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WATER REDISTRIBUTION WITHIN THE POTATO ROOT ZONE FOLLOWING IRRIGATION

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ABSTRACT: Monitoring crop water uptake and soil water movement within the root zone is critical for designing drainage systems. The objective of this study was to monitor the water movement within the root zone after the soil was fully saturated by irrigation. This experiment was conducted in Winkler, Manitoba, in a potato field instrumented with 15 Time Domain Reflectometry (TDR) miniprobes embedded in a vertical plane within the root zone for each replicate. The TDR miniprobes were installed at five different depths (0.1, 0.2, 0.4, 0.6, and 0.8 m) and at three different radial distances (0.15, 0.3, 0.45 m) from the base of the potato plant. Three such replicates of TDR probes were installed at vertical planes located one meter apart. A 5 m by 5 m area was blocked off, and 50 mm depth of water was applied to bring the soil to saturation within this area. The initial water content measurement prior to this irrigation event and at periodic intervals thereafter was carried out over a four-day period. In general, the volumetric water content showed an increasing trend with depth during the four-day period. However, with time, the water content decreased in every layer except the deepest layer indicating upward movement of water from below the root zone. The results also showed that moisture depletion in the upper layers of soil was replenished overnight. The overnight increase in water content within the root zone can be attributed to capillary rise of water from below the root zone as well as hydraulic lift caused by the potato plants. Hydraulic lift is a phenomenon in which the plant roots act as a conduit, for water transport from deeper layers of soil to the drier shallower layers within the rootzone. This process is enhanced further in the absence of transpiration during the night. This paper presents evidence of this phenomenon in potato plants.

Keywords: TDR miniprobes, soil water redistribution, hydraulic lift in potatoes.

INTRODUCTION Drainage is used in agriculture to reduce soil salinity and improve the yield and quality of the crops. Better understanding of soil moisture movement and crop water uptake is crucial for developing effective irrigation and drainage solutions. However, continuously monitoring the soil water movement while the crops are growing is a challenging task. Since there is a need for repetitive measurements at the same locations within a short time interval, destructive measurements of soil moisture are not suitable for these types of experiments. Time Domain Reflectometry (TDR) and neutron scatter probes are two widely used non-destructive soil moisture-measuring methods.

However, neutron scatter probe poses a health hazard and takes more time for taking readings.

The TDR technique can be used to make repetitive measurements of soil water content non-destructively (Topp and Reynolds, 1998). Another advantage of TDR is that it can be used for making real-time measurement of soil moisture. Multiple TDR probes connected via multiplexers to a data logger enable the collection and analysis of temporal and spatial variation in soil moisture distribution. Flexibility in TDR design, portability of TDR equipment and ease of use allowed researches to measure water content rapidly at field scale (Topp et al. 1996).

Several studies in the past demonstrated that TDR technology could be used to analyse temporal and spatial variability at fine scale resolution (Green et al. 1997; Evett et al. 1993; Topp et al. 1996; van Wesenbeeck and Kachanoski 1998; Li et al. 2002; Polak and Wallach 2001). Green et al., (1997) used TDR technology to monitor soil water status around roots of apple trees during localised irrigation. In this study, 110 mm long TDR probes were used to see the effect of localized drip irrigation. Evett et al. (1993) used a combination of TDR and neutron scatter probe to estimate evapotranspiration (ET) of winter wheat in a lysimeter study and they found this combination had the potential to measure the daily ET accurately. Topp et al. (1996) used TDR probes to observe the diurnal pattern of water uptake and release from corn roots at very fine scale.

van Wesenbeeck and Kachanoski (1988) used TDR probes to monitor spatial and temporal distribution of soil moisture in surface soil layer in corn field. Difference in soil moisture contents was found between row and inter-row positions. Most of the time inter-row position had higher water content than row position. In a different study, TDR probes were used to study the spatial and temporal variation in water uptake by corn (Li et al. 2002). Polak and Wallach (2001) investigated soil moisture variation in irrigated orchard by using TDR probes and gypsum blocks. Coelho and Or (1999) used an array of TDR probes to monitor water uptake by corn plants at fine (0.1 m) spatial and temporal resolution.

