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# EFFECT OF PRD IRRIGATION METHOD AND POTASSIUM FERTILIZER APPLICATION ON CORN YIELD AND WATER USE EFFICIENCY

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## Abstract

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Innovations for saving water in irrigated agriculture and thereby improving water use efficiency are of paramount importance in water-scarce regions. Therefore, to see how restricted irrigation systems and different potassium fertilizer affect water use efficiency and yield of corn, an experiment was conducted in an arid area in Khuzestan, Iran in 2011. A split-plot experimental design was used, based on a complete randomized block design with three replications. The main plots consisted of three irrigation methods: FI (full irrigation), variable and fixed partial root zoon drying (PRD-V and PRD-F). Each subplot received three rates of K fertilizer application: 0, 150 or 300 kg ha$^{-1}$. The results showed that the plots receiving the full irrigation resulted in significantly higher grain yields, 1000-kernel weight and grain number per cob than both PRD treatments. However, the highest WUE and IWUE were obtained in PRD-V and 300 kg K ha$^{-1}$ and the lowest one was found in the FI treatment and 0 kg K ha$^{-1}$. Potassium application increased RWC and grain protein percent in PRD-V and PRD-V than FI treatment. Full irrigation and PRD-F treatments produced the lowest and the highest ABA concentration at any potassium levels.

*Key words:* corn, grain yield, water use efficiency, PRD irrigation, potassium

## Introduction

Maize (*Zea mays* L.) is the third most important cereal after wheat and rice all over the world as well as in Iran. Global demand for maize will increase from 526 million tons to 784 million tons from 1993 to 2020, with most of the increased demand coming from developing countries (Rosegrant and Gerpacio, 1999). World area under maize crop was 147.6 million hectare with a grain production of 701.3 million tones and overall yield of 4752 kg per hectare during 2006-07. In Iran maize was grown on 1051.7 thousand hectares with annual production of 3604.4 thousand tones and average yield of 3427 kg per hectare (FAO, 2002).

Water scarcity and drought are the major factors constraining agricultural crop production in arid and semi-arid zones of the world. Irrigation is today the primary consumer of fresh water on earth (Shiklomanov, 1998), and thus agriculture has the greatest potential for solving the problem of global water scarcity. Consequently, improvements in management of agricultural water continue to be called for to conserve water, energy and soil while satisfying society is increasing demand for crops for food and fiber (Kassam et al., 2007). Innovations for saving water in irrigated agriculture and thereby improving water use efficiency are of paramount importance in water-scarce regions. Conventional deficit irrigation (DI) is one approach that can reduce water use without causing significant yield reduction (Kirda et al., 2005). Partial root zone drying (PRD) is a further development of DI. PRD is commonly applied as part of a deficit irrigation program

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because it does not require the application of more than 50–70% of the water used in a fully irrigated program (Marshal et al., 2008). PRD is an irrigation technique based on alternately wetting and drying opposite parts of the surface soil under which the plant root system is thought to be located. This new irrigation strategy allows the exploitation of drought-induced ABA-based root-to-shoot signaling system to water saving. These irrigation techniques, and particularly PRD, are promising for saving water in drought-prone regions. Novel deficit irrigation techniques such as PRD allow enhanced water use efficiency in crop production by exploiting the plant's long-distance signaling mechanisms that modify plant growth, development and functioning as the soil dries. The novel science behind these mechanisms was revealed in the last 15 years (Davies et al., 2001). The idea of using PRD as a tool to manipulate plant water deficit response has its origin in the observation that root-generated ABA can be transported to shoot regulating stomata of the leaves as shown in a number of crop species, such as corn (Bahrun et al., 2002) and soybean (Liu et al., 2005). Because of plant response, the aperture of stomata can be regulated so that a partial closure of stomata at a certain level of soil water deficit may lead to an increase in WUE (Liu et al., 2005). PRD also affects hydraulic conductivity of the root system. North and Nobel (North and Nobel, 1991) observed that hydraulic conductivity of *Agave deserti* roots increased significantly after drying and rewetting cycles. In maize PRD irrigation reduced water, consumption by 35% with a total biomass reduction of 6–11% as compared with fully watered plants (Kang and Zhang, 2004). Another experiment with hot peppers and drip irrigation showed that PRD reduced water used for irrigation by about 40% and maintained similar yield as in fully watered plants (Kang et al., 2001).

