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Design and Manufacturing of a New Rail-Type Irrigation System for Modern Seedling Greenhouses

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Solidworks

Abstract: In this study, a new rail-type automatic irrigation system was designed and manufactured to provide sustainable and efficient irrigation, which is one of the most important requirements of modern seedling greenhouses. Irrigation and pesticides spraying can be done at the same time with the new rail-type irrigation system (RTIS), and water/pesticides spraying pressure and irrigation height can be adjusted based on seedling type. The RTIS were achieved approximately 60% water savings compared to the old irrigation system. The RTIS is expected to increase seedling yield while lowering greenhouse maintenance costs significantly.

Modern Fide Seraları İçin Yeni bir Raylı Sulama Sistemi Tasarımı ve İmalatı

Anahtar Kelimeler
Modern sera,
Sulama sistemi,
Yeni ray tipi tasarım,
AutoCad ve Lumnion
Solidworks

Öz: Bu çalışmada, modern fide seralarının en önemli gereksinimlerinden biri olan sürdürülebilir ve verimli sulamanın sağlanması için yeni bir raylı tip otomatik sulama sistemi tasarlanmış ve üretilmiştir. Yeni raylı sulama sistemi ile sulama ve ilaçlama aynı anda yapılabilmekte ve fide tipine göre su/pestisit püskürtme basıncı ve sulama yüksekliği ayarlanabilmektedir. Yeni tip raylı sulama sistemi ile eski sulama sistemine göre yaklaşık %60 su tasarrufu sağlanmıştır. Yeni raylı sulama sisteminin, sera bakım maliyetlerini önemli ölçüde düşürürken fide verimini artırması beklenmektedir.

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1. Introduction

Greenhouses are structures that allow the production of seeds, saplings, and seedlings under the most appropriate environmental conditions, regardless of the environmental conditions that change depending on the climate. In greenhouses, the necessary conditions such as relative humidity, temperature, light, air, and carbon dioxide circulation, can be controlled [1-4]. Greenhouse farming began in Turkey around 50-55 years ago, in the provinces of Antalya and İçel [5]. Turkey is one of the top four greenhouse cultivation countries in the world, while Europe ranks second (after Spain) [6]. Turkey has a total greenhouse area of 789603.5 decares as of 2019. Plastic greenhouses account for 47.96% (378670.5 daa), low plastic tunnels account for 28.42% (224400.4 daa), high plastic tunnels account for 14.06% (111037.9 daa), and glass greenhouses account for 9.56% (75494.7 daa) of existing greenhouse areas (789603.5 daa) [7].

Modern (closed) greenhouse (automated agriculture) practices that offer sustainable and efficient production for four seasons were accelerated by agricultural technology that was developed in parallel with technological developments in the fields of electronics and mechatronics [8-11]. In modern greenhouses where sensors, wired-wireless communication technologies, and digital electronics are used effectively, optimum operating conditions can be achieved in the greenhouse. In modern greenhouse enterprises, the optimum conditions determined for plant growth defined in the automation system are compared with the instantaneous data received via sensors, and automatic interventions could be made to optimize the greenhouse conditions. In other words, irrigation if irrigation is required, heating if heating is required, humidification if humidification is required, etc. can be made out automatically in the greenhouse. Thus, it is ensured that the products are grown in the modern greenhouse grow and develop under optimum conditions. Thus, plant growth rate and product quality can be improved [12]. The constantly changing factors in the greenhouse in the horizontal and vertical directions could be measured in real-time in modern greenhouses, saving energy, water, and fertilizer. Furthermore, in recent years, efforts were accelerated to meet the ever-increasing population's food needs sustainably, to increase product efficiency/quality, and, most importantly, to ensure the efficient use of limited natural resources such as water. The significance of developing and implementing automation-based effective irrigation systems in agricultural production was recognized in this context. Therefore, the studies in this context was accelerated. [13-17].

Çakır and Calis (2007)[18], who was studying the development of a remote-controlled automatic irrigation system, used PIC 16F877 microcontroller in their studies. The system they designed allows for automatic or manual irrigation over the PSTN telephone line. The soil moisture was used as trigger data. It was stated that with the developed remote-controlled irrigation system, water and labor savings are achieved. Fidan and Karasekreter (2011)[19] designed an SMS-controlled irrigation automation control unit (SKB). The system could be controlled by an SMS message by the user. It was reported that electricity and water savings are achieved with the system, which can send an information message to the user by adjusting the irrigation time in case of natural precipitation. Sakaguchi et al. (2011)[20] measured the water level of the plants with the help of electrodes placed on the leaves of the plants and transferred the data to the computer. In their study, it was revealed that there was no change in the amount of liquid of the plants that went into sleep mode under closed-heat stable environmental conditions. In a study using activators and special sensors, a WNS-based irrigation system was designed (Angelopoulos et al. 2011)[21]. Another research group made a new design they call iRain. They designed an automation system that transfers the moisture value of the soil to the network environment with the help of XBee. With this design, irrigation for three days was prevented automatically in the case of natural precipitation (Caetano et al. 2014)[22]. Abbas and his working group (2014)[23] were designed a smart irrigation system for gardens using 6 sensor nodes points, 1 base station, USB programming card, data acquisition card, a radio module, and wireless sensor network. They reported that with this system, excessive irrigation can be prevented in rainy seasons. This design, which was a smart automatic irrigation system application, can evaluate the data it receives from the moisture sensors placed in the soil with a Java application, and according to the data, can be directed through the sendroid valves of the irrigation process. In another study, the researchers who took temperature and humidity measurements from every point of the garden and evaluated the measurement data with a fuzzy logic method designed a Zigbee-based garden irrigation system (Al-Ali et al. 2015)[24]. Agrawal and Singhal (2015)[25] developed a low-cost drip irrigation system using Arduino and Rasberry Pi. The measurement data was evaluated using the irrigation automation system, if necessary, the irrigation process was activated with the solenoid valves. As a result, it was reported that the developed irrigation system in the study provides energy and water savings.

