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Stemflow of water on maize and its influencing factors

Haijun Liu[a,*], Ruihao Zhang[a], Liwei Zhang[a], Xuming Wang[a], Yan Li[b], Guanhua Huang[b]

[a] College of Water Sciences, Beijing Normal University, Beijing, 100875, China
[b] College of Water Resources and Civil Engineering, China Agricultural University, Beijing, 100083, China

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ABSTRACT

Stemflow is important for analyzing soil water dynamics and plant growth in regions with limited rainfall. The objective of this study was to determine the amount of stemflow in relation to plant and rainfall properties. In this study, stemflow was measured using a high water adsorption sheet method during the period of maize plant height growth approximately from 100 cm to 230 cm when the leaf area index increases from 1.0 to 4.5. There were 28 rainfall events with rainfall amounts for each event ranging from 0.4 to 12.6 mm and rainfall intensities ranging from 0.4 to 35 mm/h. The results show that stemflow increased with increasing total rainfall and leaf area index but decreased with increasing rainfall intensity. Throughout a maize season, stemflow amounts ranged from 10 to 70 mm when the total rainfall amounts ranged from 30 to 135 mm, with a mean stemflow rate of 0.42. These results may help farmers in irrigation scheduling of maize under surface-mulching conditions in arid region.

1. Introduction

Rainfall on farmlands is generally divided into four components: canopy interception, evaporation within the canopy, stemflow and throughfall. Stemflow refers to the portion of precipitation that, after canopy interception and blade assembling, flows down the crop stem, and eventually infiltrates into the crop roots soil (Lamm and Manges, 2000). This process is also called trunk stemflow in forest hydrology. In arid regions, plants can intercept light rain and concentrate it around their bases in a sufficient quantity and depth to be of probable value to their survival (Gwynne and Glover, 1961; Glover and Gwynne, 1962; Carlyle-Moses, 2004). In rain-rich regions, stemflow may be a source of soil surface flow, which can then flush the soil, resulting in soil erosion and nutrition losses (Lamm, 1984; Bui and Box, 1992; Paltineanu and Starr, 2000; Cattan et al., 2007; Liang et al., 2009a,b). Therefore, plant stemflow has been studied for at least half century. Paltineanu and Starr (2000) summarized the methods and results related to maize stemflow in published literature and showed that stemflow generally ranges from 12 to 57% of total rainfall, throughfall ranges from 35 to 84%, and direct measurements of water remaining on the plants after sprinkler irrigation ranges from 0.1 to 0.36 mm.

The plant stemflow volume generally depends on the total rainfall amount, rainfall density, plant species, plant growing stages and plant density (Bui and Box, 1992; Dunisch et al., 2003; Cattan et al., 2007; Lin et al., 2011; Base et al., 2012). Typically, plant stemflow is positively correlated with the total rainfall amount and increases with increasing plant height and plant leaf area (or leaf area index, LAI) (Cattan et al., 2007; Lin et al., 2011). Plants with a greater leaf area and a clear water-transferring tunnel may produce higher stemflow compared to those plants with a smaller leaf area and sparse leaf distribution under the same rainfall amount and density (Bui and Box, 1992; Kang et al., 2005; Base et al., 2012).

The Hetao Irrigation District is located in northwest China. This region experiences approximately 130 mm of precipitation per year, with approximately 70% of it falling during the plant growth period from May to September. Approximately 70% of the rainfall events have total rainfall amounts of less than 5 mm, and approximately 85% of the rainfall events have total rainfall amounts of less than 10 mm. Although most of the fields in this region are irrigated with Yellow River water to produce greater crop yields, some areas are not irrigated or are only partially irrigated using pumped water. Maize is one of the main crops cultivated in this region. The soil between the maize plants is generally covered with plastic sheets to reduce soil evaporation. Therefore, stem flow is particularly important for the maize crop growth, and accurate estimation of stemflow is important for planning irrigation schedules, especially in regions where pumped water is used for irrigation. To date, few studies have investigated stemflow and its influencing factors in this region. Although the stemflow of maize plants has been studied in other regions, these results cannot be directly applied to the Hetao region because stemflow is dependent upon plant species,

* Corresponding author. Tel.: +86 10 58802739; fax: +86 10 58802736.
E-mail addresses: shanxilhj@bnu.edu.cn, shanxilhj@163.com (H. Liu).

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plant density and rainfall characteristics. Therefore, it is necessary to measure stemflow and influencing factors locally in the Hetao region.

The purpose of this study was to determine the relationship between stemflow and rainfall amount and density as well as plant height and leaf area index.

2. Materials and methods

2.1. Experimental design

This study was carried out from May to September in 2013 at Linhe Agricultural Experimental Station, in the Inner Mongolia Autonomous Region, northern China (latitude 40°43′24″N, longitude 107°13′26″E, altitude 1042 m). The experimental site is in a typical continental temperate climate zone with a mean annual temperature of 7.8 °C, annual precipitation of 105 mm, a mean annual pan evaporation of approximately 2300 mm and an average annual sunshine duration of 3156 h (Wang et al., 2014). Soils in the experimental site are silt loam in the 0–20 cm soil layer and loam in the 20–60 cm soil layer. The physical properties of the experimental soil are listed in Table 1. The bulk density ranges from 1.59 to 1.63 g cm^{-3}, field capacity ranges from 0.20 to 0.22 cm^3 cm^{-3}, and saturated soil water content from 0.35 to 0.36 cm^3 cm^{-3}.