Potassium plays a vital role in: photosynthesis, translocation of photosynthesis, protein synthesis, control of ionic balance, regulation of plant stomata and water use, activation of plant enzymes and, many other processes (Marschner, 1995; Reddya et al., 2004). Potassium is not only an essential macronutrient for plant growth and development, but also is a primary osmotic in maintaining low water potential of plant tissues. Therefore, for plants growing in drought conditions, accumulating abundant K+ in their tissues may play an important role in water uptake along a soil–plant gradient. In water stressed plants, increased abscisic acid (ABA) levels are known to stimulate the release of potassium from guard cells, giving rise to stomatal closure (Assmann and Shimazaki, 1999). Numerous studies have shown that the application of K fertilizer mitigates the adverse effects of drought on plant growth (Sangakkara et al., 2001). Fusheing (2006) has revealed that lower water loss of plants well supplied with K+ is due to a reduction in transpiration, which not only depends on the osmotic potential of mesophyll cells but also is controlled largely by opening and closing of stomata. Corn leaf green parts decreased because of water pressure deficit in particular in lack consumption of potassium in soil. This reduction is 25% whereas consumption of potassium decreased corn green leaf parts only 3%. Consumption of potassium was caused to increase the rate (46.1 until 101.4%) under the water deficit condition Consumption of potassium was caused to increase leaf area rate (61.4 until 86.4%) as compared with unconsumption of potassium under the suitable soil water condition (Cox, 2001).

Iran faces a serious problem of water shortage for crop production. The water resources are becoming limiting and it has been estimated that water for irrigation purposes may be reduced up to 50% (Anonymous, 2005). Therefore, the objective of this study was to examine the effects of partial root zone drying (PRD) strategies and the role of potassium application on grain yield and water use efficiency of the corn crop under the Mediterranean climatic conditions in Southern Iran.

## Materials and Methods

### Plant material, growth conditions, potassium and water stress treatments

A field experiment with the hybrid corn variety SC-500 was conducted in an arid area in west of Iran, at the Islamic Azad University of Ramhormoz, Khuzestan, Iran (31°16′ N, 49°36′ E and 150.5 m above the sea level) in 2011. Some metrological data in the experimental location was shown in Table 1. A split-plot experimental design was used, based on a complete randomised block design with three replications. The main plots consisted of three irrigation methods: FI (full irrigation) was the conventional way where every furrow was irrigated during each watering cycle with 100% of the water typically applied to the crop in Khuzestan according with crop requirements, PRD-V (variable alternate furrow irrigation) and PDR-F (fixed alternate furrow irrigation). Each subplot received three rates of K (in the form of potassium sulphate) fertilizer application: 0, 150 or 300 kg ha$^{-1}$. Irrigation treatments were applied 30 days after planting. To determine the soil characteristics 5 samples from 30 cm depth were collected and analyzed for physical and chemical properties (Table 2). N and P fertilizer were applied according to recommendations of soil testing in forms of urea and super phosphates, respectively. Plots were sown on 31 July 2011 with a four rows planting machine, and were 9 m long and 4.5 m wide, with 6 rows 0.75 m apart. Plots were plowed and disked after winter wheat harvest in June. During the growth period, all plots were weeded manually. No serious incidence of insect or disease was observed and no pesticide or fungicide was applied. Drip irrigation system was used in the study. The soil water content measurements were done one day before irrigation until harvest in three replications for all treatments by gravimetric sampling in 0–0.30 m.

**Water use efficiency (WUE),** was computed as the ratio of corn grain yield to seasonal water use.

**Irrigation water use efficiency (IWUE)**, was determined as the ratio of corn grain yield for a particular treatment to the applied water for that treatment (Howell et al., 1995).

In order to determine total dry matter above the ground level, five plants within 0.5–0.6 m of a row section in each plot were cut at the ground level at maturity stage. Plant samples were dried at 65°C until constant weight was achieved. Corn grain yields were determined by hand harvesting the 8 m sections of three center rows in each plot on November 21, 2011. Then, grain yield values were adjusted to 15.5% moisture content. In addition, 1000-kernel weight, grain number per cob, and harvest index values were also evaluated. Harvest index (HI) is calculated as the ratio of the grain yield (GY) to above-ground dry matter yield (DM) at harvest.

**Total chlorophyll**. Chlorophyll content of five ear leaves in each plot was measured at anthesis stage by the chlorophyll content meter device (Hansatech Instruments - model-Cl-01, Tokyo, Japan).

