Dynamic remote monitoring system for plant root growth and water consumption

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Abstract: In order to improve the level of multi-functional and automatic observation of crop root system growth, a soil column monitoring system was designed to facilitate in situ dynamic monitoring of root growth and water consumption. The system consists of 20 plastic tubular backfill soil columns, each with an inner diameter of 32 cm and height of 300 cm. The crops were planted at the top of the soil column with the surrounding leveled with the ground surface and the site is in a greenhouse. The underground portion of the soil column contains small round windows on the tube through which root growth can be monitored, roots can be pruned and soil samples can be obtained. A multiport serial weighing system was designed and placed at the base of the soil column. Twenty electronic balances were connected to the personal computer through three CP-168U multiport serial cards and RS-232 serial cables. The host software was developed on the browser/server (Browser/Server), and data collection and remote data transmission and data sharing were implemented using the Java programming language and applying Internet data transmission technology and Web application technology. System tests showed a relatively good stability and real-time capability, and with accuracy up to 50 g and the evapotranspiration of each soil column was 0.25-0.65 kg per day. The root-system observation system developed in this study surpassed the traditional method of root-digging sampling and thus provided an alternative that could be used to automatically monitor the root system growth status.

Keywords: root system monitoring, soil column, real time weighing system, root system growth
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1 Introduction

Roots are organs that anchor plants, and absorb and transport water and nutrients from the soil. They directly exploit the soil and make important contributions to plant productivity. In Germany, Halls (1724) began to study roots in the early 18th century. This research topic progressed very slowly over the next 100 years. In the 1830s, root system research gained increasing attention. However, because the root system grows beneath the ground, root sampling processes are destructive and labor intensive, which has hindered the in-depth development of root system research. Recently, novel root observation methods (beyond the previous root-digging sampling) have been developed. The plastic tube soil column method has frequently been used in crop root research, especially for dry-land crops. This

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method has various advantages, including simple sampling, reduced work, easy operation, maintained root integrity and consistency with farmland growth[1].

To study the balance between water and matter in the farmland-root system, the Chinese Academy of Science constructed a large weighing soil column system consisting of a 5-m long circular steel tube with a surface area of 3.14 m^2 at Yucheng city in Shandong province in 1985[2]. Yang et al.[3] designed a three-meter long square-shaped soil column with a surface area of 3 m^2 (1.5 m × 2 m) in 1997 and γ-ray transmission was introduced into the large weighing soil column system. The soil moisture content was determined by measuring γ ray attenuation after they penetrated a soil body of a certain quality, volume and thickness. In 1998, Yang et al.[4] studied the water loss that occurred through evapotranspiration in the soil-plant-root system and groundwater exchange for winter wheat and corn under rotating cropping in northern China. In 1999, Sun et al.[5] designed an industrial PC-based soil column control system based on the tests performed by Yang et al.[4] to indirectly measure seepage, evapotranspiration and soil moisture distribution with a high-accuracy displacement sensor. In 2002, Barani et al.[6] constructed a large weighing backfill soil column system with a circular steel tube (175 cm in height and 300 cm in diameter) to study the total field evapotranspiration in the soil-root system. In 2007, Takamatsu et al.[7] performed a laboratory study on solute soil migration using a titanium-alloy and stainless steel tube (150 cm in height and 80 cm in diameter) in conjunction with a rotating device to create an undisturbed soil column. In 2011, Garré[8] studied the three-dimensional electrical resistivity tomography to monitor root zone water dynamics using one column. In 2013, Yanagawa[9] conducted an experiment to study the tolerance of canola to drought and salinity stresses in terms of root water uptake model parameters using nine columns with two plants in each.

In summary, the soil column system plays an important role in research on the plant root growth and water consumption. The function and level of automation for the soil column monitoring system is essential for root observation and data obtaining. The objectives of the study are to design and develop a soil column performing multiple functions like root observation through transparent column wall, easy soil sampling at different soil deep length, soil column automatic weighting and remote observation. To achieve these functions, the soil column system has the aboveground part and the underground part. The aboveground portion consists of an automatic rain shelter and a large crane, and the underground portion consists of plastic tubular soil columns and a web-based multiport serial automatic soil column weighing system. This system facilitated in-situ dynamic observation of the plant root system growth and dynamic monitoring of the water consumption process.

2 System design

2.1 Hardware design

The system designed in the study consists of aboveground and underground portions as shown in Figure 1.

