Improving potato cultivation using siphons for partial root-zone drying irrigation: A case study in the Blue Nile river basin, Ethiopia

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Abstract: Partial root-zone drying (PRD) is an irrigation technique which consists of alternating the water supply from one furrow to another, and keeping the other one dry during the weekly alternation period. Studies assessing PRD in potato have reported a 30-50% of water savings with no tuber yield reductions and an increase of antioxidant concentrations and marketable tubers. In this study, we adapted the PRD technique to rural Ethiopian conditions and compared it against the customary (C) irrigation practiced by local farmers. Two PRD alternatives were evaluated; with (PRDs) and without (PRDw) locally made flexible-hose siphons. Only PRDs showed no significant differences in total (35.8±1.6 t ha⁻¹) and marketable (34.2±1.6 t ha⁻¹) tuber yield when compared with customary irrigation (39.4±1.3 and 37.6±1.2 t ha⁻¹) corresponding to total and marketable yield, respectively. The PRDw was more water restricted, showing significantly lower total (29.7±1.1 t ha⁻¹) and marketable (27.6±1.2 t ha⁻¹) yields. PRDs had the benefit of a better control of applied water allowing a saving of 50% of the irrigation water without negatively affecting yield. The use of the siphons PRD technique provides options for saving scarce water and reaching out to many smallholder farmers who are in serious need of irrigation water in the Blue Nile river basin.

Keywords: Bahir Dar, demonstration strip design, irrigation techniques, Jalene variety, PRD, siphon, water saving

1 Introduction

Water supply for agricultural purposes will face the dilemma of higher water demanded (projected to reach 10-13 trillion m³ a year by 2050; Lal 2013) by an increasing population, concomitant with water scarcity driven by Climate Change (Iglesias and Garrote 2015). The reduction of agricultural water demand through the improvement of the irrigation efficiency is considered as an important option for adaptation and mitigation of Climate Change effects (Jiménez Cisneros et al. 2014). Water saving techniques in potato cultivation, the fourth most important edible crop worldwide (FAO 2016), constitute a crucial research topic to address the current problem of water scarcity which is expected to be exacerbated in the future (Monneveux et al. 2013). The Partial Root-zone Drying (PRD) - alternate irrigation between neighbouring furrows i.e. the dry one is irrigated the following cycle - is a promising irrigation technique that saves water (39 – 50%) through increased water use efficiency (WUE) with no significant tuber yield reduction in this crop (Liu et al. 2006a; Liu et al. 2006b; Jensen et al. 2010; Xie et al. 2012; Yactayo et al. 2013). The benefits of PRD in potato production are also associated with a higher marketable tuber size, soil N-availability and antioxidants in tubers (Rojas et al. 2007; Shahnazari et al. 2007; Shahnazari et al. 2008; Jovanovic et al. 2010). However, PRD is mainly performed under furrow irrigation with limited studies...
assessing PRD with some improvements like the use of siphons (Yactayo et al. 2013; Posadas et al. 2008), which are small diameter pipes that allow water to be obtained from a canal to be applied to the soil (Brouwer et al. 2001). Siphons can reduce the waterlogging at the head of the furrows, achieving a better water distribution efficiency and allowing greater control of the volume of water applied (Abdelmageed 2013). Some studies (Saffat 1980) emphasize that the use of siphons in alternate furrow irrigation allows water saving with low yield penalization. Based on achievements made by the International Potato Center’s (Xie et al. 2012; Yactayo et al. 2013; Rojas et al. 2007) positive and published work using PRD on potato, an initial step based on a demonstration trial and oriented to the scaling-out of the technique in Ethiopia was conducted. The aim of this short communication is to present preliminary results comparing potato yield under PRD with and without siphons in furrow watering against the customary irrigation practiced by local farmers.

2 Materials and Methods

2.1 Study site

The field trial was carried out at Koga Irrigation Testing Site (12.1°N, 37.0°E, 1953 m above sea level) in Bahir Dar, Ethiopia from December 6th, 2014 to March 30th, 2015. The station is located in the Blue Nile River basin which has an average yearly precipitation and minimum – maximum temperatures of 1200-1400mm and 11.5-30°C, respectively. The soil type is Nitosol with field capacity and bulk density of 52.4% and 1.33g cm⁻³, respectively.