**Relative water content.** Leaf tissue was used for Relative Water Content (RWC) determination, as follows: A composite four leaves of similar physiological maturity sample of leaf discs is taken and the fresh weight is determined, followed by flotation on water for up to 4 hr under normal room light and temperature. The turgid weight is then recorded, and the leaf tissue is subsequently oven-dried to a constant weight at about 85°C. RWC calculated according to Aliabadi Farahani et al. (2008).

$$RWC\ (\%) = \frac{(FW - DW)}{(TW - SW)} \times 100$$

where, FW is fresh weight, DW dry weight and TW turgid weight.

**ABA determination.** In this experiment, ABA content of the plant was measured at the fully expanded ear leaves at tasseling stage. Three leaves collected per plant from five plants (therefore, 15 leaves) per treatment. Leaves were frozen in liquid N2, stored at -20°C for no longer, than 10 d, then freeze-dried. Freeze-dried

**Table 1**
**Metrological statistic in the experiment location in months of experiment**

| Months of experiment | Rainfall, mm | Average minimum temperature, ºC | Average maximum temperature, ºC | Average minimum relative humidity, % | Average maximum relative humidity, % | Evaporation from Class A pan, mm |
|---|---|---|---|---|---|---|
| August | 0 | 32.6 | 46.6 | 9 | 32 | 60.2 |
| September | 0 | 22.9 | 44.5 | 11 | 38 | 366.1 |
| October | 0 | 27.7 | 39.8 | 12 | 37 | 290.6 |
| November | 13.7 | 18.2 | 32.2 | 17 | 46 | 171.5 |

**Table 2**
**Soil physical and chemical characteristics of the experimental site**

| Variable | |
|---|---|
| Texture | Si-C |
| PH | 7.57 |
| EC dS $m^{-1}$ | 4.6 |
| Organic matter, % | 1.19 |
| N, % | 0.042 |
| P mg $kg^{-1}$ | 5.7 |
| K mg $kg^{-1}$ | 174 |
| Fe | 3.1 |
| Zn | 0.78 |
| Mn | 6.5 |
| Cu | 0.98 |

tissue (1 g) was homogenized in 20 ml of methanol-ethyl acetate-acetic acid, 50:50:1 (v/v/v), containing 20 mg/L butylated hydroxytoluene as an antioxidant, filtered through Whatman No. 1 filter paper, then made to a volume of 100 ml (Hubick and Reid, 1980). Tritiated ABA (1.44 TBq/ mmol, Amersham) was added during grinding as an internal standard. Filtrates were evaporated to dryness in vacuo at 35C. Residue was extracted with 10 ml 500 mM K-phosphate (pH 8), filtered, and then partitioned three times (10 ml) into ethyl acetate by lowering the pH to 2.5 (Hubick and Reid 1980). Ethyl acetate was evaporated under an air stream. Samples were dissolved in 5 ml of methylene chloride and filtered through Millipore prefilters. Filtrates were evaporated under air. Samples were redissolved in 100 gl 1% (v/v) acetic acid in methanol and 80 Ml injected onto a preparative C18 (25 cm x 10 mm i.d.) HPLC column (Ackerson 1980). Isocratic elution was with 40:60:1 (v/v/v) methanol:water:acetic acid at 2.5 ml/min (Markhart 1982). Fractions with retention times (29 to 31 min) corresponding to standard ABA (A254) were pooled and dried under air. These fractions were redissolved in 20 ul 1% (v/v) acetic acid in methanol and 10 ,ul injected onto an analytical C18 (15 cm x 4.6 mm i.d.) HPLC column (Ackerson, 1980). Isocratic elution was with acetonitrile: water. formic acid (25:74.9:0.1, v/v/v) at 1 ml/min. Fractions with retention times (8-9 min) corresponding to standard ABA (A254) were collected and radioactivity determined. Quantification was by comparison of sample A254 with that of ABA standards. Isotope dilution measurements were used to correct for losses during the procedures.

**Statistical analysis.** Data were analysed by analyses of variance using the general linear model (GLM) procedure provided by SAS (2004). When significant differences were found ($p$ = 0.05), the Duncan's multiple range test (DMRT) was carried out.

## Results and Discussion

**Plant height.** There was only significant difference between irrigation treatments in this trait (Table 3 and 4). Table 3 shows that the highest plant high (210 cm) was obtained in full irrigation treatment.

