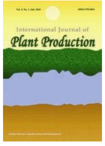

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# Water-saving irrigation strategies affect tuber water relations and nitrogen content of potatoes

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## Abstract

The dynamic and static deficit (DDI, SDI), partial root drying (DPRD, SPRD) and full (FI) irrigation strategies were applied in Agria and Ramos potato cultivars in a semi-arid area. FI received 100% of the potential evapotranspiration (ET); SDI and SPRD received 75% of ET during the growth period; DDI and DPRD received 90% of ET in the first third, 75% of ET in the second third and 50% of ET in the last third of growth period. Results showed that fresh tuber yield and tuber nitrogen (N) content were negatively correlated meaning that by increasing the tuber N content, tuber yield decreased. PRD irrigation strategy had significantly the highest tuber N content than FI and DI. Dry matter water productivity ($WP_{DM}$) was significantly different between the irrigation strategies. The DI strategies had significantly higher $WP_{DM}$ than FI and PRD ones. DDI and DPRD increased $WP_{DM}$ by 26 and 19% compared to SDI and SPRD, respectively. $WP_{DM}$ in Ramos (1.08 kg $m^{-3}$) was higher than Agria (0.82 kg $m^{-3}$). The newly introduced Dry Matter-Water Content Index (DMWCI) was higher in PRD and Agria than DI and Ramos, respectively. Conclusively, the DI treatments are the recommended water saving-irrigation strategies under these experimental conditions in terms of highest $WP_{DM}$ and greater dry matter allocation to tubers, though the PRD irrigation strategy had higher tuber N content. Ramos is the favored potato cultivar for processing industry based on its higher $WP_{DM}$ and tuber dry matter content than Agria.

***Keywords:*** Static and dynamic deficit irrigation; Static and dynamic partial root drying irrigation; Tuber nitrogen; Dry matter water productivity; Dry matter-Water Content Index; Potato.

***Running Title:*** Water-saving irrigation strategies on tuber water relations and nitrogen content.

## Introduction

Potato (*Solanum tuberosum*, L.) is one of the world's main stable crops that produce more protein per unit area than the major cereals crops. Potato tubers with high nutritional quality are an important factor for the human health and world food consumption (FAO, 2012). Potatoes are the most important non-grain product feeding in developing countries of the world that supply the major nutrients for the human beings (Wishart et al., 2013; White et al., 2009). Due to its root characteristics and sensitivity to water stress, potato production needs substantial amount of water for high tuber production (Shi et al., 2015; Stalham and Allen, 2001; Stalham and Allen, 2004). Therefore, under limited water resources, it is required to apply irrigation water efficiently to maintain sustainable potato tuber production (Vadez et al., 2014).

Potatoes are very responsive to irrigation and nitrogen (Ahmadi et al., 2011a; Darwish et al., 2006). Under limiting water resources the physiological crop parameters show differences in responses to water stress (Azizian et al., 2015; Vadez et al., 2014; Xie et al., 2012). The dynamic and static partial root drying irrigation (PRD) and deficit irrigation (DI) methods are the common water-saving irrigation strategies to enhance water productivity in agricultural production systems (Ahmadi et al., 2014; Jovanovic et al., 2010; Sadras, 2009; Kang and Zhang, 2004). Generally, static and dynamic DI refers to the traditionally well known continuous (CDI) and regulated (RDI) deficit irrigation strategies. However, unlike the DI that the whole root system is not fully irrigated, the PRD irrigation involves full irrigation of half of the root zone while leaving the other half to dry to a predetermined level before the next irrigation such that the wet part maintains high plant water status and controls vegetative growth (Kang and Zhang, 2004). Comprehensive and detailed reviews on the agronomic and physiological effects of PRD, DI and full irrigation (FI) for different types of crops are summarized in Kang and Zhang (2004), Dodd (2009) and Sepaskhah and Ahmadi (2010).

Nitrogen (N) content is directly proportional to the protein content of the potatoes which is a nutritional value of tubers (van Gelder, 1981). Several studies indicated that tuber N content was influenced by irrigation water managements. Shayannejad (2009) showed that PRD had no significant effect on N content of potato. However, Jovanovic et al. (2010) showed that PRD increased the N content in potato tubers. Shahnazari et al. (2008) studied the effects of DI and PRD strategies on N dynamics in the soil-plant system of potatoes in two consecutive years 2005, 2006 and showed that the soil residual N content at harvest in PRD was 29 and 33% lower than FI in the whole root zone in 2005 and 2006, respectively; though, the differences were not significant in 2006. Moreover, they reported that PRD and FI taken up more N than DI. In another study, Ahmadi et al. (2011a) investigated the interactions of FI, PRD and DI with different soil textures on the N uptake of potatoes and showed that the irrigation treatments were not significantly different in terms of N uptake in the tubers, shoot and the whole crop. In general, evidences demonstrated that PRD increased the N uptake and N inflow rate to the roots, which resulted in elevated N use efficiency (Romero et al., 2014; Wang et al., 2009; Wang et al., 2012; Hu et al., 2009). Nevertheless, potatoes are shallow rooting crops and have poor N utilization efficiency (Wishart et al., 2013) and their ability to absorb N from soil is a challenging process as it is estimated that the potato roots recover less than 70% of the applied N (White et al., 2005).