2.2 Trial description and demonstration strip design

The potato variety planted was Jalene (CIP387792.5) which is a semi-early variety recommended by the National Potato Program for this particular environment. A demonstration strip design, one of the simplest designs used in agricultural extension (http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sag3024#demo), was modified to go beyond observational assessment (Havlin et al. 1990). Each strip in the design consisted of independent simple experiments (LeClerg et al. 1962) for demonstrating and evaluating three irrigation treatments: Customary Irrigation (the normal irrigation used by the residents of this area) as control (C, normal irrigation), PRD without siphons (PRDw, the commonly tested PRD) and a PRD with siphons (PRDs, to test the hypothesis of an improvement of this technique). Each simple experiment, in turn, contained 21 subplots or sampling units to estimate field variation (Figure 1). Subplots (3.8 m x 3 m) had four rows at a distance of 0.75 m, with 11 plants each. Planting distance within the same row was 30 cm. Siphons consisted of commercial flexible-hoses (1.5 m length and 5.08 cm of diameter) which were adjusted to the shape of the irrigation ditch as an adaptation to the protocol developed by (Brouwer et al. 2001).

The irrigation schedule for all treatments was based on soil water requirements, determined by infiltration assessments (Table 1) using the cylinder infiltrometer method (FAO 2012), fitting the following power function:

\[ WI = 0.95 \times T^{0.737} \]  

Where WI is infiltrated water layer (mm) and T is irrigation time. The irrigation frequency was every 7 days.

2.3 Data collection and analysis

Only two inner rows were used for total and marketable fresh tuber yield collection at harvest, excluding the first and last plants in each row. In order to ascertain whether a statistical comparison among the irrigation treatments or simple experiments was feasible, the homogeneity of variances of tuber yields were assessed using Bartlett’s Test. Once the variances homogeneity was demonstrated a goodness-of-fit test was also made for the analysis of variance. Finally, the Scott-Knott Test (Scott and Knott 1974) for individual experiments was used to compare irrigation treatments. The corresponding analyses were run in R v. 3.0.3 Software (R Core Team).

3 Results and Discussion

The results of Bartlett’s test indicated variance homogeneity for total tuber yield (Bartlett’s K-squared = 2.9122, \( P = 0.2331 \)) and marketable tuber yield (Bartlett’s K-squared = 1.8534, \( P = 0.3959 \)). According to the goodness-of-fit test, differences between irrigation treatments for tuber yields were significant and the balanced one-way analysis of variance power calculation were very high (>0.9, see Table 2).

No differences (\( P>0.05 \)) between PRDs and C treatments in terms of total and marketable fresh tuber yield were found (Figure 2). However, PRDw showed a reduction (\( P < 0.05 \)) both in total and marketable tuber
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Figure 1. Demonstration trial conducted in Ethiopia in 2014. C = Customary irrigation, PRDs = partial root-zone drying with siphons, PRDw = partial root-zone drying without siphons

Table 1. Assessment of infiltration rates of the experimental field

<table>
<thead>
<tr>
<th>Starting time (local time)</th>
<th>Change in time (minutes)</th>
<th>Infiltrated depth (cm)</th>
<th>Infiltration rate (cm/minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15:00</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>15:05</td>
<td>5</td>
<td>3</td>
<td>0.6</td>
</tr>
<tr>
<td>15:10</td>
<td>5</td>
<td>2.5</td>
<td>0.5</td>
</tr>
<tr>
<td>15:20</td>
<td>10</td>
<td>4</td>
<td>0.4</td>
</tr>
<tr>
<td>15:40</td>
<td>20</td>
<td>3</td>
<td>0.6</td>
</tr>
<tr>
<td>16:10</td>
<td>30</td>
<td>8.5</td>
<td>0.28</td>
</tr>
<tr>
<td>16:40</td>
<td>30</td>
<td>7.5</td>
<td>0.25</td>
</tr>
<tr>
<td>17:40</td>
<td>60</td>
<td>13.5</td>
<td>0.23</td>
</tr>
<tr>
<td>18:40</td>
<td>60</td>
<td>13</td>
<td>0.22</td>
</tr>
<tr>
<td>20:40</td>
<td>120</td>
<td>11</td>
<td>0.09</td>
</tr>
</tbody>
</table>