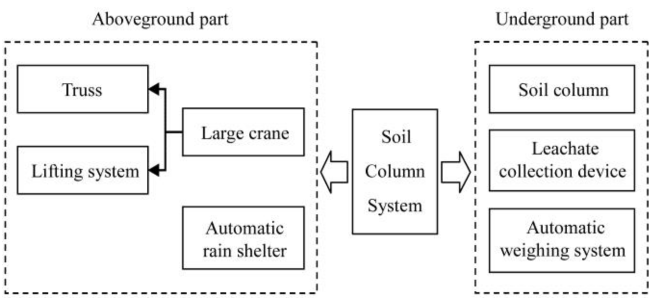


Figure 1 Scheme of the soil column system framework

The aboveground portion consists of a large crane and an automatic rain shelter. The large crane includes the truss and the lifting system, and it is used to replace the soil in the soil column. The automatic rain shelter is located above the truss and is used to control the amount of rainfall. The underground portion includes the soil columns, leachate collection device and web-based multiport serial automatic soil-column weighing system. The leachate collection device collects the filtered liquid from the soil column. The automatic weighing system dynamically monitors the total water loss that occurs through evapotranspiration in real time for 24-hour periods using a host computer and subordinate equipment.

2.1.1 Soil column design

Each of the 20 soil columns has an inner diameter of 32 cm, height of 300 cm and wall thickness of 2 cm. The tube is made of polyvinyl chloride (PVC). The top surface of the soil column is located at ground level. The top of the soil column is open and exposed at ground level to facilitate crop planting. Twelve small, round windows (each with a diameter of 8 cm) in the tube wall facilitate root sampling, physiological and biochemical measurements and analyses and root pruning at different soil layers. These windows also facilitate the installation of sensors that automatically monitors the root growth and soil parameters.

The system design utilized a backfill soil column system to maintain the original status of the soil, which is conducive to studying soil moisture migration in the soil column, water uptake by crops and evapotranspiration. The soil was backfilled into the round-shaped or square-shaped soil column container or device, and a percolation layer was laid at the bottom. Leachate can be collected through outlet in the bottom to test the ingredient content in soil[10]. The percolation layer of the system consists of a 10-cm-thick gravel layer at the bottom and a 25-cm-thick sand layer in the middle. The structure of soil column is shown in Figure 2.

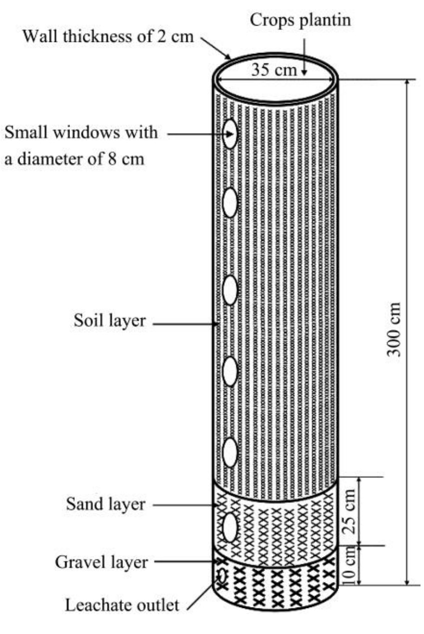


Figure 2 Structure of the soil column

2.1.2 Automatic soil column weighing system design

The multiport serial soil column weighing system collects, transmits and queries the soil column weighing data. The system consists of subordinate devices, a multiport serial card and a host computer (Figure 3). Twenty electronic balances are connected to the personal computer through three CP-168U multiport serial cards and RS-232 serial cables[11]; these balances monitor the weight change of the soil column in real time and transmit the weighing data to the database on the web server in real time for storage and sharing[12].

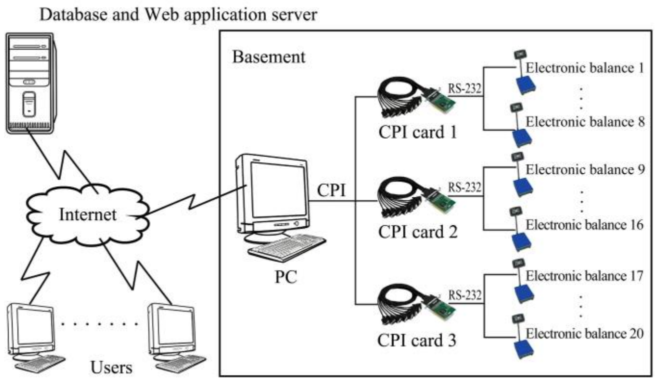


Figure 3 Schematic of the multiport soil column automatic weighing system

2.1.2.1 Overall design of the subordinate devices

Due to the need to measure crop transpiration, the electronic balances used in our study are accurate to 50 g and feature LED displays and RS-232 communication ports that facilitate displaying and reading the weighing data. The hardware modules in the electronic balance include a pressure sensor, an analog/digital (A/D) conversion module, a microcontroller, a display module, a key module and an interface module (Figure 4).

