International Journal of Plant & Soil Science

19(1): 1-7, 2017; Article no.IJPSS.36515
ISSN: 2320-7035

In situ Method for Measurement of the Stem Flow of Maize

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Authors' contributions

This work was carried out in collaboration between all authors. Authors HL, LZ and RZ designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors XW and YL managed the analyses of the study and the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2017/36515
Editor(s):
(1) Alejandro Hurtado Salazar, Departamento de Produccion Agropecuaria, Universidad de Caldas, Colombia.
Reviewers:
(1) M. Yuvaraj, Tamil Nadu Agricultural University, India.
(2) Şeref Kiliç, Ardahan University, Turkey.
Complete Peer review History: http://www.sciencedomain.org/review-history/21152

Short Research Article

Received 30th August 2017
Accepted 21st September 2017
Published 26th September 2017

ABSTRACT

Measurement of stem flow is important for analyzing the water balance and evaluating the soil erosion in agricultural fields with crop stands under precipitation. Most used methods for stem flow measurement now are ex situ, this may yield big error because plant canopy structure is greatly modified. In this study, an *in situ* method was proposed for measuring stem flow of water for maize plant under natural condition. In this method, a high-water-adsorption-sheet (HWAS) was wrapped around the stem base, and the stem flow amount is the mass differences of HWAS measured before and after rainfall event. Results showed that the measured stem flow was approximately 41% of the total precipitation and canopy interception capacity was approximately 0.63 mm when the maize height is 220 cm and the leaf area index is 4.5. These results of stem flow rate and canopy interception capacity are confirmed by the data in the published literatures. The HWAS method is easy performance and reliable and is therefore recommended for *in situ* stem flow measurement as an alternative to the current methods.

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Keywords: Water cycle; soil water balance; soil erosion; rain simulator; canopy interception.

1. INTRODUCTION

In agricultural fields with crop stands, rainfall always is partitioned into three components, canopy interception, throughfall and stem flow. Compared with canopy interception and throughfall, stem flow attracts more attention. One reason for the interest in stem flow is that it is essential to plant growth, especially in arid regions, because this water directly infiltrates into the soil layer, where the main roots develop, and then supports leaf transpiration and nutrient elements adsorption [1-6]. While in rainfall rich regions and slope areas, great stem flow will flush the soil surface and cause soil erosion [7-9]. Therefore, the stem flow is measured or estimated for various plants. Literature reports indicate that the stem flow ranges from 10% to 70% of the total rainfall, depending on plant varieties, growth stage, plant density, rainfall characteristics and measurement methods [10-11].

The usual methods for measuring stem flow can be classified into two groups: *in situ* measurement and offsite measurement. For *in situ* measurement, a collector is generally deployed around the stem and a tube is used to deliver the water in the collector to a container on the ground [3,10,12-14]. After each rainfall event, the water in the container is measured, which is considered as the stem flow of the measured plant. The merit of this *in situ* method is that the measured water is the stem flow under natural conditions. However, the problems of the *in situ* method are: 1) deploying this collector should be carefully performed to prevent water leakage through the gap between the collector and the round stem and 2) the method is time consuming because it depends on rain fall events. For the offsite method, plants are always cut down and then inserted into a container [8,15-17]. Subsequently, an artificial rain simulator is used to produce rainfalls of various rates. Such offsite measurement could save time and be performed under different rainfall intensities. Because the characteristics of leaf and canopy are changed when the plants are cut, these may increase the measurement error with an unknown range. To avoid the effects of plant wilting caused by cutting, fresh plants are used each day [14]; this replacement requires the destruction of many plants for the measurement. Therefore, an alternative method to *in situ* measurement of the stem flow that is less time consuming and easily performed is desired.

In this study, a simple method is evaluated to *in situ* measurement of the stem flow of maize under natural and artificial rainfall events. In this method, a high-water-adsorption sheet (HWAS) is tied around the stem, and then used to adsorb the water flowing down through the stem. The stem flow is the mass difference of the HWAS before and after the precipitation event. The results of this measurement method and the stem flow amount are presented in the following sections.

2. MATERIALS AND METHODS

2.1 Crop Agronomy

The experiment was performed at the Linhe agricultural station in north China. The climate in this station is characterized as warm, dry and windy during the crop growing season, generally from May to September. Although crops in this region are irrigated 3-4 times for high production, the available rainfall water is still important for crop production and water resources management.

The main crops cultivated in this region include maize, sunflower and spring wheat. In this study, the maize is cultivated with line spaces of 70-30-70 cm and plant spaces of 25 cm. Maize is planted at April 26 and harvested at September 18 in 2014. The measurement was performed during the period from middle June to middle August. During this period, the plant height ranged from 100 to 220 cm and the leaf area index (LAI) ranged from 1.5 to 4.5.

