Factors Affecting Sensitivity of Wetting Front Detectors

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Abstract

Wetting Front Detectors (WFD) are simple instruments that provide a yes/no response when a front of certain strength passes a set depth. This paper describes two different designs of wetting front detector and determines their sensitivity under experimental conditions. The FullStop WFD comprises a specially shaped funnel that distorts the downward flow of water through the soil, producing saturation at its base. The sensitivity was determined by applying water via intermittent misting at rates of 0.1 to 0.8 mm/h. For the soil type under study, the minimum flux at which water was collected by the WFD was 0.2 mm/h. The experiment was repeated for drip irrigation, and the FullStop WFD collected water at application rates less than 0.05 L/h, corresponding to a soil suction of about 2 kPa. Whereas these application rates are lower than what can physically be applied in the field, wetting fronts do weaken with depth and time after the irrigation is turned off. Fronts can then move at rates below 0.2 mm/h or suctions drier than 2 kPa, which could go undetected. A second WFD design, termed a LongStop, was also tested to determine if it would respond to lower flux rates. When fluxes are low, convergence by the funnel is less important than the need to counteract capillary emptying by the surrounding soil. A pipe-like design is therefore more appropriate than a funnel. A LongStop having a diameter of 50 mm and length of 600 mm was able to detect wetting fronts up to 6 kPa suction, and the volume of water in the LongStop was well correlated to the suction in the soil around the opening.

INTRODUCTION

Wetting Front Detectors (WFDs) are simple instruments that provide a signal when a wetting front caused by rain or irrigation passes the depth where they are buried. WFDs are used to improve the scheduling of irrigation (Zur et al., 1994; Stirzaker, 2003; Stirzaker and Hutchinson, 2005), leaching of salt (Stirzaker and Thompson, 2004), and the management of nitrate (Stirzaker et al., 2004b). The strength of the front that a WFD can detect depends on its design. In order to give a signal, the WFD must collect water from an unsaturated soil, by impeding the downward flow of water.

The FullStop WFD consists of a specially shaped funnel, a filter and a mechanical float mechanism. The funnel is buried in the soil within the root zone of the plants or crop. When the infiltrating water converges inside the funnel, the soil at the base becomes so wet that water seeps out of it, passes through a filter, and is collected in a reservoir. This water activates a float, which in turn operates an indicator flag above the soil surface (Fig. 1a).

The WFD concept has much in common with passive soil solution samplers and mini-lysimeters as reviewed by Litaor (1988), but when used in an irrigation context it is essential to know the soil tension at which the WFD collects a sample i.e. its sensitivity limit. The FullStop WFD has performed well, particularly when placed at shallow depths (Stirzaker and Hutchinson, 2005), but there is evidence that weak fronts can pass the instrument undetected (Stirzaker et al., 2004a).

Water converges in and diverges around the detector, and the volume of water reaching the base of the funnel is a function of its geometry, the surrounding soil properties and the strength of the wetting front. Put simply, the sensitivity of a WFD is determined by the balance between convergence of water films in the funnel (filling) and the effect of capillarity forces around the device (emptying). It follows that the sensitivity of the detector is determined by the diameter of the funnel (assisting convergence) and the depth from the rim of the funnel to the filter (restricting capillary emptying).

Fronts get weaker as they move down through the soil as each soil layer retains and slowly releases some of the infiltrating water. When the flux is low, a funnel shape is not the best option for producing free water from unsaturated soil. When there is low flux, convergence is less effective, and the shallow depth of the funnel does not counter emptying by capillarity. In these cases, a pipe-like design is more appropriate than a funnel, since sensitivity at low flux rates is determined by length (Hutchinson and Bond, 2001). The LongStop WFD is comprised of two concentric tubes open at the top end and closed at the bottom. The outer pipe is 50 mm wide and 600 to 1000 mm long, and filled with a porous material. The inner pipe is air or water filled and hydraulically connected to the outer pipe via a screen filter near the base. A water-table develops in the inner pipe in response to the matric suction at opening of LongStop (Fig. 1b).

In this paper, the sensitivity of the funnel shaped and pipe shaped designs of the WFD are determined experimentally.

MATERIALS AND METHODS

The sensitivity of the funnel shaped design (FullStop) was carried out in drums with a diameter of 580 mm and height of 900 mm. The drums had an outlet 100 mm from the base and the lower 150 mm was filled with sand. Replicate drums were then filled with different soils. The FullStops were buried so that the depth of front detection was approximately 250 mm from the soil surface. The soil water content was measured over the 50 to 250 mm depth by time domain reflectometry at 15 minute intervals.