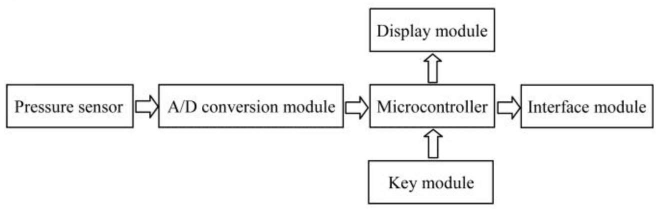


Figure 4 Schematic of the modules of the electronic balance

A CS5530 analog-to-digital converter (Kemeida, Shenzheng City, Shandong Province, China) was used in the A/D conversion module. It has a low noise level and flexible word output rate. The converter uses charge-balancing technology, which can perform at up to 24 bits and is ideal for a weighing balance. In the electronic balance, the converter converts the analog output signal from the pressure sensor into a digital signal that can be recognized by the microcontroller. An LED display was used in the display module. In the testing stage of the multiport weighing system, the weighing data from the electronic balance were manually recorded with the LED display and were subsequently compared with the data collected by the collecting system to verify and test the reliability of the data collection of the system. A RS-232 interface module was used to establish serial communication between the host computer and the balances.

2.1.2.2 Multiport serial card selection

Serial cards that are typically supplied with a personal computer cannot support the 20 serial ports necessary for this experiment; thus, the cards must be upgraded. Commercially available serial port expansion devices include devices such as multiport serial cards, USB-serial hubs and serial servers. Multiport serial cards are the most convenient and simplest solution to increase the number of peripheral devices supported by a computer. A CP-168U multiport serial card (Moxa Inc., Taipei, Taiwan, China) was used in the study to connect the subordinate devices to the host computer[13]. This card is a smart, PCI (Peripheral Component Interconnection) standard-based, microcomputer-oriented, high-performance multiport serial communication card. The technical parameters of the card are shown in Table 1.

Table 1 Technical parameters of the CP-168U multiport serial card

Specification	Parameters
Power requirement	180 mA (+5 V)
Working environment	Temperature 0-55 degrees centigrade, relative humidity 5%-95%
Bus interface	32-bit general-purpose PCI
Serial port	RS-232
Number of ports	8, requires only 1 IRQ(Interrupt ReQuest)
Baud	50 bps-921.6 Kbps
Operating system	Windows Vista/2003/XP/2000/98/ME, Linux, UNIX
Programming language	Visual Basic, Visual C++, Java, Borland Delphi

2.2 Software design

The multiport automatic soil column weighing system software in the Windows XP-based host computer was developed on the browser/server (BS) using the Java programming language. The software system includes the communication program between the host computer and the subordinate devices, the data collection software and the browser/server software.

2.2.1 Communication program between the host computer and the subordinate devices

The communication program is divided into two parts; one controls the host computer, and the other controls the subordinate devices. The subordinate devices are primarily responsible for tasks such as collecting data and uploading data to the host computer, as well as receiving commands from the host computer. The host computer is primarily responsible for collecting data from the subordinate devices and transmitting these data to the server database. A flowchart depicting the data collection on the host computer and the subordinate devices is shown in Figure 5. During system operation, the host computer first turns on the first serial port to initialize the serial port and send a read command to the subordinate device. Upon receiving the read command,

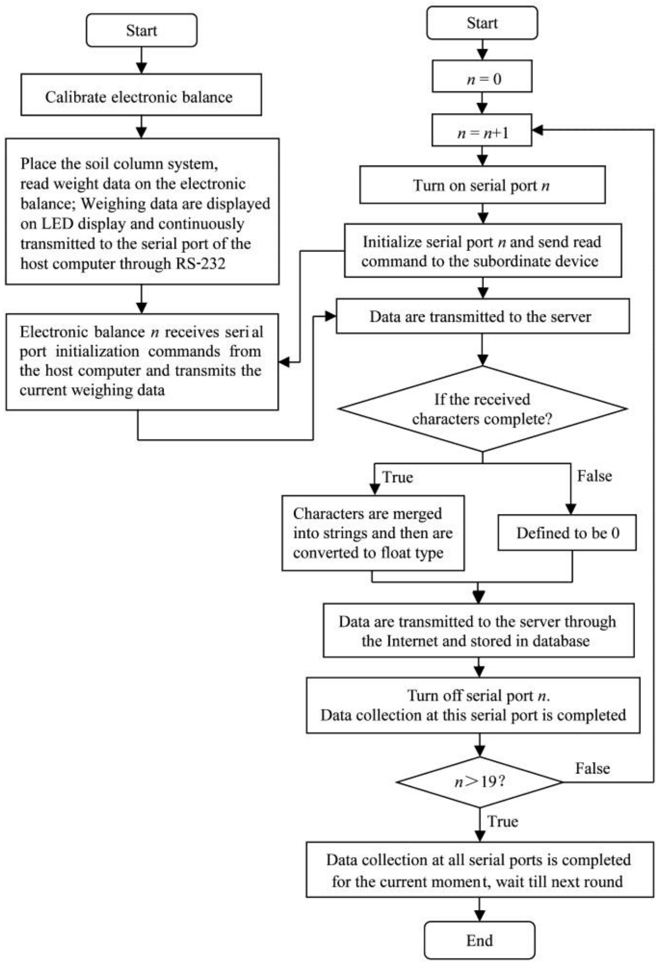


Figure 5 Flow chart of data collection and communication between host computer and subordinate device

