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Subsurface drainage for promoting soil strength for field operations in southern Manitoba

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ABSTRACT

Successful field operations depend on the ability of the soil to provide traction and support for agricultural traffic and be workable in a desirable manner. This minimizes the risk of soil structural damage to ensure soil conservation and long-term crop yield. In the present study, the objective was to evaluate the performance of subsurface drainage in promoting soil strength for field operations in southern Manitoba. Data obtained from a field study and modeling exercise were used to achieve the objective. The field data include soil water content and watertable depth, which were measured in a potato field during the 2011 growing season. Soil samples were also collected from the field to determine the lower plastic limit (LPL) of the soil. Seventeen-year weather data were used to estimate the reference crop evapotranspiration. The soil strength of drained and undrained sandy-loam fields was compared to evaluate subsurface drainage in promoting soil strength for field operations. The subsurface tile drain was installed at 0.9-m depth and at 15-m spacing. A validated HYDRUS (2D/3D) model was used to extend the study by simulating soil water content dynamics due to different drain spacings (8 m, 10 m, 12 m, 15 m, 20 m, and 30 m) for different years and weather conditions. The soil strength to allow field operations was assessed based on soil water content corresponding to 90% of the LPL in the top 0.3-m depth of the soil, and soil water content corresponding to the LPL in the soil layer between 0.3-m to 0.5-m depth of the soil profile. The soil strength was sufficient to allow field operations when the two criteria were met. In the top 0.3-m depth, the soil strength was sufficient to allow field operations for all the years with or without drainage. Drainage impact was found to be more significant within the 0.3-m to 0.5-m depth of the soil profile throughout the years. Drain spacing less or equal to 12 m promoted soil strength to allow field operations without any significant impact on the number of field workable days during the growing season.

1. Introduction

Soil strength plays a key role in planning field operations for optimum crop yield. During field operations, the soil should have the ability to provide traction, and support for agricultural traffic and be workable in a desirable manner (Earl, 1997). Field operations performed on wet soil result in compaction (Müller et al., 2011). Compacted soil limits water movement, which leads to ponding and decreases the availability of water and nutrient for crop growth and performance. Compacted soil also restricts root development, which can cause yield losses in the short term and poor soil structural generation and regeneration in the long term (Whalley et al., 1995; Alakukku et al., 2003). Poor soil structural generation and regeneration result in the inability of the soil to absorb high intensity rainfall leading to anaerobic soil conditions that promote the leaching and accumulation of toxic substances, which are harmful to the crops (Whalley et al., 1995; Shaw and Meyer, 2015).

Drainage systems have been useful in removing excess soil water from fields with "poor" natural drainage to improve the soil strength for timely field operations and minimize soil compaction (Madramootoo et al. 2007; Abid and Lal, 2009; Jia et al. 2008; Müller et al. 2011). Drainage also extends the growing season especially in fields under freeze-thaw conditions (Cordeiro, 2014). It improves the soil water content for enhanced nutrient uptake and aeration for root metabolism and development (Wang et al., 2016; Kaur et al., 2017). It also leaches accumulated salts in the root zone for improved crop production (Cordeiro, 2014). The main types of field drainage systems are surface and subsurface drainage systems. The surface drainage systems remove excess water from the land by lateral flow due to impeded infiltration and percolation at shallow depth by poorly permeable layers (Smedema

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et al., 2004). Subsurface drainage systems are useful when soil water is able to percolate through the soil to recharge the groundwater. They remove gravitational water in the soil profile by means of buried perforated corrugated pipes to lower the watertable (Guitjens et al., 1997; Cordeiro, 2014). Subsurface drainage is often superior to surface drainage by allowing more timely field operations (Paul and De Vries, 1979; Müller et al., 1990; Evans et al., 1996; Müller et al., 2011).

In southern Manitoba, farmers experience excess soil water content at the beginning of the growing season following snowmelt and occasionally with heavy rainfall at mid-season or at the time of harvest due to the "imperfect" to "poor" drainage characteristics of many agricultural soils in the region (Eilers et al., 2002). Delays in seeding, mid-season input application or harvest lead to yield losses and crop quality deterioration (Angadi et al., 2004; McKenzie et al., 2011), and thus have a significant economic impact on the agriculture industry. Surface drainage has been used for many years in this region to improve drainage, but subsurface drainage is a recent addition (Dietz, 2010). Subsurface drainage in this region improved corn yield by 10–15% (Cordeiro, 2014) and potato yield by 20–30% (Satchithanantham, 2013). The objective of this study was to assess the performance of subsurface drainage in promoting soil strength sufficient to allow field operations without significant damage to the soil structure.

2. Materials and methods

2.1. Field characteristics

A field study was carried out in a potato field operated by the Hespler Farms during the growing season (i.e. from June 3 to September 24) of 2011. The farm is south of Winkler (49° 10`N Lat., -97° 56`W Long., 272-m elevation) in the Rural Municipality of Stanley, Manitoba, and it is within the fertile western section of the Red River Valley (Eilers et al. 2002). The topography of the study site is "nearly level" with a slope ranging from 0.5%–2%. The soil at the study site is classified as Reinland series with "imperfect" internal drainage (Smith and Michalyna, 1973). The Reinland series is made up of Gleyed Carbonated Rego Black soils (Smith and Michalyna, 1973), which corresponds to Udic Boroll subgroups in the US soil taxonomy (Soil Classification Working Group, 1998). The soil textural class at the study site was sandy loam with average textural percentages of 70% sand, 19% silt, and 11% clay. These average textural percentages were based on soil samples obtained down to 1.2 m depth of the soil profile. An impermeable layer of clay was located at 6 m below the soil surface (Cordeiro, 2014).