To the best of our knowledge, no study has been done on comparing the dynamic and static water-saving and full irrigation strategies on the potato tuber qualities in terms of N and water content. In our earlier work, Ahmadi et al. (2014) compared the agronomic characteristics of the potatoes (such as tuber yield, tuber sizes and harvest index) subject to these current irrigation strategies. Therefore, the objective of this study was to compare the effects of dynamic and static PRD and DI irrigation strategies with the FI irrigation management on the tuber N content and tuber-water relations of two common potato cultivars in the semi-arid area of Iran.

## Materials and Methods

### *Experimental site*

The details of the study are reported earlier in Ahmadi et al. (2014). Here a brief overview is provided. The field experiment was carried out in summer 2012 at the experimental fields of Faculty of Agriculture, Shiraz University, Iran, located 16 km north of Shiraz (29º 36′ N, 52º 32′ E, 1810 m.s.l). The climate of the area is warm with an annual average rainfall of about 386 mm. Weather data was collected at a climate station situated approximately 20 m from the field. The mean air temperature during the growing period was 23.5 ºC. The reference evapotranspiration ($ET_o$) varied between 3.2 and 10.2 mm day$^{-1}$ and the mean temperature varied between 12.2 and 29 ºC during the growing season.

The soil texture was silty clay loam. The top soil (0-0.3 m depth) contains 21% clay, 49% silt, 30% sand and 1.44% organic matter. Laboratory-measured field capacity (FC), permanent wilting point (PWP) and bulk density of the soil at depths of 0-0.3 m were 0.32 m$^3$ m$^{-3}$ and 0.17 m$^3$ m$^{-3}$ and 1.29 g cm$^{-3}$, respectively.

### *Experimental procedure*

Potato seed tubers were planted on 19 April 2012 at 75 cm inter-row and 25 cm inter-plant distances. Seed tubers were ridged with 20 cm soil in prepared furrows. The whole potato growing period was divided into three growing stages according to the BBCH scale (Hack et al., 2001) and the fertilizers were applied at the start of each stage. The BBCH-scale is a scale that has been frequently used to identify the phenological development stages of potatoes from planting to harvest and distinguishes the main growing periods such as vegetation and reproduction from the other ones (Ahmadi et al., 2014; Shahnazari et al., 2008). First fertilizer application was just before the plantation at the rate of 100 kg ha$^{-1}$ of Di-ammonium Phosphate (18-20-0 NPK). Later on, 300 kg ha$^{-1}$ of Urea (46-0-0 NPK) was applied at the second one-third of growing period, 82 days after planting (DAP), representing the BBCH code of 40-69. Finally, during the last one-third of growing period (BBCH code of 70-99) foliar application at the rate of 90 and 72 g l$^{-1}$ of NPK (20-20-20) was applied at 108 and 115 DAP, respectively.

The experimental area was divided into 30 plots where each one measured 4 m long and 5 m wide that led to 6 rows in each plot. Experimental plots were separated by a 1 m wide guard area. The experimental design was a completely randomized factorial design with two experimental factors of irrigation strategies in five levels and potato cultivars as two commercial types in three replications. The two potato cultivar treatments were Agria and Ramos and the five furrow irrigation treatments that started at the onset of tuber initation on 35 DAP. The PRD irrigation was practiced and implemented as the alternate furrow irrigation (Sepaskhah and Hosseini, 2008). The irrigation treatments were 1) FI receiving 100% of the potential crop evapotranspiration ($ET=K_c \times ET_o$) that received 950 mm water, 2) static deficit irrigation (SDI) receiving 75% of ET during the whole growing period that received 712 mm water; 3) dynamic deficit irrigation (DDI) receiving 90% of ET in the first third of growing period (BBCH code 0-39), 75% of ET in the second third of growing period (BBCH code 40-69) and 50% of ET in the last third of growing period (BBCH code 70-99), which totally received 681 mm water; 4) static partial root drying irrigation (SPRD) receiving 75% of ET during the whole growing period that received 712 mm water; and 5) dynamic partial root drying irrigation (DPRD) receiving 90% of ET in the first third of growing period, 75% of ET in the second third of growing period, 50% of ET in the last third of growing period that totally received 681 mm water. All the 30 experimental plots were totally pre-irrigated of 30 mm for crop establishment within the first two irrigations at 8 and 22 DAP, respectively. Former studies have confirmed that for potato tuber yield maintenance, the PRD treatments should be started after tuber initiation (5-6 weeks after planting) (Yactayo et al., 2013; Ahmadi et al., 2010a; Shahnazari et al., 2008; Saeed et al., 2008). No rainfall occurred during the growing season. The irrigation interval was 7 days and the amount of water for each irrigation event was determined based on daily reference evapotranspiration ($ET_o$) and the FAO recommended crop coefficient ($K_{c)}$.

