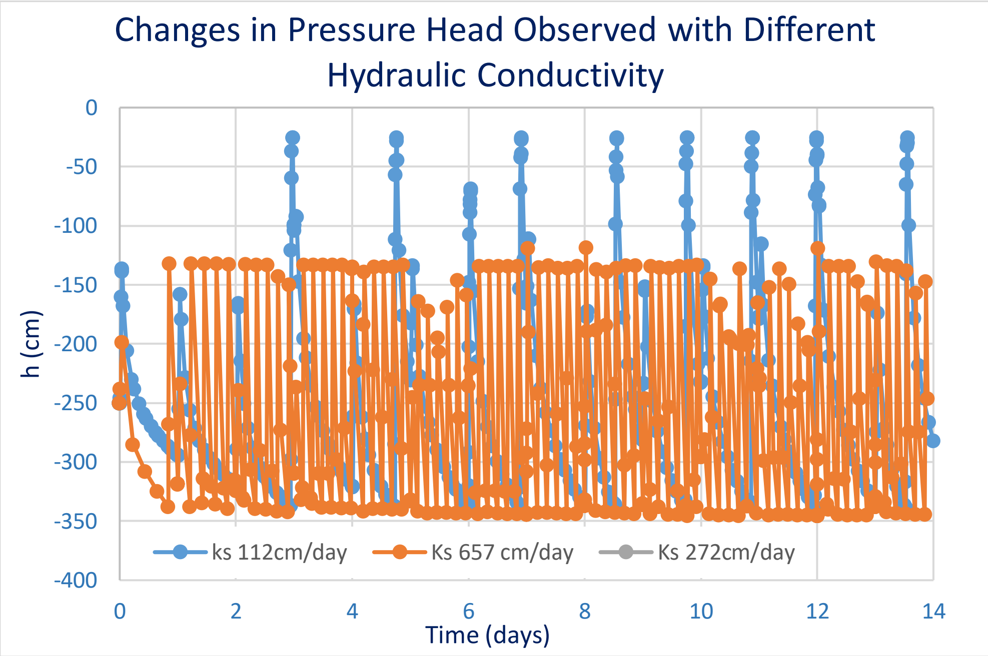

Figure 22. Effect of the changes in pressure head (one hour irrigation duration)

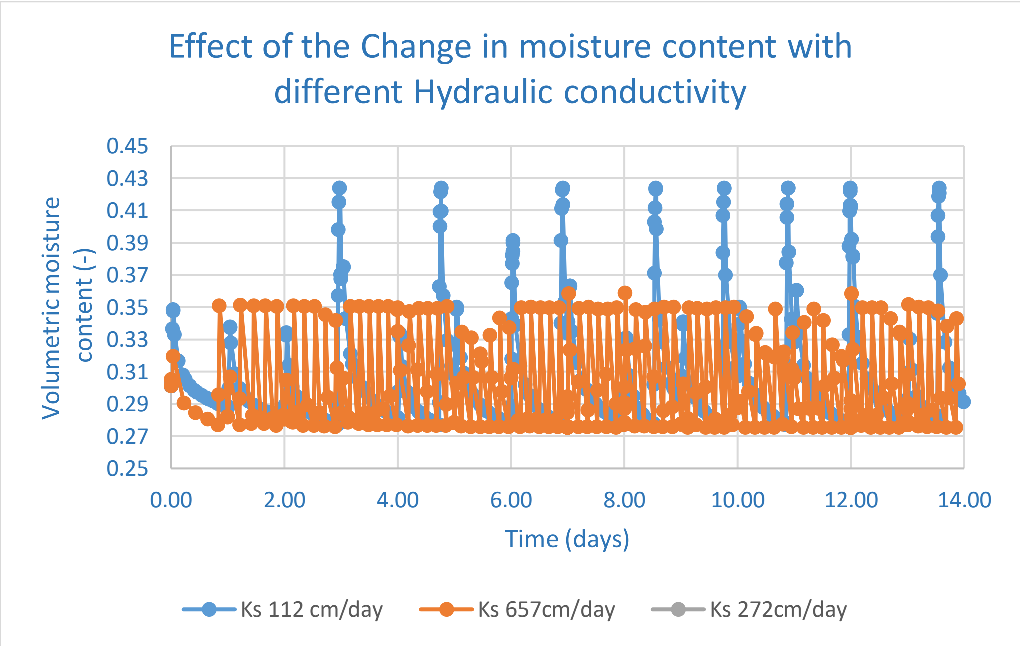

Figure 23. Effect of the changes in moisture content (one hour irrigation duration)

