Agricultural Water Management 165 (2016) 230–236

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Impact of soil moisture and temperature on potato production using seepage and center pivot irrigation

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ARTICLE INFO

Article history:
Received 23 June 2015
Received in revised form 19 October 2015
Accepted 25 October 2015
Available online 18 November 2015

Keywords:
Irrigation
Water table
Potato yield
Volumetric soil water content
Soil temperature

ABSTRACT

Irrigation, soil moisture and temperature play an important role in potato production. This field study was conducted at a private potato farm in SW Florida from 2012 to 2014. The randomized complete block design was used: four production farms each with a pair of seepage and hybrid center pivot irrigation systems. Soil moisture and temperature at five soil depths, rainfall, and water table in situ were monitored. Nitrate levels at the top 20 cm soils were measured at harvest in the second growing season. Water usage was calculated by the flow meters and rain gauges. Potato yields were measured. The stepwise linear regression showed that the potato yield was mainly regulated by the surface (10 cm) soil temperature and soil water moisture at 20 and 30 cm depths. Hybrid center pivot can save more than 50% of irrigation water without significant yield loss, suggesting center pivot has great potential in water savings. Hybrid center pivot irrigation had relatively low nitrate concentrations at the top 20 cm soil, indicating a new fertilizer program may be needed for overhead irrigation.

1. Introduction

Potato (*Solanum tuberosum* L.) is a shallow rooted crop and extremely sensitive to water stress (Jefferies and Heilbronn, 1991; Fabeiro et al., 2001; Alva et al., 2012). The deficit irrigation is not practical for commercial potato production (Alva et al., 2012). Florida is ranked 7th nationally for its potato production with a value of $ 146 million and produces one-third of the winter/spring crop in the nation (Mossler and Hutchinson, 2014). Because of its high economic value, growers may opt to apply excessive amounts of water and nutrients as an "insurance" to minimize production risks (Trippensee et al., 1995).

Seepage irrigation for commercial potato production is the predominant practice in Florida (Smajstrla et al., 2000; Zotarelli et al., 2013a). With seepage irrigation, the water table is managed based on the target depth to irrigate the crop. This type of irrigation involves pumping groundwater to maintain the desired depth to the water table. The water table in the field is controlled at a depth just below the plant root zone by either adding or removing water from the field. As a result, seepage irrigation is likely to input excessive water to raise the water table, which frequently results in water and nutrient/fertilizer loss through deep drainage and runoff. In contrast, sprinkler irrigation, namely, overhead irrigation has greater water-use efficiency compared to seepage irrigation (Simonne et al., 2002). Overhead irrigation has also shown potential to improve water quality by reducing nutrient leaching associated with high irrigation volume application (Singh et al., 2011).

Using soil moisture measurements is one of the best and simplest ways to get feedback to help make improved water management decisions (Peters et al., 2013). Soil moisture sensors can be used to determine the appropriate interval between irrigation events, depth of wetting, depth of extraction by roots and adequacy of wetting (Hanson et al., 2000). Besides, soil temperature can affect soil microbial processes and the nutrient movement in the soil, which will further have a great influence on plant growth (Wilkinson 1967; Power and Willis, 1975; Reddell et al., 1985). Both soil water and temperature have been shown to influence potato plant growth and tuber production (Epstein 1966; Singh 1969; Wang et al., 2005). Various models have been developed to predict potato yields, among which soil water and temperature are considered as the core parameters (Hartz and Moore, 1978; MacKerron and Waister, 1985; Jefferies and Heilbronn, 1991; Kooman and

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http://dx.doi.org/10.1016/j.agwat.2015.10.023
0378-3774/

Table 1
Soil particle size distributions of the four farms.

Farm ID	Sand (%) >0.05	Silt (%) 0.05–0.002	Clay (%) <0.002
1	94.8 ± 0.2	1.9 ± 0.2	3.3 ± 0.2
2	94.7 ± 0.5	2.5 ± 0.3	2.8 ± 0.2
3	95.8 ± 0.1	1.7 ± 0.0	2.5 ± 0.1
4	95.4 ± 0.1	1.8 ± 0.2	2.8 ± 0.1

Table 2
Summary of analysis of variance (ANOVA) with farms as blocks and irrigation methods as treatments to test their effects on potato yield for the 2013/2014 winter/spring season.

	Degree of freedom	Sum square	Mean square	*F* value	*P*
Farm	3	5641.5	1880.51	30.2959	<0.001
Irrigation	1	150.7	150.68	2.4276	0.1309
Residuals	27	1675.9	62.07		

Haverkort, 1995; Šťastná et al., 2010). However, few researches have discussed how soil water content and temperature at different soil depths affect potato production.

The objectives of this study are to (1) compare the water usage, potato yields, and nutrient status between seepage irrigation and hybrid center pivot irrigation; (2) monitor and compare soil water content and temperature at different soil depths in the two irrigation systems; (3) explore how soil water content and temperature at different soil depths affect the potato yields.

