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Effects of Deficit and Cutoff Irrigation During Different Phenological Stages of Fruit Growth on Production in Mature Almond Trees cv. 'Mamaei'

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Abstract

Regulated deficit irrigation (RDI) is commonly used during different phenological stages of fruit growth and development in almond trees to reduce the amount of irrigation water applied without or with only very small reductions in yield. Therefore, to study the effects of deficit and cutoff irrigation during different phenological stages of fruit growth and development in almond cv. "Mamaei" production, an experiment was carried out in a split plot on randomized block design with three replications. The main plots were three different phenological stages of fruit growth and development i.e. Stage I (fruit growth period), Stage II (kernel growth period) and stage III (preharvest period). The subplots had different irrigation regimes, namely T1= 100% ETc (Full irrigation), T2= 80% ETc (deficit irrigation), T3= 40% ETc (deficit irrigation) and T4= 0% ETc (cutoff or drought period). Traits such as fruit size (length, width and diameter), fresh and dry weight of fruit, fresh and dry weight of kernel, percentage of fruit drop, kernel percentage and yield were measured. The results showed that deficit and cutoff irrigation during stage-I decreased fruit size, both fresh and dry weight of fruit. Deficit and cutoff irrigation during stage-II decreased fruit fresh weight, fresh and dry weights of kernel, but no significant differences were observed for the measured traits when irrigation treatments were applied at stage III. These results indicated that preharvest stage (stage III) in 'Mamaei' cultivar has low sensitivity to deficit irrigation. Therefore, it is concluded that deficit irrigation with 40% of full irrigation (%40 ETc) during stage III for two months prior to harvest can be used without considerable reduction of yield for this cultivar under the climatic conditions in Saman region.

Keywords: Almond, Drought, Fruit development, Irrigation levels, Yield.

Introduction

The scarcity of water resources is one of the main limiting factors of agricultural production especially in arid and semi-arid regions. Iran, a country with a mainly arid and semi-arid climate, is one of the main producers of almond. Almond (*Prunus dulcis*) is one of the major and oldest nut tree crops throughout the world. Iran is one of the largest almond producing countries, ranking after USA and Spain. The Chaharmahal and Bakhtiari province, located in the southwest of Iran, is one of the areas for almond cultivation in Iran. Almond is considered to be a drought-tolerant plant and it is often grown as a rainfed crop in marginal Mediterranean areas (Girona *et al*., 1988; Germana, 1997).

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Although, almond shows a drought tolerance and is adaptable to a wide range of water availability, for commercial production it needs to be irrigated during the growing season (Germana, 1997; Girona et al., 1997). Water requirement of almond is variable at different phenological stages of fruit growth and development, and during different seasons (Girona *et al*., 1998). Irrigation may improve almond yields in dryland and increase grower benefits, but the lack of water in traditional almond areas requires development of new strategies (Goldhamer, 1996). In order to develop these new irrigation strategies it is necessary to know annual and seasonal water requirements of almond in detail (Girona *et al*., 1993 and 1997), including its response to different regulated deficit irrigation strategies (Girona *et al*., 1993 and 1998; Goldhamer and Smith, 1995).

Some studies indicate that it is necessary to avoid water stress during active vegetative and fruit growth periods (Goldhamer and Smith, 1995; Goldhamer, 1996; Goldhamer and Viveros, 2000). Yield in almond trees may be seriously affected when water stress occurs during the active vegetative and fruit growth period (stages I and II, March-June). However, almond yield is relatively insensitive to mild and moderate water stress during preharvest or kernel filling (stage III, June-August) (Girona *et al*., 2005; Goldhamer, 1996). The strong sink activity of the fruit during this period compared to other plant organs may be the cause of this behavior (Romero *et al.,* 2004). For this reason, phase III (preharvest) has been considered the most suitable for the application of deficit irrigation. Nevertheless, avoidance of severe stress in almonds seems highly desirable for a crop where nut size is determined before harvest. Furthermore, it should be noted that processors pay less for smaller fruit (Goldhamer*et al*., 2006).