### *Tuber nitrogen content*

Potato tubers were harvested on 12 and 13 September 2012, (146 and 147 DAP). Three 1 $m^2$ quadrants per plot were harvested from the center of each plot for determining the total fresh tuber yield. Within each quadrant, the potato tuber yield per each plant was measured. Having measured the tuber fresh weight, the potato tubers were sliced and oven-dried at 85 ºC for 24 h to measure the tuber dry matter (Ahmadi et al., 2014). The Kjeldhal method was used to measure the total N content of the harvested potato tubers (Bremner, 1979).

### *Dry matter water productivity and Dry Matter-Water Content Index*

Dry matter water productivity ($WP_{DM}$) recommended by Steduto et al. (2007) was calculated as the potato tuber dry weight (kg) divided by the total applied water ($m^3$) after starting the irrigation treatments at 35 DAP. $WP_{DM}$ evaluates the efficiency of the applied water for tuber dry matter production in different irrigation treatments and potato cultivars.

In order to assess the relative water contents of the tubers, we introduce a new water-based crop stress index defined as "Dry Matter-Water Content Index" (DMWCI) that is the ratio of normalized tuber water content (W) divided by the normalized tuber dry matter (DM). This index compares the physiological value of tuber dry matter in different irrigation treatments and potato cultivars. The DMWCI is calculated as:

$$\mathrm{DMWCI} = \frac{\frac{W_s}{W_r}}{\frac{DM_s}{DM_r}} \quad (1)$$

where $W_s$ is the tuber water content in the stressed treatment, i.e. water-saving irrigation strategies (Mg $ha^{-1}$), $W_r$ is the tuber water content in the non-stressed or reference treatment, i.e. full irrigation (Mg $ha^{-1}$), $DM_s$ is the tuber dry matter in the stressed treatment (Mg $ha^{-1}$), $DM_r$ is the tuber dry matter in the non-stressed treatment (Mg $ha^{-1}$).

### Data analysis

Data was subjected to analysis of variance (ANOVA) with the GLM procedure (SAS Software, version 9.0). Duncan's multiple range tests at $p$=0.05 probability level was applied to compare the means of different treatments. Error bars as the standard deviations (±SD) of the means were calculated for the measurements.

## Results and Discussion

### Tuber N content

Table 1 shows that there were significant differences between N contents of tubers under different irrigation treatments. PRD irrigation treatments had significantly higher tuber N contents than FI and DI treatments, though the differences between the DI treatments and FI were not significant. Within any of the water-saving irrigation managements there was no significant difference, which means the dynamic and static irrigation managements had similar effect on the tuber N content. Therefore, considering that N leaching is a great environmental pollution threat, it seems that applying the PRD irrigation would improve the nitrogen uptake from the soil reserve, which lowers the risk of N leaching below the root zone (Skinner et al., 1999).

Table 1. Values of tuber N content (%DW) and dry matter water productivity, $WP_{DM}$, (kg $m^{-3}$). Different letters in a column of each experimental factor show significant differences at 0.05 probability level.

| Factor | Tuber N content | $WP_{DM}$ |
|---|---|---|
| Irrigation treatment | | |
| FI | $1.48^{c} \pm 0.17$* | $0.9^{b} \pm 0.33$ |
| SDI | $1.59^{bc} \pm 0.13$ | $1.39^{a} \pm 0.34$ |
| DDI | $1.46^{c} \pm 0.22$ | $1.75^{a} \pm 0.73$ |
| SPRD | $1.79^{ab} \pm 0.15$ | $0.33^{c} \pm 0.19$ |
| DPRD | $1.90^{a} \pm 0.21$ | $0.39^{c} \pm 0.29$ |
| $p$-value | <0.001 | 0.005 |
| Potato cultivar | | |
| Agria | $1.62^{a} \pm 0.22$ | $0.82^{a} \pm 0.61$ |
| Ramos | $1.68^{a} \pm 0.26$ | $1.08^{a} \pm 0.75$ |
| $p$-value | 0.41 | 0.35 |
| Irrigation × Potato cultivar | | |
| $p$-value | 0.16 | 0.43 |

* Represents the standard deviations (±SD) of the means for each treatment.