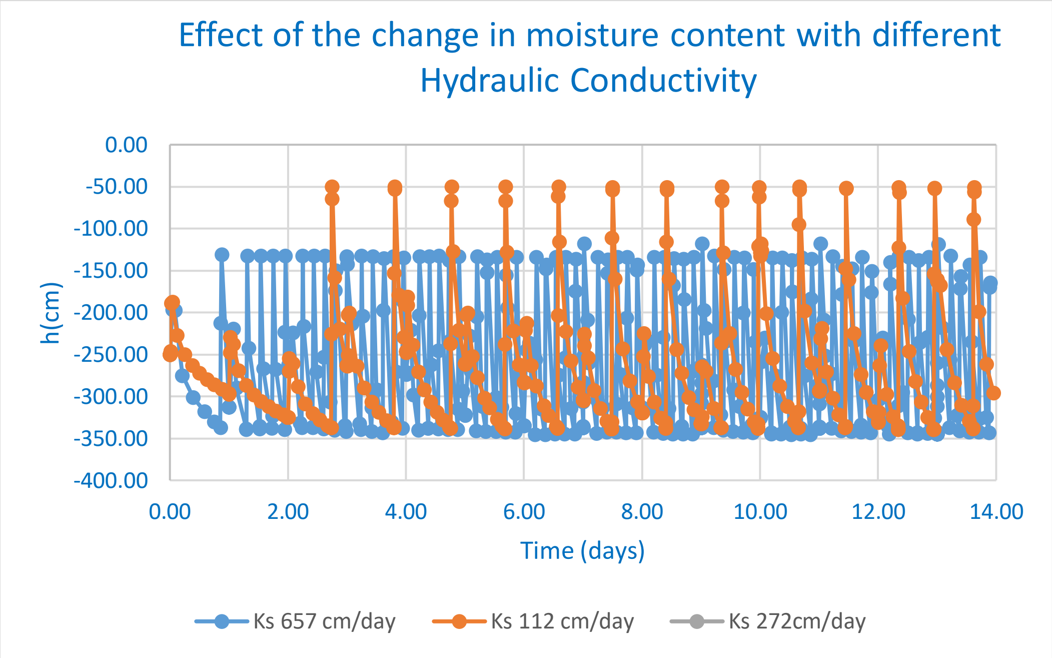

Figure 24. Effect of the changes in pressure head (two hours irrigation duration)

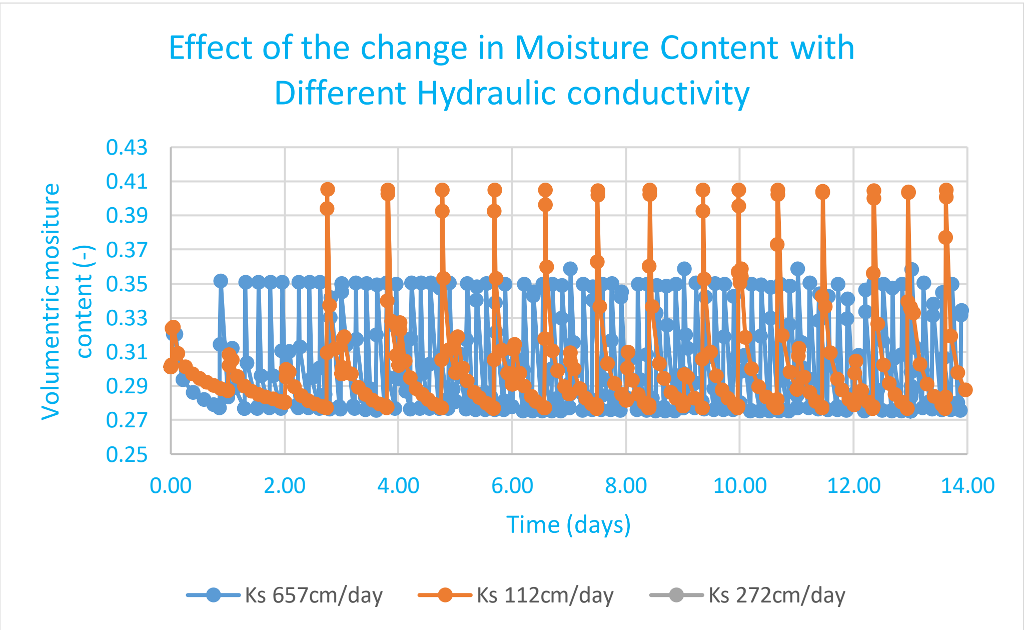

Figure 25. Effect of the changes in Moisture Content (two hours irrigation duration)

Comparisons for volumetric water contents in different depth in different time scales is presented in Figure 26 and

Figure 27. Similar comparisons could be made for water content changes selected ON representing the profile for selected times (Figure 28).