According to Hutmacher (1994), the yield of almond decreased with reduction of water to 50% ETc (Evatranspiration) irrigation. The low yield was due to a decrease of canopy size and the weight of fruit, as well as the number of flowers. Germana (1997) reported that drought from June 15th to July 25th decreased the fruit weight and yield of almond trees. Other studies have determined that almond is a drought-tolerant crop, indicating that almond yield is relatively insensitive to mild or moderate water stress during the preharvest stage (Girona and Marsal, 1995; Goldhamer and Shackel, 1990; Goldhamer, 1996; Girona *et al*., 2005; Goldhamer and Viveros, 2000). However, the same studies indicate that it is necessary to avoid water stress during active vegetative and fruit growth periods (Germana, 1997; Girona *et al.*, 1997; Goldhamer and Viveros, 2000; Romero *et al*., 2006; Goldhamer*et al*., 2006). Irrigation water up to 25% ETc may be economized during slowdown periods of fruit growth (preharvest) without major negative effect up on yield for almond trees (Razouk*et al*., 2013).

Goldhamer*et al*., (2003) found that with the less severe regulated deficit irrigation (RDI) regime, less water was applied relative to the cooperativenearly fully irrigated trees with no significant reduction in kernel size or other important almond parameters. In fact, the RDI regimes accelerated hull-split, decreased kernel water content and increased the nut-kernel percentage at harvest. In semiarid areas such as Iran with reduced water supplies, Regulated deficit irrigation (20% ETc) applied during the kernel-filling stage (preharvest stage) is profitable for almond cultivation, especially if the price of water is high as in this area (Romero *et al*., 2006).The aim of this experiment was to study effects of drought and deficit irrigation during phonological stages of fruit growth and to determine the seasonal sensitivity of almond cv. “Mamaei” to water stress.

Materials and Methods

The experiment was conducted in the almond orchards of Emamiye Station in Chaharmahal and

Bakhtiari province (32° 29′ N, 50° 58′ E, elevation 1900 m with 300 mm rainfall) during 2002 and 2003 years (Table 1). The almond cv. "Mamaei" was as the main cultivar and cv. "Rabie" as a pollinizer. "Mamaei" is one of the main (about 60 - 65%) cultivars in almond orchards in Chaharmahal and Bakhtiari province. Ten-year-old "Mamaei" trees were grafted onto almond bitter rootstocks and were planted on loamy, sandy soil with a spacing of 5× 6 m under drip irrigation system that was modified for the experimental purposes.

The main plots were three different phenological stages of fruit growth i.e. stage-I (fruit growth from March 21st to May 25th), stage-II (kernel growth from May 26th to June 30th) and stage-III (preharvest period from July 1st to August 15th). The subplots utilized four irrigation regimes:T_1 = 100% ETc (Full irrigation), T_2 = 80% ETc (deficit irrigation), T_3 = 40% ETc deficit irrigation) and T_4 = 0% ETc (drought period). The water requirements (ETc) were estimated by Penman-Mantith method, according to the soil water content and ETo values, which were obtained from a climatology weather station that was located about one kilometer from the almond orchards. Irrigation treatments were applied during each of phenological stages of fruit growth and development. The experiment was carried out in a split plot, based on a randomized complete block design (RCBD) with three replications. Each block consisted of 12 trees (3×4) for experimental measurements; four trees were used as guard trees. At the end of each stage, 100 fruits (50 fruit per tree) per treatment were collected. Fruit size (length, width and diameter) and fresh and dry weight of fruit, shell and kernel were determined. At harvest time, total yield of each tree was collected and measured. Also a sample of 100 fruits was used to determine kernel percentage. Dry weight of fruit and kernel were measured after drying the fresh tissues for 72 hours at 65°C in an oven. The data were statistically analyzed by SAS software program and means were compared by Duncan's multiple range test.

Table1. Rainfall (mm) and Temperature (°C) in different months during the experiment.