As it is obvious from Figure 1, the PRD treatments increased the N contents of potato tubers compared to FI and DI, which were in agreement with the results of Shahnazari et al. (2008), Jovanovic et al. (2010) and Sun et al. (2013) who reported that the PRD treatment increased the N content of potato tubers. Likewise, Wang et al. (2009) investigated the effect of PRD and DI on N uptakes in potatoes and showed that PRD led to higher N contents in tubers compared to the FI and DI plants. Similar findings have also been reported for other crops such as maize (Wang et al., 2012; Skinner et al., 1999), wheat (Sepaskhah and Hosseini, 2008) and tomato (Wang et al., 2010b; 2013). On the other hand other results are inconsistent with our study, Shayannejad (2009) reported that there was no significant difference between N contents under PRD and FI irrigation strategies of potatoes. Li et al. (2007) have also reported that PRD did not increase the N uptake in maize but they suggested that N uptake could be improved under sufficient fertilizer and soil moisture. However, the reasons for enhanced N uptake in the PRD irrigation strategies could be due to enhancement of root growth and root surface area that assists in higher N uptake (Wang et al., 2012; Ahmadi et al., 2011b; Shahnazari et al., 2008; Mingo et al., 2004) and stimulation of soil organic N mineralization under wetting/drying cycles (Sun et al., 2013; Wang et al., 2009; Wang et al., 2010a; Wang et al., 2013).

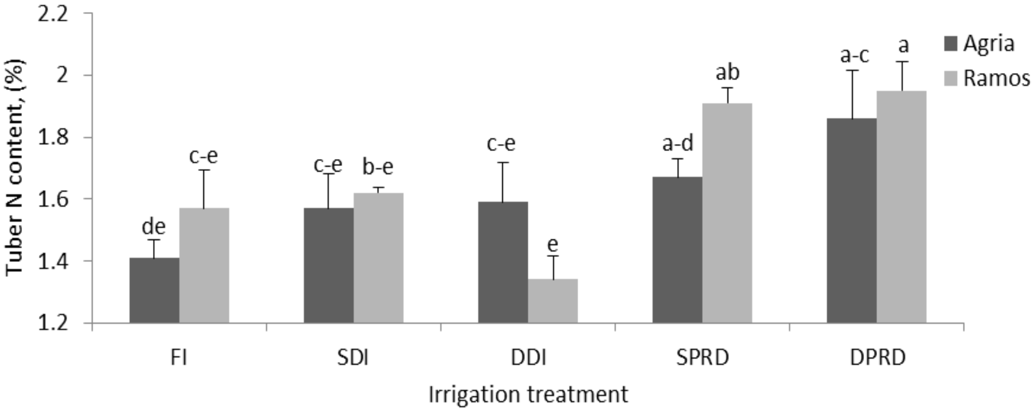


Figure 1. Measured nitrogen content of potato tubers under different irrigation treatments and potato cultivars. Different letters show significant differences between cultivars across irrigation treatments at 0.05 probability level. Error bars indicate ± SD of mean.

Figure 2 shows the linear relationship between tuber N content and fresh tuber yield as it showed stronger correlation compared with the dry tuber yield (data not shown). The negative slope of the relationship obviously illustrates that the fresh tuber yield declined with increasing tuber N content in this study. It seems that high amount of available N may reversely reduce the tuber production. In former studies on potatoes, increased N levels stimulated the vegetative plant growth, which was followed by additional allocation of dry matter in the shoots rather than to the tubers (Darwish et al., 2006; Darwish et al., 2003). The intercept of the fitted equation showed that the potato cultivars could potentially produce as high as approximately 75 Mg ha$^{-1}$ of fresh tuber yield, but the tuber yield decreased about 29 Mg ha$^{-1}$ per 1% increase in the tuber N content, which implies excessive application of N in the field may adversely affect the tuber yield production due to elevated accumulation of N in the tubers. Our result was consistent with the findings of Ahmadi et al. (2011a) and Alva et al. (2012) who reported that fresh tuber yield declined with increasing the tuber N content; though potato cultivars might show different responses to tuber N uptake accumulation under similar conditions (Zebarth et al., 2004). White et al. (2009) also determined the tuber N content of 26 commercial potato cultivars and reported that there was a clear tendency that higher tuber N content was adversely associated with lower tuber yield. Accordingly, there were evidences that high-yielding potato genotypes had lower contents of mineral elements in their tubers than low-yielding genotypes when grown in the same environment (White et al., 2009). Therefore, these reports show that developing such relationships between the tuber N content and the tuber yield could be a practical tool for identifying the potato cultivars that could produce their potential yield (Zebarth et al., 2004).