Modern seedling greenhouses are the greenhouse sector that requires the most careful maintenance among other production types. Even though the investment costs are quite high than the others, the investment costs can be quickly recovered with the correct/appropriate seedling growing techniques. For this reason, it is well known, the care shown in the maintenance of modern seedling greenhouses and growing seedlings is important. The most important factor influencing seedling growth and yield is the effective supply of water to the seedlings. For this reason, a new rail-type automatic irrigation system (RTIS) was designed and manufactured in this study to provide sustainable and efficient irrigation, which is one of the most important requirements of modern seedling greenhouses. The goal of the RTIS was to be able to perform irrigation and pesticides spraying at the same time, as well as to be able to adjust the water pressure and irrigation height based on the seedling type. Furthermore, the RITS was intended to reduce operating, labor, and maintenance costs of the greenhouse. The new design was expected to increase seedling yield while significantly lowering greenhouse maintenance costs.

2. Material and Method

The new rail-type irrigation system (RTIS) was designed to ensure the uniform distribution of irrigation water/fertilizer and pesticides to seedlings in seedling production greenhouses, thereby supporting seedling rapid growth. The working principle of the new type of rail irrigation system was based on the fact that the installation sets (where the irrigation nozzles were located) on a rail line connected to the greenhouse cages and the hose car carrying the water to the nozzles are moved back and forth along the tunnel. This movement was driven by the reducer and steel ropes in the greenhouse area.

2.1. Material selection and technical parameters

Seedling greenhouse cultivation is a type of agricultural production that necessitates a high level of precision. The irrigation system as a whole should proceed at the same level during irrigation, and equal amounts of water should be distributed to each point of the seedling benches. For this reason, the rail line used was one of the most important pieces of equipment in the movement of the rail irrigation system. It was made of galvanized material to ensure the feasibility of the irrigation system and to minimize the vibration that changes depending on the irrigation/ pesticides spraying pressure (2-4 bar).

The idea of producing the rail line with 3 different galvanized profiles (pipe profile, box profile, or D profile) was investigated. It was decided to make it from galvanized box profile for simultaneous minimization of both rail movement vibration and irrigation system installation cost. In the selection of the box profile, strength, ease of supply, and the amount of load on the greenhouse were also taken into account.

The number of double-row nozzles mounted on the installation set designed from galvanized box profiles and the distance between the nozzles can be adjusted according to the greenhouse tunnel width and the length of the seedling benches. In addition, the distance between the nozzles can be adjusted depending on the plant type, the amount of pesticide to be applied, and the irrigation flow. The chosen nozzles are resistant to high pressure (2-4 bar). A double row nozzle system was designed so that pesticide spraying and irrigation can be done at the same time. In this way, time, energy, and labor savings were achieved. The water going to the nozzles was transmitted by plastic-based pipes connected to the hose trolley.

Table 1. Technical design parameters of RTIS

Features	Value ranges
The maximum and minimum speed of the new irrigation system on the rail line	2-10 m/min
Water pressure range (max-min) in the new irrigation system	1-3 bars
Distance between nozzles in the new irrigation system	20 cm
Spraying pressure range (max-min	2-4 bars
How to decide the irrigation time	Data from humidity and temperature sensors are being evaluated
Sensors used in automation based irrigation system	Soil moisture sensor, Temperature sensor
The device on which the controller interface of the automation is installed	Computer
Variable parameters in the automation system	temperature, humidity
Max-min operating ranges of variable parameters	T= 16-20 °C Rh= 60-80%
Irrigation height range of the new type irrigation system according to the seedling type	0.2-0.5m
If the "0" point of the seedling bench is accepted, the max.-min operating height range	15cm-1m
Number of pumps in the new rail type irrigation system	2 pumps
How many valves and valve type in the new irrigation system	3 manual valves per turn
Track length of the new irrigation system	100 meters per acre
The length of the sub-set to which the nozzles are attached in the new irrigation system	10 meters
Number of nozzles installed in the lower plumbing kit	42 pieces
Construction material of nozzles	polyethylene
Parts not produced from galvanized material in the irrigation system	All of them
Type of engine used in the irrigation system, its feature	30-40 m^3/h 40 ss-cast body

The irrigation system was controlled by a frequency inverter motor-reducer. The purpose of choosing this control system was to enable in cases where sensitive irrigation and fertilization were required, the rail connected to the engine to move along the tunnel at the speed determined by the grower, with the frequency change on the engine, and for allowing made for irrigation/fertilization by the needs.

The height of the irrigation system plumbing set was designed adjusted according to the seedling type/size. The irrigation/ pesticides spraying was able to do at a height of a minimum of 35 cm from the seedling stand. In this way, irrigation/pesticide spraying efficiency was increased and damage to the seedling was prevented. Besides, thanks to the adjustable height of the irrigation system, fogging/humidification could be done under required conditions.

