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# Effect of partial root-zone drying irrigation timing on potato tuber yield and water use efficiency

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ABSTRACT

Partial root-zone drying (PRD) is an irrigation technique which has shown increased water use efficiency (WUE) without yield reductions in potato and other crops. However, questions remain as to the effect of the water restriction initiation timing and the level of alternate water restriction on the response of the potato crop. In this study, we tested: two PRD treatments with 25% ($PRD_{25}$) and 50% ($PRD_{50}$) of total water used in full irrigation (FI, as control), and a deficit irrigation treatment with 50% of water restriction ($DI_{50}$). Two water restriction initiation timings were tested at: 6 weeks (WRIT6w) and 8 weeks (WRIT8w) after planting. Osmotic potential ($\pi$), osmotic adjustment, relative water content and chlorophyll concentration were assessed in four dates during the growing period. $PRD_{50}$ initiated at WRIT6w showed the highest WUE without a tuber yield reduction respect to the control. While plants under PRDs and $DI_{50}$ showed lower $\pi$ than FI, PRDs treatments promoted higher osmotic adjustment particularly in WRIT6w. Our study suggests that early PRDs with mild water restriction allow drought hardiness (improving water stress response) and water saving avoiding a dramatic yield tuber reduction.



## 1. Introduction

The potato (*Solanum tuberosum* L.) cropping area has been expanding in developing countries, particularly in Asia and Africa (Haverkort et al., 2004). This expansion is opening new cropping areas in some environments that could be negatively affected by global warming (Thiele et al., 2010). A reduction of 18–32% of potato global yield caused by climate change is projected to occur during 2010–2039 (Hijmans, 2003). Alongside temperature and atmospheric $CO_2$ increases, climate change will bring about a larger rainfall variability and evaporative demand (Kundzewicz et al., 2007), a situation that will affect potato, which is a drought sensible crop (van Loon, 1981). Furthermore, competing water use for agriculture and other activities is becoming an important issue worldwide (Naylor, 2009). Under these unpredictable and highly variable conditions, increasing water use efficiency (WUE, tuber yield per amount of water applied) by irrigated potato crops is an important objective.

Irrigation water saving techniques have not been investigated in potato to the same extent as in other crops, particularly cereals and fruit trees (Kang and Zhang, 2004). However, work so far conducted in irrigated potato indicates that deficit irrigation (DI, irrigated water below the maximum crop evapotranspiration) and partial root-zone drying (PRD, alternated irrigation of the root-zone by watering of one furrow and keeping dry the adjacent one until the next watering cycle) are two promising irrigation techniques to save water with a concomitant WUE increase and no yield reduction (Liu et al., 2006a,b; Jensen et al., 2010; Xie et al., 2012). In several experiments, PRD has given better results than DI and full irrigation, allowing for 39–50% of water saving, while increasing WUE without significant tuber yield reduction (Liu et al., 2006a; Saeed et al., 2008; Shahnazari et al., 2008; Jovanovic et al., 2010; Xie et al., 2012). Higher marketable tuber size, soil N-availability and antioxidants in tubers have been obtained in PRD trials in potato (Rojas et al., 2007; Shahnazari et al., 2007; Shahnazari et al., 2008; Jovanovic et al., 2010). Notwithstanding these promising results and in order to maximize the benefits of the technique, issues such as the best combination of initiation timing, duration, and intensity of water restriction (*sensu* Jefferies, 1995) remain to be addressed. It is also important to assess how water restriction trials could contribute to enhance the expression of drought tolerant traits without tuber yield penalization. Saeed et al. (2008) and Xu et al. (2011) obtained higher tuber yield in PRD treatments when water restriction was initiated soon after tuber initiation, both in pot and in field trials, respectively. Although these experiments tested different initiation timing and duration of water restriction, the amount of water applied was similar across treatments. On the other hand, PRD trials with different levels of water restriction (*e.g.* Xie et al.,

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2012) have not considered the assessment of the initiation timing and duration of the restriction.

Osmotic adjustment (accumulation of low-molecular organic substances into the cell that promote the osmotic influx of water; Larcher, 2003) and “stay green” (delayed senescence) are some of the desirable traits in the selection programs for drought resistance in crops (Blum, 2011). The expression of both traits have been enhanced using different PRD treatments in potato (Xu et al., 2011; Jensen et al., 2010) which indicates that an appropriate combination of initiation timing, duration and intensity of water restriction would induce the activation of these traits with a concomitant WUE rise (see Xu et al., 2011). In this paper we report the results of PRD trials with different initiation timing, duration and levels of water restriction under field conditions in an arid region with no rain, and thus without rainfall confounding effect. The aims of the work were: i) to assess WUE under contrasted PRD treatments with different water restriction initiation timing, ii) to determine whether the PRD treatment induced water stress tolerance as indicated by osmotic adjustment and “stay green” effects.

## 2. Materials and Methods

### 2.1. Experimental site

The study was carried out at the International Potato Center (CIP) experimental station in Lima, Peru (12.08°W; 76.95°S, 244 m asl) from June to November 2010. The station is located in the Peruvian desert with average yearly precipitation, maximum – minimum temperatures, atmospheric humidity and global radiation of 23 mm, 22.4–16.5 °C, 79.7% and 14.1 MJ $m^{-2}$ $d^{-1}$, respectively (2008–2010, CIP Meteorological Station). The soil is sandy loam (50, 32 and 18% of sand, lime and clay, respectively), with an organic matter content, field capacity, bulk density, pH and electric conductivity of 8%, 14.6%, 1.4 g $cm^{-3}$, 7.6 and 2.4 dS $m^{-1}$, respectively (Laboratorio de Análisis de Suelo, Plantas, Aguas y Fertilizantes–Universidad Nacional Agraria La Molina, Lima, Peru).