**Yield and yield components.** Corn grain yield, above ground dry-matter yield, and yield components data are summarized in Table 3 and 4. Variance analysis of the grain yield data indicated that irrigation treatments significantly affected the yields ($p < 0.05$). As for the Duncan classification made with respect to irrigation treatments, the plots receiving the full irrigation (FI) resulted in significantly higher grain yields than both PRD treatments (Table 3 and 4). Grain yields varied from 8654 to 11650 kg $ha^{-1}$ among the treatments. The highest average grain yield was observed in FI treatment as 11650 kg $ha^{-1}$, and the lowest yields were found in fixed PRD treatment as 8654 t $ha^{-1}$, when irrigation was reduced by 50%. Variable alternate PRD and fixed alternate PRD treatments significantly ($p <$ 0.05) resulted in lower grain yield (30 and 35 %, respectively), compared to FI treatment. Yield in fixed alternate PRD treatment was 5% lower than variable alternate PRD treatment. The highest and lowest grains yield in consumption of 300 kg K $ha^{-1}$ was 11945 kg $ha^{-1}$ and in control 6542 kg $ha^{-1}$. Consumptive levels of 150 and 300 kg K $ha^{-1}$ were in the same statistical group. Potassium fertilizer in comparison with control increased grains yield as rate 56 and 82%, respectively (Figure 1). Potassium fertilizer application in deficit irrigation treatments increased grain yield more than full irrigation treatment. In full irrigation treatment at the highest potassium fertilizer treatment grain yield increased 25%, however, at the same potassium level grain yield increase to 35% at variable alternative PRD treatment (Table 4). Corn grain yields were reported to

**Table 3**
**Mean values of the traits under three irrigation methods and potassium fertilizer**

| Treatments | Plant height, cm | -1000 Kernel weight, g | No of grain per cob | Biologic yield kg ha$^{-1}$ | Grain yield kg ha$^{-1}$ | Harvest Index, % | Grain protein, % | WU † m$^3$ ha$^{-1}$ | WUE ‡ kg grain m$^{-3}$ | IWUE § kg grain m$^{-3}$ | Chlorophyll content |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Irrigation | | | | | | | | | | | |
| FI | 210 a | 220 a | 451a | 21668a | 11650a | 49a | 8.85 a | 10870 a | 1.08b | 1.13b | 22.25 a |
| PRD-V* | 189 b | 190 b | 394ab | 19549b | 8975b | 46b | 9.71b | 6914 b | 1.29a | 1.43a | 20.35 a |
| PRD-F+ | 186 b | 182 b | 347b | 18246b | 8654b | 44b | 9.95 b | 7154 b | 1.20a | 1.32a | 20.54 a |
| Potassium fertilizer | | | | | | | | | | | |
| 0 | 187 a | 169 b | 256 c | 18456 b | 6542 b | 43 b | 8.57 b | 9587a | 0.68 c | 0.74 c | 17.80 c |
| 150 | 191 a | 192 a | 338 b | 21763 a | 10289 a | 49 a | 9.76 a | 7826 b | 1.31 b | 1.45 b | 25.14 a |
| 300 | 197 a | 210 a | 412 a | 23168 a | 11945 a | 51 a | 9.75 a | 7542 b | 1.58 a | 1.81 a | 21.32 b |

†Water use, ‡: Water use efficiency, §: Irrigation water use efficiency. *Variable alternate PRD, + Fixed alternate PRD. Same letters in columns are not significantly different at p 0.05.

