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Monitoring Soil Moisture under Wheat Growth through a Wireless Sensor Network in Dry Conditions

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Abstract: Drought research requires data on precipitation and actual soil moisture of fields because precipitation is variable among years and the soil textures differ with crop fields. Measurement of soil water content in the field is simple but labor-intensive. A prototype of an automatic field data monitoring system has been recently developed to collect data more efficiently. Using this system, data of soil water contents was successfully transmitted onto the personal computer approximately 700 m away from wheat field plots, for the period from March to May which was critical for soil drying and wheat growth. In addition, sample data of soil water content and grain yield was obtained from field plots of three bread wheat genotypes.

Key words: Soil water content, soil moisture, drought, monitoring system, wireless sensor network, wheat.

1. Introduction

Drought is a major limiting factor to food production in Central and West Asia and North Africa (CWANA). Breeding drought-tolerant cultivars is a major goal of ICARDA's wheat program [1]. Research on drought requires collection of data from the field on precipitation and how it changes with each year. A prototype of an automatic field data monitoring system, known as a Field Server, composed of a micro-computer with web server, sensors (camera), ad-hoc wireless LAN and battery supply has been recently developed [2, 3]. This field data monitoring system utilizes wireless transmission of meteorological data from multi-channel sensors of multi-sites. This study used this system to collect soil moisture data in field plots of wheat.

2. Materials and Methods

Three genotypes selected from synthetic bread wheat derivatives, Haurani/*Ae. tauschii* ICAG400709, and a recurrent parent genotype "Cham 6" [4] were planted in adjacent plots 8 m^2 each during the 2004/05 cropping season at Tel Hadya, ICARDA's main research station. The plot soil was classified as fine clay and had a permanent wilting point of 24% by weight [5].

The Field Server composed of a micro-computer which acted as a web server, three soil moisture probes, a monitoring camera, a battery, an antenna, a wireless LAN, and a data storage program. Three probes of soil moisture were set up in the plot soil of bread wheat genotype "Cham 6" at depths of 10, 20, and 40 cm.

Another set of three soil moisture probes of a conventional data logger was used for three synthetic bread wheat genotypes at 20 cm soil depth, which showed different tolerance to soil water deficit condition in the previous paper [6]. Some agronomic traits were collected from bread wheat genotypes at the times of heading and maturity.

Before the installation of the Field Server in the wheat field plots, the wireless transmission coverage of each

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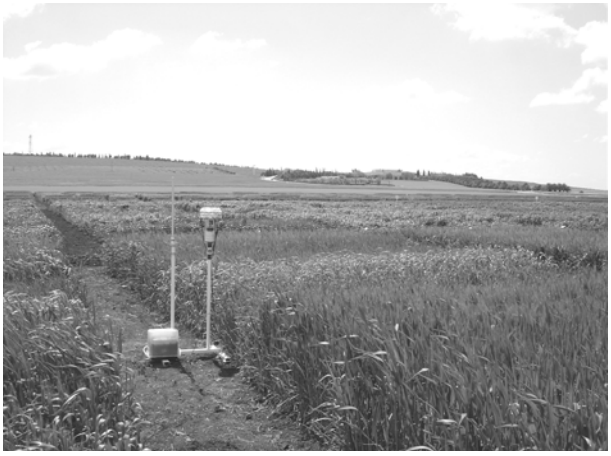

Fig. 1 Installation of an automatic field data monitoring system, Field Server, in the wheat plots at ICARDA's research station.

Field Server was tested. A Field Server was then installed in the aisle of the experimental field plots of wheat approximately 700 m away from the access point in a laboratory where data was stored in a personal computer (Fig. 1). Readings of soil dielectric permittivity in voltage were collected every 30 minutes for three months from the beginning of March to the end of May 2005, and were then transformed to the volumetric percentages of soil water content after sensitivity calibration.

3. Results and Discussion

3.1 Coverage of Wireless Transmission

The access point was set in the near center of the research station. Wireless transmission reached more than one kilometer of visible distance between the access point and the Field Server, but was completely blocked by trees, buildings and hills (Fig. 2). Direct visibility between the access point and the Field Server was critical for wireless LAN transmission, suggesting that the linkage of several Field Servers with ad-hoc connection was required for bypassing these blokes and covering the whole fields.

3.2 Collection of Samples of Soil Moisture Data

The meteorological station at ICARDA reported that the accumulated precipitation was 302 mm from the beginning of September 2004 to the end of May 2005, with a heavy rain of 23 mm at the beginning of April. The cropping season 2004/2005 was then drier than the average season. The bread wheat plants grown in the experiments reached the stage of heading in mid-April and the physiological maturity stage at the end of May. Data of soil water contents was successfully collected onto the personal computer, except for the duration of interruption of electronic power supply. The internal sensor of the Field Server with air ventilation recorded a maximum temperature of 44 ℃ when the air temperature was 34 ℃. The digital pictures of growing wheat plants in a field were also obtained through a monitoring camera.