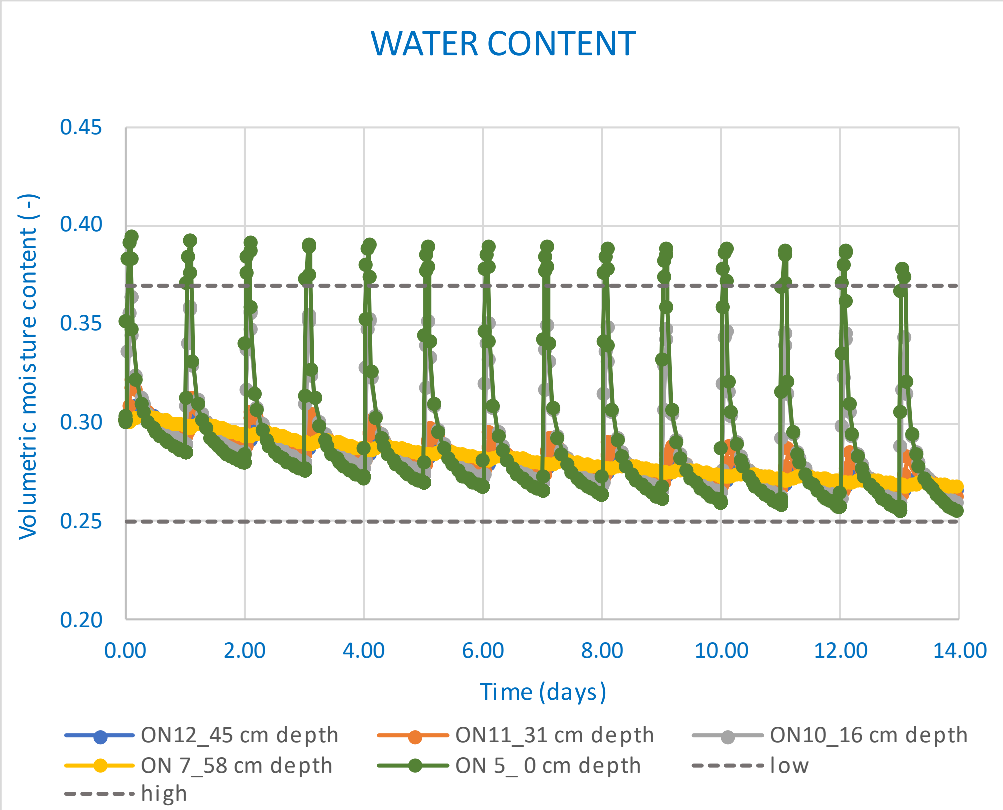

Figure 26. Comparison of moisture content at different observation nodes (ON) located in different depths (2 hours of irrigation every day, Ks=112 cm/day)

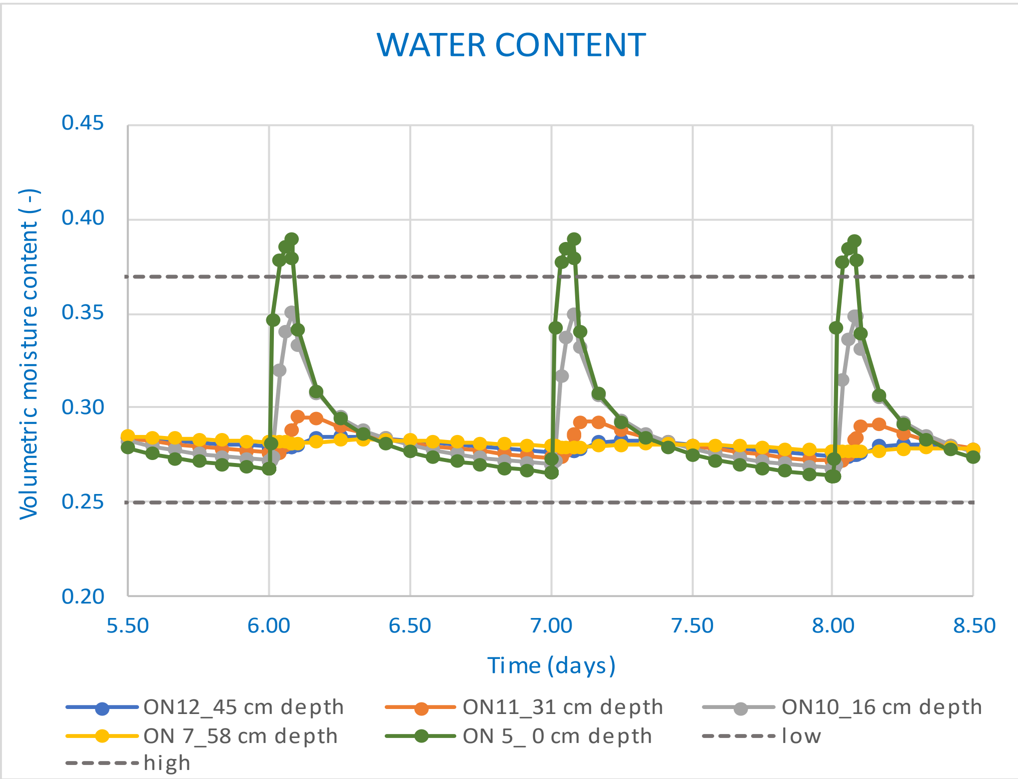

Figure 27. Comparison of moisture content at different depth - day 5.0-8.50 (2 hours of irrigation every day, Ks = 112 cm/day)

