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Investigation on the effects of conventional irrigation (CI), regulated deficit irrigation (RDI) and partial root zone drying (PRD) on yield and yield components of sunflower (*Helianthus annuus* L.)

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ABSTRACT

This study was carried out to understand the yield and yield components response of sunflower to conventional and limited irrigation and to determine the irrigation method which gives the greatest production per unit irrigation water in the Ahwaz Plain of Iran. Three irrigation methods i. e. conventional irrigation [CI, both sides (both furrows) of plant row watered; applied 100% of water requirements during the whole season], regulated deficit irrigation [RDI_{70} and RDI_{50}, both sides of plant row watered; applied 100% of water requirements upto V8 stage (Plant with 8 leaves) then 70 and 50%, respectively, thereafter] and partial root-zone drying [PRD_{70} and PRD_{50}, both sides of plant row alternatively watered; applied 100% of water requirements upto V8 stage (Plant with 8 leaves) then 70 and 50%, respectively, thereafter] with full (about 623 mm) or limited (50 and 70%) irrigation water, were applied to the hybrid Hysun 33 planted on loamy soil. The highest seed yield (6687.7 kg/ha) and oil yield (3553 kg/ha) were obtained from the CI treatment, and the lowest seed yield was related to PRD_{50} and RDI_{50} irrigation treatments (3537.3 and 3615.3 kg/ha, respectively). Also, the lowest oil yield was obtained from the RDI_{50} and PRD_{50} irrigation treatments (1464.3 and 1584.7 kg/ha, respectively). A linear relationship was found between irrigation (mm) and seed and oil yield (kg/ha) at 99% level of confidence (R^2=0.99 and R^2=0.98, respectively). Seed and oil yield responded linearly to applied water i. e. the seed and oil yield increased as irrigation amount was increased. Therefore, we confirm that CI irrigation treatment is the best choice for maximum yield under the local conditions, but this irrigation scheme must be re-considered in areas where water resources are more limited.

Key words : Conventional irrigation, oil yield, regulated deficit irrigation, seed yield, sunflower

INTRODUCTION

Plant-available water is the factor most limiting to yield potential in the agriculture of arid and semi-arid regions. Therefore, in the Ahwaz Great Plains of the Iran, water is often the primary factor influencing management decisions about appropriateness of cropping systems and crop selection within cropping systems.

Sunflower production has potential to occupy large acreages of the Ahwaz Plains that are faced with limited irrigation. With recent droughts reducing river flow and amplifying ground water declines, limited irrigation has become a common term in the region.

Sunflower is generally considered a drought-tolerant crop and has been suggested as a good crop for limited water situations (Schneekloth, 2005). Sunflower is drought

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tolerant because of its deep root system and ability to extract soil water to a lower percentage than many crops without showing signs of stress (Baltensperger *et al.,* 2004). With ability to extract upto 70% of water in the soil profile without stress they have potential to fit many limited irrigation situations. (Baltensperger *et al.,* 2004).

Research and farmer testimony has demonstrated that sunflower responds to irrigation with yield increases of 100 to 200% over dryland yields common on droughty soils and in extremely dry years (Berglund, 2008).

Stockton *et al.* (2001) evaluated the limited irrigation of sunflower in north-west Kansas, USA. In 2001, oil type sunflowers were grown on a cooperator's center pivot irrigated field. The dryland control replicates produced 1687 kg/ha, while the irrigated treatment produced 3128 kg/ha with 21 cm of irrigation. In 2002, yields ranged from 791 kg/ha dryland to over 2793 kg/ha with 19.56 cm of irrigation. The 2002 yields were decreased by uncontrolled insect pressure and bird and deer predation.

Erdem *et al.* (2002) investigated the water use characteristics of sunflower (*Helianthus annuus* L.) under deficit irrigation. Five irrigation treatments were applied, designated as T_1 full irrigation, and T_2, T_3, T_4 and T_5 received 75, 50, 25 and 0% of applications of the fully irrigated treatment on the same day. Seed yields averaged highest with full irrigation treatment (T_1) and differences between full irrigation and other treatments were significant. Also, linear relationships were found between seed yield versus total irrigation water, and seed yield versus seasonal evapotranspiration, respectively.