The soil water content in the field plot of bread wheat genotype "Cham 6" which was approximately 35% at the beginning of March decreased to 28%, 21% and 12% in the soil depths of 40 cm, 20 cm and 10 cm at the end of May, respectively (Fig. 3). The soil water contents varied largely due to occasional precipitation before heading time, and soils less than 20 cm deep generated sever stresses of water deficit to the wheat plants, in particular, after the heading time.

The soil water contents in field plots of three synthetic bread wheat genotypes are shown in Fig. 4. Genotypes A, B and C were tolerant, moderate and susceptible to soil water deficit condition, respectively [6]. Sample data of soil water contents was collected stably after interruption of power supply, and the plot soil of genotype A and B were considerably drier that of genotype C. Three genotypes A, B and C in these plots produced the biomasses of 1118, 1005 and 1048 g/m^2 at the maturity time with distinct difference in grain yields of 433, 328 and 239 g/m^2, that is, harvest indices of 38.7, 32.6 and 22.8%, respectively.

The efficiency of plant water use greatly affects the amount of biomass and grain yield in wheat [7]. Synthetic bread wheats have an advantage to improve kernel weight [8]. Less soil moisture in plots is the result of higher transpiration that may associate greater accumulation of photosynthetic products to grains, such as a higher harvest index. More morpho-physiological

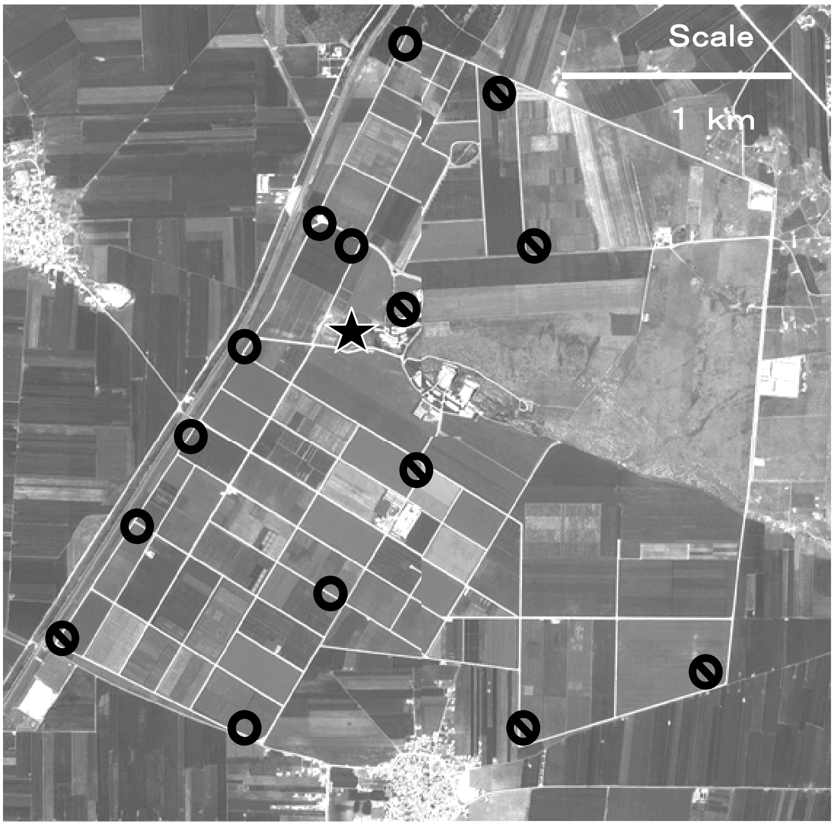

Fig. 2 ICARDA field map showing the distance of wireless transmission between the access point and the Field Server. Access point was located at ★, and the Field Servers were at ○ (successfully transmitted), or ⊘ (not transmitted).