Each drum was irrigated by four misting jets attached to a timer switch, providing a specified number of seconds every 10 minutes, to give flow rates of between 0.1 and 0.8 mm/h. Since soil evaporation was significant at such low application rates, six catch cups were placed on the surface and measured each morning and evening. The assumption was made that evaporation from the cups would be similar to that from the bare wet soil. The volume of water collected in the reservoirs at the base of the FullStop, and the water draining from the base of the drums, was measured every 12 hours.

Sensitivity was also evaluated under drip irrigation at rates of 0.025 to 0.05 L/h, equivalent to 0.1 - 0.2 mm/h averaged over the surface area of the drum. Tensiometers were placed 70 mm laterally away from the rim of funnel, with the ceramic cup at the approximate depth of wetting front detection (250 mm depth). Tension was read with an electronic pressure gauge, with a resolution of 10 mm (0.1 kPa).

The LongStop pipe-shaped design, 600 mm long x 50 mm diameter, was tested in a furrow irrigated field site. The outer pipe was filled with a fine sand material, having 50% of the mass with particle size < 100 µm. A 50 mm auger was used to make holes on the shoulder of raised beds. The LongStops were lowered into the holes so that the openings at the upper end were 0.5 and 1.0 m below the bed surface. The same fine sand material was then poured down the hole to fill any gaps between the LongStop and the wall of the hole and to provide a 100 mm 'wick' above the LongStop. The role of the wick was to keep the LongStop and the soil in hydraulic equilibrium. The hole was refilled with soil, with a 50 mm concrete cap 200 mm below the surface, so that no water could enter the LongStop via the disturbed soil. The water had to enter the LongStop radially via the wick immediately above it. A tensiometer was placed in the wick material and 300 mm away in the soil at the same depth of the wick.

RESULTS

Results are shown for one soil type (44% clay, 21% silt, 35% sand) under sprinkler, drip and furrow irrigation methods. For the sprinkler example, the misting system was run for a couple of days at around 0.3 mm/h (around 7 mm per day), to make sure a wetting front had reached the 250 mm soil depth. The flux was then dropped to just over 0.1 mm/h, and then increased gradually to 0.8 mm/h over 15 days (a solenoid malfunction interrupted supply on day 12). The rate that water was captured in the FullStop was about one third lower than the application rate, suggesting some water flowed around the outside of the funnel (Fig. 2). The threshold application rate, below which no water was captured, was about 0.2 mm/h. The water content increased slightly with the increasing application rate, and then dropped after irrigation was stopped on day 22.

Drip irrigation was applied at rates of 0.1 to 0.2 mm/h, averaged over the drum surface area, or 0.025 to 0.05 **L**/h, for a period of 8 days. On day three the soil suction at 250 mm depth started to fall. Water was not collected in the FullStop until the soil suction fell to around 20 cm of suction, or 2 kPa (Fig. 3).

The sensitivity evaluation of the LongStop was carried out over a five month period in the field. The tensiometer record shows 7 wetting events, five of which reduced the soil suction to within the theoretical sensitivity range of the LongStop (6 kPa), as set by the 600 mm length (Fig. 4). Each of these events is clearly recorded by the volume of water collected by the LongStop. Wetting event number 3 falls just short of the theoretical sensitivity limit, but a small amount of water was collected. Wetting event number 6, which decreased the suction from around 150 to 90 cm, was not recorded by the LongStop.

Within its theoretical sensitivity range, the LongStop responded rapidly to the changing suction. The linear correlation between suction in the wick of the LongStop and water inside the LongStop gave an r value of 0.91 with a y-intercept of 660 mm. The correlation coefficient was 0.69 when the suction measurement in the soil 300 mm away from the LongStop was used as the independent variable. The lower r value shows that the wick is not completely in equilibrium with the soil, although it should be noted that tension measurements can vary substantially over short distances under irrigated conditions.

DISCUSSION

The FullStop WFD was triggered by an irrigation application rate as low as 0.2 mm/h for a soil type with 44% clay, 21% silt and 35% sand. Several other soil textures gave a similar result, except for coarse sand, which required an application rate above 0.5 mm/h (data not shown). Since sprinkler irrigation cannot physically be applied at such low rates, it would seem the FullStop WFD would always record the passing front. This would be true for steady state conditions, where the low application rate was maintained for a very long period. In the field, however, wetting fronts are transient, and weaken with time and depth. Assuming an irrigation applied at 5 mm/h over 2 hours, a soil that is already at the upper drained limit with no evapotranspiration, the water may be passing 200 mm depth at 2 mm/h for 5 hours, 300 mm depth at 0.5 mm/h over 20 hours and 400 mm depth at 0.1 mm/h for 100 hours. In this example, the FullStop WFD would respond to the front at 300 mm depth but not at 400 mm depth, even though the same amount of water moved past. The 300 to 400 mm depth is called the ‘grey zone’. The FullStop should be placed sufficiently shallow to capture redistributing fronts before they fall below the detection limit.