the corresponding subordinate device prepares to communicate with the host computer. In the communication, the protocol between the two devices is set to "carriage return (CR)": CR appears before the host computer reads the character sent by the subordinate device. After the characters are recorded one by one, a CR re-appears, suggesting that the host computer has completed the data collection procedure from the subordinator device[14].

Then the host computer converts the received individual characters into string-type and converts the strings to float point before transmitting the float point weighing data to the server database. Finally, the host computer turns off the serial port and collects data from the next serial port. The process is repeated until data are collected from serial port 20, which indicates that the data collection process has been completed. The previously described workflow will be repeated in the next cycle. If the subordinate device fails during system operation, the host computer will self-define the collected weighing data as 0 and upload them to the database.

2.2.2 Data collection software in the host computer

The functions of the data collection software developed in our study primarily include the collection interval, data storage and collection starting command. Because the multiport serial soil column weighing system can monitor crops in different seasons, measured crop evapotranspiration may be very different[15]. Therefore, the "setting collection interval" function was added into the software program so that a time interval between two adjacent rounds of data collection could be set. Because evapotranspiration is consistent during the entire root system growth process, the time interval unit in the software was set to "hour". A appropriate data collection interval can lower the workload of the database and is convenient for system operation.

2.2.3 Server design

A World Wide Web (WWW) server with a fixed IP (Internet Protocol) address remotely collects, stores, processes and analyzes the collected weighing data, and sets the system parameters. The service center provides the capability of data storage and analysis. The center also provides the functions such as dynamic information query and web display[16].

The server database provides data storage and data access in the system. The MySQL database was utilized in the study. The data collection date, time, electronic balance serial number and weighing data are the primary data contents in the database.

The previous monitoring system for the soil column weighing and data collection was built in the basement, which is necessary for operating staff to monitor and obtain the root system data in real time but under poor working conditions. Therefore, a web-based information management and query software system was designed[17]. The user can utilize a web browser, such as Internet Explorer (IE), to browse the query module in the web page. The software system will display the corresponding weighing data from the MySQL database in data tables or line charts on the web pages. This web interface is user-friendly to perform data queries and data downloads. The query software primarily includes four query modules: date query, time query, time interval query and daily's update data query.

3 System testing

The dynamic monitoring system of the plant root system growth and water consumption process was built in the Institute of Water-saving Agriculture in Arid Areas of China at Northwest Agriculture and Forestry University, Yangling, Shaanxi Province, China. The aboveground portion of the root system monitoring system is shown in Figure 6 and the underground portion of the root system monitoring system is shown in Figure 7.

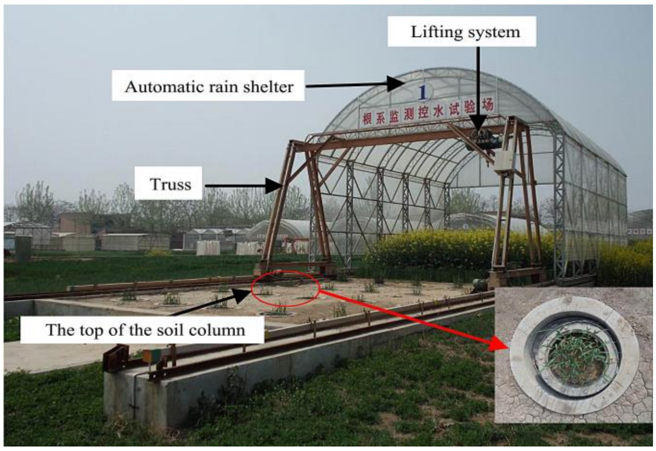


Figure 6 Aboveground portion of the root system monitoring system

Figure 7 Underground portion of the root system monitoring system

The large lifting crane and automatic rain shelter of the aboveground portion of the system located on the surface of the rails, and they were controlled via switches to automatically fill the soil in the soil column and control rainfall. Twenty soil columns system was built in a 60 m^2 basement and was laid out in a four-by-five array in the lab. Because the host computer is connected to the subordinate devices through RS-232, the collection monitoring system was placed in the basement to accommodate the communication distance constraint. The server was placed in the Digital Water Saving Laboratory at Institute of Water-saving Agriculture in Arid Areas of China. In this test, the database and the web application were located on the same server to simplify the system and reduce network traffic.