Several previous studies have examined the effect of vegetation on water redistribution and other soil properties. Root density, root length, and age of plants, can play a major role in water uptake pattern as well as soil moisture redistribution. Irrigation patterns and methods, and soil hardpan formation also have their effect on water uptake by plants. Stalham and Allen (2004) conducted an experiment to explore the effect of different irrigation regime on potato rooting and water uptake patterns. Potato crops with no irrigation extracted water away from the rooting front while for potato plants with irrigation water uptake was from soil layers shallower than the rooting depth. Soil moisture deficit across the ridge was varied and changed with season. It was found that regardless of water status of the surface layers of soil, roots from deeper layers contributed significantly to water uptake in potato plants.

Maximum rooting density was 5.5 cm cm^{-3} while the potato roots were found to reach deeper layers of soil varying from 59 to 140 cm and 40-73% of roots were distributed within the upper 30 cm of soil (Stalham and Allen 2001). A study by Lesczynski and Tanner (1976) on field grown Russet Burbank potato revealed that root density generally varied from 2 to 6 cm of roots per cm^3 of soil. They found the root density to vary along

with depth as well as throughout the growing season. Iwama (1987) reported variation in root dry weight between different years and within cropping seasons. Tanner et al (1982) studied the effect of hardpan on Russet Burbank rooting and found that root growth below the hardpan was restricted. In corn it was found that younger roots that grow into wetter deeper layers of soil extracted more water per unit length of roots (Taylor and Klepper 1973).

The main objective of this research was to non-destructively monitor the soil water redistribution pattern within the root zone of irrigated potatoes grown in a fine sandy loam soil in Southern Manitoba.

METHODOLOGY This study was conducted in a field located in Winkler, Southern Manitoba during the growing season of 2009. The dominant soil type in this field is Reinland and its surface texture is classified as fine sandy loam (Smith and Michalyna, 1973). A 5m x 5m plot consisting of potato plants in a commercial potato field was selected for this purpose. Potato plants were planted on ridges that are 0.9 m (36 in) apart. Soil moisture probes using TDR technology were installed at five different depths (0.1, 0.2, 0.4, 0.6 and 0.8 m) at three different distance from base of the plant (0.15, 0.30 and 0.45 m). The TDR probes located at radial distances of 0.15 and 0.45 m represent ridge and furrow positions with the probes installed at 0.15 m distance were located deeper to match the elevation of the outer TDR probes. The 15 TDR miniprobes formed an array of probes in the vertical plane and three such planes were used as replicates. All the probes were installed at 60° to horizontal through pilot holes, which were then sealed with bentonite to avoid any preferential flow.

A volume water equivalent to a depth of 50 mm (1.25 m³) was applied onto the 5m by 5 m plot to saturate the soil within this area. The moisture redistribution within the rootzone was thereafter monitored over a period of four days from 31st August to 4th September 2009. Three sets of readings were taken in a day at fixed time windows such as morning (9:30-10:30 am), afternoon (1:30-2:30 pm) and evening (5:30-6:30 pm). A TDR cable tester (Textronix 1502B) was used to measure the volumetric water content of the soil. WinTDR software was used to collect data with a portable computer to control the measurement sequence and to save the waveforms. Multiplexers were used to take sequential readings of each replicate consisting of 15 TDR probes. Multiplexer and cable tester were connected by a 17 m long RG-58 coaxial cable. The TDR readings were corrected for temperature as outlined by Kahimba and Sri Ranjan (2007).