Year	Rainfall (mm) in different months											
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
2001 - 2002	4.9	30.7	140.6	106.0	22.8	42.9	65.6	0.4	0.0	0.0	0.0	0.0
2002- 2003	0.2	37.9	69.2	69.0	52.0	68.6	35.6	2.7	0.0	0.0	0.0	0.0
	Average the temperature (°C) in different months											
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
2001 - 2002	14.7	7.2	4.9	0.4	3.5	7.3	10.9	15.7	20.3	23.2	23.2	20.1
2002- 2003	14.3	7.2	2.6	-0.8	1.7	5.5	11.2	13.7	19.2	23.8	21.8	17.4

Results

The results showed that deficit irrigation and drought during stage-I decreased fruit size (length, width and diameter) and increased the percentage of fruit drop. However the fresh and dry weights of fruits were not affected significantly (Table 2).Deficit irrigation and drought during stage-II decreased fruit fresh weight and the fresh and dry weights of kernels, but the fruit dry weight and fruit size were not significantly decreased (Table 3). According to the results, the interaction between irrigation and growing seasons did not show any significant differences on measured parameters during stage I and stage II.

The results showed that irrigation treatments had no significant effect on measured traits during stage III (Table 4). Overall, the results indicated that deficit irrigation and drought during of the all phenological stages of fruit growth significantly decreased kernel dry weight, kernel percentage and yield (Figs. 1, 2 and 3), but that the interactions between of growing seasons, fruit growth stage and irrigation did not have any significant on these characteristics.

Table 2.Variance analysis of measured traits in different irrigation levels (T) during phenological stage-III of fruit growth

S.O.V.	df	Mean of square (M.S.)							
		Fruit fresh weight (gr)	Fruit dry weight (gr)	Kernel fresh weight(gr)	Kernel dry weight(gr)	Kernel percentage (%)	Fruit Length (mm)	Fruit Width (mm)	Fruit Diameter (mm)
Year (Y)	1	6.683^{ns}	1.317^{ns}	0.865^{*}	0.75^{**}	64.955^{**}	25.834^{**}	18.113^{*}	0.0001^{ns}
Year × rep	4	3.237	0.540	0.06	0.008	19.01	1.091	1.792	2.851
Irrigation (I)	3	0.087^{ns}	0.107^{ns}	0.034^{ns}	0.01^{ns}	2.195^{ns}	1.519^{ns}	0.491^{ns}	0.255^{ns}
I × Y	3	0.107^{ns}	0.125^{ns}	0.019^{ns}	0.017^{ns}	1.215^{ns}	2.523^{ns}	0.221^{ns}	0.0001^{ns}
Error	12	0.475	0.084	0.023	0.012	4.099	2.229	0.511	0.909
CV%		10.80	6.51	7.98	8.73	7.13	3.86	3.14	5.86

*: Significant differences at 1% level, *: Significant differences at 5% level, ^{ns}: Not significant

Table 3. Mean values* of the effects of irrigation levels on length, width, diameter and drop of Almond fruit during phenological stage I of fruit growth.

Irrigation levels	Fruit size			Fruit drop (%)
	Fruit Length(mm)	Fruit Width (mm)	Fruit Diameter (mm)	
T_1= 100% ETc	45.46 a	30.08a	25.31 a	12.50 c
T_2=80% ETc	45.21 a	29.25 ab	24.85 a	15.83 c
T_3= 40% ETc	43.87 b	28.81 b	23.47 b	23.00 b
T_4=0% ETc	42.16 c	26.36 c	22.42 c	33.17 a

* Means within column that have the same letter are not significantly different at 5% level (DMR test).

Table 4. Mean values* of the effects of irrigation levels on fruit fresh weight and kernel fresh and dry weight during phenological stage II of fruit growth.

Irrigation levels	Fruit fresh weight (gr)	Kernel fresh weight (gr)	Kernel dry weight (gr)
T_1(100% ETc)	17.17 a	1.986 a	0.5050 a
T_2(80% ETc)	16.41 a	1.808 b	0.4772 a
T_3 (40% ETc)	14.22 b	1.668 c	0.4232 b
T_4 (0% ETc or Cutoff)	14.12 b	1.657 c	0.4178 b

* Means within column that have the same letter are not significantly different at 5% level (DMR test).