**Table 4**
**Mean values of the traits as affected by irrigation and potassium fertilizer**

| Treatments: Potassium fertilizer | Irrigation | Plant height, cm | 1000-Kernel weight, g | No of grain per ear | Biologic yield, kg ha$^{-1}$ | Grain yield, kg ha$^{-1}$ | Harvest Index, % | Chlorophyll content | IWUE §, kg grain$^{-3}$ | WUE ‡, kg grain m$^{-3}$ | WU †, mm | Grain protein, % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | | 198 | 194 | 353 | 20062 | 9096 | 46 | 20.12 | 0.94 | 0.89 | 10228 | 8.71 |
| 150 | FI | 200 | 206 | 394 | 21715 | 10969 | 49 | 23.7 | 1.29 | 1.2 | 9348 | 9.3 |
| 300 | | 203 | 215 | 431 | 22418 | 11597 | 50 | 21.78 | 1.47 | 1.34 | 9206 | 9.29 |
| 0 | | 193 | 179 | 325 | 19002 | 7758 | 45 | 19.07 | 1.09 | 0.99 | 8250 | 9.14 |
| 150 | PRD-V* | 195 | 191 | 366 | 20656 | 9632 | 48 | 22.75 | 1.44 | 1.31 | 7370 | 9.73 |
| 300 | | 198 | 200 | 403 | 21358 | 10460 | 49 | 20.83 | 1.62 | 1.44 | 7228 | 9.71 |
| 0 | | 191 | 175 | 301 | 18351 | 7598 | 44 | 19.17 | 0.98 | 0.95 | 8370 | 9.26 |
| 150 | PRD-F+ | 193 | 187 | 342 | 20124 | 9471 | 47 | 22.84 | 1.39 | 1.26 | 7490 | 9.85 |
| 300 | | 196 | 196 | 379 | 20707 | 10299 | 48 | 20.93 | 1.57 | 1.4 | 7348 | 9.82 |
| | LSD (0.05) | 56 | 10 | 89 | 4561 | 2895 | 12 | 5.1 | 0.124 | 0.115 | 4253 | 1.5 |
| Sources of variation | | | | | | | | | | | | |
| Irrigation (I) | | ns | * | * | ** | * | * | ns | * | ** | ** | * |
| Potassium fertilizer (P) | | ns | * | * | * | ** | * | * | * | * | * | * |
| I × P | | ns | * | ns | * | * | ns | ns | * | * | ns | ns |
| CV (%) | | 14.35 | 19.41 | 13.25 | 7.31 | 12.18 | 21.22 | 18.71 | 21.22 | 12.18 | 7.31 | 18.71 |

†: Water use, ‡: Water use efficiency, §: Irrigation water use efficiency. *Variable alternate PRD, + Fixed alternate PRD. Same letters in columns are not significantly different at p 0.05.

vary from 3.26 t ha$^{-1}$ in dry-treatment to 8.51 t ha$^{-1}$ for the full irrigation for sprinkler irrigated corn by Boz (2001); varying between 8.22–8.61 t ha$^{-1}$ in PRD-50 and 8.30–8.04 t ha$^{-1}$ DI-50, respectively, to 9.19–10.79 t ha$^{-1}$ in full irrigation treatment for surface irrigated corn in the first and second year by Kirda et al. (2005); and from 6.18 t ha$^{-1}$ for deficit irrigation to 9.79 t ha$^{-1}$ for full irrigation for drip-irrigated corn in the same experimental site by Bozkurt et al. (2006). Water stress increased growth hormone level for example cytokinin

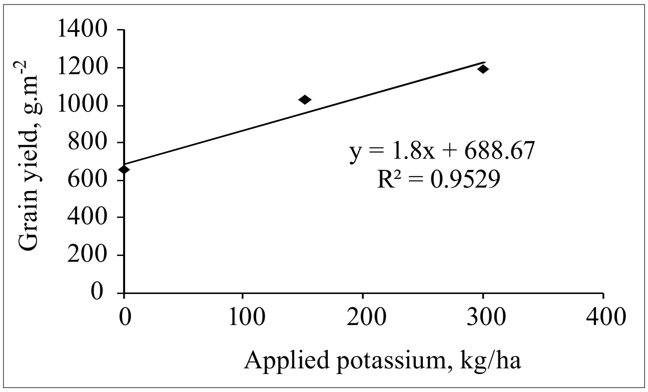


**Fig. 1. Mean grain yield response of corn to potassium fertilizer**

and decreased inhibitor hormones for example ABA, but potassium increased cell division, grains number per row, row numbers per row, 1000 grains weight and grains yield (Nesmith and Ritchie, 1992). Potassium regulate stoma closure and prevent water wasting and regulating osmosis, increase water use efficiency and improved growth condition in corn (Wiebold, and Scharf, 2006).