TDR Miniprobos: The TDR miniprobos were fabricated in the lab using RG-58 50 Ω coaxial cable (3m long) and 1.6 mm (1/16th in) diameter stainless steel welding rods. Distance between two outer rods was 10 mm. The TDR probes had three equally spaced steel rods connected to a coaxial cable. The coaxial cable was stripped at one end and the outer wire was soldered with a 0.08 m long U shaped rod that made the two outer prongs of the probe. Another 0.08 m rod was soldered to the central wire of the cable. Rods were placed in a mould made of aluminum and the soldered part of the probe was encased in epoxy resin. The resin was allowed to cure for a minimum of three hours after which the probe was removed from the mould. All the TDR probes were trimmed to a length of 50 mm and calibrated using deionised water. WinTDR software was used to calibrate the TDR miniprobos and the calibration constants were saved for future data acquisition in the field.

RESULTS The main objective of the study was to monitor the dynamic nature of soil water uptake by potato plant roots and the consequent soil water redistribution within the root zone. The use of 50-mm long TDR miniprobos enabled us to monitor the soil water content within a small volume. Sri Ranjan and Domytrak (1997) reported that TDR miniprobos have smaller effective volume compared to the commercial TDR probes that tend to be larger. The miniprobos are also more accurate for point measurements of soil moisture on depth intervals of 0.10 m or less. When a small TDR probe is used, the zone of influence also becomes smaller, thus making the miniprobos ideal for detailed study of rootzone soil water movement.

Results showed that the evapotranspiration during the day depleted the water within the upper portion of the rootzone, which was later replenished by water moving from the surrounding areas during the night. This pattern of fluctuating water content between day and night is seen in Figure 1, which shows the change in moisture content at different depths measured at different radial distance (0.15, 0.30, 0.45 m) from the base of the plant. Soil moisture decreased towards the end of the day and increased overnight due to redistribution. The following day the water content started to decrease again with replenishment during the night. This resulted in a diurnal cycle of soil moisture depletion and replenishment.

When mean soil water contents are compared temporally within the same location, they showed significant differences between the morning and evening most of the time (Table 1). However, this difference was not significant in the deeper layers. Near the soil surface, there was considerable difference in soil moisture with the radial distance from the plant (Table 2) but this difference decreased with depth (Table 3).

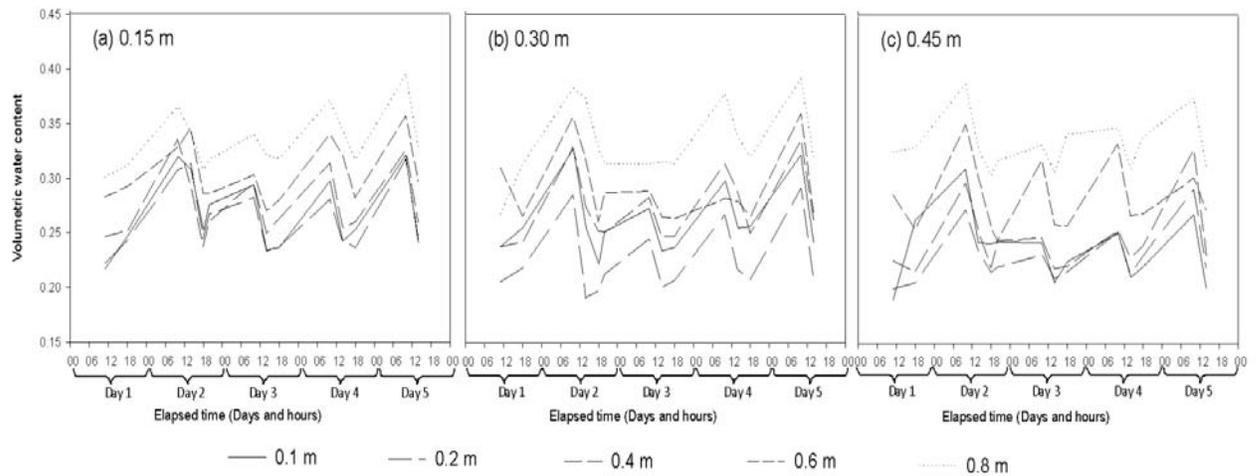


Figure 1 Variation in soil water content measured by TDR miniprobes at different depths positioned from (a) 0.15 m (b) 0.30 m and (c) 0.45 m from plant base. Note that irrigation was done between 12:00 to 1:00 pm of day 1.