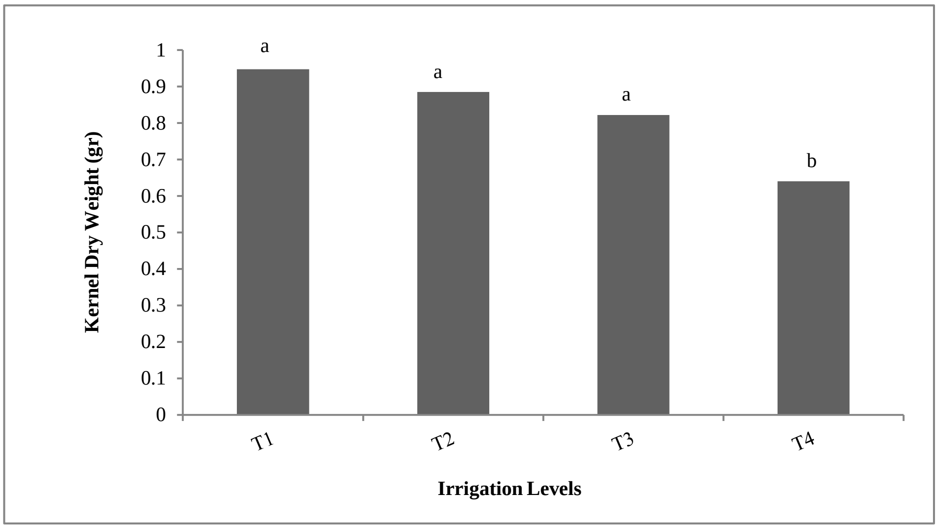

Fig.1. Effects of irrigation levels on kernel dry weight at the harvest time

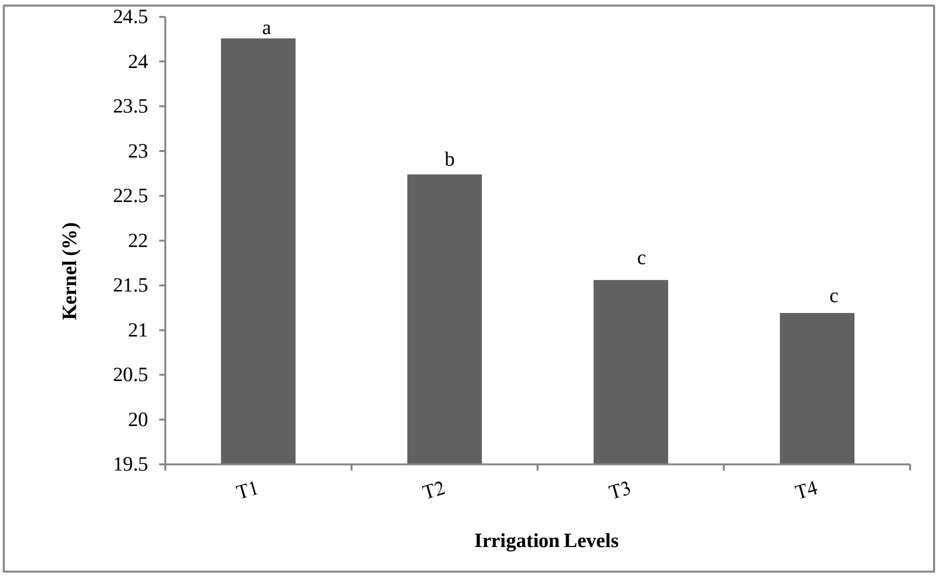

Fig.2. Effects of irrigation levels on kernel percentage at the harvest time

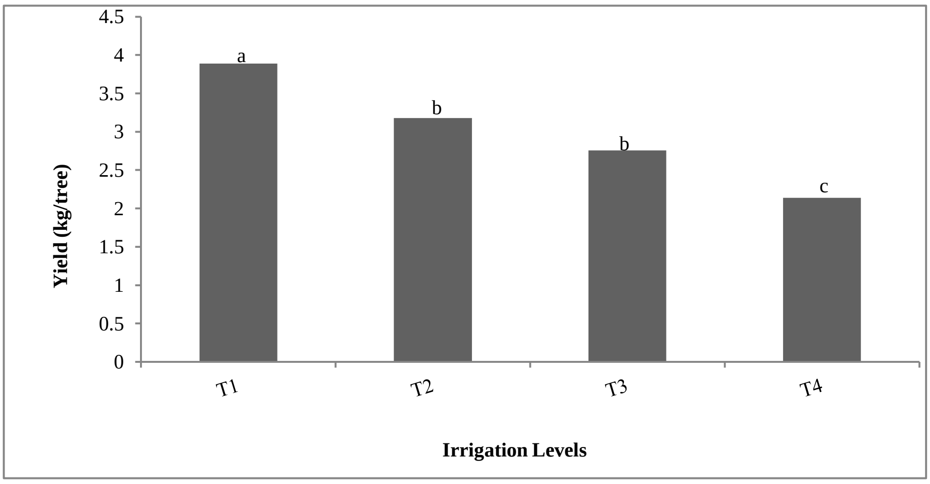

Fig.3. Effects of irrigation levels on yield of almond tree cv. “Mamaei” at the harvest time

Discussion

Stage-I began with pollination and fruit set. Fruit growth was very fast during this stage and reached its maximum at the end of this stage (Micke, 1996).

The data (Table 2) confirms the results reported previously by others (Girona *et al*., 1993 and 1997; Goldhamer and Smith, 1995; German 1997). The first stage of fruit growth is accompanied by vigorous shoot growth which, competes for water with fruit growth. Therefore the period of rapid fruit growth stage is very sensitive to water stress, and drought causes a decrease fruit size as well as an increase in the percentage of embryo abortion and fruit drop (Mick, 1996).Water stress and drought treatments during the kernel growth stage (stage II), decrease kernel weight and increase kernel shriveling (Mike, 1996; Goldhamer and Smith, 1995).

Girona *et al.* (1997) reported that a cutoff of irrigation during May 15th to June 14th (Stage-I) and also during June 14th to August 1st (Stage-II) significantly decreased fresh and dry weight of fruit, kernel and yield, which are confirmed by our stage-I and stage-II results. The reduction of water supply or cut off of irrigation during the preharvest period (Stage III) did not affect almond yield significantly which again confirms previous

reports (Girona *et al*., 1994 and 2005; Goldhamer and Smith 1995; Goldhamer and Viveros, 2000;