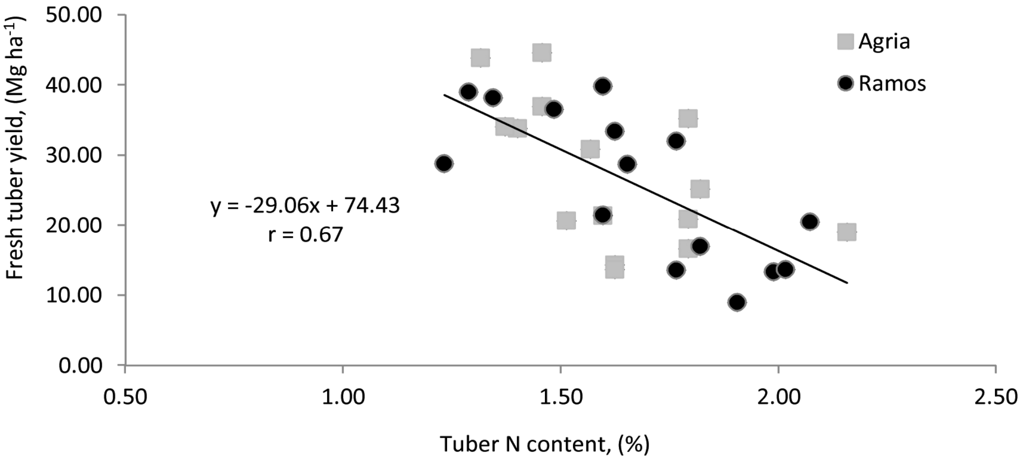


Figure 2. Relationship between fresh tuber yield and tuber nitrogen (N) content pooled over the irrigation treatments and potato cultivars.

However, it is worth mentioning that N uptake is affected by water stress too. Badr et al. (2012) stated that increased N uptake resulted in higher tuber yield in fully irrigated potatoes, while elevated N level negatively affected potato tuber yield under severe water stress. This finding also agrees with Rop et al. (2009), Errebhi et al. (1998) and Zebarth et al. (2004) who suggested that high levels of N content may influence as a stressing factor for potato tuber yield production. However, the exact amount of N content as a yield stimulator or inhibitor is complex and depends on cultivar, soil type, climate and soil water balance (White et al., 2009; Rop et al., 2009; Brueck, 2008). Since soil moisture content considerably affects the available soil N and mineralization process that leads in N flux into the root system (Badr et al., 2012; Zebarth et al., 2004), it is likely that soil moisture content variations affect the available N for the crop. This means that potato response to N is primarily related to the amount of applied water and soil moisture, whereas the N level required for maximum yield decreases as water deficit increases.

However, the contribution of N in crop production is not straight-forward, while N and soil water levels interactively affect the crop physiological and morphological processes in a very complex manner (Brueck, 2008; Zebarth et al., 2004), though it is stated that increasing tuber yield via irrigation appears to have a little effect on tuber N content (White et al., 2009). Further analysis showed that there were significant relationships as polynomial models between the fresh tuber yield ($Y_t$), the tuber N contents ($N_t$) and the fresh tuber weight per plant ($W_t$) (Figure 3). Equations 2 and 3 show these relationships for the Agria and Ramos cultivars, respectively. These models are fitted under different tuber nitrogen content and different irrigation strategies including full and water-saving irrigations.

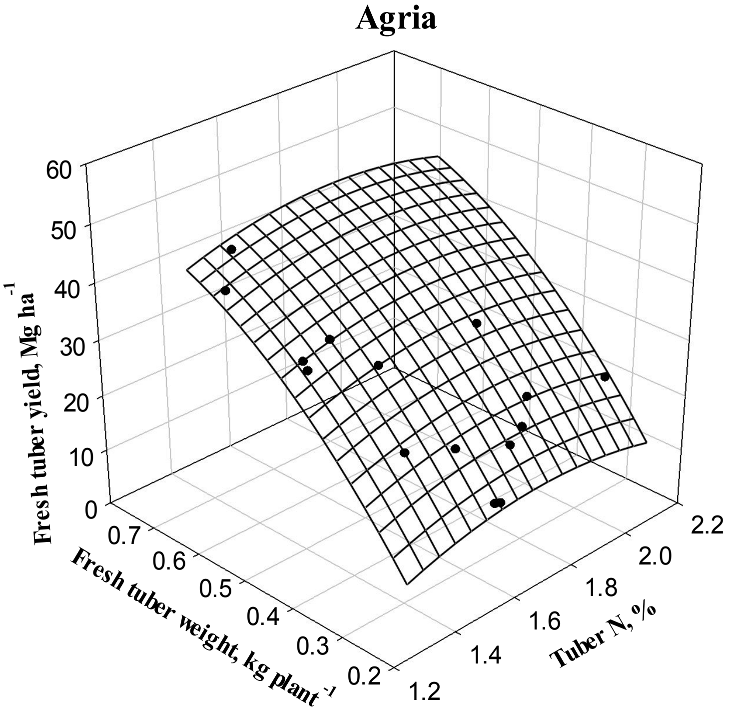
$$\text{Agria } Y_t = -90.13 + 75.03N_t + 173.54W_t - 21N_t^2 - 91.59W_t^2 \qquad (2)$$