In the study, there was significant difference in 1000-kernel weight among different irrigation treatments. 1000-kernel weight varied from 182 to 220 g. The highest 1000-kernel weight was observed in FI treatment as 220 g, and the lowest one was found in PRD-F treatment as 182 g. Deficit irrigation reduced 1000-kernel weight; however, there were not significant differences between PDR-V and PRD-F treatments. Water shortage led to smaller kernels compared to those gained from the full irrigation cases. Generally, the 1000-kernel weight production with full irrigation is higher than the deficit irrigation treatments. Results showed that significant difference exist among different potassium fertilizer levels from on 1000-kernel weight. The highest 1000-kernel weight was obtained with consumption rate of potassium 300 kg ha$^{-1}$ (210 g) and the lowest was in control (169 g). This indicates that 1000-kernel weight was increased with consumption of 300 kg ha$^{-1}$ relative to control as 24% (Table 3). However, there were no significant difference between 150 and 300 kg K ha$^{-1}$. Potassium has important role in water use efficiency, improves in growth plant in water use efficiency, and improves in growth plant protein and quick transportation toward grains (Marschner, 1995).

Irrigation treatments had a significant effect on grain number per cob ($p < 0.05$). The highest grain number per cob was observed in FI treatment as 451, and the lowest grain number per cob was found in PRD-F treatment as 347. As the applied irrigation amount increased, the grain number per cob also increased (Tables 3 and 4). Mean comparison showed that application of potassium at the rate of 300 kg ha$^{-1}$ produced the highest grains number per cob as 412. Control produced the lowest grains number per cob 256 with significant difference with 150 kg ha$^{-1}$. Therefore applying potassium as 300 kg ha$^{-1}$ increased grains number per cob to 61 and 22 % compared to 0 and 150 kg K ha$^{-1}$ (Table 3). Potassium affected cell metabolism and enzyme activity and regulates cell osmosis and increase absorption of water and photosynthesis. Material transition in phloem vascular effected transition of growth stimulation material and increased cell division grains number per cob (Marschner, 1995).

**Biologic Yield.** The highest dry matter yield was observed in FI treatment as 21668 kg ha$^{-1}$, and the lowest dry matter was found in PRD-F treatment as 18246 kg ha$^{-1}$ (Table 3). Generally, the dry matter production under the full irrigation was significantly higher ($p < 0.01$) than those under the deficit irrigation treatment. The reason for higher dry matter yield in the FI treatment can be attributed to favorable soil water conditions created in FI plots, which enhanced the vegetative development. The highest and lowest biomasses obtained respectively at 300 kg ha-1 23168 kg ha-1 and control 18456 kg ha$^{-1}$. However, there was not significant difference between 150 and 300 kg K ha$^{-1}$. Wiebold and Scharf (2006) indicated that potassium increased yield of dry substance in corn. Potassium could increase the rate of CO stabilizing with interference in osmosis regulation, improving stoma closure, increased CO2 conductivity and enzyme activity because of photosynthesis and carbohydrate produce. Therefore, potassium increased in carboxilation efficiency in water deficit condition and this increased dry weight of shoot (Marschner, 1995).

**Harvest Index.** Harvest Index (HI), known as the proportion of the corn/grain yield to the dry matter for the different treatments, is presented in Table 3. The highest harvest index was observed in FI treatment as 49%, and the lowest harvest index was found in PRD-F treatment as 44. Harvest index was affected by soil water deficit that developed during the grain filling period following anthesis in PRD-V and PRD-F treatment plots. It appears that irrigation treatments had significant effect on harvest index ($p < 0.05$). HI values were reported to vary form 0.20 to 0.43 by Boz (2001); from 0.33 to 0.42 by Bozkurt et al. (2006) in the same experiment station. Effect of K application as well as water stress on harvest index was also significant. The optimum dose of K for maximum harvest index was K150 and K300, respectively (Table 3).