2. Methods and materials

2.1. Study site

The study was conducted at a commercial potato production farm in Manatee County, Florida. There were four farms (1–4) which belong to the same owner in the same potato production area. The soil type was coarse-loamy, siliceous, superactive, hyperthermic, typic Argiaquolls (NRCS Soil Survey Staff, 2008). Respective Mechlich I extracted P, K, Ca, Mg, Fe, Mn, Zn, Cu and B (mg/kg) were 163.5 ± 8.3, 25.0 ± 1.8, 672.9 ± 25.7, 44.2 ± 2.0, 27.9 ± 1.9, 5.7 ± 0.2, 8.4 ± 0.4, 9.5 ± 0.6, and 0.2 ± 0.0. Soil pH was 5.9 ± 0.0 and CEC, 4.9 ± 0.2. Soil particle size distribution of sand, silt, and clay is listed in Table 1. Two varieties were evaluated in this study, i.e., a chipping potato, 'Atlantic' and a tablestock potato, 'Red LaSoda'. Fertilizer (N, P, and K) application to 'Atlantic' was 840.6 kg ha^{-1} (9–15–20) at preplant, 560.4 kg ha^{-1} (21–0–18) at emergence, and 280 kg ha^{-1} (21–0–21) at sidedress timing as 65 days after planting. Only the first two fertilizer rates were applied to 'Red LaSoda' plus 560.4 kg ha^{-1} gypsum at emergence.

2.2. Experimental design

The randomized complete block design (Oehlert, 2000) was used with farms as blocks each with four replications and irrigation methods as treatments. The trials were done in two growing seasons from October 2012 to April 2014. Farm 1 and Farm 4 were used for this research for the first season and all of the four production farms were used for the second season. A total of production area was 982 acres. The farm sizes were: 167, 180, 215, and 420 acres for Farms 1, 2, 3 and 4, respectively. Four plots for each of the treatments were flagged out in each of the four sites. The size of each sampling plot was 180 m^2 (15 m in length and 12 m in width) with a guide zone with 15 m in length for either of the ends for each row. Each farm had two irrigation treatments, i.e., seepage and hybrid center pivot (i.e., center pivot with the supplementation of seepage). For seepage, irrigation was conducted twice a week for 12 h each (from 7 pm to 7 am) to keep the water table between 46 and 60 cm below the ground. For hybrid center pivot irrigation, the center pivot was run twice a week delivering 10.2 mm of irrigation water during each irrigation, and the supplemented seepage was applied only once every two weeks for 12 h each (from 7 pm to 7 am).

2.3. Field measurements

Before planting, a water flow meter (WMX101-600 6 Inch Magnetic Flow Meter, Gold River, CA) was installed at the inlet of each of the two treatments in each of the four sites. For each irrigation at each site, a rain gauge (Model # BAR206_RGR126, Oregon Scientific, Tualatin, Oregon) was set up to investigate the contribution of rainfall to water usage. Besides, a screened-PVC well, with an internal diameter of 5 cm, fitted with a pressure transducer (Levelogger gold 3001, Solinst Canada Ltd., Georgetown, Ontario, Canada) was installed to monitor the water table. A 5TE sensor (Decagon Devices, Inc., Pullman WA, USA) was installed adjacent to the screened-PVC well to determine soil volumetric water content (VWC, %), soil temperature, and electrical conductivity at five soil depths of 10, 20, 30, 50, and 70 cm. The data that collected within four days when rainfall was greater than 10 mm were excluded to minimize the interference. All of the above sensors were installed in the third row from the edge of the field. The data were recorded every 15 min with the Em50 digital/analog data logger (Devices, Inc., Pullman WA, USA) for each treatment and downloaded every other week. Based on the data collected from the flow meters and tuber yields at harvest, water use efficiency was defined as g tuber of potato produced by using one liter of water including both irrigation and rainfall:

$$\mathrm{WUE(g/l)} = \frac{Y_{\mathrm{tuber}}}{\mathrm{WU}}$$

where WUE is water use efficiency; Y_{tuber}, tuber yield (g); WU, water usage (liter).

2.4. Nutrient analysis

At harvest, two 6 m-long rows (row spacing: 102 cm, plant spacing: 20 cm) from each of the sampling plots (plot size: 180 m^2) were randomly selected for tuber yield measurements for both seepage and hybrid center pivot irrigation in each of the four sites. To avoid any interference from the fallow rows, the first two rows from both sides were never used for any samplings or measurements. Potato tubers in those plots were manually harvested, weighed, and graded. A composite soil sample (0–20 cm deep) was collected from each of the plots to measure extractable nitrate (NO_3–N). Briefly, 2.5 g dry soil sample was weighed into a 50 ml tube; 25 ml of 2 M KCl solution was added. The suspension was shaken on an Eberbach reciprocal shaker (Model E6010, Ann Arbor, MI) for 1 h, and filtered through #41 filter paper. Concentration of NO_3–N was analyzed by Automated Discrete Analyzer (AQ2, SEAL Analytical, Hanau, Germany) using U.S. EPA Method 353.2 (US EPA, 1993).

2.5. Statistical analysis

All the statistical analysis were computed using R (version 3.1.0, R Development Team, Vienna, Austria), and results were considered significant at $P < 0.05$. The ANOVA (analysis of variance) test was used to evaluate the effects of irrigation methods on tuber yield. Because of different weather conditions between the two growing seasons, we only used the 2013/2014 data to construct the ANOVA table. Linear regression model was performed to investigate the association between moisture content and water table at