Table 1. Comparison of mean volumetric soil water content by time of day.

| Depth | 0.15 m | | | 0.30 m | | | 0.45 m | | |
|-------|---------|-----------|----------|---------|-----------|---------|---------|-----------|----------|
| | Morning | Afternoon | Evening | Morning | Afternoon | Evening | Morning | Afternoon | Evening |
| 0.1 | 0.268 a | 0.215 b | 0.237 c | 0.305 a | 0.247 b | 0.243 b | 0.308 a | 0.257 b | 0.247 b |
| 0.2 | 0.262 a | 0.219 b | 0.217 b | 0.272 a | 0.204 b | 0.208 b | 0.297 a | 0.259 b | 0.240 b |
| 0.4 | 0.281 a | 0.233 b | 0.224 b | 0.316 a | 0.268 b | 0.248 c | 0.318 a | 0.264 b | 0.253 b |
| 0.6 | 0.326 a | 0.275 b | 0.259 b | 0.322 a | 0.283 b | 0.264 c | 0.322 a | 0.309 ab | 0.285 bc |
| 0.8 | 0.360 a | 0.314 b | 0.328 ab | 0.367 a | 0.337 b | 0.319 b | 0.368 a | 0.334 b | 0.314 c |

Letters a to c compare row-wise, the means between different times of day at the same radial distance and depth.

Table 2. Comparison of mean volumetric soil water content by radial distance.

| Depth | Morning | | | Afternoon | | | Evening | | |
|-------|---------|---------|---------|-----------|---------|---------|---------|---------|---------|
| | 0.15 m | 0.30 m | 0.45 m | 0.15 m | 0.30 m | 0.45 m | 0.15 m | 0.30 m | 0.45 m |
| 0.1 | 0.268 m | 0.305 n | 0.308 n | 0.215 m | 0.247 n | 0.257 n | 0.237 m | 0.243 m | 0.247 m |
| 0.2 | 0.262 m | 0.272 m | 0.297 n | 0.219 m | 0.204 m | 0.259 n | 0.217 m | 0.208 m | 0.240 n |
| 0.4 | 0.281 m | 0.316 n | 0.318 n | 0.233 m | 0.268 n | 0.264 n | 0.224 m | 0.248 n | 0.253 n |
| 0.6 | 0.326 m | 0.322 m | 0.322 m | 0.275 m | 0.283 m | 0.309 m | 0.259 m | 0.264 m | 0.285 n |
| 0.8 | 0.360 m | 0.367 m | 0.368 m | 0.314 m | 0.337 m | 0.334 m | 0.328 m | 0.319 m | 0.314 m |

Letters m to t compare row-wise the means between different radial distances at the same depth and time of day

Table 3. Comparison of mean volumetric soil water content by depth.

| Depth | 0.15 m | | | 0.30 m | | | 0.45 m | | |
|-------|----------|-----------|----------|----------|-----------|----------|---------|-----------|---------|
| | Morning | Afternoon | Evening | Morning | Afternoon | Evening | Morning | Afternoon | Evening |
| 0.1 | 0.268 x | 0.215 x | 0.237 xy | 0.305 xy | 0.247 v | 0.243 wx | 0.308 x | 0.257 x | 0.247 x |
| 0.2 | 0.262 x | 0.219 x | 0.217 x | 0.272 x | 0.204 w | 0.208 w | 0.297 x | 0.259 x | 0.240 x |
| 0.4 | 0.281 xy | 0.233 x | 0.224 x | 0.316 y | 0.268 y | 0.248 x | 0.318 x | 0.264 x | 0.253 x |
| 0.6 | 0.326 yz | 0.275 y | 0.259 y | 0.322 y | 0.283 y | 0.264 y | 0.322 x | 0.309 y | 0.285 y |
| 0.8 | 0.360 z | 0.314 z | 0.328 z | 0.367 z | 0.337 z | 0.319 z | 0.368 y | 0.334 y | 0.314 z |

Letters v to z compare column-wise the means at different depths at the same radial distance and same time of day.