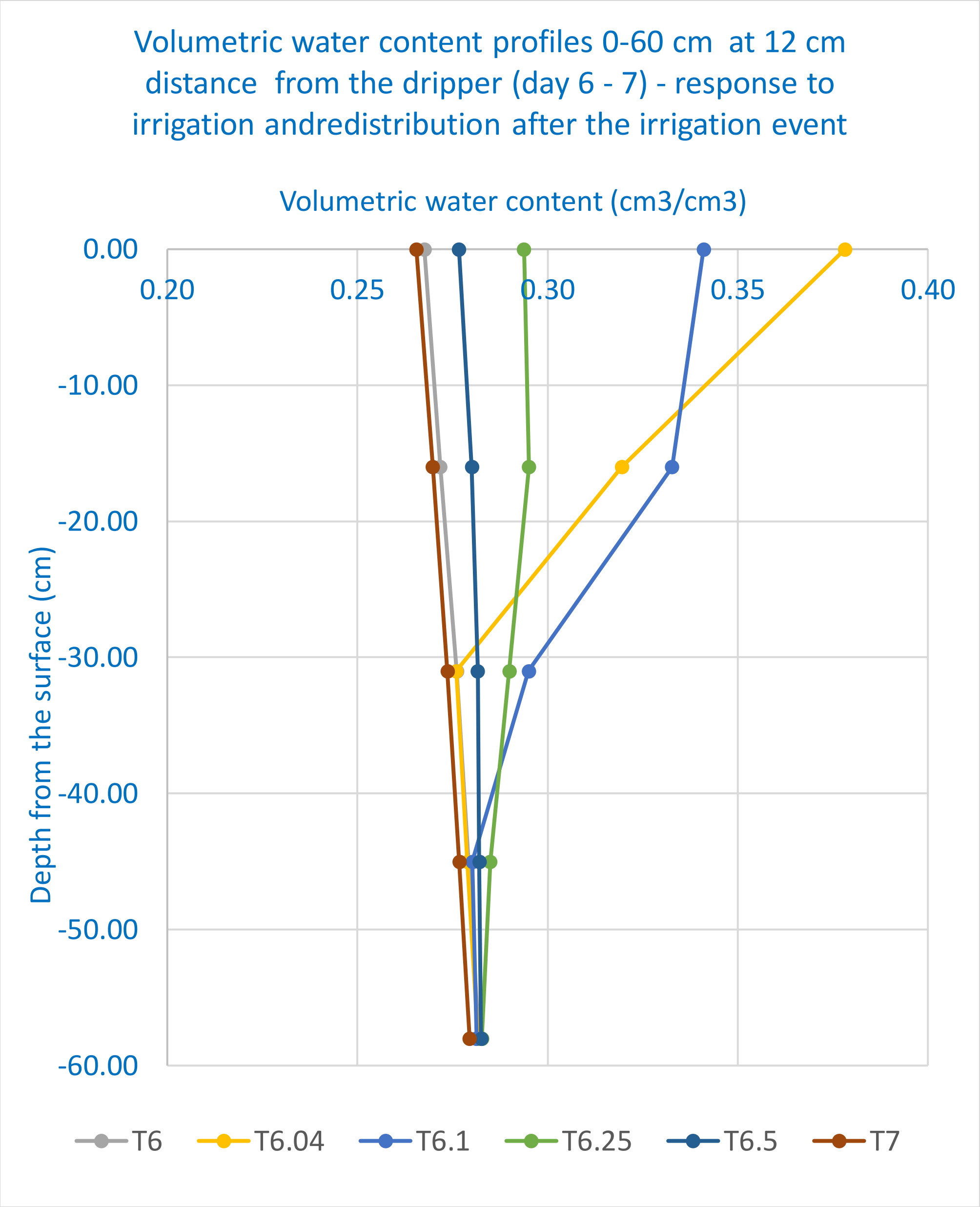

Figure 28. Volumetric water content profile (day 6-7), 2 hours of irrigation duration every day, Ks=112 cm/day (T indicates time in days)

Similarly, to the plotted data, graphical output from Hydrus enables to evaluate the profiles for given print times as well. Two irrigation events, one on day 6 and another on day 7 are shown in Figure 29 together with the water redistribution in time between the irrigation events. Comparison of volumetric water content changes in two different depths of 16 cm (ON10) and

45 cm (ON12) for irrigation duration of 30 minutes and Ks value 112 cm/day is presented in Figure 30.