Karam *et al.* (2004) studied evapotranspiration, seed yield and water use efficiency of drip irrigated sunflower under full and deficit irrigation conditions. Average across years, seed yield at dry basis on the well-irrigated treatment was 5.36 t/ha. Deficit irrigation at early (WS_1) and mid (WS_2) flowering stages reduced seed yield by 25 and 14% ($P < 0.05$), respectively, in comparison with the control. However, deficit irrigation at early seed formation was found to increase slightly seed yield in WS_3 treatment (5.50 t/ha).

Todorovic *et al.* (2005) investigated the deficit irrigation of sunflower under Mediterranean environmental conditions. The experiment excludes five irrigation regimes : A–Optimal water supply, B–Application of 100% of water requirement upto flowering and 70% thereafter, C–Application of 70% of water requirement through the whole season, D–Application of 70% of water requirement upto flowering and rainfed condition thereafter and E–Rainfed conditions during the whole season. The highest average yield was obtained for treatment A with optimal water supply (6.14 t/ha) and the lowest average yield was related to rainfed treatment (2.07 t/ha).

Demir *et al.* (2006) studied the response of sunflower (*Helianthus annuus* L.) to 14 irrigation treatments in a sub-humid environment (Bursa, Turkey) in the field for two seasons. The yield increased with irrigation water amount, and the highest seed yield (3.95 t/ha) and oil yield (1.78 t/ha) were obtained from the HFM treatment (full irrigation at three stages); 82.9 and 85.4% increases, respectively, compared to the control. It is concluded that HFM irrigation is the best choice for maximum yield under the local conditions, but these irrigation schemes must be re-considered in areas where water resources are more limited. In the case of more restricted irrigation, the limitation of irrigation water at the flowering period should be avoided.

Angadi *et al.* (2007) compared the irrigation timing and amount effects on oilseed sunflower production in the southern high plains, USA. The effect of irrigation on sunflower seed yield was significant. The highest seed yield was produced with 30 cm of irrigation. But, the oil content did not respond to irrigation amount.

Berglund (2008) evaluated the irrigation of sunflower in the Agricultural Experiment Station, NDSU Extension Service, USA. Average yields of 26 sunflower hybrids and varieties at the NDSU Carrington Irrigation Research Station were 3600 kg/ha for irrigated sunflower compared with 1259 kg/ha for dryland sunflower. These average yields represent a 196% yield increase of irrigated over dryland sunflower.

There is no research on sunflower irrigation in the region (Ahwaz Great Plains and all of Khuzestan Province) where the study was carried out. Therefore, the main objective of this research was to compare the effects of conventional irrigation (CI), regulated deficit irrigation (RDI) and partial root zone drying (PRD) on yield and yield components of sunflower (*Helianthus annuus* L.) in Ahwaz Plain.

MATERIALS AND METHODS

The experiment was carried out during the growing season of 2010, between the months of February and June, on the Irrigation Research Station of Ahwaz Shahid Chamran University, in the Khuzestan Province, located in the south-west of Iran, latitude 31°18´18´´ N, longitude 48°39´68´´ E, and altitude 18 m above sea level. The local climate is arid, summers are hot and dry, and winters are sub-mild. According to long-term meteorological data (1966-2009), annual mean rainfall, temperature and relative humidity are 230.3 mm, 25.4°C and 48.9%, respectively (Table 1) (KWPA, 2009). An arid climate prevails in the region according to mean rainfall amount, and rainfall amounts are low in the winter period. Seasonal rainfall amount is 111 mm, which coincides with 48% of total annual rainfall, for the winter period (January, February and March). Additionally, total annual evaporation is nearly tenfold of annual rainfall (2035.3 mm) and seasonal evaporation in the winter months is twofold higher than seasonal rainfall amount (KWPA, 2009). Climatologic data of trial years were measured at the synoptic meteorological station nearby the experimental area.

Table 1. Mean air temperature, relative humidity and total monthly rainfall and evaporation (1966-2009) at Ahwaz

Parameter	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Average
Temperature (°C)	12.2	14.3	18.6	24.5	30.6	35.0	37.2	36.7	33.2	27.7	20.2	14.2	25.4
Relative humidity (%)	74.1	66.5	57.1	47.7	36.5	29.4	31.2	34.5	36.6	44.2	57.3	72	48.9
													Total
Rainfall (mm)	48.4	37.2	26	22.6	10.3	0.2	0.0	0.1	0.2	2.5	30.2	52.6	230.3
Evaporation (mm)	53	71.96	124	174.9	249	301	300	274.4	209.2	143	82	53	2035.5

