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Response of potato to full and deficit irrigation under semiarid climate: Agronomic and economic implications

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ABSTRACT

Yield, cost, and revenue functions of potato (cv. *Agria*) were developed from field experiments in 2007–2008, which were designed to determine the response of tuber yield to no irrigation for two weeks at tuber bulking (TB) and tuber ripening (TR). Deficit-irrigated treatments were compared to a well-irrigated control (C) throughout the growing season. The yield-profit maximization methodology of English (1990) was reviewed and a new procedure based on optimization software was proposed. Treatment with deficit irrigation at TB achieved marketable yield 12% lower than that obtained in the well-irrigated control (60.5 Mg ha^{-1}), whereas deficit irrigation at TR reduced tuber yield by 42%, compared to the control. However, yield reduction was compensated by an increase in tuber dry matter in the deficit-irrigated treatments. The results of the newly proposed yield-profit maximization procedure show that when land is limiting, the level of water applied at which net income per unit of land is maximized (W_l) fits the yield maximizing (W_m) strategy, while when water is limiting, the level of water applied at which net income per unit of water is maximized (W_w) would result in as much water saving as 10–15% of total applied water. The results also suggest that the target yield that was obtained in the treatment with deficit irrigation at tuber bulking (53.6 t ha^{-1}) was in the range of 500–560 mm of water application. We concluded that deficit irrigation at tuber bulking for two weeks is a suitable scenario for potato farming, with potential benefits resulting from reduced irrigation costs.

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1. Introduction

Potato (*Solanum tuberosum* L.) is an important vegetable crop in Lebanon and is widely planted under irrigation in the alluvial soils of the Bekaa Valley. Potato rates second among Lebanon crops in production volume, after wheat, with nearly 15,000 ha cultivated every year. The production of fresh tubers forms an important portion of the agricultural economy of the country; potatoes are used for both fresh vegetable markets, as well as value-added processed food.

The large area that is put into potato production each year requires full irrigation in order to meet the crop water requirements, especially during the most sensitive growth stages (tuber bulking and tuber ripening) to water stress, which coincide with the hottest summer months (July–August) (Karam et al., 2005a).

Many irrigation experiments have shown the sensitivity of potato to water stress (Shock et al., 1998; Opena and Porter, 1999; Porter et al., 1999; Deblonde and Ledent, 2001; Fabeiro et al., 2001; Ferreira and Carr, 2002; Kashyap and Panda, 2003; Onder et al., 2005; Unlu et al., 2006). Adequate irrigation supply before and during tuber initiation increases the number of tubers per plant (Shock et al., 1992), while after tuber initiation, water supply stimulates tuber size (Eldredge et al., 1996; Shock et al., 1998). Fabeiro et al. (2001) found that treatments with deficit irrigation during the last part of the crop cycle have had the lowest tuber production. Likewise, Liu et al. (2006) found that treatments with deficit irrigation at early tuber bulking resulted in yields similar as produced under full irrigation.

Optimal scheduling of water application is critical to make the most efficient use of water for potato production. This requires that water application is kept at the optimum level to achieve maximize returns. Deficit irrigation – the deliberate and systematic

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under-irrigation of crops (English et al., 1990; Jurriens and Wester, 1994) is one way of optimizing water use efficiency (WUE) to achieve higher crop yields per unit of irrigation water (Saeed et al., 2008; Domínguez et al., 2012a). It is applied by eliminating irrigation that has the lower impact on yield (English, 1990; English et al., 1990; English and Raja, 1996; DaCosta and Huang, 2006; Geerts and Raes, 2009). Using the deficit irrigation approach, the crop is exposed to a certain level of water stress either during a particular growth period or throughout the whole growing season. This is done without significant reduction in yields (Kirda, 2002). The resulting yield reduction may be small compared with the benefits gained by diverting the saved water to irrigate other crops (Kirnak et al., 2002).

Many authors, namely Alizadeh (1993), Diaz and Brown (1996) and Tarjuelo et al. (1997) used economic models to optimize land use and water allocation to crops at farm level. Others have used analytical methods and found that optimum conditions change when land and water limitations are considered (Yaron and Bresler, 1983; Reca et al., 2001). English and Raja (1996) and English et al. (2002) proposed an analytical methodology to understand the potential benefits and risks associated with deficit irrigation strategy based on yield maximization and the optimal level of water applied that would produce maximum net income. The methodology is based on deriving quadratic relationships of yield and revenues *vs*. applied water and linear cost function. However, the linear cost function is not always realistic, as shown in Domínguez et al. (2012b) and Krupnik et al. (2012), and a quadratic representation of the cost function may be better accepted. In this study, the procedure proposed by English and Raja (1996) and English et al. (2002) for the determination of the optimal water applied level was revised. The objectives of this study were to (i) assess potato yield and water productivity responses to different irrigation strategies; (ii) fine-tune the analytical approach of English (1990) and English et al. (2002) to obtain the optimal level of irrigation supply; and (iii) propose irrigation management guidelines for potato farming in the semiarid Lebanon's Bekaa Valley.