3. Result And Discussion

3.1. Design of New Rail Type Irrigation System

The AutoCAD drawing of the new type of rail irrigation system was presented in Figure 1, and the photographs of the Lumion simulation application are presented in Figure 2. Also, the Lumion application video was given in the supplementary document. Solid-works design of all parts of the RITS were made and presented systematically in Figure (3-7). Detailed design of the rail system and butt gear reducer were presented in Figure 3, installation undercarriage in Figure 4, the irrigation system installation hanger set in Figure 5, installation top set in Figure 6, and the irrigation system hose trolley in Figure 7.

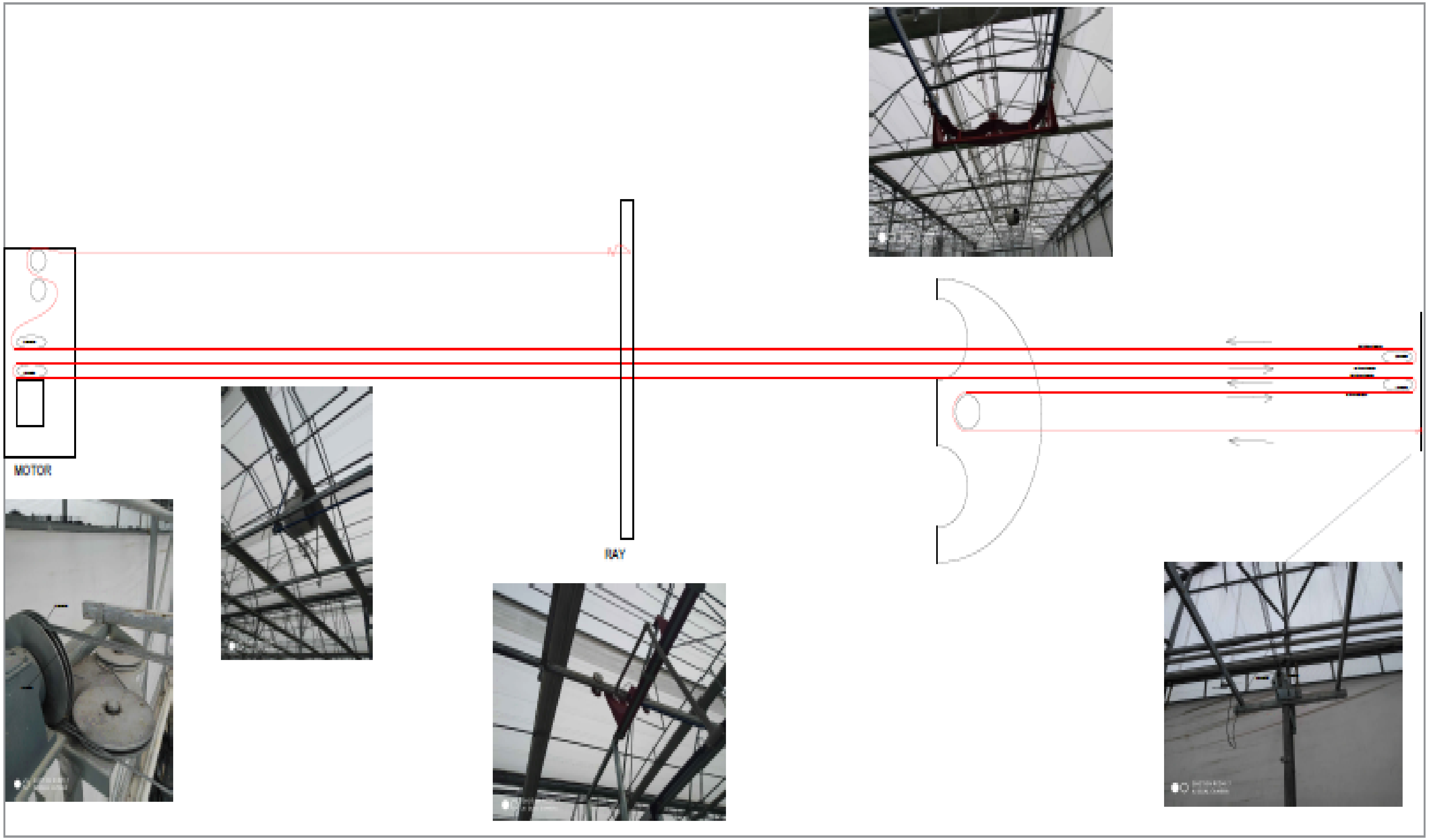

Figure 1. AutoCAD drawing of the new rail type irrigation system

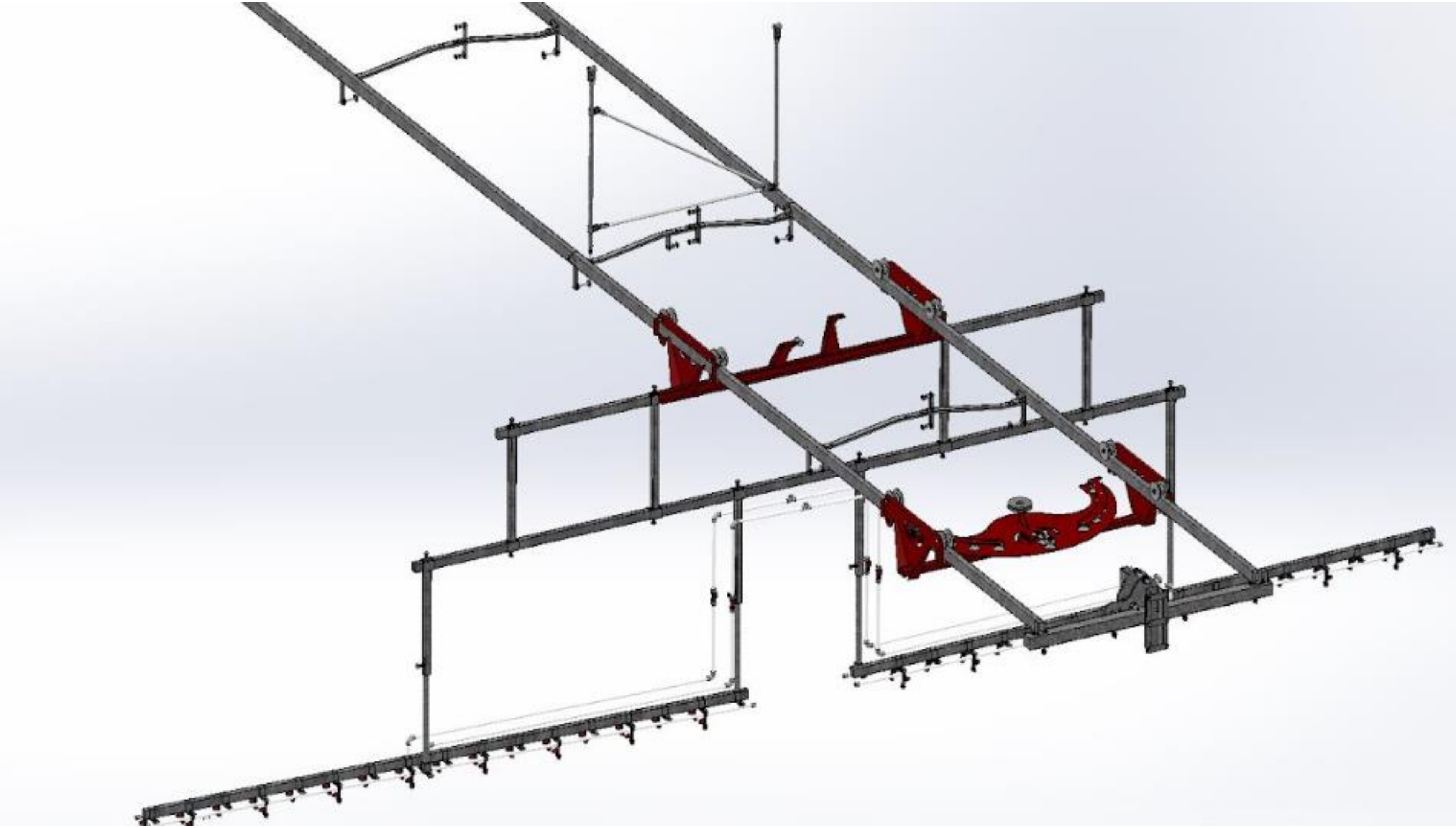

Figure 2. Lumion program images of the RTIS

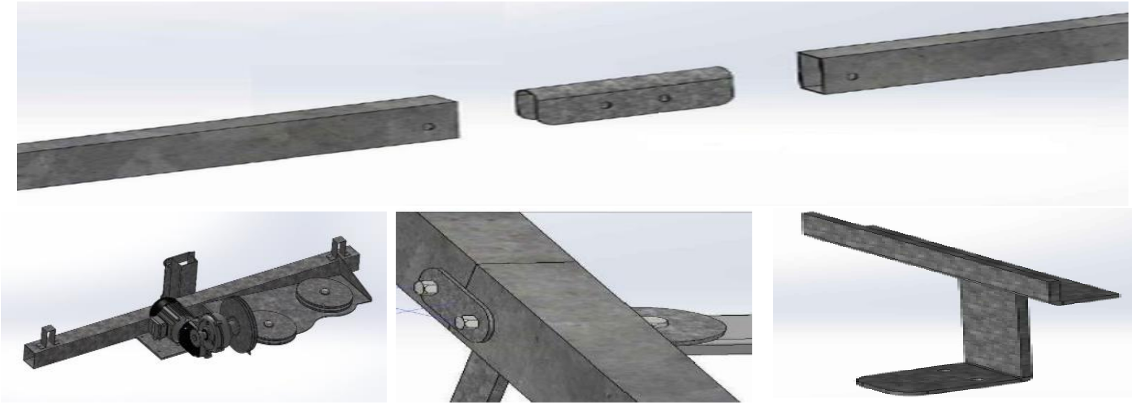