$R^2=0.90$ S.E.=3.87 $p<0.0001$ n=15

$$\text{Ramos } Y_t = -47.95 + 70.41N_t + 73.11W_t - 24.05N_t^2 - 28.94W_t^2 \qquad (3)$$

$R^2=0.88$ S.E.=4.37 $p=0.0001$ n=15

In this study we only measured the tubers N content and did not measure the N content in the other plant organs such as root, leaf and stem. So, further studies on the N dynamic of the whole plant system subject to the dynamic and static water-saving irrigations are required because it would help to understand how plants benefit from the N resources in the soil.



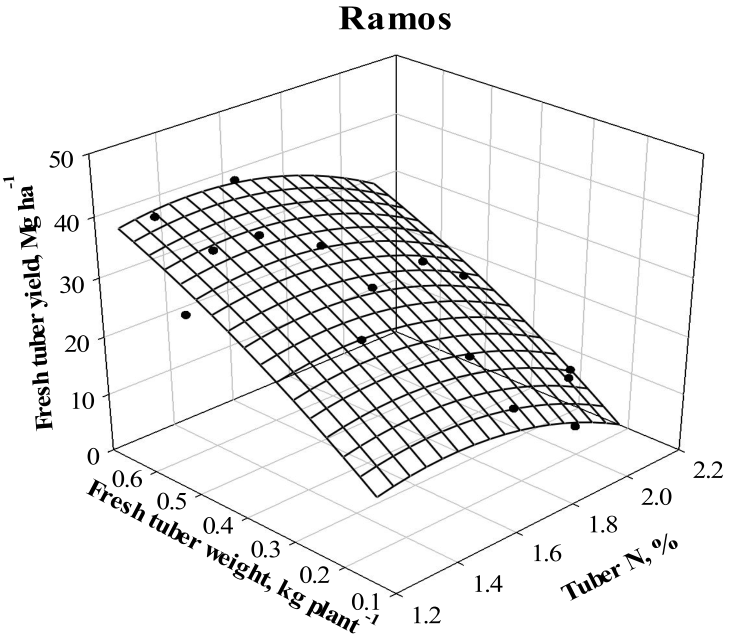


Figure 3. Fitted polynomial models on the measured fresh tuber yields of Agria and Ramos potato cultivars as a function of tuber N content and fresh tuber weight per plant.

### *Dry matter water productivity*

Crop water productivity ($WP_C$) is generally defined as tuber fresh weight divided by total applied water that does not consider the net produced dry matter of the tuber yield. Tuber dry matter content varies between potato cultivars and is strongly an inherited characteristic (Xie et al., 2012; Epstein and Grant, 1973). The $WP_{DM}$ that considers produced tuber dry matter shows the physiological production per applied water. Although, the fresh weight is important in direct consumption of vegetable crops such as potato and tomato, $WP_{DM}$ analysis on such crops defines how efficiently the applied water is utilized to produce assimilate in the harvested organ in contrasting cultivars which could be likely an indicator for food processing industries.

Among the irrigation treatments, both the SDI and DDI treatments had significantly higher $WP_{DM}$ than FI and the PRD treatments (Table 1). Within any of the water-saving irrigation managements (dynamic or static), there were no significant differences between the $WP_{DM}$ values (Figure 4), but both dynamic irrigation strategies (DDI and DPRD) increased $WP_{DM}$ compared to the corresponding static ones (SDI and SPRD) by 26 and 19%, respectively, which showed that the dynamic irrigation strategy was more efficient than the static irrigation strategy in utilizing the applied water.

Comparing the potato cultivars, Ramos (1.08 kg $m^{-3}$) had higher $WP_{DM}$ than Agria (0.82 kg $m^{-3}$), though the difference between the potato cultivars was not significant ($p$=0.35) (Table 1). The highest $WP_{DM}$ was obtained in Ramos under DDI (2.06 kg $m^{-3}$) followed by the SDI (1.53 kg $m^{-3}$) strategy (Figure 4). Posadas et al. (2008) reported $WP_{DM}$ of 2.3 and 2.4 kg $m^{-3}$ for FI and PRD, respectively; which are almost twice of which obtained in our study. On the other hand, Xie et al. (2012) reported similar $WP_{DM}$ values for three potato cultivars under FI, DI and PRD, which ranged between 0.97 kg $m^{-3}$ in FI to 1.32 kg $m^{-3}$ in PRD depending on the location of experiments. This implied that irrespective of the water stress level and irrigation treatment, the $WP_{DM}$ is probably a spatial-temporal variable that also depends on climatic condition such that a potato cultivar may have 100% increases in $WP_{DM}$ upon changing the location under similar irrigation treatments (Xie et al., 2012; Ahmadi et al., 2010b).