**WU, WUE and IWUE.** The highest water use efficiency (WUE) averaging 1.29 kg m$^{-3}$ was obtained in PRD-V treatment, followed by PRD-F- with 1.20 kg m$^{-3}$ and the lowest one was found in the FI treatment as 1.08 kg m$^{-3}$ (Table 3). The range of WUE reported is very large (0.68–1.58 kg m$^{-3}$) and thus offers tremendous opportunities for maintaining or increasing agricultural production with 20–40% less water resources (Zwart and Bastiaanssen, 2004). Kang and Zhang (2004) reported that water use as percent of fully irrigated treatment is decreased and irrigation water use efficiency (IWUE) is increased essentially by PRD as reported in a number of species, e.g. cotton, tomato, pear grapevine and hot pepper. PRD irrigation of corn reduced water consumption by 50 and 55 % in PRD-F and PRD-V as compared with fully watered plants. Irrigation water use efficiencies (IWUE) varied from 1.13 kg m$^{-3}$ in FI to 1.43 kg m$^{-3}$ in PRD-F treatments. In all the cases, IWUE values related to deficit irrigations were higher than those of full irrigation were. IWUE increased with decreasing irrigation amounts and/or water use. Therefore, the results clearly indicate that the efficient use of water is possible with PRD technique under the conditions of drought. Water use decreased proportionally with application of potassium fertilizer (Table 3). The highest water use efficiency (WUE) and irrigation water use efficiency (IWUE) averaging 1.58 and 1.81 kg m$^{-3}$ was obtained in 300 kg K ha$^{-1}$ and the lowest ones was found in the 0 kg K ha$^{-1}$ treatment as 0.68 and 0.74 kg m$^{-3}$ (Tables 3 and 4). Potassium regulate stoma closure and prevent water wasting and regulating osmosis, increase water use efficiency and improved growth condition in corn (Wiebold and Scharf, 2006). Growth may delay in potassium intensive deficit and canopy may not close fully (Umar and. Moinuddin, 2001). While potassium consumption lead to accelerate canopy formation and cause to more available water use by plant and even plant early maturating (Cakmak, 2005). Potassium is important for a plant's ability to withstand extreme drought stress. Some field crops showed ability of water relations adjustment, which refers to water use efficiency. Soil nutrients as if as potassium ions affect water transport in whole plant, maintain cell pressure and regulate the opening and closing of stomata (Wortmann et al., 2009; Parsons et al., 2007).

**Relative water content.** RWC was significantly lower in water-stressed plants than in plants grown under normal conditions. Application of K improved RWC under both moisture levels with the maximum effect figuring at K300. The highest K application increased RWC by 9 % under normal conditions, and by 11 % and 15 % under water stress conditions in PRD-V and PRD-V (Figure 2), respectively.

**Grain protein content.** Both irrigation methods and potassium fertilizer had significant effect of grain protein percent (Tables 3 and 4). Grain protein percent increased up to 10 and 13 % in PRD-V and PRD-F than FI treatment, respectively. Potassium fertilizer also increased grain protein by 14 % than control. However, there were not significant difference between 150 and 300 kg K ha$^{-1}$.

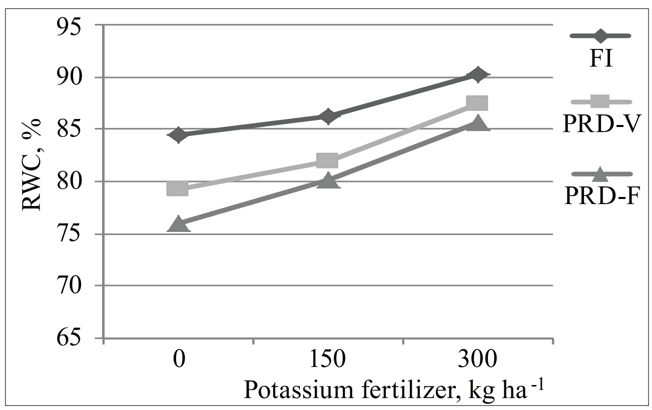


**Fig. 2. Relative water content of ear leaf as afected by potassium fertilizer and irrigation methods**

**Chlorophyll content.** There was no significant difference in irrigation methods in this trait (Table 3). Mean comparison also showed that application of potassium at the rate of 150 kg ha$^{-1}$ produced the highest chlorophyll content. Application of potassium more than 150 kg ha$^{-1}$ decreased chlorophyll content. Control produced the lowest value with significant difference with 150 kg ha$^{-1}$. Therefore applying potassium as 150 kg ha$^{-1}$ increased grains number per cob to 42 and 18 % compared to 0 and 300 kg K ha$^{-1}$.