Figure 3. Solidworks drawing of the rail system and butt gear reducer

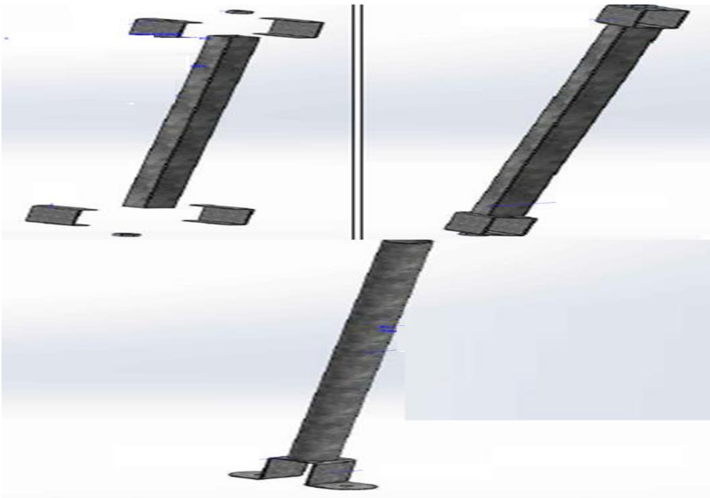

Figure 4. Solidworks design of irrigation system installation undercarriage

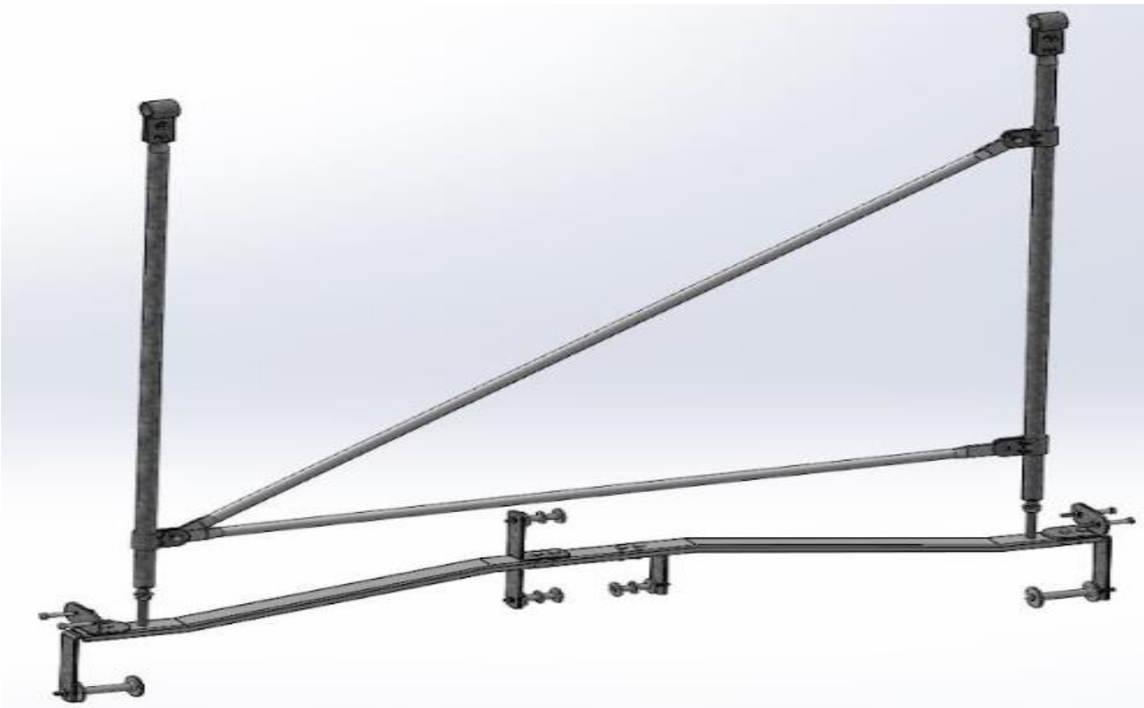

Figure 5. Solidworks design of irrigation system installation hanger set

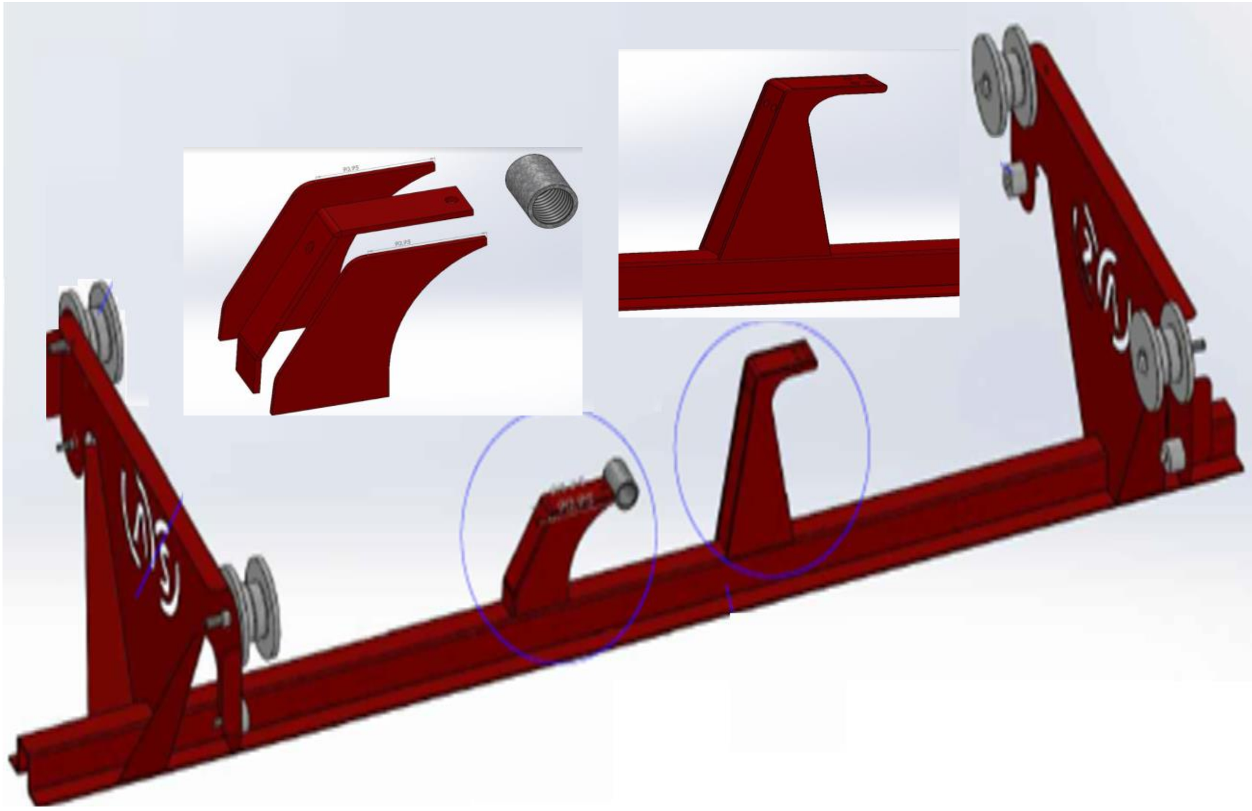

Figure 6. Solidworks design of irrigation system installation top set

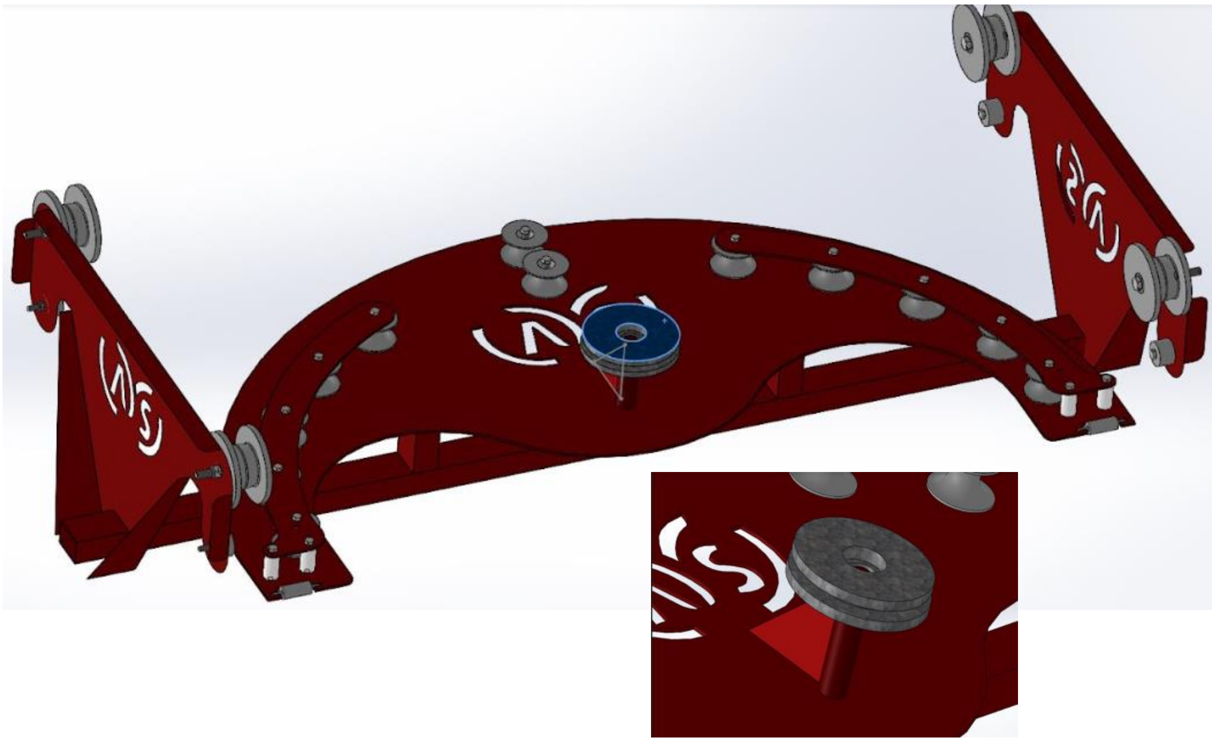

Figure 7. Solidworks design of irrigation system hose trolley

3.2. Assembly Plan and Installation of the New Rail Type Irrigation System

The installation of the RTIS was done in two steps. (a). the installation steps were schematized, and the installation was planned with CAD program (b). Installation of the RTIS was carried out in the application greenhouse. Figure 8 depicts schematic design of the new irrigation system's assembly stages. The assembly process's technical details were summarized in six main steps (Figure 8 a-f).