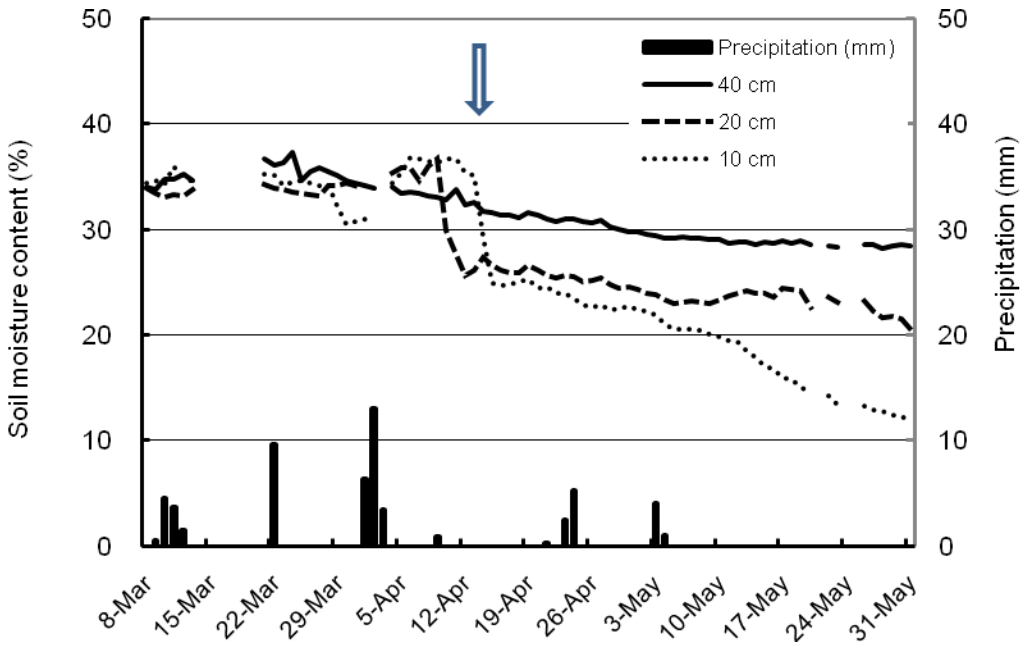

Fig. 3 Soil water content at depths 10, 20 and 40 cm in a field plot of bread wheat genotype "Cham 6", collected through a Field Sever. Arrow indicates the heading time of wheat material.

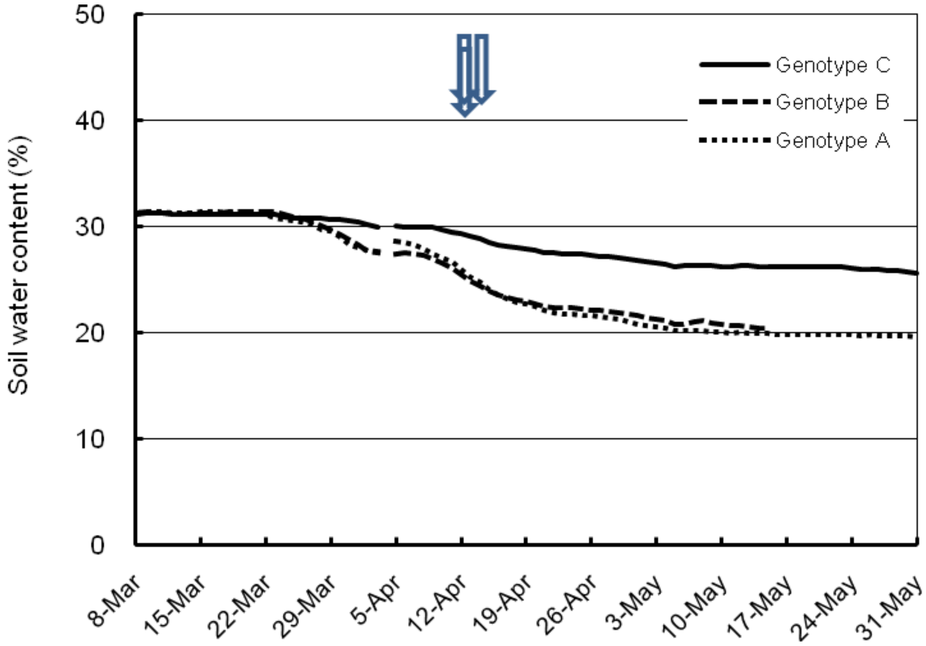

Fig. 4 Soil water contents in field plots of three synthetic bread wheat genotypes, collected in a conventional data logger. Arrows indicate the heading times of wheat materials.

examinations may be required on root development and photosynthetic ability in these wheat materials.

4. Conclusions

Real-time reading, in addition to data storage, of the automatic field data monitoring system is an advantage to collect data in a laboratory far removed from the filed. More information on water dynamics in the soil profile and crop genotype × soil moisture interaction obtained through monitoring of soil water content under drought stress is useful for understanding the drought tolerance of crops in relation to growth stage.

Drought research is always conducted in high temperatures in the fields. Protection of the monitoring system from direct sunlight and heating may be required. The system has been still developing as a hand-made in compatibility with upgrading of the component parts. A single apparatus is not enough to cover the fields where soil moisture data is collected. Linkage of several apparatus makes ad-hoc wireless LAN effective and data collection feasible even when there are blocks to the direct wireless connection. Furthermore, remote access to the soil moisture monitoring network equipped with wireless LAN and Internet may accelerate the development of a drought early warning system in CWANA.

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