The example for drip irrigation was similar to that for sprinkler, although the FullStop WFD collected water at even lower application rates. This is because the FullStop was placed directly under the dripper, and the flux would be higher there than towards the edge of the drum. There is no dripper than can apply water at rates as low as 0.05 L/h, but the case for weak redistributing fronts is similar to that described for sprinklers. However, drip irrigation invariably has higher application rates per wetted area than sprinklers, and for that reason the optimum placement of FullStop WFDs is deeper for drip compared to sprinkler irrigation.

The soil suction around the FullStop wetting front needed to fall to around 20 cm (2 kPa) before it started to collect water. The data clearly showed that the sensitivity of the LongStop was 60 cm or 6 kPa. This increased sensitivity would be advantageous for deeper placements where fronts are weaker. This is particularly the case for furrow irrigation, where large amounts of water tend to be applied at infrequent intervals. The aim is to wet deeply, so deeper placement is needed. A further advantage of the LongStop is that the hole in which it is placed is sealed, so soil disturbance is much less of an issue.

There are two advantages of the FullStop WFD over the LongStop. First, it takes longer to install the LongStop in most soils, as the hole must be 600 mm deeper than the desired depth of measurement. Second, the FullStop is better for nutrient sampling. The FullStop retains a water sample from each wetting front and the sample is taken as soon as the front reaches it. The fill material in the Longstop is often saturated, so the water entering the open end of the LongStop is not the same water that moves through the filter into the central tube. Moreover there can be nutrient transformations as water moves through the saturated zone.

The choice of which type of WFD to use and the depth of placement, requires some local knowledge. In some soils, FullStop WFDs have easily detected fronts at and below 600 mm depth, but on others, particularly apedal fine sandy and silty soils, a much shallower placement is necessary. In general, it appears the FullStop WFD is best suited to depths shallower than 500 mm, and the LongStop WFD to depths deeper than 500 mm.