The Karun River supplies all of the water demands of the region. The application of irrigated agriculture has been common in the study area. The soils of the trial field are Aridic Ustifluvents according to American Taxonomic Classification (Soil Survey Staff, 2006) and Calcaric Fluvisol according to FAO/UNESCO Classification System in which soils are alluvial. The soil of the area is of Entisols orders. Also, the soil moisture regime is Ustic, while the soil temperature regime is Hyperthermic. The type of soil in research area was loam (Average 24% clay, 35% silt and 44% sand content), and having 0.07% total nitrogen content (Kjeldhal method), 0.11 kg/ha phosphorus (Olsen method, P_2O_5), 1.26 kg/ha exchangeable potassium (ammonium acetate method, K_2O), 1.1% organic matter (Walckey-Black method), EC 5.7 dS/m, and a bulk density of 1.59, 1.57, 1.50 and 1.49 g/cm^3 in 0-0.30, 0.30-0.60, 0.60-0.90 and 0.90-1.20 m profile, respectively. The soil pH was 7.97. The water holding capacity (WC) of the experimental site was observed as 133.1 mm in a 0.9 m soil profile. WC was determined by the difference between the water content at field capacity (FC) and at permanent wilting point (PWP). There is no waterlogging problem in the area and the water table of soil is deeper than 170 cm in early spring. The sunflower hybrid Hysun 33, characterized with early flowering and maturity and medium yield potential was sown on a total surface area of about 1200 m2 of a rectangular shape. In the experiments, plot size was 400 m^2 (25 × 16 m^2) at harvest. The crops were hand sown on 17 February 2010, row spacing was 0.5 m, plant-plant spacing was 0.15 m, and hand harvested on 1 June 2010, using fertilizer rate of 250, 125 and 250 kg/ha of N, P and K, respectively. Weed control was realized manually at monthly basis without any chemical input. Forty-five plants were randomly selected from each plot (treatment) (at maturity period of the plants) for measurement of biomass, seed yield, harvest index, oil percentage, oil yield, 100-seed kernel weight, 100-seed weight, kernel to total seed percentage and seed numbers in head. Biomass was estimated by weighing the total dry matter at harvest and obtaining its water content from a sub-sample that was oven-dried at 70°C until constant weight. Harvest index was calculated as the ratio of measured yield to total biomass. Crude oil percentage was determined by the Soxhlet extraction technique (Pomeranz and Clifton, 1994). Oil yield was calculated as a function of seed yield and crude oil percentage.

Irrigation water was delivered to the plots with polyethylene pipes, 75 mm in diameter, and was applied to the trial plots as controlled by a tank which has a water meter. Required irrigation water was applied to the plots by short blocked-end furrows. Therefore, runoff and runon was assumed as zero because the plots had earthen embankments. Deep percolation was assumed as zero in practice (Hanks *et al.,* 1976). There was no recorded problems with water quality.

Three irrigation methods i. e. conventional irrigation [CI, both sides (both furrows) of plant row watered; applied 100% of water requirements during the whole season], regulated deficit irrigation [RDI_{70} and RDI_{50}, both sides of plant row watered; applied 100% of water requirements upto V8 stage (Plant with 8 leaves) then 70 and 50%, respectively, thereafter] and partial root-zone drying [PRD_{70} and PRD_{50}, both sides of plant row alternatively watered; applied 100% of water requirements upto V8 stage (Plant with 8 leaves) then 70 and 50%, respectively, thereafter], were applied.

Fifteen irrigation treatments were applied as described below (Table 2). The individual irrigation application depths were determined on the basis of soil water storage depletion. Soil water contents were monitored prior to irrigation (each 1-2 days before irrigation) using the gravimetric method (Black, 1965) from the plots of the second replication of the various treatments, and then these values were converted to volumetric water contents using bulk density. According to the soil water contents measured, the plots of the treatments were irrigated from deficit moisture content (60% depletion of available water) of 0-90 cm soil layer to FC at each irrigation.

Under full irrigation condition (conventional irrigation), irrigation water was applied to 0.9 m of the soil profile to achieve FC. But for limited irrigation treatments, they were applied 100% of water requirements upto V8 stage (Plant with 8 leaves) then 70% (RDI_{70} and PRD_{70}) and 50% (RDI_{50} and PRD_{50}), respectively, thereafter. The greatest amount of irrigation water was applied to the CI treatment (623 mm), and the lowest of irrigation amount was applied to the RDI_{50} and PRD_{50} irrigation treatments (311.5 mm). The layout of the experiments was a completely randomized block design with three replications.