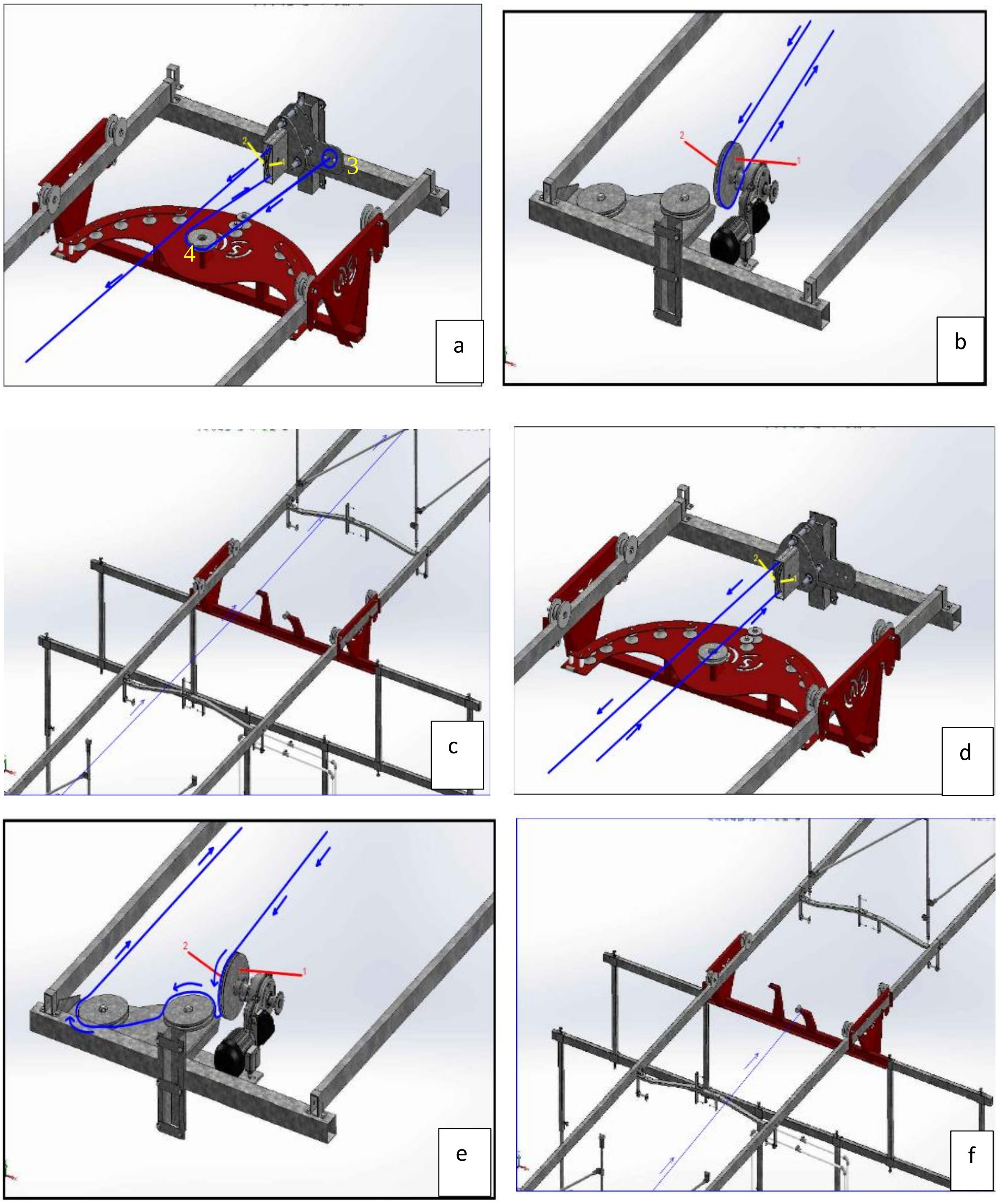

Figure 8. The installation procedure of the RTIS

The RTIS irrigation system, the assembly of which was planned with CAD program, was installed in the Mersin application seedling-greenhouse within the AYTEKIN Group. The field photos of the installation stages was presented in Figure 9. In addition, the video of the RTIS into the application seedling-greenhouse was given in the supplementary document.