ACKNOWLEDGEMENTS

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Figures

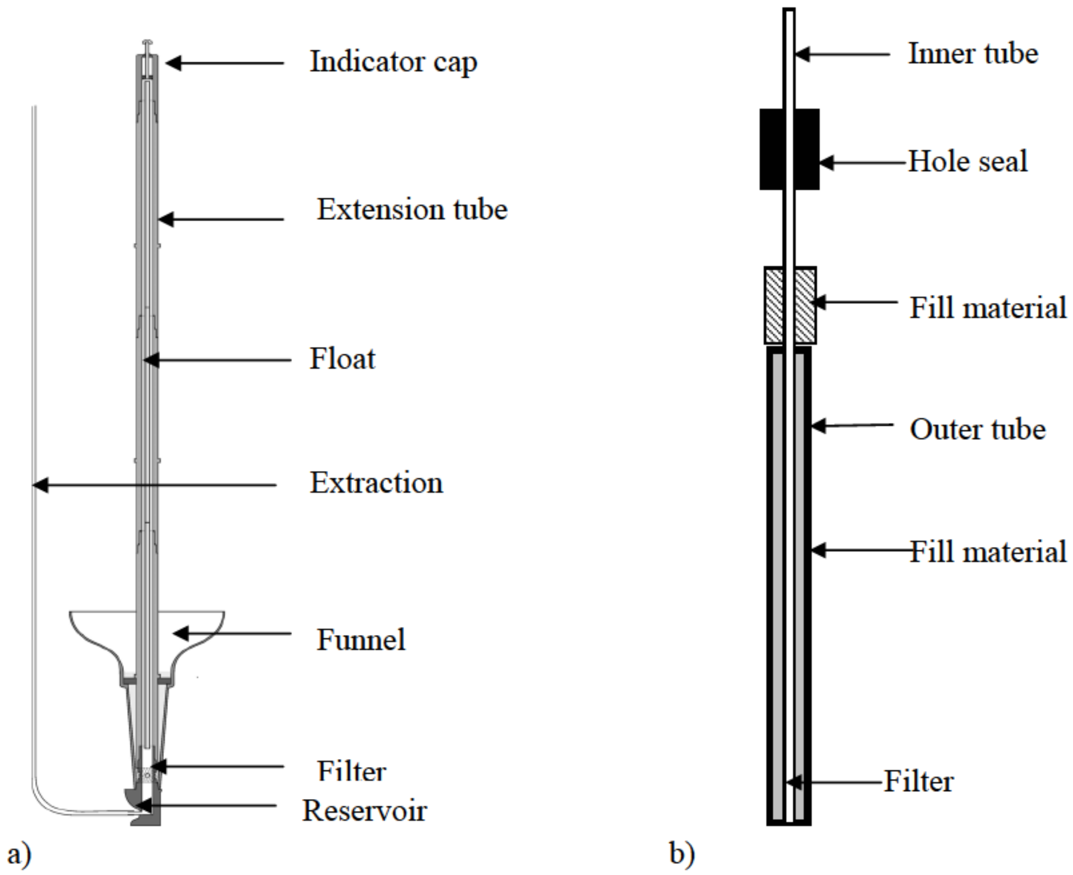

Fig. 1. Schematic of FullStop (left) and LongStop (right) Wetting Front Detectors. The FullStop is comprised of a 200 mm diameter x 250 mm depth funnel with extension tubes to the surface housing a float which activates a magnetically latched indicator above the soil surface. The LongStop is comprised of two concentric pipes: the outer 50 mm in diameter and the inner 20 mm in diameter. The length of the outer pipe depends on the desired sensitivity and the inner pipe runs to the surface. The space between inner and outer pipes is filled with a fine sand material. In both designs saturation occurs at the base and water moves through a screen filter into a reservoir.

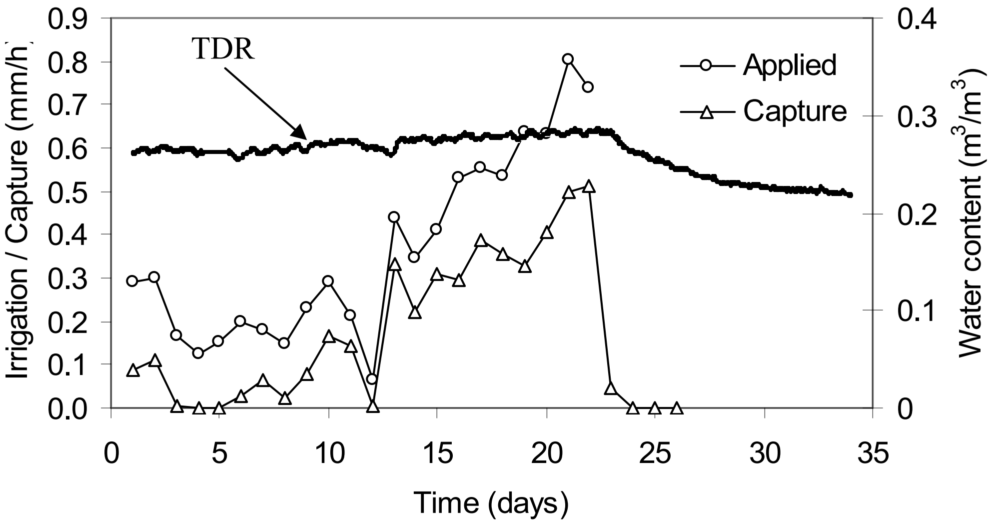

Fig. 2. The flux of sprinkler irrigation applied to the drum and the capture rate of water in the WFD. The heavy line shows the change in volumetric water content as measured by time domain reflectometry.