2.2 Artificial Rainfall Simulator

Considering the lack of rainfall events and the small amount of total rainfall (less than 100 mm) during the crop growing season, an artificial rainfall simulator was designed and used in the study, as shown in Fig. 1. The frame of the simulator system is 3 m in height, 3 m in length and 2 m in width. The height of the system was designed considering the maximum plant height and can be adjusted according the plant height. In the top surface of the simulator frame, there were six sprinkler tapes, with two tapes for each group. Each tape group was connected to a sub-pipe, and then the sub-pipe was connected to the main pipe. A valve was deployed on each sub-pipe to control the operation of a tape group. In the main pipe, a pressure gauge and water meter were deployed for controlling the system operation pressure and measuring the water used. A pump was deployed in a water tank for pumping water when the simulator system is operating. The three groups of sprinkler tapes were operated individually or combined to generate the different precipitation rates.

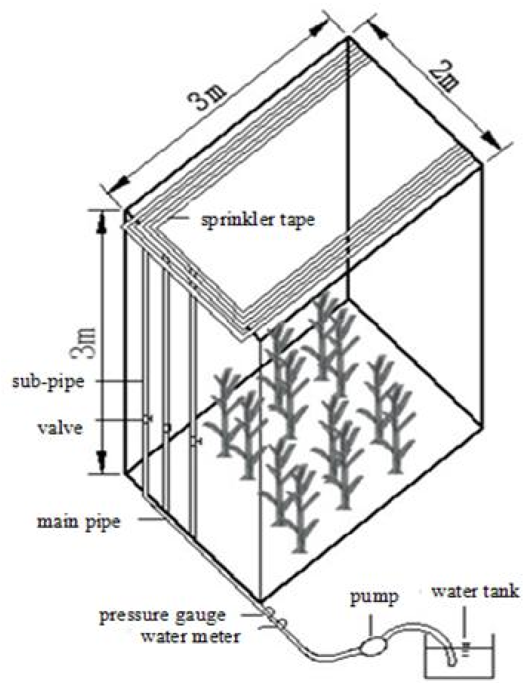

Fig. 1. Schematic diagram of the rainfall simulator system

2.3 Stem Flow Measurement

In this study, high-water-adsorption sheets (HWAS), i.e., the diapers, were used for stem flow measurement. First these sheets were measured by a 0.05 g - resolution balance in laboratory to know its initial weight before measurement. Then these selected HWASs were wrapped around each maize stem. The downside of the use of the HWAS, approximately 10 cm above the ground surface, was that they must be fastened around the stem to ensure no water leakage occurs. The upside of the use of HWAS was that the HWAS must be wrapped around the maize stem but not as tightly as mentioned in the downside to provide sufficient space for water infiltrating into the HWAS. Following, rainfall simulator was operated to simulate rainfall event as designed water amount. After rainfall event, all sheets were removed from plants and measured again to know the weight after a rain event. The difference in sheets' weights before and after rainfall were the stem flows of plants.

The HWAS used in this study measured 10 cm in width and 20 cm in length. This size was selected to ensure the maize stem can be fully wrapped. Before the experiment, the water holding capacity of this HWAS was investigated and was found to be approximately 1000 g per sheet. In this study, the maximum stem flow per plant was approximately 270 g when the precipitation amount was 5.7 mm and the plant height was 227 cm. Given a linear relationship between the stem flow and the precipitation amount under full canopy condition, this HWAS can completely adsorb the stem flow, even when the precipitation amount reaches 20 mm. After each measurement, we observed that the soils around the stem base were dry, thus indicating that all of the stem flow was absorbed by the material. The schematic diagram and *in situ* stem flow measurement system are shown in Fig. 2.

In this study, the stem flow was measured 10 times, including 3 artificial rainfalls and 7 natural rainfalls. For each measurement, 10-20 plants of similar stem heights were chosen. Meanwhile, the leaf area and plant height for each plant were measured. The total rainfall amount for each event ranged from 0.4 to 12.6 mm, and the rainfall density ranged from 0.4 to 28.8 mm/h.

3. RESULTS AND DISCUSSION

3.1 Measured Stem Flow

We selected the stem flow data measured at a plant height of approximately 220 cm and a leaf area index of approximately 4.5 to evaluate this stem flow measurement method. For these measurements, the rainfall amounts ranged from 0.4 to 5.7 mm, and the mean stem flow ranged from 6 to 270 ml per plant, which is equivalent to 0.05 to 2.16 mm. Stem flow accounted for 11.5% to 61.0% of rainfall amount. The least stem flow was 11.5% of rainfall when rainfall was the smallest, 0.4 mm, while stem flow reached more than 50% of rainfall amount when rainfalls were greater than 2 mm.