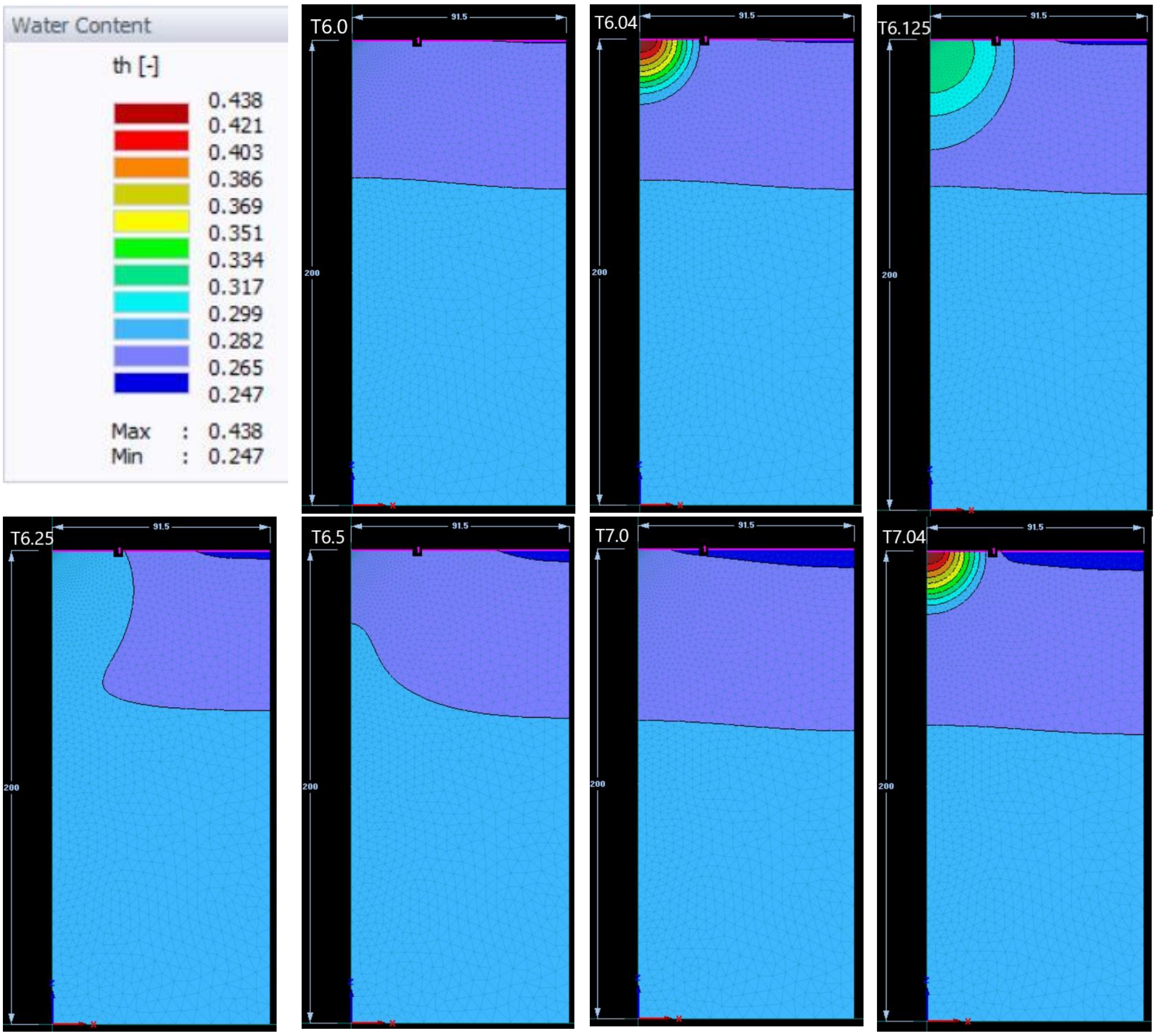

Figure 29. Graphical comparison of soil moisture profiles (day 6-7), 2 hours of irrigation duration every day, Ks=112 cm/day (T indicates time in days)

