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Potato canopy growth, yield and soil water dynamics under different irrigation systems

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ABSTRACT

The aim of this research was to compare two irrigation and N application systems, gun irrigation (GI) and drip fertigation (DF), in terms of soil water dynamics, N uptake, N use efficiency, and yield of table potatoes. Two treatments were set up in a three-year field experiment. Treatments differed by irrigation and N application methods, and scheduling. Water and N management in GI was managed according to typical best-practice while irrigation and N for DF was applied through drip fertigation according to a crop simulation model. Results showed that DF provided high soil water content at the center of the ridge. Average soil water content across the ridge soil profile was higher for DF than GI. Compared to DF, GI led to relatively high canopy growth early in the season through applying all N at planting, while the opposite trend was detected later in the growing season. Tuber yields in GI were 46, 43 and 44 t ha^{-1} in 2013, 2014 and 2015, respectively. Tuber yields in DF were 48, 43 and 40 t ha^{-1} in 2013, 2014 and 2015, respectively. There was no significant difference in yield between systems for any of the three seasons of the experiment. However, DF led to significantly higher tuber N recovery and agronomic N use efficiency in one of the years (2013). In addition, GI caused greater nitrate leaching during the growing season in both 2013 and 2014, as measured by suction cups and simulated by the Daisy simulation model.

1. Introduction

Due to its sparse root system, potato production is strongly influenced by drought timing, severity, and duration (Porter et al., 1999; Onder et al., 2005; Ünlü et al., 2006). In Denmark, arable land for potato is dominated by coarse-textured soil, which has low water holding capacity, highlighting the necessity of irrigation to maintain yield and quality (Shock et al., 1992; Shock et al., 2007).

Irrigation for potato production in Denmark is done almost solely by traveling gun irrigation (GI), a type of sprinkler system. The main advantage of GI is that it can be set up easily and rapidly. Nevertheless, water is susceptible to evaporation and wind losses (Kendy et al., 2006; Bavi et al., 2009), often in the range of 10–20% (Aslyng, 1978) but up to 40% or more in some cases (Yazar, 1984; Kincaid et al., 1996). GI also results in further water loss through leaf interception, which increases with canopy growth. In addition, it is hard for sprinklers to apply irrigation in a uniform way, i.e. the soil wetting pattern across the field is often uneven (Saffigna et al., 1976; Stieber and Shock, 1995; Robinson, 1999; Starr, 2005). As a large proportion of GI-applied water concentrates in the furrows, the water is at risk of deep percolation, which is often associated with N loss by nitrate leaching (Jury et al., 1976; Starr, 2005). Since water uptake occurs mostly in the potato ridge (Starr et al., 2008), the efficiency with which an irrigation system supplies water to the ridge will increase water use efficiency (WUE). An alternative irrigation system to GI is drip irrigation, which can save water by applying water close to the base of the plant (i.e. the ridge center) and only wetting a small area of soil. Drip irrigation is a more water efficient alternative to traditional sprinkler irrigation systems for potato (Waddell et al., 1999; Starr, 2005; Wang et al., 2006; Patel and Rajput, 2007).

Drip fertigation (DF), which supplies soluble fertilizer through drip irrigation lines, is a technique that combines drip irrigation with fertilization. One merit of DF is its flexibility to conduct in-season split fertilization, which can reduce nitrate leaching and increase nitrogen use efficiency (NUE) compared to the usual practice of applying all N at planting. Most of the potato rhizospere is confined to a small area (Lesczynski and Tanner, 1976; Asfary et al., 1983), especially during early stages of growth. Applying all the basal N at one time will potentially increase N loss by nitrate leaching and leave inadequate N available for crop use at later stages. By applying N continuously

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throughout the season, DF is a promising means for maintaining N concentration in the soil without undue leaching losses (Papadopoulos, 1988; Hebbar et al., 2004), as well as maintaining LAI, crop N concentration, and ultimately tuber yield (Hebbar et al., 2004).

A wide array of studies have derived optimal application rates of N for potato production (Meyer and Marcum, 1998; Badr et al., 2012), but these results were relatively static and did not consider how N mineralization in the root zone depends on varying environmental conditions. For example, soil texture, root depth, mineralization of soil organic matter, and climate have significant effects on N availability in the root zone of potato and N requirements. To assess N dynamics in both crop and soil and estimate crop N requirements, crop models have been developed and used under varying environmental conditions (Peralta and Stockle, 2002; Van Delden et al., 2003). Daisy (Hansen et al., 2012) was chosen to simulate N dynamics and subsequently guide in-season N fertigation in the current study, and a description of the model is presented in the M&M section of this paper.

The objective of the study was to explore the response of crop growth, tuber yield and soil water dynamics under two irrigation systems: conventional gun irrigation (GI) and drip fertigation (DF). The hypothesis was that compared to DF, GI may lead to inadequate soil water content in the center of the ridge, which in turn causes lower N uptake, tuber yield, and N use efficiency.

2. Materials and methods

2.1. Site description and crop management

Three field experiments with potato (*Solanum tuberosum L. cv. Folva in 2013 and cv. Sava in 2014 and 2015*) were carried out at Jyndevad Research Station, Denmark (54°53′60″N, 9°07′30″E). The soil at this experimental site was a coarse-textured sandy soil containing ca. 76% coarse sand (0.2–2.0 mm), 15% fine sand (0.02–0.2 mm), 4% silt (0.002–0.02 mm) and 3% clay (< 0.002 mm).