Corn was the monitored crop in the test. The collection interval was set to one hour during the test, and the system continuously operated for three months. During system operation, when data collection is completed, the host computer remotely transmits and uploads the weighing data to the server database through a fixed IP[18]. Meanwhile, a web-based information query system was also deployed so that lab users can conveniently obtain the testing data.

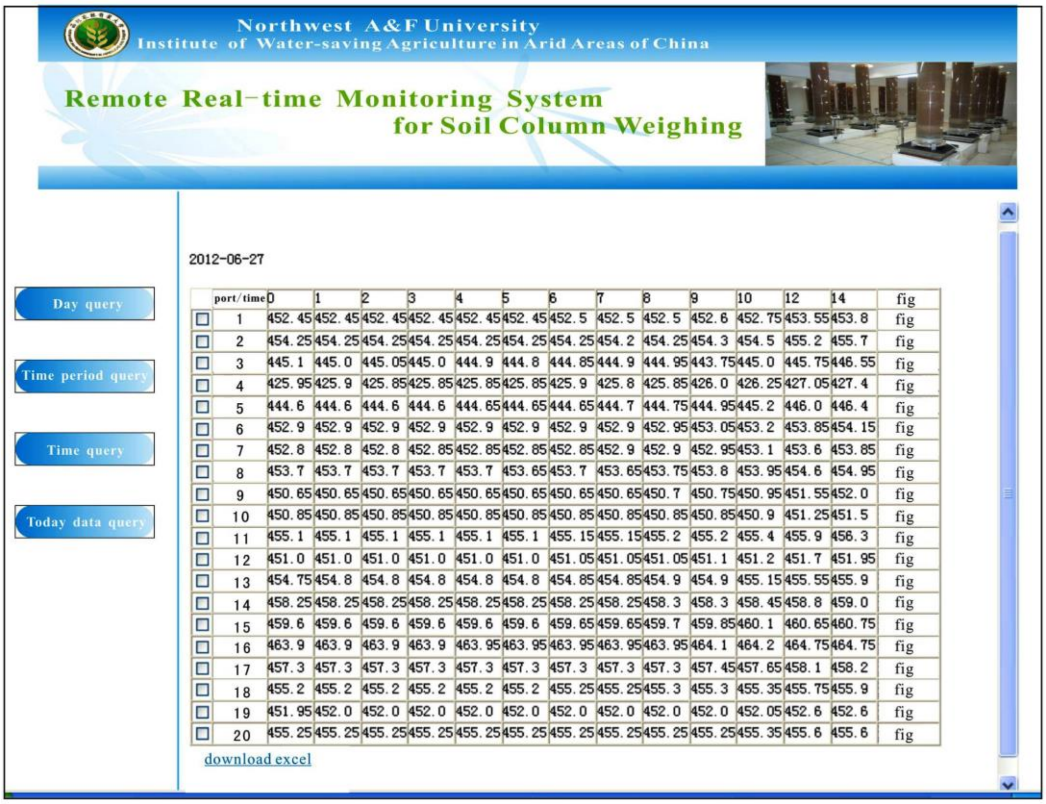
4 Results and discussion

During the testing stage of the system, with the exception of the external internet and power connections, the host computer, subordinate devices and server operated normally, and the users could query weighing data or charts/tables from the current day or past days. The system was able to accurately obtain the 20 sets of weighing data from the 20 electronic balances each hour to record water evapotranspiration in the soil column.

The data in the system database can be updated at any time. For example, if the user enters the “today’s data update” module in the query software program and performs the data update command, the updated data from the weighing system can be displayed and stored in real time. For example, if the user enters the “today’s data update” module at 14:10 on June 27, 2012, the soil column weighing data from 0:00 until 14:00 from the 20 electronic balances would be as shown in Figure 8. The figure shows that the data collected at 14:00 were already entered into the table, suggesting that the system updated the weighing data in real time.

The line chart of the soil column weight collected at 12:00 pm during the period of June 21-27, 2012 is shown in Figure 9. The changes for each of the 20 datasets are clearly shown in the line chart. The consistent changes the line chart showed that the weighing data increased over the previous seven days due to water irrigated into the columns. The weight of No. 4 soil column was less than others. The reason was that no irrigation water added into this column according to irrigation schedule treatments. The weighing results of all these 20 are consistent with the documented corn growth, suggesting that the system worked stably. All of the weighing data could be viewed directly or downloaded into an Excel spreadsheet.