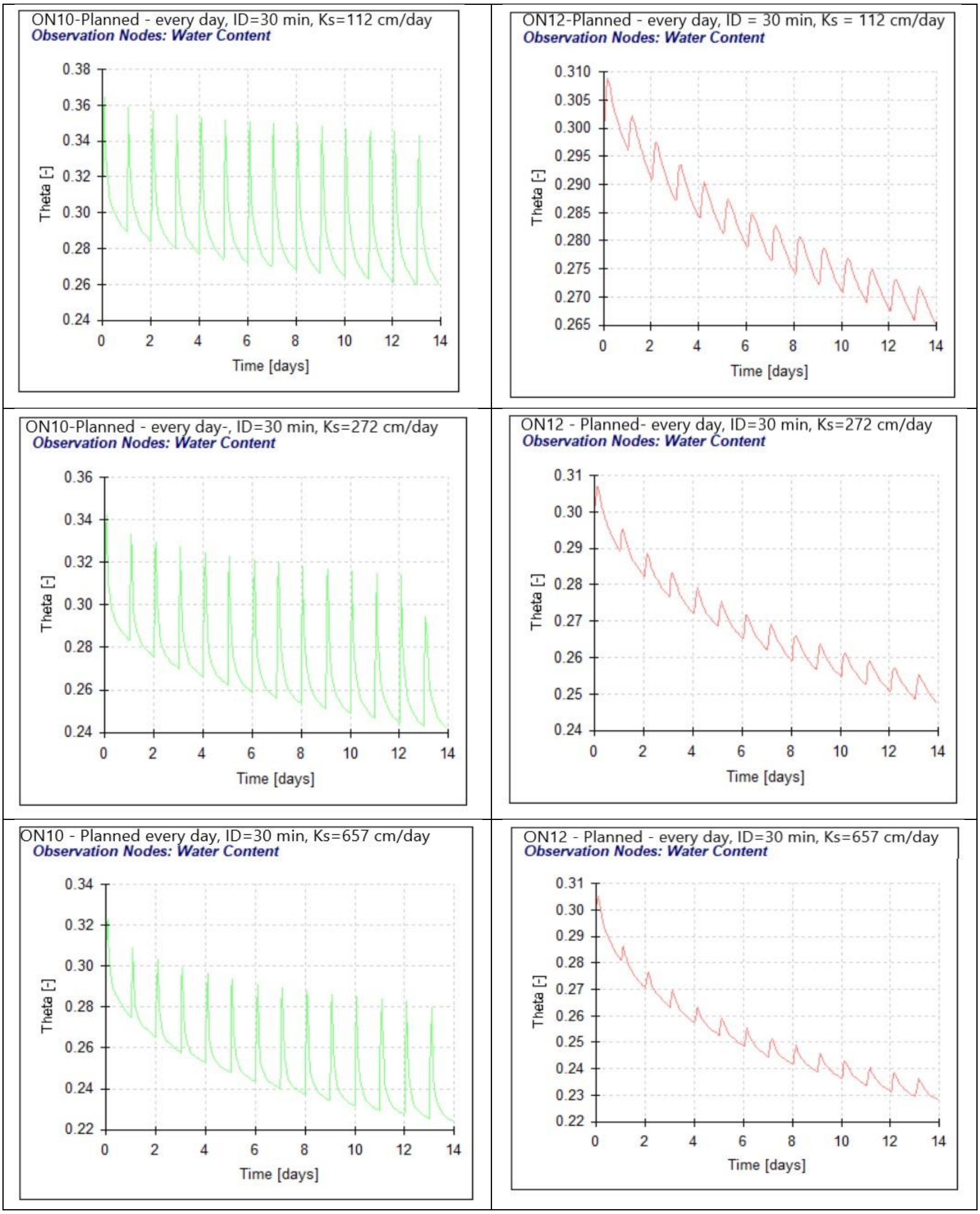

Figure 30. Showing different irrigation duration and different hydraulic conductivity for water content changes in different depths (16 cm in green, 45 cm in red) within the 14 day-simulation period

6 Discussion

To improve the longevity of irrigation system, it will require the optimization of operational parameters such as irrigation duration, irrigation threshold and irrigation quantity. Numerical modelling is a fast and accurate means to optimize such operational parameters. The accuracy of a simulation depends on the quality of the hydraulic parameter estimates, taking detailed measurements of hydraulic properties is expensive and time consuming but the ROSETTA neutral network model in Hydrus 2D/3D make use of more easily obtained data (bulk density, percentages of sand, silt and clay and water contents) and these parameters worked well for Hydrus 2D/3D numerical model. The ROSETTA model offers a quick and easy way to estimate the soil hydraulic parameters that are needed for the simulations and the emitter discharge rate is very important in drip irrigation because if the volume of the water applied is low, the pressure head and the moisture content value will be low, and this will reduce the water flux towards the root. The volume of water discharge by the emitter must be constant through the irrigation process. Hydrus 2D/3D can be used to evaluate irrigation thresholds, if correct input data such as water flow parameters, hydraulic parameters are provided.

