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Shallow groundwater uptake and irrigation water redistribution within the potato root zone

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ABSTRACT

Knowing the crop water uptake pattern and soil water movement within the root zone is important for the optimum design of irrigation and drainage systems. The objective of this study was to monitor the soil water redistribution within the potato root zone after irrigation and to quantify shallow groundwater contribution to water use by potatoes. The water uptake pattern in a vertical plane was monitored by TDR miniprobes installed at five different depths and at three different radial distances from the base of the potato plants. Three such planes of TDR miniprobes were used as replicates. The soil within the root zone was brought to field capacity by surface application of water. The water content measurements were carried out prior to this irrigation event and at periodic intervals thereafter over a four-day period, three times/day. The groundwater level was measured at 3 h intervals. Soil core samples were taken at each TDR probe location to determine the root density. The soil water content and upward flux from the groundwater was simulated using HYDRUS-1D model and the results were compared with the upward flux estimated from the change in groundwater levels. The maximum root density was found to be 14.5 and 252 g/m^{-3} at two and three months after planting. Soil layers at shallower depths showed signs of drying while the deeper layers remained wet. Model simulations closely matched the measured soil water contents and upward flux. In a fine sandy loam, up to 92% of the crop water demand was met by capillary rise from the shallow groundwater table. Knowing the shallow water table contribution can decrease the net depth of irrigation water applied and save water and energy needed for pumping.

1. Introduction

Potato is a shallow rooted and moisture sensitive crop and moisture stress can cause negative impacts on yield and quality of potato. The pattern of redistribution of irrigation water within the root zone is important for designing the irrigation systems. Measuring both the water redistribution pattern within the potato root zone as well as the root distribution will help determine the water uptake pattern during the growing season.

A better understanding of soil moisture movement and crop water uptake is crucial for developing effective irrigation and drainage systems. However, continually monitoring the soil water content at discrete locations while the crops are growing is a challenging task because it precludes the use of destructive methods for soil moisture measurement. Time domain reflectometry (TDR) is a widely used non-destructive technique to measure soil water content and has been used in the past to make repetitive measurement (Topp et al., 1980, 1996; Dalton and Van Genuchten, 1986; Topp and Reynolds, 1998a,b; Sri Ranjan and Domytrak, 1997).

Several studies in the past have demonstrated that TDR technology can be used to analyse temporal and spatial variability of water content at fine scale resolution (Green et al., 1997; Evett et al., 1993; Topp et al., 1996; van Wesenbeeck and Kachanoski, 1988; Li et al., 2002; Polak and Wallach, 2001).

Water and nutrient redistribution within the root zone of agricultural crops is greatly affected by plant water uptake. Therefore, knowing the root distribution is crucial for understanding the water uptake pattern. The type of measurement of root distribution, either weight-based or root length-based, is largely determined by the purpose for which the information is collected (Smit et al., 2000). In this study, the root mass distribution was used as a measure of the ability of the root zone to uptake water from a particular location.

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 further away from the rooting front while for potato plants with irrigation extracted water from soil layers shallower than the rooting depth. It was found that regardless of water status of the surface

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layers of soil, roots from deeper layers contributed significantly to water uptake in potato plants. Cooley and Lowery (2007a,b) monitored soil water content dynamics under potato hill using an array of 8 TDR probes to compare drip and sprinkler irrigation.

Wang et al. (2006) examined the effects of different irrigation treatments on the root development of potato crops, in Northern China, by measuring both the root-length density and root dry weight density. Although root-length density is most commonly used to describe the extent of the root systems of agricultural crops, the root weight density provided a more accurate description of the root system of potatoes due to the thinness of the roots (Wang et al., 2006). Although potato roots were found at depths up to 140 cm, a majority of them were distributed within the top 30 cm (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. Iwama (1988) 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.

Use of shallow groundwater would help to reduce the volume of water required for irrigation and amount of water disposed through drainage. White (1932) was one of the first few authors to investigate the groundwater contribution towards crop water requirement. Grismer and Gates (1988) presented groundwater contribution in the form of a nomograph which shows the contribution to ET of cotton from the groundwater table as a function of depth to groundwater for different textural classes. In a review summarised by Ayars et al. (1999), the saline groundwater was found to supply up to 45% of the water requirement of cotton. Crop salt tolerance, groundwater quality, rooting depth, depth to groundwater, soil type, and presence of compact layer were the main factors that could affect the beneficial use of shallow groundwater. Groundwater use potential increases as the root depth and the density increases (Ayars et al., 1999, 2006). Babajimopoulos et al. (2007) reported up to 18% of groundwater contribution under maize.