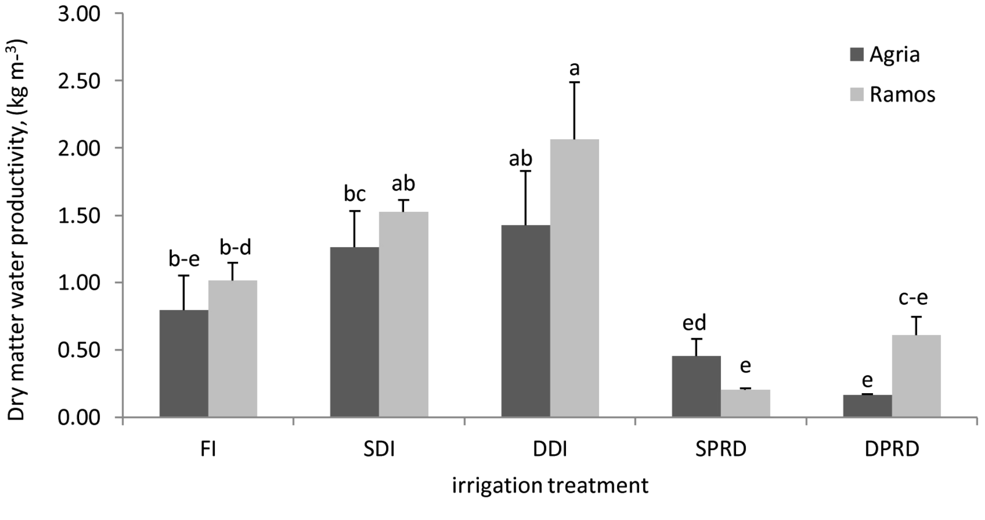


Figure 4. Dry matter water productivity (DMWP) in the different irrigation treatments and potato cultivars. Different letters show significant differences between cultivars across irrigation treatments at 0.05 probability level. Error bars indicate ± SD of mean.

## *Dry matter-Water content index*

Neither $WP_{DM}$ nor $WP_C$ gives any information about how much water is stored in bulk potato tubers. It is most likely that potato tubers in different irrigation treatments might have similar fresh tuber yields but the tuber dry matter would be different, which indicates the differences in the stored water content in the tubers. Generally the relative water content indices are among the most reliable indicators for defining water retention in plants (Shi et al., 2015). Therefore, the DMWCI values within irrigation strategies are shown in Figure 5. It is observed that the PRD strategies (DPRD, SPRD) had higher DMWCI than DI strategies (DDI, SDI). This revealed that the PRD irrigation strategies tended to increase the tuber water content than the DI strategies. This finding would clearly support the physiological principles behind the PRD that this water-saving irrigation strategy improves the crop water status (Jovanovic et al., 2010; Kang and Zhang, 2004).

Figure 5 demonstrates that Agria had higher DMWCI in the DDI, SDI and DPRD; but Ramos had higher DMWCI in SPRD. It implies that Agria tubers had more water content than Ramos tubers. It means that Ramos tended to partition more photosynthetic assimilate into the tubers. Posadas et al. (2008) reported that water stress improve the quality of potato chips as higher tuber dry matter gives chips a clearer and more uniform color. Karam et al. (2014) also found that deficit irrigation improved the processing industry's competitiveness of potato tubers. So, Ramos is a suitable potato cultivar for the industrial purposes. In addition, although both the DI irrigation strategies (SDI and DDI) had relatively similar DMWCI in Ramos, the DPRD (1.14) had lower DMWCI than SPRD (2.32), suggesting that it would be better to apply DPRD instead of SPRD in order to produce potato tubers for industry purposes.

Indeed, the DMWCI is the slope of the linear correlation between the relative tuber water content ($\frac{W_s}{W_r}$) and the relative tuber dry matter ($\frac{DM_s}{DM_r}$). This correlation is illustrated in Figure 6. The slope of the fitted lines for Agria and Ramos were 0.35 and 0.31, respectively. The larger slope in Agria means that more water was required for producing one unit of relative tuber dry matter. However, this is the first time that DMWCI is introduced and the applicability of DMWCI could be also checked for other irrigation managements, crop cultivars and environmental stresses. Nevertheless, the $\frac{DM_s}{DM_r}$ may vary by environment, cultivar and timing of water stress during the growing period (Karam et al., 2014) and therefore it should be tested if this index would be universal for different climates and environment.