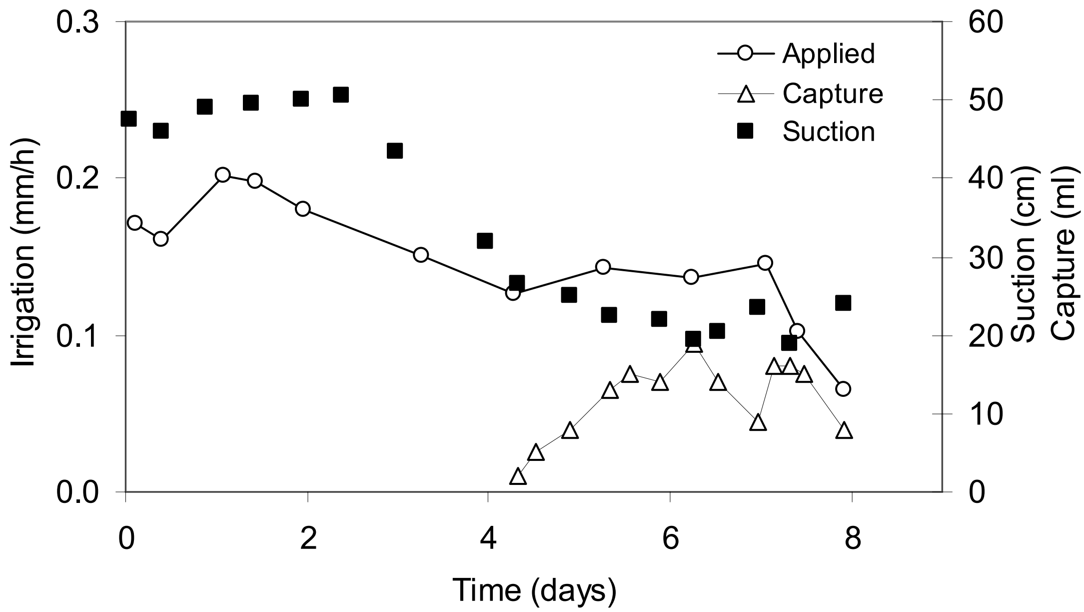

Fig. 3. The rate of drip irrigation applied to the drum, the capture rate of water in the WFD and the soil suction at the depth of measurement of the WFD.

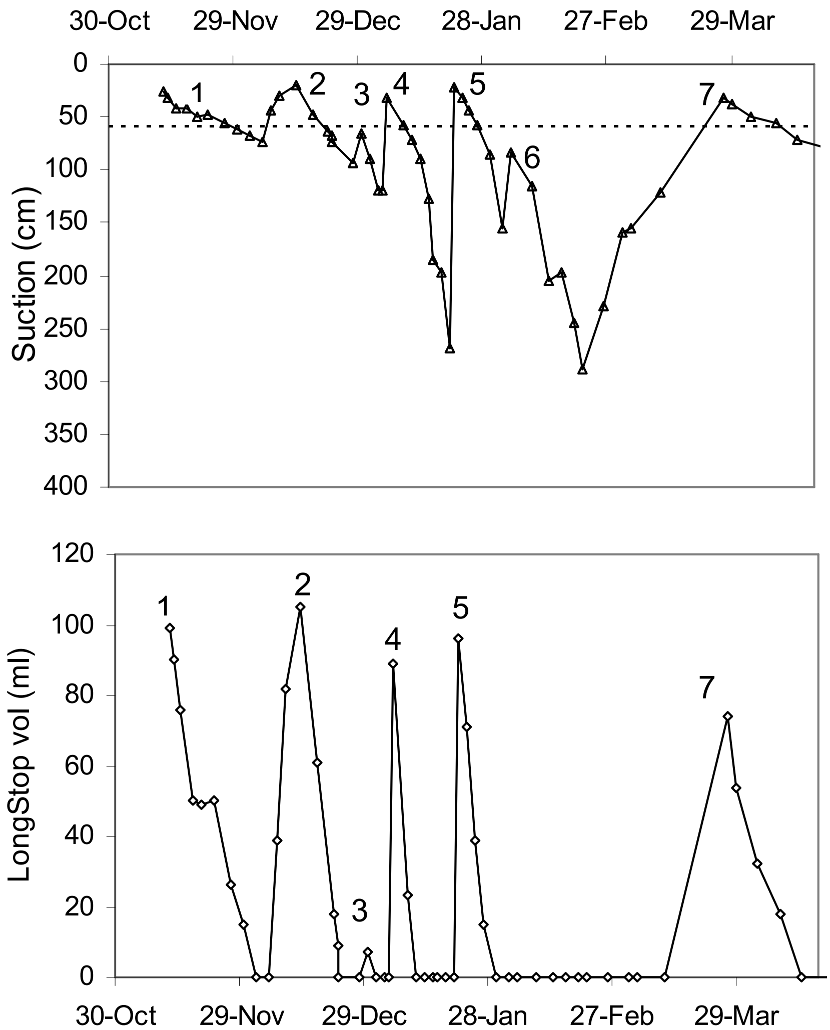

Fig. 4. The soil suction in the 'wick' of the LongStop (top) and the volume of water in the LongStop (bottom). The horizontal dotted line in the top graph demarks the theoretical sensitivity limit of the LongStop, above which the WFD should contain water. The numbers refer to the seven irrigation or rainfall events.