Romero *et al*., 2004; Goldhamer*et al*., 2006). Girona *et al*. (2005) reported that kernel dry matter accumulation did not decrease with RDI treatment (applied irrigation water as 20% of %100 ETc) during the kernel-filling phase (from late June to harvest) during two experimental years. Their results indicated kernel growth during the kernel-filling phase (preharvest period) seemed to be relatively resistant to water stress. However, drought during the harvest period decreased yield in the subsequent year because of yield and reduction in response to water stress during the harvest period associated with reduced annual growth and renewal of fruiting positions (Esparza *et al*., 2001).The almond trees can tolerate drought stress fairly well during the two months prior to harvest. This allows for the successful use of deficit irrigation strategies. Therefore we can apply treatments of 40% of full irrigation during stage III without considerable reduction of kernel weight and yield. However almond trees should not be exposed to severe drought in this period because it prevents hull dehiscence, decreases kernel size and increases kernel shriveling (Mike, 1997; Goldhamer and Smith, 1995). Therefore we should supply the almond trees with enough water near hull split to avoid stick tights. The effect of water deficits and water stress (drought) treatments during the postharvest period is substantially affected by preharvest conditions (Goldhamer and Viveros, 2000). According to our results, deficit irrigation and drought during of the all of the phenological stages of fruit growth significantly decreased kernel dry weight, kernel percentage and yield (Figs. 1, 2 and 3), but the interactions between of growing seasons, fruit growth stage and irrigation did not have any significant on these characteristics, which confirms previous reports (Torrecillas*et al*., 1989; Girona *et al*., 1997; Golhamer*et al*., 2006).