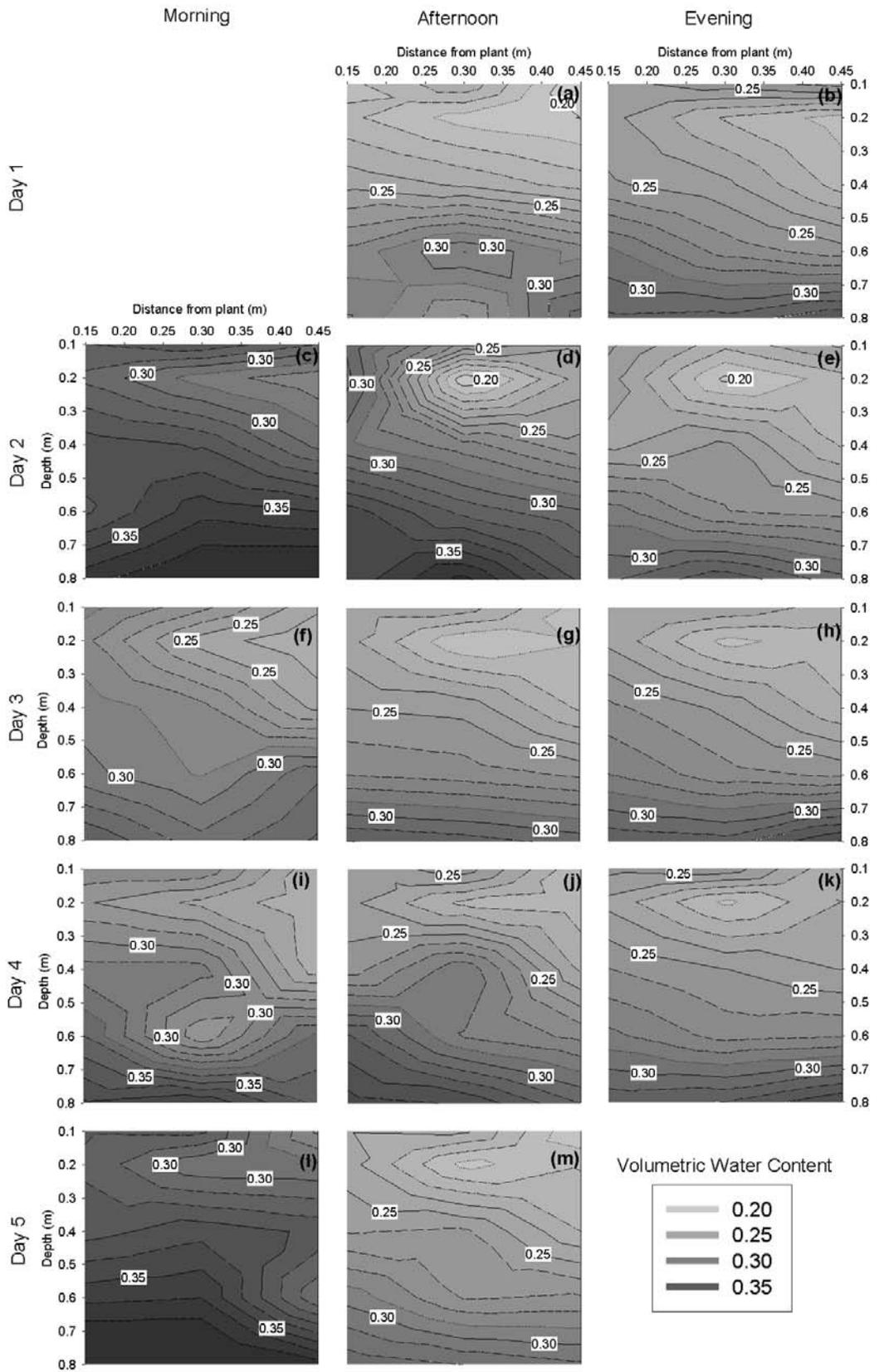


Figure 2 Soil water content distribution shown as contours in the rootzone of the potato plants. Graph (a) shows the soil water content distribution before irrigation and graphs (b)-(m) show water content distribution after irrigation and are in chronological order.