2. Materials and methods

2.1. Experimental site

Field experiments were conducted from March to August in 2007 and 2008 at Tal Amara Research Station in the Central Bekaa Valley of Lebanon (33°51′44″ N, 35°59′32″ E, 905 m above sea level). The details of the experimental site have been described elsewhere (Karam et al., 2005b, 2006, 2007, 2009, 2011). Tal Amara has a well-defined hot and dry season from May to October and a very cold one for the remainder of the year, with average minimum air temperature recorded in January (0.2 °C) and average maximum air temperature recorded in August (33.1 °C). Average annual rain is 592 mm, with 95% of the rain falling between November and March and a maximum of 145 mm in January. Historical data indicate no rain fall from June through September. Average annual potential evapotranspiration (ET_o) as calculated with the FAO modified Penman Monteith equation (Allen et al., 1998) is 1185 mm. A negative water balance appears thus as the difference between potential evapotranspiration and rainfall, justifying the need for irrigation during late spring and summer periods.

The soil of the experimental site has high clay content (40%), alkaline pH, low organic matter and total nitrogen and high potassium content. The soil is nearly flat, deep and fairly-drained. Ambient weather data were recorded daily using an automated weather station (AURIA 12E, DEGREANE, France), located within 50 m of the experimental site.

2.2. Crop management and irrigation scheduling

The soil was plowed and disked and single row beds were prepared 70 cm spacing. Seeds of cultivar *Agria* (30–50 mm size) were planted into the top 4–5 cm of the soil depth on March 25th and 29th in 2007 and 2008, respectively. At sowing, NPK-fertilizer (17–17–17) was broadcasted mechanically in the plots. Plants were supplemented with adequate rates of nitrogen (NH_4NO_3; 34–0–0) and potassium (K_2O; 0–0–46) fertilization at shoot growth and tuber bulking, respectively (Table 1). After sowing, the soil surface was thoroughly moistened using a portable sprinkler irrigation system. When plants reached 8–10 cm in height (two weeks after emergence), a drip irrigation system was installed along the furrows. The drip system consisted of polyethylene distribution lines, 40 m in length, 16 mm in diameter, 40 cm drippers away, and each delivering 4 l h^{-1} of irrigation capacity at 100 kPa of head pressure. Drip lines were 0.7 m apart, equally spaced in the potato furrows.

The experiment consisted of three irrigation treatments: (C) control that received full irrigation at 100% of field capacity with no water restriction during the entire growing period; (TB) treatment irrigated at 100% of field capacity with no irrigation at the beginning of tuber bulking (75 days after sowing) for two weeks and (TR) treatment irrigated at 100% of field capacity with no irrigation at tuber ripening (90 days after sowing) for two weeks.

The experiment was set out in a completely randomized block design (CRBD) in a 2646 m^2 field (63 m N–S × 42 m W–E) divided into three blocks of 882 m^2 each (21 m N–S × 42 m W–E). Each block contains three replicates, 294 m^2 each (7.0 m N–S × 42 m W–E), representing the three irrigation treatments. Each replicate contains ten single beds, 0.7 m N–S × 42 m W–E, each. The central two beds of each replicate were used for harvest sampling. Consequently, a total of eighteen yield samples (six per treatment) were obtained every year. Statistical analyses were carried out through one-way analysis of variance (ANOVA) using the SAS System for Window statistical software (SAS Institute, Inc., Cary, NC, USA, 1993). The treatments means were compared using the Fisher's Least Significance Difference (LSD) test ($P < 0.01$). Multiple comparisons were made using the Duncan's multiple range test at 5% significance level.

At the end of each water stress cycle plants were supplied with sufficient amounts of water to replenish actual soil water deficit in the upper 60 cm of the soil profile. A rooting depth of 60 cm is considered maximum for potato crop during tuber development stages (Allen et al., 1998). Total available water (TAW) and readily available water (RAW) in the 0–60 cm depth of the soil profile were calculated as (Allen et al., 1998):

$$TAW = (\theta_{FC} - \theta_{pwp})Z_r \quad (1)$$

$$RAW = p \cdot TAW \quad (2)$$

where θ_{FC} is the volumetric soil water content at field capacity (0.42 $m^3\ m^{-3}$) and θ_{pwp} at permanent wilting point (0.22 $m^3\ m^{-3}$), Z_r = rooting depth (mm), and p is the average fraction of the TAW that can be depleted from the root zone before water stress occurs (ranging between 0 and 1). For potato, p is equal to 0.35 (Allen et al., 1998). Both TAW and RAW are in mm.

Soil water content in the plots was measured using a Sentry 200-AP Frequency Domain Reflectometer (Sentry 200-AP, 1994). It was calibrated to the soil at Tal Amara over a wide range of soil water content. Two access PVC tubes, 50 mm in diameter and 1.0 m in length, were inserted in the central two beds of each replicate that are used for harvest samplings. In total, eighteen access tubes, at the basis of six tubes per treatment, were installed across the three treatments. Readings were taken twice a week throughout the growing period at 0–30 and 30–60 cm depths of the soil profile, and were converted to soil water content values using a locally

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