Moderate water deficits during preharvest and mild postharvest had no significant effects on bloom density in almond in the subsequent year (Ruiz-Sanchez et al., 1988). In almond trees, bud differentiation continues through September. Therefore, severe water stress during perharvest and especially postharvest period has been found to reduce flowering and fruit set dramatically in the subsequent year (Mike, 1996; Goldhamer, 1995; Goldhamer and Smith, 1995; Goldhamer and Viveros, 2000; Romero *et al*., 2004). Romero et al. (2004) reported that regulated deficit irrigation during the pre-harvest period produced no significant reduction in kernel yield and had no effect on kernel size in almond trees, results that confirm ours. Deficit irrigation during preharvest period on almond trees with 30% ETc is a sustainable strategy to improve almond productivity as well as water-use efficiency under limited water resources in semiarid regions (Garcia-Tejero*et al*., 2011). Goldhamer and Viveros (2000) reported a slight reduction in kernel dry weight for severe drought conditions (withholding irrigation) during a period of 50 days before harvest, whereas under less severe conditions no negative effect on kernel dry weight was observed (Girona *et al*., 1997; Goldhamer and Viveros, 2000; Esparza *et al*., 2001).Girona *et al.* (2005) applied RDI during the kernel filling phase with 20% of full irrigation and reported did it did not decrease kernel dry matter accumulation during the first two experimental years. This suggests that kernel growth during the kernel filling phase seems to be relatively resistant to water stress. They reported although yield reductions for RDI trees were significant (20% with respect to T-100), the water savings obtained (about 60% of that applied with respect to T-100), may help to promote the adoption of RDI in areas where water availability is reduced. Crop consumptive water use and irrigation could be reduced without significant detrimental effects on almond production. Deficit irrigation during the hull-split period had no significant effect on yield, although average kernel weight was slightly lower. Thus water savings can be achieved without affecting yield, even in soils with low water-holding capacity (Stewart *et al*., 2011).

Conclusions

According to the results, rapid fruit growth (stage I) and kernel growth (stage II) were sensitive to deficit irrigation and water stress, but the preharvest period (stage III) was not very sensitive to water stress, in confirmation of results previously reported by others investigators (Micke 1996; Girona *et al*., 1993, 1997 and 2005; Goldhamer and Smith, 1995; Goldhamer and Viveros, 2000; Germama, 1997). These results indicated that during preharvest stage (stage III) the Iranian almond cultivar 'Mamaei,' an almond cultivar of the Saman region, has low sensitivity to water stress. Therefore this allows for the successful use of deficit irrigation strategies during a two-month period. We recommend using deficit irrigation with 40% of full irrigation (%40ETc) during stage III for this cultivar in the climatic conditions of Saman region for two months prior to harvest, as it will not cause significant reduction of kernel weight and yield.

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References

Castel JR, Fereres E (1982) Responses of young almond trees to two drought periods in the field. Journal of Horticultural Science. 57(2), 175-187.

Egea G, Nortes PA, González-Real MM, Baille A, Domingo R (2010) Agronomic response and water productivity of almond trees under contrasted deficit irrigation regimes. Agricultural Water Management. 97, 171-181.

Esparza GT, Dejong M, Weinbaum SA, Klein I (2001) Effects of irrigation deprivation during the harvest period on yield determinate in mature almond trees. Tree Physiology. 21, 1073-1079.

Girona J, Mata M, Marsal J (2005) Regulated deficit irrigation during the kernel filling period and optimal irrigation rates in almond. Agricultural Water Management.75, 152-167.

Garcia-Tejero IF, Duran-Zuazo VH, Velez LM, Hernandez A,Salguero A, Muriel-Fernández JL (2011) Improving Almond Productivity under Deficit Irrigation in Semiarid Zones. The Open Agriculture Journal. 5, 56-62

Germana C (1997) Experiences on the response of almond plants (*A. communis* L.)to water stress. Acta Horticulture. 449(2), 497-503.

Girona J, Marsal J, Cohen M, Mata M, Miravete C (1993) Physiological and yield response of almond (*Prunus dulcis* L.) to different irrigation regimes. Acta Horticulture. 335, 389-398.