### 2.2. Description and design of experiment

The potato variety tested was UNICA (CIP code N°392797.22) which is an early variety and considered to be tolerant to viruses and high temperature (Gutiérrez et al., 2007). The fertilizer application consisted of 200:140:160 kg $ha^{-1}$ as N:$P_2O_5$:$K_2O$. One half of the N was supplied at planting and the rest at hilling. The phytosanitary control against pests and diseases was carried out every 20 days.

The experimental unit consisted of a 4.5 × 4.5 $m^2$ plot divided into 6 rows (0.9 m apart from each other) and 5 ridges. Each plot contained 65 plants at a distance of 0.3 m. The evaluations were conducted on 13 plants from the center of the plot to avoid border effects. The irrigation treatments were: full irrigation (FI), which supplied 100% of the crop water demand, deficit irrigation (DI), amounting to 50% of FI, partial root-zone drying (PRD) which supplied 50 and 25% of FI ($PRD_{50}$ and $PRD_{25}$, respectively). The furrow irrigation schedule for all treatments was based on infiltration assessments using the method of cylinder infiltrometer (FAO, 2012) fitting the following power function:

$$WI = 0.24\,T^{0.77} \quad (1)$$

where WI is infiltrated water layer (mm) and $T$ is irrigation time (min). Each 12 days the gravimetric soil water content ($\theta$) of the plots was assessed at 0.25 m depths and the crop water demand (from evapotranspiration and percolation) was calculated by subtracting field capacity minus $\theta$. The furrow irrigation time, required to compensate crop water demand, was calculated from (1). Watering was performed using siphons to obtain similar water flow into the furrows. In order to test the effect of different water restriction initiation timing (WRIT) the irrigation treatments began at 6 (WRIT6w) and 8 (WRIT8w) weeks after planting. The irrigation frequency was every 12 days (with a respective shift of furrows in the PRD treatments) with the following total number of irrigation events from planting to harvest: 3 and 4 before the initiation of the different irrigation treatments for WRIT6w and WRIT8w, respectively; 6 and 5 during the experimental phase for WRIT6w and WRIT8w, respectively. The length of the cropping period was 17 weeks with 10 and 8 weeks of experimental phase for WRIT6w and WRIT8w, respectively.

### 2.3. Ecophysiological and agronomic measurements

All the ecophysiological measurements were carried out in four occasions during the experimental period in samples taken from three central rows within the plot. Two plants per plot were sampled and one leaflet from an expanded and sun-exposed leaf located in the upper third section of the plant canopy collected between 6:00 and 7:00 am local time and their fresh weight (FW) were recorded. The samples were immersed in distilled water during 6 h at 6 °C and weighted again (saturated weight, SW). Leaflets were then dried during 48 h at 80 °C and weighted (dry weight, DW). Relative water content (RWC) was estimated as:

$$RWC = (FW - DW) * 100/(SW - DW) \quad (2)$$

Osmotic potential ($\pi$) was measured using Turner’s (1981) protocol which involves the rupture of the cell membrane brought about by an abrupt leaf defrosting which causes that water potential equals $\pi$. A leaflet circular sample (0.5 cm of diameter) was immersed in liquid nitrogen and after that conserved at −80 °C. The water potential was measured in defrosted samples using a dew point potentiometer (Wescor, Logan, UT, USA). Linear regressions were fitted through the value pairs (RWC, $\pi$). Osmotic adjustment was estimated as the slope ($\Delta$RWC/$\Delta\pi$) of the fitted functions where low slope values were interpreted as high osmotic adjustment and *vice versa* (Morgan, 1983, 1992).

Chlorophyll content was estimated with a portable chlorophyll meter (SPAD-502 model, Konica Minolta, Sakai, Osaka, Japan). Nine readings per leaf were averaged per plant.

Tuber yield (kg $ha^{-1}$) was estimated from tuber fresh weight produced by the plants harvested from the three central rows of the plots. Irrigation water use efficiency (WUE, kg $m^{-3}$) was calculated as the ratio between tuber yield and total WI.

### 2.4. Statistical analysis

Main irrigation treatment effects and interactions were assessed by ANOVA using a randomized block design. For comparing water restriction treatments against the control (FI) the Dunnett MRT test was applied. Furthermore, Duncan’s test was also applied to the data in order to assess differences among irrigation treatments in both early and late irrigation onset timing. Ecophysiological measurements taken sequentially over time introduce carry over effects, *i.e.* observations close in time may be more related than observations far apart in time. Repeated measurements analyses, as described by Wolfinger and Chang (1998), was used as a corrective measure. The analysis of variance generated by the General Lineal Model (GLM) allows the determination of statistical differences between treatments, as a function of time, with a pre-established probability level (*P value*) of 5%. A significant difference indicates that, on the one hand, the variation due to treatment, at a particular time within the experiment, was greater than the variation among plants within each treatment. On the other hand, it indicates that the number of replicates was enough to reach a robust assessment of the differences between plants submitted to different irrigation