**ABA content in ear leaf.** Full irrigation treatment produced the lowest ABA concentration at any potassium levels (Figure 3). The highest value of ABA was belonged to the PRD-F treatment, which was 6 fold more than FI treatment (Figure 3). The results in the present study did not differ from what has been reported before that water stress causes ABA accumulation in stressed plants (Unyayar et al., 2004). According to Tardieu and Simmonneau (1998) isohydric species have a markedly increase of ABA in response to water stress that is linked to the effects of PRD in the leaves. The idea of using PRD as a tool to manipulate plant water deficit response has its origin in the observation that root-generated ABA can be transported to shoot regulating stomata of the leaves as shown in a number of crop species, such as corn (Bahrun et al., 2002) and soybean (Liu et al., 2002). Because of plant response, the aperture of stomata can be regulated so that a partial closure of stomata at a certain level of soil water deficit may lead to an increase in WUE (Liu et al., 2005). To sustain the effect of PRD on stomata, it is necessary to regularly alternate the wet and dry compartments, usually every period of 10–14 days (Stoll and Loveys, 2000) Dry; the length of the period depends on crop species, evaporative demands and soil conditions. Application of potassium decreased ABA concentration in all irrigation treatments. Average ABA concentration in K1, K2 and K3 was 45, 70 and 100 ng g$^{-1}$ fresh weight of ear leaf, respectively. A substantial increase of ABA was observed in roots kept under potassium deficiency. Potassium deficiency also caused an accumulation of endogenous ABA in root tissues (Schraut et al., 2005). Soils of extreme habitats are often alkaline, or loaded with large amounts of sodium chloride, or deficient in the major nutrients. Potassium deficiency was reported to stimulate ABA biosynthesis in roots and to intensify the root-to-shoot ABA signal (Peuke et al., 2002).

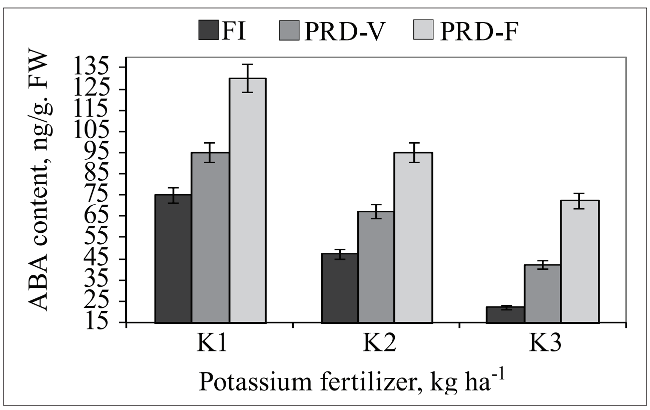


**Fig. 3. ABA content of ear leaf as afected by potassium fertilizer and irrigation methods**

## Conclusion

In this study, we evaluated the effects of partial root zone drying (PRD) and full irrigation (FI) strategies on yield and water use efficiency of corn crop under the Mediterranean climatic conditions in Southern Iran in 2011. PRD-V and PRD-F treatments received about 50% of irrigation water applied to the FI plots after August 31, and water use in these two treatment plots was reduced about 39 and 35%, respectively. On the other hand, the 50% deficit irrigation techniques (PRD-V and PRD-F) reduced corn yields by 30 and 35% compared to FI irrigation. Both irrigation strategies, the PRD-V and PRD-F, were equally effective in saving irrigation water. Although this technique was reported by Kang and Zhang (2004) to have the potential to increase canopy vigor, and maintain yields when compared with normal irrigation methods, our results are not in accordance with this finding. In other words, many situations need to be considered before it can be concluded whether PRD is practically useful in all situations. According to the research results, the highest water use efficiency (WUE) averaging 1.29 kg m$^{-3}$ was obtained in PRD-V, followed by PRD-F with 1.20 kg m$^{-3}$ and the lowest one was found in FI treatment as 1.08 kg m$^{-3}$. The research results revealed that the PRD irrigation practice for corn provide water use efficiency benefit as compared to full irrigation (FI). It is known for long that plants growing in dry land with periodic soil drying have a higher WUE (Bacon 2004). Apparently, the increased WUE should be an integrated result of both short-term, as a function of atmosphere condition, and long-term, as a function of soil water availability, regulation of water loss. Improved WUE with a responsive stomatal behavior is indeed predicted by Cowan (1982) from an analysis of the optimization pattern of water use by plants. The value of benefits from water savings should be balanced with value of yield reductions and cost of implementing PRD irrigation system compared with conventional systems.

Potassium fertilizer application in deficit irrigation treatments increased grain yield more than full irrigation treatment. 1000-kernel weight, grains number per cob, biologic yield and harvest index were increased with consumption of 300 kg K ha$^{-1}$ relative to control as 24% (Table 3). However, there were no significant difference between 150 and 300 kg K ha$^{-1}$. Water use decreased proportionally with application of potassium fertilizer. Potassium fertilizer improved RWC under three moisture levels with the maximum effect at K300. Irrigation methods and potassium fertilizer had significant effect of grain protein percent. ABA concentration at any potassium levels produced the lowest values in full irrigation treatment

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