The plant available water capacity is about 67 mm in the top 60 cm of soil. Further details on soil properties are described in Zhou et al. (2016). The annual average precipitation is 1000 mm.

When the soil temperature was at least 8 °C at 0.10 m soil depth, mother tubers were planted 0.08 m below ground level. Mother tubers were ridged with 15 cm of soil. The plant density was 49382 plants per hectare. Planting occurred on 15th May, 10th April and 23th April, and emerged 7th June, 21th May and 27th May for 2013, 2014, and 2015, respectively. Fungicides were sprayed to control fungal diseases.

2.2. Daisy crop model description

Daisy simulates soil water, carbon, N balances, heat, and crop production in agro-ecosystems under various management strategies (Hansen et al., 2012). Soil water balance is described by a numerical solution to the Richards equation (in 1-D or 2-D), and the saturated water flow is described by Darcy's equation (Hansen et al., 1990). Root water uptake is simulated by the single root concept (Hansen and Abrahamsen, 2009). Photosynthesis is simulated by a simple light response curve (Hansen, 2002). Weather data (solar radiation, mean air temperature, precipitation, wind speed and relative humidity) were measured at the Danish Met Office meteorological station situated within 1 km from the field site. Management practices (irrigation and N application) were recorded daily. To estimate the initial soil water and mineral N content at the start of each season, Daisy was run with a warm-up period of 10 years using the historical weather and crop rotation records. Daisy has been demonstrated to excellently simulate dry matter and N balance in soil-crop-atmosphere systems in Danish and other European condition (Heidmann et al., 2008). Moreover, Daisy potato module was calibrated by Heidmann et al. (2008) under the drip irrigation and sandy soil conditions prior to the current study, and the potato variety *Folva* used in the current study (only year 2013) has been parameterized and included in Daisy (Heidmann et al., 2008). Therefore, the model calibrated prior to the current study provides a starting point for using Daisy as decision support tool for N and irrigation scheduling.

2.3. Experimental design

Two treatments representing different systems were set up in each season: gun irrigation ($G_{ds}N_{120}$) and drip fertigation ($F_{ds}N_{ds.}$).

Irrigation was initiated when plant height was approximately 15 cm. Irrigation of $G_{ds}N_{120}$ was scheduled whenever the soil water deficit exceeded 25 mm, using the results calculated in Daisy. The upper threshold of soil moisture was field capacity (FC, volumetric), which was determined at the start of season with the Time Domain Reflectrometry (TDR-100; Campbell, Logan, Utah, USA) equipment. Irrigation of $F_{ds}N_{ds}$ was scheduled every two days according to the preceding two days of soil water use, which was also simulated using Daisy. The upper threshold of soil moisture for $F_{ds}N_{ds}$ was 90% FC. Drip lines with an emitter (1 l h^{-1}) distance of 0.20 m were buried 0.03 m below the surface of the ridge.

Both treatments had 30 kg P ha^{-1} and 180 kg K ha^{-1} applied at planting. 120 kg N ha^{-1} was applied to $G_{ds}N_{120}$ as a basal dressing at planting. N fertilization scheduling for $F_{ds}N_{ds}$ followed Daisy model simulations of N demand, based on critical (N_c), actual (N_a) and potential (N_p) uptake levels of N in the crop (Hansen et al., 1991). A fertilization amount of 20 kg N ha^{-1} was applied to $F_{ds}N_{ds}$ whenever N_a uptake approached the critical value N_c, which is the model threshold for N stress negatively affecting crop growth. More details on the N uptake module of Daisy are described in Zhou et al. (2017). Fertigation N was given as a mixture of ammonium nitrate and calcium nitrate (N ratio 1:2).

The experiment was a randomized complete block design with 4 replicates. This resulted in 8 plots in total, which were aligned in a north-south direction. Individual plots were 6 m wide and 10.3 m long. Adjacent plots were separated by a buffer zone (4 m wide) to prevent overlap of different irrigation systems. Shelters (3 m × 6.5 m) were used to cover the $F_{ds}N_{ds}$ when $G_{ds}N_{120}$ was receiving irrigation.

2.4. Soil water content

Soil water content was measured manually in two replicates of all irrigation treatments every two days before irrigation. Equipment used was a handheld computer (Allegro, Juniper Systems, Inc. Logan, Utah, USA) connected to vertically installed TDR-probes located at depths of 77, 60, and 43 cm measured, respectively, from the top of the ridge (A), midway between the ridge and furrow (B), and from the base of the furrow (C) (Fig. 1). Details of the probe design and TDR-trace interpretation software are given by Thomsen (1994), and soil moisture content calculations by Shahnazari et al. (2007).

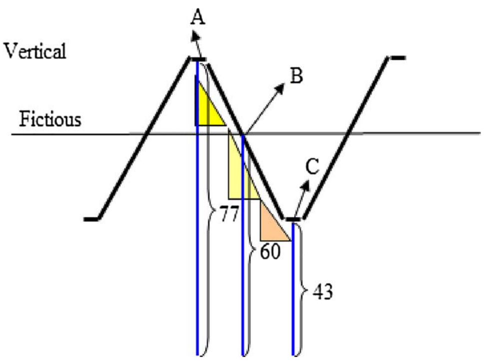

Fig. 1. Schematic of the TDR installation.