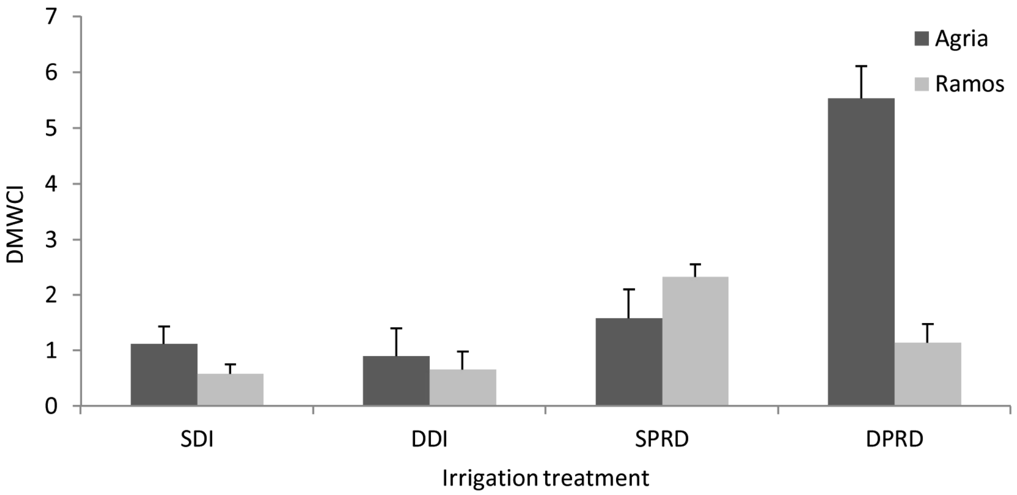


Figure 5. Dry matter-water content index (DMWCI) in the different irrigation treatments relative to the FI for the two potato cultivars. Error bars indicate ± SD of mean.

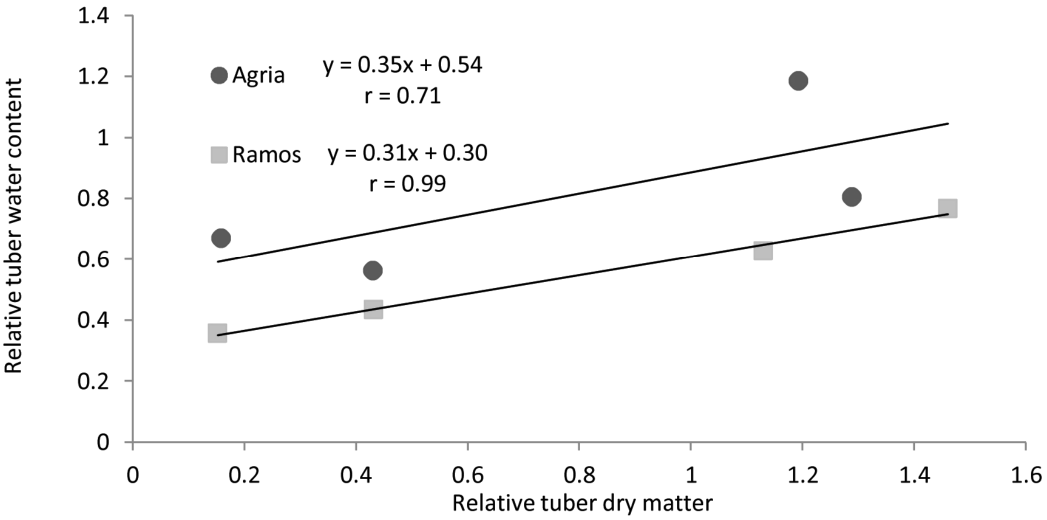


Figure 6. Relationship between the relative tuber water content ($\frac{W_s}{W_r}$) and the relative tuber dry matter ($\frac{DM_s}{DM_r}$) for the two potato cultivars.

## Conclusions

This study showed that the dynamic and static irrigation managements did not significantly change the tuber N contents under the PRD or DI water-saving irrigation strategies but PRD irrigation strategies significantly increased the tuber N contents of potatoes compared to the FI and DI treatments. In addition, the tuber fresh yield negatively correlated with tuber N content and therefore higher tuber N content led to reduced tuber fresh yield under the conditions of this study.

The $WP_{DM}$ of the static and dynamic DI treatments were approximately 4 and 2 times higher than those of PRD and FI. These findings imply that under water limiting conditions the DI treatments are the recommended water-saving irrigation strategies under the current experimental conditions. The newly introduced "Dry Matter-Water Content Index" (DMWCI) showed this index as a useful tool for tuber water relation studies based on which PRD strategies had higher DMWCI than DI ones. This concluded that Ramos might have allocated more photosynthetic assimilate into the tubers, which indeed was a good parameter for food industry purposes.

Overall, the DI treatments are the recommended water saving-irrigation strategies under these experimental conditions in terms of improved $WP_{DM}$ and greater dry matter allocation to the tubers, though the PRD irrigation strategy had higher tuber N content. Ramos is also the favored potato for higher $WP_{DM}$ and lower DMWCI that is a good indicator for food processing purposes.

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