The field had dimensions of 300 m × 84 m with 12 subplots. The dimensions of the subplots were either 50 m × 44 m or 50 m × 40 m. There were four watertable management systems tested in this field. They were subsurface free drainage with overhead irrigation (linear move irrigation system, O3000 Orbitor, Nelson Irrigation Corporation, Walla Walla, WA) (FDIR), subsurface controlled drainage with sub-irrigation (CDSI), no drainage with overhead irrigation (NDIR) and no drainage with no irrigation (NDNI). Each water management system was applied to three plots. Details of the field layout showing the different water management systems are given in Satchithanantham (2013). In the present study, the data obtained from the FDIR and NDNI replicated plots were used to assess subsurface drainage impact on soil strength. The FDIR plots were installed with three lateral drains made of perforated and corrugated plastic pipes with 0.1 m internal diameter (Satchithanantham, 2013).

2.2. Data collection

For each plot, soil water content and watertable depth were monitored from June 3 to September 24, 2011. The watertable depth was monitored at three-hour intervals over the experimental period with water level sensors (Solinst Leveloggers Junior 3001, Solinst Canada Ltd., Georgetown, ON, Canada) hung inside piezometers. The piezometers (41.3 mm internal diameter and 2.51 m length schedule 40 steel pipe) were installed to a depth of 2.2 m from the soil surface at the center of each of the NDNI plots and midway between two lateral drains of each of the FDIR plots (Satchithanantham, 2013). The screen depth of the piezometers was 1.6 m from the tip at the bottom. The sensors had a calibrated range of 0 to 5 m with an accuracy of 0.1% full scale or ± 0.006 m (Solinst Canada Ltd., 2011). The three-hour-interval data obtained were averaged for daily watertable depth.

The volumetric soil water content (θ) was measured at three-hour intervals with dedicated EC-5 (Decagon Devices, Inc., Pullman, WA, USA) probes on each plot. The EC-5 probe determined the volumetric soil water content using the frequency domain technique operating at a frequency of 70 MHz (Decagon Devices, Inc., 2016). The EC-5 probes were telemetrically connected to the Weather Innovations Network to provide real time soil water content data through their website. The EC-5 probes were installed at five depths, which were 0.2 m, 0.4 m, 0.6 m, 0.8 m and 1.0 m) (Satchithanantham, 2013). The three-hour-interval data obtained were averaged for daily volumetric soil water content.

Weather data were acquired for the study area from the Environment Canada website in addition to data obtained onsite and from a nearby weather station (Canada-Manitoba Crop Diversification Centre, Winkler) to estimate reference crop evapotranspiration. The nearby weather station was about 2-km east from the study site. Three-year (year 2010 to 2012) weather data including precipitation, temperature, wind speed, relative humidity, and solar radiation data were collected using a Watchdog Weather Station (WatchDog 2900 ET, Spectrum Technologies, Inc., Plainfield, IL, USA) located onsite and from the nearby weather station (Satchithanantham, 2013). The data obtained onsite and from the nearby weather station were used to determine the reference crop evapotranspiration (ET_o) using the Penman-Monteith equation (Allen et al. 1998). For the HYDRUS (2D/3D) simulation exercise, seventeen years of weather data (year 2000 to 2016) including precipitation, minimum temperature, maximum temperature, and relative humidity were obtained from Environment Canada website (Environment Canada, 2017). These years were considered due to data unavailability prior to the year 2000. The minimum temperature, maximum temperature, and relative humidity data were also used to determine ET_o as proposed by Maulé et al. (2006). The reference crop evapotranspiration data obtained from both methods for years 2010 to 2012 were compared to ascertain the efficiency of the method proposed by Maulé et al. (2006). The data from the two methods compared reasonably well (results not shown). The method proposed by Maulé et al. (2006) accounted for more than 70% of the variation in the data obtained using the Penman-Monteith equation. The ET_o data obtained for the seventeen years using the method proposed by Maulé et al. (2006) was used as input data in the HYDRUS (2D/3D) modeling exercise to predict the soil water content changes due to different weather conditions and drain spacings.

2.3. Criteria for soil strength to allow field operations

Subsurface drainage impact on soil strength was assessed within the top 0.5-m-layer of the soil profile, which is mostly influenced by field operations (Cordeiro, 2014). To define the criteria for soil strength to allow field operations in the present study, two layers were considered. Layer one was from the soil surface to 0.3 m depth, and the second layer, was from 0.3-m to 0.5-m depth. Water content less than or equal to 90% of the lower plastic limit (0.9-LPL) of the soil was used for the top 0.3 m depth to ensure that the soil has sufficient strength to meet traction requirements and allow equipment to be maneuvered in a desirable way. In the second layer (0.3 m - 0.5 m), due to a higher average bulk density of 1370 kg m^{-3} compared to 1030 kg m^{-3} of layer one, soil water content corresponding to the LPL was used to assess its suitability to allow field operations. This is because at relatively high bulk density, the soil susceptibility to compaction is low (Imhoff et al.,