Take the “data query” module on June 21, 2012 for example, which is shown in Figure 10. In this table, blue area on the left refers to the minimum weight of the 20 soil columns, blue area on the right refers to the maximum weight of them, and the area marked with red is the difference of the maximum and minimum weight, which also refers to the biggest evapotranspiration of each soil column per day. Despite the slight difference between crops, we can see from the difference marked with red that the evapotranspiration is in a stable range which is 0.25-0.65 kg and also we can see that the accuracy of the soil column system reaches 50 g.



	port/time	0	1	2	3	4	5	6	7	8	9	10	12	14	fig
☐	1	452.45	452.45	452.45	452.45	452.45	452.45	452.5	452.5	452.5	452.6	452.75	453.55	453.8	fig
☐	2	454.25	454.25	454.25	454.25	454.25	454.25	454.25	454.2	454.25	454.3	454.5	455.2	455.7	fig
☐	3	445.1	445.0	445.05	445.0	444.9	444.8	444.85	444.9	444.95	443.75	445.0	445.75	446.55	fig
☐	4	425.95	425.9	425.85	425.85	425.85	425.85	425.9	425.8	425.85	426.0	426.25	427.05	427.4	fig
☐	5	444.6	444.6	444.6	444.6	444.65	444.65	444.65	444.7	444.75	444.95	445.2	446.0	446.4	fig
☐	6	452.9	452.9	452.9	452.9	452.9	452.9	452.9	452.9	452.95	453.05	453.2	453.85	454.15	fig
☐	7	452.8	452.8	452.8	452.85	452.85	452.85	452.85	452.9	452.9	452.95	453.1	453.6	453.85	fig
☐	8	453.7	453.7	453.7	453.7	453.7	453.65	453.7	453.65	453.75	453.8	453.95	454.6	454.95	fig
☐	9	450.65	450.65	450.65	450.65	450.65	450.65	450.65	450.65	450.7	450.75	450.95	451.55	452.0	fig
☐	10	450.85	450.85	450.85	450.85	450.85	450.85	450.85	450.85	450.85	450.85	450.9	451.25	451.5	fig
☐	11	455.1	455.1	455.1	455.1	455.1	455.1	455.15	455.15	455.2	455.2	455.4	455.9	456.3	fig
☐	12	451.0	451.0	451.0	451.0	451.0	451.0	451.05	451.05	451.05	451.1	451.2	451.7	451.95	fig
☐	13	454.75	454.8	454.8	454.8	454.8	454.8	454.85	454.85	454.9	454.9	455.15	455.55	455.9	fig
☐	14	458.25	458.25	458.25	458.25	458.25	458.25	458.25	458.25	458.3	458.3	458.45	458.8	459.0	fig
☐	15	459.6	459.6	459.6	459.6	459.6	459.6	459.65	459.65	459.7	459.85	460.1	460.65	460.75	fig
☐	16	463.9	463.9	463.9	463.9	463.95	463.95	463.95	463.95	463.95	464.1	464.2	464.75	464.75	fig
☐	17	457.3	457.3	457.3	457.3	457.3	457.3	457.3	457.3	457.3	457.45	457.65	458.1	458.2	fig
☐	18	455.2	455.2	455.2	455.2	455.2	455.2	455.25	455.25	455.3	455.3	455.35	455.75	455.9	fig
☐	19	451.95	452.0	452.0	452.0	452.0	452.0	452.0	452.0	452.0	452.0	452.05	452.6	452.6	fig
☐	20	455.25	455.25	455.25	455.25	455.25	455.25	455.25	455.25	455.25	455.25	455.35	455.6	455.6	fig