Figure 2 shows the soil water content distribution within the root zone of potato over the entire period of the experiment. When comparing graphs (a) and (b) it is obvious that right after the irrigation event, the soil water content increased. When comparing graphs ((c), (d), and (e)) across a day, generally the soil water content is depleted by evening. In the morning, soil water content status was comparatively higher than during the evening. Interestingly, the following morning, the soil water content increased in comparison to the previous evening (graphs (e) and (f)). Soil water content depleted towards the end of day and had replenished by the following morning. However, there was no irrigation or rainfall event during the experiment beyond the initial wetting. This phenomenon of nocturnal soil water depletion-replenishment cycle continued throughout the experiment showing a distinct behaviour of soil water content redistribution by potato plants. Results suggest that this might be an evidence of hydraulic lift caused by potato plants as well as by capillary rise.

Hydraulic lift is a nocturnal behaviour of some plants, where the plant roots extract water from deeper layers and release it into the upper layers of the soil. (Richards and Caldwell 1987). Richards and Caldwell (1987) reported that experiments with sagebrush (*Artemisia tridentate*) showed pronounced diurnal fluctuations in soil water content. Topp et al. (1996) observed the diurnal pattern of water uptake and release from corn roots and showed that corn roots exudes water during nighttime. Dawson (1993) reported this behaviour in sugar maple when the capillary rise did not completely explain the rewetting of upper soil layers during nighttime.

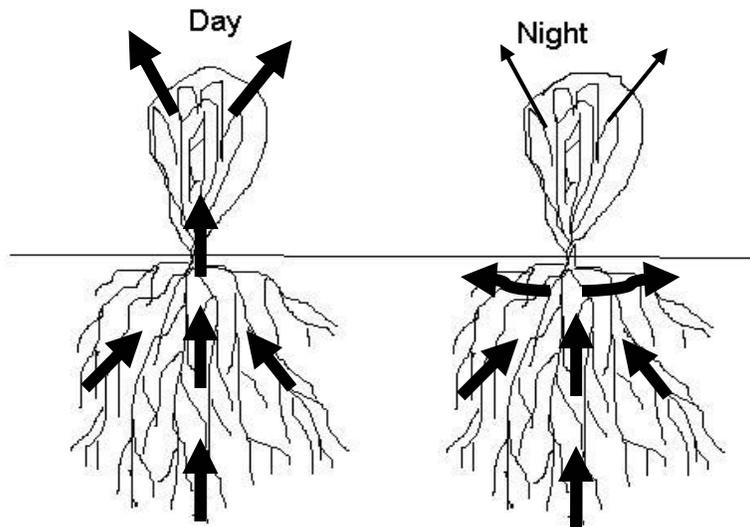


Figure 3: Hypothesised model of hydraulic lift by plants showing water movement during day and night (based on Caldwell, et al. 1998).

Figure 3 shows water movement in a hypothesised model of a plant during the day and at nighttime showing hydraulic lift. Plants draw water from all depths during the daytime and it became part of the transpiration stream. When transpiration decreased during the night, water passively moves down a water potential gradient. If the shallower layers of soil are dryer than the deeper layers, then water will move from deeper layers to the shallower layers (Caldwell, et al. 1998).

CONCLUSION Advances in the TDR technology along with data logging and multiplexing make it possible for point-measurements of soil water content on multiple spatial and temporal dimensions at a fine resolution. Monitoring and understanding soil water uptake and redistribution by crops is a useful undertaking in any drainage related studies. When a potato field is monitored after an irrigation event, a unique pattern of nocturnal soil water movement was observed. This resembles a phenomenon reported by other authors as hydraulic lift in other plants. However, further detailed studies are required to validate and quantify the effect of hydraulic lift and separate it from capillary rise.

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