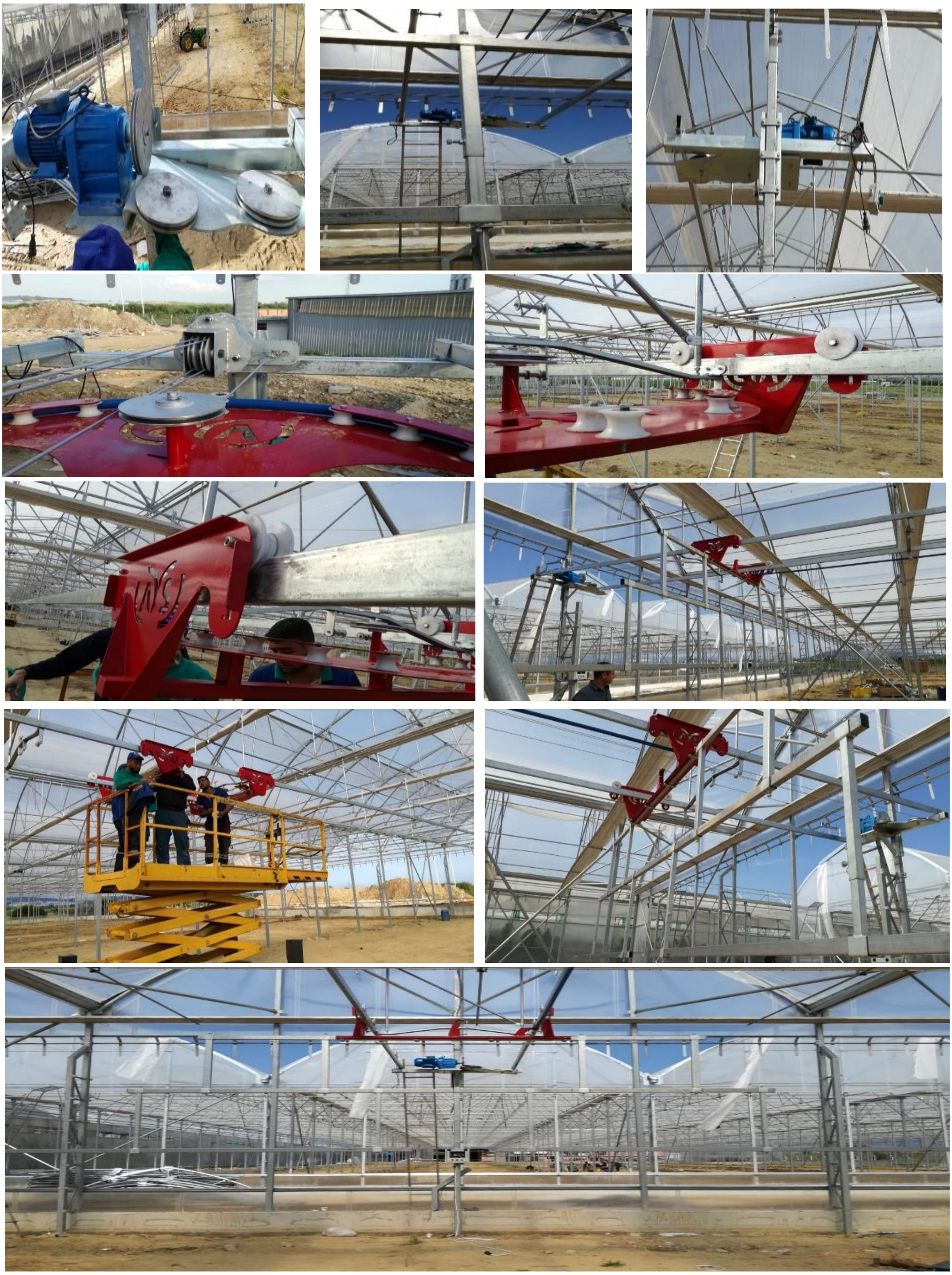

Figure 9. Installation of the RTIS in the application greenhouse

4. Conclusıon

In the tradational type irrigation system (TIS) (Figure 10), irrigation was carried out only by the movement of the water hoses on the rails, without the use of ropes. The required hose length was three times the length of the greenhouse tunnel. The RTIS's hose length was only half the length of the greenhouse's tunnel (Figure 11 and supplementary information video 1-2). The datailed compared features are presented in Table 2.

As a result,

- The RTIS has reduced the cost of the hose, which must be replaced at regular intervals.
- In the tradational type irrigation system, the hose mess of the installation set had been creating a crowded environment in the greenhouse. The RTIS resulted in an increase in useful free space in the greenhouse.
- Due to the pressure created while pesticide spraying in the tradational type irrigation system, there had been a significant level of vibration during the movement of the installation set. For this reason, it was known that optimum pesticides spraying could not be done. Since vibrations can be minimized with the newly designed RTIS, effective pesticides spraying can be done.
- In the tradational type irrigation system, irrigation and pesticides spraying could not be done at the same time, in the new design, it can be done in two processes at the same time.
- In the tradational type irrigation system, there was no fogging/humidification feature. In the new design, the humidity content of the greenhouse can be regulated if necessary.
- In the tradational type irrigation system, water pressure/flow rate and irrigation height were fixed values. With the new type of rail irrigation system, irrigation parameters (irrigation/ pesticides spraying pressure, flow rate, and irrigation height) can be adjusted according to the seedling type and size using automation.
- Since the RTIS was operated on an automation basis, labor and greenhouse maintenance costs were decreased compared to the old irrigation system.
- Since the RTIS system enables the water to be distributed equally and efficiently to the entire greenhouse area, approximately 60% water savings were achieved compared to the old irrigation system.
- It was observed that the new irrigation system will lead to an increase in seedling quality and productivity.
- Considering the water and food bottleneck scenarios anticipated at the international level in the coming years, the advantage of the RTIS will be more clearly observed.

Figure 10. The tradational type irrigation system

Figure 11. The new rail-type irrigation system

Table 2. The datailed compared features

Compared feature	Tradational type irrigation system	New Raily type irrigation system
Amount of water consumed (per plant)	4 L/day	1,2 L/day
Water consumption (per m^2)	16 L/day	4,8 L/day
Water saving with new system (per m^2)	12.2 L/gün	
Hose length used per unit tunnel length (m/m)	1	0.5
Annual hose cost consumption (per m/m)	1 TL	0,5 TL
Number of workers per square meter (person/m2)	5	2
Annual labor costs (TL)	180000	72000
Annual labor savings with new system (TL)	108000	
The annual energy savings with new system (%)	50%	

ASSOCIATED CONTENT

Supplementary Information
Video 1-Click to watch the Lumion simulation of the new rail-type irrigation system.
Video 2-Click to watch the video of the new type of rail irrigation system.

Notes
The authors declare no competing financial interest.

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