3.2 Relationship between Stem Flow and Rainfall

Rainfall is divided into three components when going through crop canopy: canopy interception, thorough fall water and stem flow. These three components are indicated as Sections A, B and C in Fig. 3. Section A is the area from points a to b in the X coordinate axis. Section B is the area enclosed by dash line through the X coordinate axis and the regression line of bc. In addition, section C is the area enclosed by the X coordinate axis and the regression line of bc. Clearly the total stem flow depth generally increased with the increase of the total precipitation (Fig. 3), and their relationship can be expressed as a two-order polynomial with a high determination coefficient of 0.9.

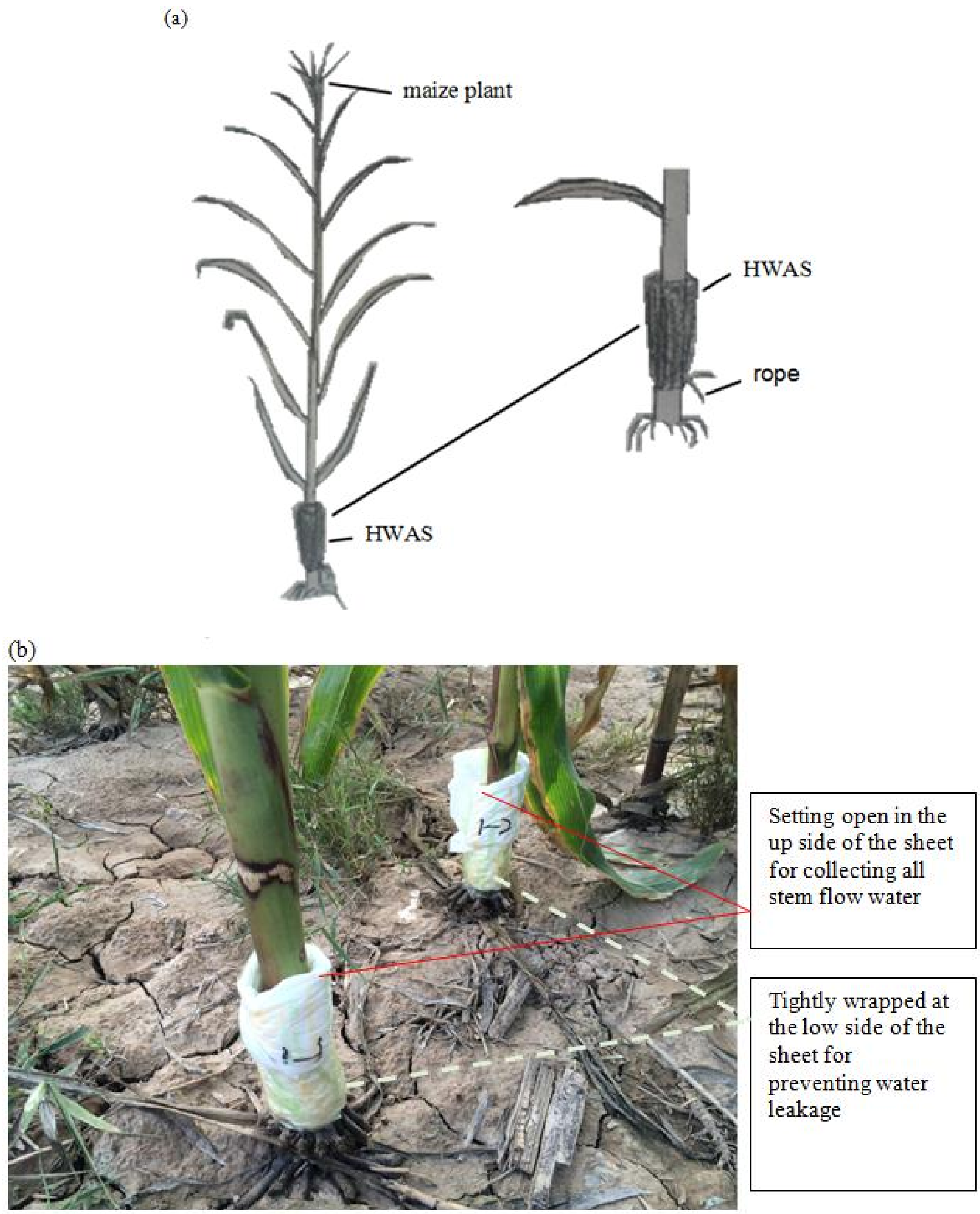

Fig. 2. Schematic diagram of stem flow water measurement (a) and *in situ* measurement picture (b)