Data Analysis

All statistical analyses were carried out using SAS (2006), to determine significance among irrigation treatments. Duncan Multiple Range Test (α=0.01 and α=0.05) was used for mean separation. Also, EXCEL (2007) was used to drawing the histograms.

RESULTS AND DISCUSSION

Biomass

Test results showed that a significant difference was found at the 1% probability level between different irrigation treatments in biomass (Table 3). On this basis, the maximum biomass was related to CI treatment averaged 26920 kg/ha. PRD_{70} treatment, averaged 18987 kg/ha was found the next rank. RDI_{70} treatment averaged 16858 kg/ha was ranked in the third place and the minimum biomass was related to RDI_{50} and PRD_{50} irrigation treatments in yield average of 13575 and 14146 kg/ha, respectively (Table 4).

Proper water consumption would likely be resulted in increase in leaf activity in CI treatment and thereafter would be led to increase photosynthesis and produce food materials and as a result plant biomass weight would be increased. While occurring drought stress through the leaf area loss and their falling would result in dropping in photosynthetic supply and falling in enzyme activities influencing this process and as a result plant biomass weight would be reduced. Turner and Sobrado (1987) in their research found that water deficit in sunflower reduced dry leaf, stem and root weight and resulted in lowering dry plant weight (biomass) and impeding growth trend. Karam *et al.* (2004) during a study stated that the maximum biomass was related to well-irrigated treatment averaged 19.87 t/ha and the minimum biomass was related to WS_1 (Deficit irrigation at early flowering stages) and WS_2 (Deficit irrigation at mid flowering stages) irrigation treatments in yield average of 16.48 and 17.89 t/ha, respectively. Todorovic *et al.* (2005) reported that the full irrigation

Table 2. Irrigation treatments applied

Treatment	Description
R_1CI	Replication 1–Conventional irrigation applied 100% of water requirements during the whole season
R_1RDI_{70}	Replication 1–Regulated deficit irrigation applied 100% of water requirements upto V8 stage (Plant with 8 leaves) and 70% thereafter
R_1RDI_{50}	Replication 1–Regulated deficit irrigation applied 100% of water requirements upto V8 stage and 50% thereafter
R_1PRD_{70}	Replication 1–Partial root zone drying applied 100% of water requirements upto V8 stage and 70% thereafter
R_1PRD_{50}	Replication 1–Partial root zone drying applied 100% of water requirements upto V8 stage and 50% thereafter
R_2CI	Replication 2–Conventional irrigation applied 100% of water requirements during the whole season
R_2RDI_{70}	Replication 2–Regulated deficit irrigation applied 100% of water requirements upto V8 stage and 70% thereafter
R_2RDI_{50}	Replication 2–Regulated deficit irrigation applied 100% of water requirements upto V8 stage and 50% thereafter
R_2PRD_{70}	Replication 2–Partial root zone drying applied 100% of water requirements upto V8 stage and 70% thereafter
R_2PRD_{50}	Replication 2–Partial root zone drying applied 100% of water requirements upto V8 stage and 50% thereafter
R_3CI	Replication 3–Conventional irrigation applied 100% of water requirements during the whole season
R_3RDI_{70}	Replication 3–Regulated deficit irrigation applied 100% of water requirements upto V8 stage and 70% thereafter
R_1RDI_{50}	Replication 3–Regulated deficit irrigation applied 100% of water requirements upto V8 stage and 50% thereafter
R_3PRD_{70}	Replication 3–Partial root zone drying applied 100% of water requirements upto V8 stage and 70% thereafter
R_3PRD_{50}	Replication 3–Partial root zone drying applied 100% of water requirements upto V8 stage and 50% thereafter

Table 3. Results of variance analysis (mean square) of seed yield and yield components of sunflower at Ahwaz Region (2010)

Source	d. f.	Biomass	Harvest index	Seed yield	100-seed kernel weight	100-seed weight	Kernel to total seed percentage	No. of seeds/ head	Oil percentage	Oil yield
Replicates	2	23901097.4*	0.00117207ns	326371.27ns	0.0721ns	0.093ns	1.20ns	19217.40**	8.26ns	8351.89ns
Treatments	4	87178607.3**	0.00073757ns	4874241.10**	0.331*	0.734*	1.51ns	39966.73**	60.50ns	2067083.23**
Error	8	2805683.6	0.00099732	276751.35	0.059	0.13	0.75	1291.98	98.85	205709.75
Coefficients variance (CV)	-	9.25	12.05	11.23	8.49	9.09	1.23	4.14	21.77	20.85

*,**Significant at P<0.05 and P<0.01 level, respectively.
NS : Not Significant.