Figure 8 Soil column weighing data table

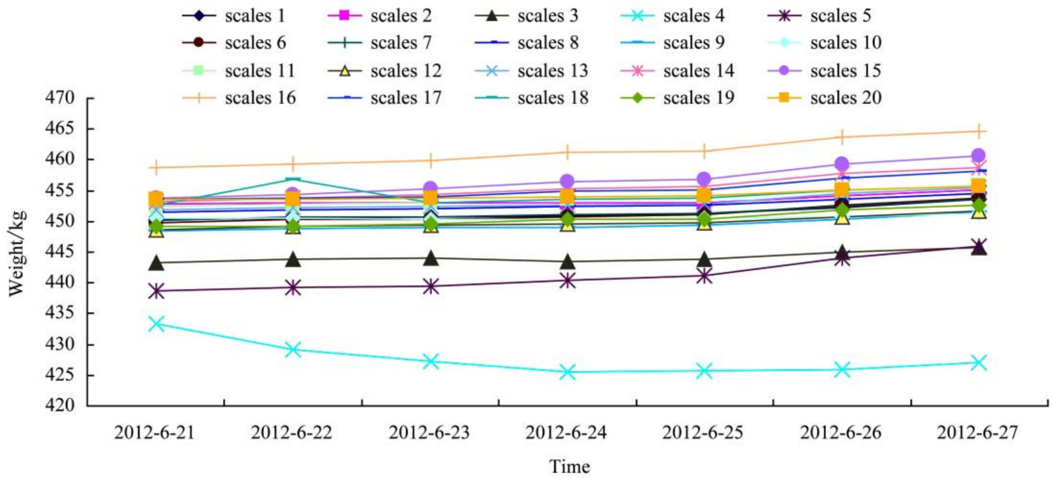
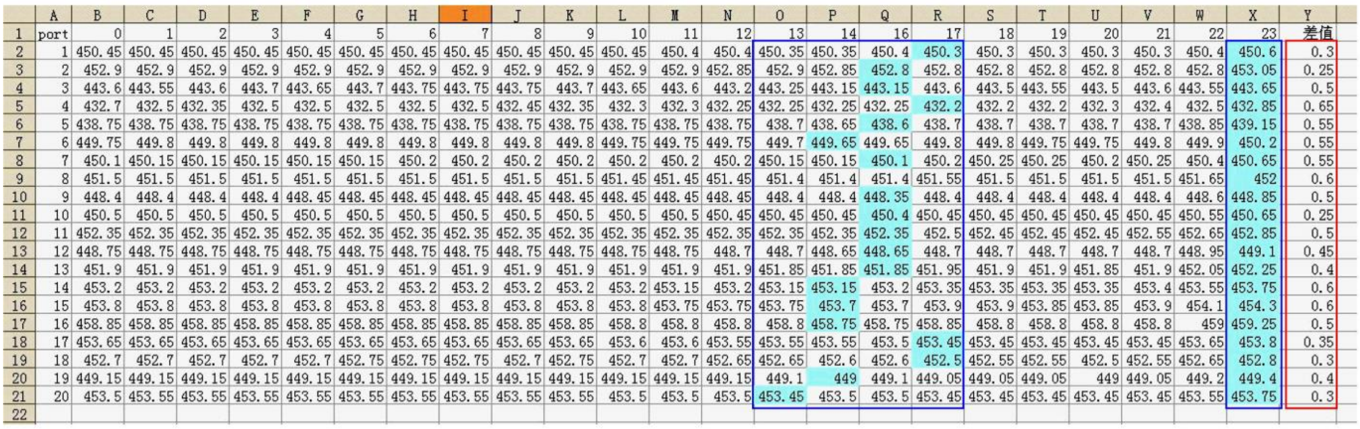


Figure 9 Line chart of the soil column weighing data



	A	B	C	D	E	F	G	H	I	J	K	L	M
1	port	0	1	2	3	4	5	6	7	8	9	10	11
2	1	450.45	450.45	450.45	450.45	450.45	450.45	450.45	450.45	450.45	450.45	450.45	450.4
3	2	452.9	452.9	452.9	452.9	452.9	452.9	452.9	452.9	452.9	452.9	452.9	452.9
4	3	443.6	443.55	443.6	443.7	443.65	443.7	443.75	443.75	443.75	443.7	443.65	443.6
5	4	432.7	432.5	432.35	432.5	432.5	432.5	432.5	432.5	432.45	432.35	432.3	432.3
6	5	438.75	438.75	438.75	438.75	438.75	438.75	438.75	438.75	438.75	438.75	438.75	438.75
7	6	449.75	449.8	449.8	449.8	449.8	449.8	449.8	449.8	449.8	449.8	449.75	449.75
8	7	450.1	450.15	450.15	450.15	450.15	450.15	450.2	450.2	450.2	450.2	450.2	450.2
9	8	451.5	451.5	451.5	451.5	451.5	451.5	451.5	451.5	451.5	451.5	451.45	451.45
10	9	448.4	448.4	448.4	448.4	448.45	448.45	448.45	448.45	448.45	448.45	448.45	448.45
11	10	450.5	450.5	450.5	450.5	450.5	450.5	450.5	450.5	450.5	450.5	450.5	450.5
12	11	452.35	452.35	452.35	452.35	452.35	452.35	452.35	452.35	452.35	452.35	452.35	452.35
13	12	448.75	448.75	448.75	448.75	448.75	448.75	448.75	448.75	448.75	448.75	448.75	448.75
14	13	451.9	451.9	451.9	451.9	451.9	451.9	451.9	451.9	451.9	451.9	451.9	451.9
15	14	453.2	453.2	453.2	453.2	453.2	453.2	453.2	453.2	453.2	453.2	453.2	453.15
16	15	453.8	453.8	453.8	453.8	453.8	453.8	453.8	453.8	453.8	453.8	453.8	453.75
17	16	458.85	458.85	458.85	458.85	458.85	458.85	458.85	458.85	458.85	458.85	458.8	458.8
18	17	453.65	453.65	453.65	453.65	453.65	453.65	453.65	453.65	453.65	453.65	453.6	453.6
19	18	452.7	452.7	452.7	452.7	452.7	452.75	452.75	452.75	452.7	452.75	452.7	452.7
20	19	449.15	449.15	449.15	449.15	449.15	449.15	449.15	449.15	449.15	449.15	449.15	449.15
21	20	453.5	453.55	453.55	453.55	453.55	453.55	453.55	453.55	453.55	453.55	453.5	453.5
22													