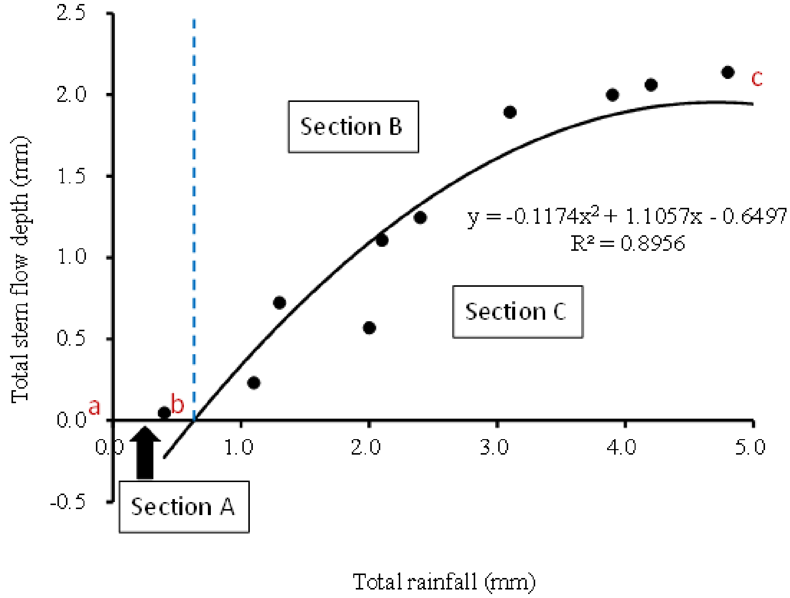

Fig. 3. The relationship between the total stem flow depth and the rainfall amount when the plant height is approximately 220 cm and the leaf area index is approximately 4.5

For a precipitation event, the precipitation water is first intercepted by the plant canopy, and then it reaches the ground as stem flow or/and thorough fall, when the soil surface is completely covered with the crop canopy. The value of the intersection point between the regression line of ab and the X coordinate axis on Fig. 3 is 0.63, indicating the maximum canopy interception of 0.63 mm. In other words, when the precipitation amount is less than 0.63 mm, there is slight or no throughfall water and stem flow. This conclusion can be confirmed by a measurement in this study. That is, the measured stem flow is approximately zero for a precipitation amount of 0.40 mm. Similarly, Ma et al. [18] measured the canopy interception of maize using the misting method and found that the canopy interception was 0.33 mm when the LAI is 4.19. Wang et al. [19] measured the canopy interception of winter wheat using a wiping method, and they found that the canopy interception of winter wheat is approximately 0.17-0.18 mm per LAI, and this interception rate is independent on the amount of water application. Using this interception rate and the LAI value of 4.5 in the experimental period, the canopy interception is approximately 0.77-0.81 mm, which is close to the estimated canopy interception rate of 0.63 mm. Therefore, it could be concluded that the canopy interception capacity of 0.63 mm is reasonable for a maize crop with a value of the LAI of 4.5.

The rate of stem flow to the total precipitation ranged from 0.11 to 0.61, with a mean of 0.41 and a standard error of 0.05. This means that approximately 41% of the precipitation will reach into the soil through stem flow. This stem flow rate is close to the values of 41% and 44% reported by Steiner et al. [12] and Bui and Box [8], but are slightly lower than the reported values of 49% [7] and 53% [13]. In this study, most of the stem flow was measured during natural rainfall events, which always are accompanied by strong wind in this region. In the measurement period in the first half in August, the mean wind speed during rainfall days was 2.97 m/s. High wind speed may cause leaves to swing, thus forcing much of the rainfall intercepted in the canopy to move from the leaves and flowing down as throughfall, thereby reducing the amount of stem flow. The measured stem flow rate of 41% in this study also falls in the range of 30 to 67% during the period from full maize crop canopy to the senescence and finally to the harvest period reported by Paltineanu and Starr [11], in the range of 5 to 70% for high density maize reported by Ma B et al. [13], in the range of 17.6% to 44.7% for the maturation of maize under a rain density of 0.58-1.51 mm/min by Lin et al. [17], and in the range of 19 to 49% reported by Parkin and Codling [3]. These comparisons indicate that the measured stem flow rate is reasonable and that the HWAS method is reliable.

4. CONCLUSION

In this study, we provided an *in situ* method to measure the water of stem flow for maize plant. Results showed that the measured stem flow ranged from 11% to 61% of rainfall amount, with a mean value of 41%, and the canopy interception capacity was estimated approximately 0.63 mm when the maize height is 220 cm and the leaf area index is 4.5. All stem flow data and estimated canopy interception were close to those in published literatures. Therefore, this *in situ* stem flow method was recommended for stem flow measurement for maize and similar structure plants, and for studies on water resources management and hydrological cycle in arid regions.

ACKNOWLEDGEMENT

This work was supported by the National Natural Science Foundation of China (Grant No. 51479004) and the Non-profit Industry Financial Program of MWR (grant number: 201401036). The authors also greatly acknowledge the two anonymous reviewers and the chief editor for their suggestion on this paper.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
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