Girona J, Mata M, Marsal J (2005) Regulated deficit irrigation during the kernel-filling period and optimal irrigation rates in almonds. Agricultural Water Management.75, 152-67.

Girona J, Arbones A, Miravete C (1997) Evaluation of almond (*Amygdalus commonis*)seasonal sensitivity to water stress: Physiological and yield responses. Acta Horticulture. 449(2), 489-496.

Girona J, Mata M, Marsal J (2005) Regulated deficit irrigation during the kernel-filling period and optimal irrigation rates in almond. Agricultural Water Management. 75, 152-167.

Girona J, Mata M, Marsal J, Miravete C (1998) Almond responses to different irrigation strategies. Acta Horticulture. 470, 316-321.

Goldhamer DA (1995) Water management of almond trees. In: Almond Orchard Management. (Micke WC, editor) University of California publication.Pp. 171-178.

Goldhamer DA (1996) Irrigation scheduling. In: Almond production manual (Micke WC, editor) University of California, Division of Agriculture and Natural Resources, pp. 171-178.

Goldhamer DA, Smith TE (1995) Single-season drought irrigation strategies influence almond production. California Agriculture. 49(1), 19-22.

Goldhamer DA, Fereres E (2001) Simplified tree water status measurement can aid almond irrigation. California Agriculture. 55(3), 32-37.

Goldhamer DA, Viveros M, Salinas M (2006) Regulated deficit irrigation in almonds: effects of variations in applied water and stress timing on yield and yield components. Irrigation Science. 24, 101-114.

Goldhamer DA, Viveros M, Salinas M (2006) Regulated deficit irrigation in almonds: effects of variations in applied water and stress timing on yield and yield components. Irrigation Science. 24, 101-14.

Goldhamer DA, Viveros M (2000) Effects of preharvest irrigation cutoff durations and postharrest water deprivation on almond tree performance. Irrigation Science. 19, 125-131.

Goldhamer DA, Fereres E, Salinas M (2003) Can almond trees directly dictate their irrigation needs? California Agriculture. 57(4), 139-143.

Hawker JS, Buttrose MS (1980) Development of the almond Nut (*prunusdulcis*) Anatomy and chemical composition of fruit parts from anthesis to maturity. Annals Botany. 46, 313-321.

Hutmacher RB (1994) Growth and yield responses of almond (*Prunus amygdalus*L.) to trickle irrigation.Irrigation Science. 14(3), 117-126.

Micke W (1996) Almond production manual.University of California. p 289.

Razouk R, Ibijbijen J, Kajji A, Karrou M (2013) Response of peach, plum and almond to water restrictions applied during slowdown periods of fruit growth. American Journal of Plant Sciences. 4, 561-570

Romero P, Garcia J, Botia P (2006) Cost-benefit analysis of a regulated deficit-irrigated almond orchard under subsurface drip irrigation conditions in Southeastern Spain. Irrigation Science. 24, 175-184.

Romero O, Botia P, Garcia F (2004) Effects of regulated deficit irrigation under subsurface drip irrigation conditions on vegetative development and yield of mature almond trees. Plant and Soil. 260, 169-181.

Romero P, Botía P (2006) Daily and seasonal patterns of leaf water relations and gas exchange of regulated deficit-irrigated almond trees under semiarid conditions. Environmental and Experimental Botany. 56,158-73.

Ruiz-Sanchez MC, Torrecillas A, Leon A, del Amor F (1988) Floral biology of the almond tree under drip irrigation. Advances of Horticultural Science. 2, 96-98.

Shackel K, Gurusinghe S, Kester D, Micke WC (1998) Water stress responses of almond (*Prunus dulcis*)trees under field conditions. Acta Horticulture. 470, 309-316.

Stewart WL, Fulton AE, Krueger WH, Lampinen BD, Shackel Ken A (2011) Regulated deficit irrigation reduces water use of almonds without affecting yield. California Agriculture. 65(2), 90-95.

Torrecillas A, Ruiz-Sanchez MC, Hernanseaz A (1989) The response of young almond trees to different drip-irrigated conditions: Development and Yield. Journal of Horticultural Science. 64(1), 1-7.