6.1 Irrigation settings

Hydrus 2D/3D Simulations were carried out to observe five different irrigation durations for planned irrigation as shown in Table 7, and two different irrigation for triggered irrigation as shown in Table 5 and Table 6. 3 sets of simulations were carried out every day (half an hour, one hour and two hours) for 2 weeks while 2 was carried out every 2 days for 2weeks (two hours and four hours) for planned irrigation. For the triggered irrigation scheme, pressure head triggering irrigation was set at -336.4 cm and different hydraulic conductivity values (as they were experimentally observed) were used to evaluate the best water saving strategy for irrigation. The following hydraulic conductivity values were used: 112cm/day, 272cm./day and 657cm/day. 12 observations nodes were inserted and observation node 10 with a depth of 16cm from the surface was observed for these two irrigation schemes so that the root water uptake can be closely monitored.

6.1.1 Triggered irrigation

The aim is to automatically trigger the system to avoid water stress, observation node 10 with a depth of 16 cm was set to trigger the irrigation when the pressure head drops to -336.4 cm, which is the pressure head triggering irrigation value. the pressure head, moisture content and root water uptake were closely monitored. One-hour irrigation duration and two hours irrigation duration were evaluated and compared after the simulation to determine the best method that saves more water.

One Hour Irrigation Duration

A total number of irrigation events were 14 and the total volume of water applied was 18.4 l. The value for hydraulic conductivity used was 11 2cm and it was observed that the highest number for the pressure head for this simulation was -25.38 cm which can be seen on 14th day, eight irrigation events were above -50 cm and during these irrigation events, the plants were able to extract enough water. The lowest value for soil moisture content was 0.28 which satisfy the perfect condition for a good soil moisture content according to pF 2.0 -2.7 which represents the field capacity, the highest value was 0.42 and this shows that the soil is in a good condition, it also further proves that irrigating the land one hour every day for 2weeks will be sufficient for plant growth and optimum crop yield.

Two hours irrigation duration

A total number of seven irrigation events were Recorded and the total volume of water applied was 64.4, the pressure head and soil moisture content were observed and the pressure head at the maximum level is much lower when irrigating at 2 hours every day for 2 weeks, the peak pressure head was -50.32 cm as shown the pressure head started increasing at the third day and after several irrigation events it peaked at -50.32 cm.

The soil moisture content value also showed that the soil is in a good condition. The peak value for the 2 hours irrigation duration was 0.40 as shown in which also shows that the soil is in perfect moisture content and this will lead to great plant growth and optimum crop yield.

Comparison between one hour and two hours irrigation durations

It was observed that the pressure head peak during an hour irrigation duration was much higher than in 2hours irrigation duration, although both irrigation durations showed the required level of pressure head and moisture content for optimal root water uptake.

The moisture content in the two-irrigation duration were similar which shows that the soil moisture content in those two irrigation events is in perfect condition although the moisture content in an hour irrigation duration was much higher at the peak, but the two irrigation durations have the same minimum value.

6.1.2 Planned irrigation

Another scheme that was also set up is the planned irrigation which was set to take place every morning between 5-6 am every day for 3 irrigation duration (half an hour, one hour and two hours) and every second day (two hours and four hours) for 2 weeks, it was shown in Figure 15Figure 14 that total number of volume of water applied depends on the irrigation duration and frequency, one hour and Two hour irrigation durations were evaluated and the result was put against each other to find the best planned irrigation scheme, The total volume of water used for an hour planned irrigation was 32.2 l with 14 irrigation events recorded as shown in Table 7, the moisture content depth was different for all the observation nodes and from the first day, the water keeps reaching new depth until the last day as shown in Figure 17, the pressure head value was dropping also, the peak value for the pressure head was on the first day and the value recorded was -138 cm as it was shown in Figure 16 and the lowest value was on the last day which is the 14th day and the value recorded was -230 cm. the same also applied to the moisture content the highest value for the moisture content which is 0.35 was recorded on the first day and the value dropped to 0.31 on the last day which is the 14th day as shown in Figure 17. The total volume of water used for 2hours irrigation duration was 64.4 l and 14 irrigation events was recorded as shown in Table 4, for the irrigation duration of 2 hours everyday for 14 days the highest value for pressure head was also recorded on the first day which was -109 cm, and this dropped to -146 cm on the last day as shown in Figure 18 and for the moisture content the peaked at 36 and it dropped to 34 on the last day as shown in Figure 19. Effect of hydraulic conductivity on the volume of water discharged by emitter on the soil. Wetted volume is also important, and the effect of hydraulic conductivity on the volume of water discharged by emitter on the soil was observed and how large the wetting pattern of the soil around the emitter is, the wetted area on the soil surface around emitter is usually small and this only expand with depth as it was shown in Figure 12. One hour irrigation duration was observed for the soil wetting pattern with different hydraulic conductivity, The effect of the emitter discharge on the wetting pattern after the 3rd day of irrigation duration was observed for three different hydraulic conductivity and it was observed that the irrigation duration with the lowest hydraulic conductivity has the lowest wetted volume and the pattern started from where the emitter was located, the pattern around emitter got bigger with depth as it was shown in Figure 12, the wetted volume increased as the hydraulic conductivity was increased to 272 cm/day and this was shown in Figure 13, more water started flowing from the opposite end of where the emitter is and this will eventually lead to over wetting of the surface area and when it was increased to 657 cm/day, the space around the emitter became dry and water was flowing downward from the opposite end of the emitter as it was shown in Figure 14, this is not good because the surface will be overwetted and will lead to wastage of water and as shown in Figure 27, the total volume of water used was influenced by the change in hydraulic conductivity, the higher the Ks, the higher the amount of water needed but what is interesting to observe is the effect of the irrigation duration, longer duration saturates the profile more and the effect of evaporation is smaller and thus smaller number of irrigation events leads to water saving efficiency.