Table 2. ANOVA for the Goodness-of-fit test and balanced one-way analysis of variance power, corresponding to the three populations (treatments-Trt) for total tuber yield and marketable tuber yield (** P<0.001). Df = degree of freedom, Sum Sq = Sum of squares, Mean Sq = Mean of squares.

**Total tuber yield**

<table>
<thead>
<tr>
<th></th>
<th>Df</th>
<th>Sum Sq</th>
<th>Mean Sq</th>
<th>F value</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Trt</td>
<td>2</td>
<td>167.2</td>
<td>83.58</td>
<td>13.17</td>
<td>***</td>
</tr>
<tr>
<td>Within Trt</td>
<td>60</td>
<td>380.8</td>
<td>6.35</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Marketable tuber yield**

<table>
<thead>
<tr>
<th></th>
<th>Df</th>
<th>Sum Sq</th>
<th>Mean Sq</th>
<th>F value</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Trt</td>
<td>2</td>
<td>176.2</td>
<td>88.1</td>
<td>13.86</td>
<td>***</td>
</tr>
<tr>
<td>Within Trt</td>
<td>60</td>
<td>381.5</td>
<td>6.36</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
yields in comparison to C and PRDs (Figure 2). Responses to PRD irrigation, particularly with the use of siphons, were consistent with the responses found in other published experiments where PRD reduced water usage without a significant decrease in tuber yield (Yactayo et al. 2013). An increase of marketable tuber yield under PDR conditions has been reported (Shahnazari et al. 2007), this finding was consistent with our results for PRDs but not in PRDw suggesting the research may show other benefits of the siphon’s use which are related to tuber quality factors (dry matter content, antioxidants and other nutrients).

Some authors highlight (e.g. Abdelmageed 2013) that a reduction in soil salinity and an increment in water distribution efficiency and soil permeability are some of the driving factors for yield rise when siphons are used in furrow irrigation. The use of siphons in alternate furrow irrigation or PRD trials – as the one described in this rapid communication - have precluded yield penalizations in potatoes as well as in other crops (Yactayo et al. 2013; Rojas et al. 2007; Saffat 1980). The qualitative field assessments of the crop (see Figure 3) suggested that plants under PRD treatments showed a delayed growth and reduced above ground biomass in comparison to plants under normal irrigation and this effect was more clearly noticed in the case of PRDw. Foliage cover reduction in PRD causes an increase in tuber yield per unit of water volume due to reduced transpiration and a concomitant maintenance in carbon assimilation caused by a reduction in leaf auto shading (Shahnazari et al. 2007).

4 Conclusion

Although water savings related to customary irrigation (approximately 50%) were similar for both PRD treatments, the use of siphons resulted in a higher total fresh tuber yield compared to PRD without siphons and

![Figure 2](image1.png)

**Figure 2.** Mean (± standard error) marketable (A) and total (B) tuber yield per irrigation treatment. Different letters indicate differences (P < 0.05) detected by Scott-Knott test. C = Customary irrigation, PRDs = partial root-zone drying with siphons, PRDw = partial root-zone drying without siphons

![Figure 3](image2.png)

**Figure 3.** Crop aboveground biomass at 95 days after planting. A: Customary irrigation, B: partial root-zone drying (PRD) with siphons and C: PRD without siphons
a non-significant reduction with respect to the customary irrigation. This finding emphasizes the importance of implementing PRD with siphons to optimize the water application. However, it is necessary to conduct more tests in other locations and with different varieties, exploring different irrigation schedules, frequencies and intensities of water restriction in PRD. It is also important to involve more local stakeholders and potato growers in assessing the proposed technology for faster adoption. Moreover, an economic assessment would facilitate the scale-out of this technology in the study area and beyond.

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