The main objectives of this research were (i) to non-destructively monitor the soil water content redistribution pattern within the root zone after irrigation, and (ii) to model the shallow groundwater contribution to water uptake by potatoes grown in a fine sandy loam soil in Southern Manitoba.

2. Materials and methods

This study was conducted in a potato field, which is commercially operated by Hespler Farms, south of Winkler, Manitoba during the growing seasons of 2009 and 2010. The dominant soil type is a ‘Gleyed Rego Black Chernozem’ according to the Canadian System of Soil Classification and its surface texture is classified as fine sandy loam (Smith and Michalyna, 1973). Average bulk density, field capacity, porosity, sand, silt and clay fractions were 1450 kg m^{-3}, 31.2%, 45.3%, 67.7%, 20.8% and 11.5%, respectively. A 5 m × 5 m plot consisting of potato plants within a potato field was selected for this study. Potatoes (Russet Burbank) were planted on ridges spaced 0.9 m apart. Within the row, seed potatoes were planted approximately at 0.35 m spacing and approximately at 5–10 cm depth. The vertical profiles of the ridges were determined and the ridges reached an average of 0.125 m above the furrow bottom, which was used as the datum for the depth measurements. 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 distances from the base of the plant (0.15, 0.30 and 0.45 m in 2009). These horizontal distances from the base of the plants are based on the crop spacing as well as mapping the root water uptake close to the roots of the crop. The TDR probes located at radial distances of 0.15 and 0.45 m represent ridge and furrow positions. 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 arrays were used as replicates for a total of 45 miniprobes. In 2010 growing season, the spacing of the TDR miniprobes was at 0.07, 0.22, and 0.37 m radial distances from the base of the plant. The distance was closer than that was used in 2009 to place the TDR miniprobes closer to the more dense area of root development. However, the depths of installation of the probes were similar to 2009. A detailed description of the TDR probe locations in relation to the potato plant is given in Fig. 1.

2.1. TDR miniprobes

The TDR miniprobes used for this project were three pronged, 50 mm long probes with the distance between the two outer waveguides being 10 mm. The TDR miniprobes were fabricated in the lab using RG-58 50 Ω coaxial cable (3 m long) and 1.6 mm (1/16 in.) diameter stainless steel welding rods. The TDR probes had three equally spaced steel rods connected to a coaxial cable. The outer two guides were made by bending a 0.16 m long rod into a U-shape. The coaxial cable stripped at one end and the shielding wire was soldered onto the curved part of the U-shaped rod. Another 0.08 m rod was soldered to the centre wire of the coaxial cable. Rods were placed in an aluminium mould and the soldered part of the probe was encased in epoxy resin. The resin was allowed to cure overnight after which the probe was removed from the mould. All the TDR probes were trimmed to a length of 50 mm and calibrated using de-ionised water at a known temperature. The WinTDR software (Department of Plants, Soils and Biometeorology, Utah State University, Logan, UT, USA) was used to calibrate the TDR miniprobes and the calibration constants were saved as probe constants within the software.

2.2. Installation of TDR miniprobes

Installation of the probes in the field required the use of a 60° metal triangular frame as a guide that was kept in place while a metal rod, the same diameter as the TDR probe, was hammered into the ground to create the access hole to the desired depth. The metal rod was pulled out of the soil carefully. Using the metal stand as a guide, another guide rod with a c-shaped end was used to hold the TDR miniprobe which was inserted through the access hole to the desired depth. The guide rod was then pulled out of the ground, leaving the TDR miniprobe embedded at the desired depth below the ground surface. To seal the access hole, the annular space between the coaxial cable within the hole was back-filled with crushed bentonite pellets as described by Kahimba and Sri Ranjan (2007).

2.3. Irrigation

In 2009, 50 mm depth of water was applied onto approximately 25 m^2 (5 m × 5 m) plot to saturate the soil within this area to bring it to field capacity. In 2010, the irrigation requirement to bring the soil to field capacity was calculated based on the lowest TDR reading obtained prior to irrigation. Irrigation amounts applied on 28th June, 26th July and 16th August of 2010 were 24, 51 and 62 mm respectively. Any rainfall received during the period of the experiment also contributed towards the experiment.

2.4. TDR data collection

The volumetric water content was measured both before irrigation and at three different times within the day during the