The maize variety was Ximeng 6, a widely used variety in this region. The maize was seeded in wide-narrow rows, with wide and narrow spaces between plant rows measuring 70 and 30 cm, respectively, and with plant spacing of 25 cm. This layout of the plant seeding yields a potential plant density of eight plants per square meters or 80,000 plants/ha. Under full irrigation conditions, the maize yield can reach 12–15 tons/ha. During the plant-growing period, the space between the narrow rows was covered with 70 cm – width plastic sheeting to keep the soil warm and to reduce soil evaporation.

Stemflow was measured for each plant. For each rainfall event, including both natural and artificial rainfalls, 20 plants were selected for stemflow measurement. The plant height and leaf area for each plant were measured at the same time. Additionally, the climatic condition was measured using an automatically recording weather station located approximately 50 m from the experimental plot. During the experimental period, the plant height ranged from 50 cm to 300 cm, and the leaf area index ranged from 1.0 to 6.0. There were 28 rainfall events, including 16 natural rainfall events and 12 artificial rainfall events. The total rainfall amounts for each event ranged from 0.4 to 12.6 mm and the rainfall intensities ranged from 0.4 to 35 mm/h.

2.2. Simulated rainfall device and stemflow measurement system

A rainfall simulator was developed to produce rainfalls of various intensities. The simulator includes six spray tapes, with two tapes for each group. A valve is deployed in a subpipe that connects the one – tape group and the main pipe. Under this system design, the rainfall simulator can produce three rainfall intensities. In the main pipe, a regulated pressure valve is deployed to control the system pressure, which can be read by a pressure gauge deployed on the main pipe. A water meter, also deployed in the main pipe, is used to record the quantity of water used. The main pipe is connected to a pump, which is placed in a tank with a 4 m^3 water capacity. The area controlled by this rainfall simulator measures 3 m in length and 2 m in width. The height of this simulator is adjustable, and it was maintained approximately 50 cm above the canopy throughout the experiment. During each rainfall event, the total rainfall amount was measured at five points above the canopy. The rainfall intensity was calculated by dividing the mean rainfall amount by the duration of the rainfall event. Before the experiment, the water distribution uniformity of this rainfall simulator was tested using containers that were placed at 30-cm intervals along the two diagonal lines of the simulator. The coefficient of uniformity was calculated using the Christiansen method (Li and Rao, 2000; Liu and Kang, 2007) and was found to range from 0.90 to 0.96 under low wind conditions.

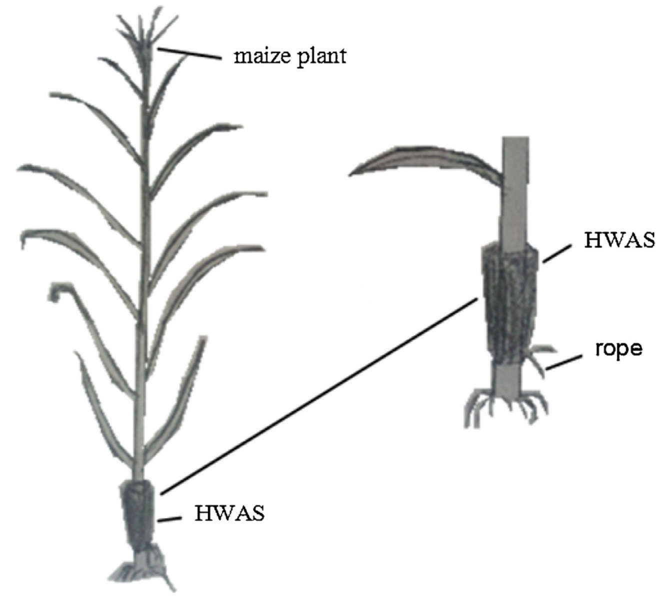

Fig. 1. The collection system for stemflow water.

In this study, high water adsorption sheets (HWAS), i.e., the diapers, were wrapped around each maize stem to measure stemflow water. Before each precipitation event, each HWAS was numbered and weighed using an electronic balance with resolution of 0.01 g, then fastened around selected maize stem tightly enough to ensure that no water leakage occurred, while still providing sufficient space in the upside of the HWAS for stem flow to infiltrate into the HWAS. When the precipitation stopped, each HWAS was quickly unwrapped and measured. The stemflow water of each plant is the difference in total mass of the HWAS before and after each precipitation event. The HWAS used in this study is measuring 10 cm in width and 20 cm in length. This size was selected to ensure that each maize stem could be fully wrapped. Before the experiment, the water holding capacity of the HWAS was measured by carefully putting water into the HWASs. When water flowed out from the HWASs, these HWASs were quickly measured. The water holding capacity of this HWAS is the difference in total mass of HWAS before and after putting water on it, and was found to be approximately 1000 g per sheet. In this study, the maximum stemflow water per plant was measured to be approximately 270 g using the HWAS at a precipitation event with amount of 5.7 mm and a plant height of 227 cm, and less than the maximum capacity of 1000 g. This implid all stemflow water in this study could be adsorbed with the HWAS. In this experiment, we observed that the soils around the stem base were dry after each measurement, thus confirming that all of the stem flow was absorbed by the material. The stem flow measurement system is shown in Fig. 1.

2.3. Calculation methods

Before each rainfall event, approximately 20 HWASs were prepared. Each HWAS was numbered and weighed. The HWASs were then carefully wrapped around the stem bases. After the rainfall event, the HWASs were removed from the maize stems and weighed again. The stemflow for each stem is the mass differ-