<u>Comparison between 5 nodes at different depth</u>

Comparison was also made between 5 nodes at different depth (5,7,10,11,12) which were close to the surface just to monitor the root water uptake and observation 5 and 10 showed the required level of moisture content while others showed lower soil moisture content as show in Figure 7, but the moisture content level still reached the required level for crop yield, although the moisture content level was lower than what was observed in observation node 5 and 10.

The soil moisture content distribution and its change as to do with the soil depth during irrigation phase and redistribution phase. The irrigation moisture content level was observed to be high at the depth of 0cm and 16cm. The soil moisture content value of each soil profile start changing when the irrigation started. The soil moisture content value at the depth of 0 and 16cm remain unchanged over the course of the irrigation.

The Effect of changes in pressure head value with different hydraulic conductivity was also observed, different hydraulic conductivity value was used which were 112 cm/day, 272 cm/day and 657 cm/day, one hour and two hours irrigation duration was evaluated just to observe the significant effect of different hydraulic conductivity value on both irrigation schedules and this was carried out on both triggered and planned irrigation schemes as it was shown in Figure 22, and Figure 23, it was observed that as the hydraulic conductivity increases the pressure head decrease and the porosity and permeability of the material also decrease due to the drop in pressure head, the also means that more water will also be needed for irrigation so as to have the required level of soil moisture content , the highest recorded value for pressure head in an hour irrigation duration was -118 cm as it was shown in Figure 22 and this value was for the lowest hydraulic conductivity value, the lowest value for pressure head and soil moisture content was seen with the highest conductivity value as shown in Figure 22 and Figure 23. Same also was observed during 2 hours irrigation duration, the pressure head and the moisture content decrease as the hydraulic conductivity was increased as shown in Figure 24 and Figure 25 Frequent irrigation event was also observed when the hydraulic conductivity was increased and this can lead to over wetting of the surface and since we are working towards the efficient use of water , A high hydraulic conductivity would not be helpful in achieving the goal of minimizing the usage of water, the changes also affected the moisture content but it was minimal when compared with the drop observed in the pressure head, the highest value recorded for moisture content was 0.35 as it was shown in Figure 30.

7 Conclusions

The influence of the soil texture, soil hydraulic properties, irrigation duration and frequency on the volume of applied water was studied numerically with Hydrus 2D/3D model. The pressure head, moisture content and the effect of different hydraulic conductivity on the volume of applied water on soil was investigated and also the effect of irrigation duration and frequency on the volume of applied water. The size of the wetting pattern increased as more volume of water was applied and high hydraulic conductivity also increase the irrigation events which lead to more water being used and over-wetting of the surface. Both of the irrigation schemes that were simulated offer an improvement in water saving strategy. The different irrigation durations that were evaluated also show that the longer the duration, the more water will be added to the system, but water movement within the profile depend on saturated hydraulic conductivity of the soil. Half an hour of irrigation also proves sufficient for green house and it reduces the amount of water being used but the pressure head and moisture content value was not as high as what was recorded in other planned irrigation durations. Regular every day irrigation of 2 hours was found to be the best suitable considered greenhouse installations.
Hydrus 2D/3D model was found to be a good tool for optimizing irrigation plan, however it should be noted that many parameters are involved in simulating an irrigation system and thus require a special knowledge to which most people especially the local farmers do not have.

Based on the above discussed findings, the tested hypothesis “Irrigation water behaviour in the greenhouse can be effectively described by numerical simulation which can lead to optimization and water saving of ongoing or planned irrigation systems” can be accepted.

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