	N	O	P	Q	R	S	T	U	V	W	X	Y
1	12	13	14	16	17	18	19	20	21	22	23	差值
2	450.4	450.35	450.35	450.4	450.3	450.3	450.3	450.3	450.3	450.4	450.6	0.3
3	452.85	452.9	452.85	452.8	452.8	452.8	452.8	452.8	452.8	452.8	453.05	0.25
4	443.2	443.25	443.15	443.15	443.6	443.5	443.55	443.5	443.6	443.55	443.65	0.5
5	432.25	432.25	432.25	432.25	432.2	432.2	432.2	432.3	432.4	432.5	432.85	0.65
6	438.75	438.7	438.65	438.6	438.7	438.7	438.7	438.7	438.7	438.85	439.15	0.55
7	449.75	449.7	449.65	449.65	449.8	449.8	449.75	449.75	449.8	449.9	450.2	0.55
8	450.2	450.15	450.15	450.1	450.2	450.25	450.25	450.2	450.25	450.4	450.65	0.55
9	451.45	451.4	451.4	451.4	451.55	451.5	451.5	451.5	451.5	451.65	452	0.6
10	448.45	448.4	448.4	448.35	448.4	448.4	448.4	448.4	448.4	448.6	448.85	0.5
11	450.45	450.45	450.45	450.4	450.45	450.45	450.45	450.45	450.45	450.55	450.65	0.25
12	452.35	452.35	452.35	452.35	452.5	452.45	452.45	452.45	452.55	452.65	452.85	0.5
13	448.7	448.7	448.65	448.65	448.7	448.7	448.7	448.7	448.7	448.95	449.1	0.45
14	451.9	451.85	451.85	451.85	451.95	451.9	451.9	451.85	451.9	452.05	452.25	0.4
15	453.2	453.15	453.15	453.2	453.35	453.35	453.35	453.35	453.4	453.55	453.75	0.6
16	453.75	453.75	453.7	453.7	453.9	453.9	453.85	453.85	453.9	454.1	454.3	0.6
17	458.8	458.8	458.75	458.75	458.85	458.8	458.8	458.8	458.8	459	459.25	0.5
18	453.55	453.55	453.55	453.5	453.45	453.45	453.45	453.45	453.45	453.65	453.8	0.35
19	452.65	452.65	452.6	452.6	452.5	452.55	452.55	452.5	452.55	452.65	452.8	0.3
20	449.15	449.1	449	449.1	449.05	449.05	449.05	449	449.05	449.2	449.4	0.4
21	453.5	453.45	453.5	453.5	453.45	453.45	453.45	453.45	453.45	453.55	453.75	0.3
22												

Figure 10 Display of the updated Excel data spreadsheet

System tests showed a relatively good stability and real-time capability, and the accuracy can reach up to 50 g and the evapotranspiration of each soil column was 0.25-0.65 kg per day. Compared with the traditional soil column system, the large lifting crane of the aboveground portion of the system developed in this study was used to change the soil and maintain sensors, and the system was located in the basement which could reduce outside interference and easy to maintain. The automatic soil column weighing system applied electronic weighing technology, Internet data transmission technology, database technology, Web application technology. It not only can monitor 20 subordinate devices with one host computer, but also can query weighing data through the network at any time for the user. The automatic soil column weighing system developed in this study surpassed the traditional method of centralized data collection and thus provided an advanced method that could be used to automatically monitor the root system growth process of evapotranspiration.

5 Cost analysis and application prospect

The soil column system developed in this study achieved real-time monitoring of 20 soil columns' weight change, thereby measured the root system water consumption. It surpassed the traditional method of digging root sampling, could directly monitor the root growth and prune roots. The cost of the 20 soil columns is $32 600, 20 electronic balances ($19 560), a large crane with an automatic rain shelter ($8 150), three multiport serial cards ($310), a PC ($815), and a server ($1 630), hence the total cost of the system is $63 065. The system can support the study of many aspects of roots, and provide a basis platform for improving crop productivity.

6 Conclusions

In the study, an underground monitoring system was designed to dynamically monitor root system growth and water consumption in situ. The system has an aboveground portion that consists of a large lifting crane and automatic rain shelter and an underground portion consisting of backfill soil columns and a web-based multiport automatic soil weighing system. The large lifting crane and automatic rain shelter of the aboveground portion of the system fill the soil in the soil column and control rainfall. The Internet server-based multiport automatic soil column weighing system was designed installed at the base of the backfill soil column. This system measures total water loss from evapotranspiration in the soil-root system and conducts remote data transmission and data sharing. The root system monitoring system that was developed in the study surpassed the traditional method of digging root sampling and thus improved the level of multifunctional and automatic observation on the crop root system.

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