Table 4. The effect of irrigation treatments on seed yield and yield components of sunflower at Ahwaz Region (2010)

Source	Biomass (kg/ha)	Harvest index (%)	Seed yield (kg/ha)	100-seed kernel weight (g)	100-seed weight (g)	Kernel to total seed percentage	No. of seeds/ head	Oil percentage	Oil yield (kg/ha)
CI	26920a	0.25a	6687.7a	3.38a	4.72a	69.64b	1038.67a	53.00a	3553.0a
RDI_{70}	16858bc	0.29a	4845.3b	2.94ab	4.11ab	69.86ab	874.33b	45.00a	2153.5b
RDI_{50}	13575c	0.27a	3615.3c	2.65b	3.62b	70.34ab	750.33c	40.67a	1464.3b
PRD_{70}	18987b	0.25a	4721.7b	2.86b	3.95b	70.52ab	897.67b	45.00a	2119.0b
PRD_{50}	14146c	0.25a	3537.3c	2.52b	3.45b	71.47a	771.00c	44.67a	1584.7b

The values with the same letter are statistically homogeneous in Duncan test.

treatment (A) had the highest final above ground dry biomass of 14.9 t/ha. Afterward, treatment B had 13.0 t/ha of biomass (87.5% of treatment A), while for treatment C (70% irrigation supply) the biomass was only 9.9 t/ ha, or about 66.5% of the full irrigation treatment. The treatment D had at harvesting approximately the same dry biomass (around 6.5 t/ha, or 43.6% of full irrigation treatment). Our results are in close agreement with the above mentioned researches.

Harvest Index (HI)

There is no significant difference between different irrigation treatments in harvest index (HI) based on variance analysis results (Table 3).

The maximum HI averaged 0.287 was related to RDI_{70} treatment and the minimum HI averaged 0.250 was associated with the PRD_{50} and PRD_{70} ones according to average comparison test (Table 4).

Mozafari *et al.* (1996) in their study announced reduction in harvest index as falling head diameter, seed numbers in head, and increase in the seed emptiness percentage. Karimzade-Asl *et al.* (2003) during a research announced that harvest index would be less affected for Hysun variety in water deficit condition. In Karimzade-Asl *et al.* (2003) test harvest index level showed a lower loss due to moisture stress in proportion to seed yield loss which meets the study results. Cox and Jolliff (1986) reported that soil water deficit reduced seed yield in sunflower to 20% but harvest index in sunflower was not affected.

Fereres *et al.* (1986) results showed that drought stress led to reduction in harvest index in all the sunflower genotypes and its reason has been identified to fall seed numbers per head, cause of seed number reduction in this test was developed as reduction in head diameter and increase in seed emptiness percentage. Flenet *et al.* (1996) study results showed that harvest index was enhanced due to mild stress but this reduced as exacerbating drought stress. In this study, harvest index was increased in RDI_{70} and RDI_{50} under stress treatments as well.

Karam *et al.* (2004) during a study stated that deficit irrigation did not result in any remarkable increase in harvest index (HI) at the 5% probability level and harvest index variations ranged from 0.24 and 0.27 which met the results obtained in this research. Harvest index variants' range therein was between 0.25 and 0.29.

Todorovic *et al.* (2005) in a study stated that sunflower harvest index (HI) had so significant difference in CI treatment and water deficit one, that it was about 0.43 in CI treatment and about 0.32 in the water deficit ones which failed to satisfy the study results.

Seed Yield

In these tests, irrigation treatments effect on sunflower seed yield was increased significantly at the 1% level of probability (Table 3).

On this basis, the maximum seed yield was related to CI treatment of 6687.7 kg/ha and RDI_{70} and PRD_{70} irrigation treatments were found the next rank averaged 4845.3 and 4721.7, respectively. The minimum seed yield was related to PRD_{50} and RDI_{50} irrigation treatments averaged 3537.3 and 3615.3 kg/ ha, respectively (Table 4).

Seed yield decreased as irrigation water level was reduced, moisture stress led to loss of the final crop yield components. Seed yield reduction in deficit irrigation conditions can be assigned to reduction in growth period and seed filling, head diameter, seed numbers in head, 1000-seed weight and increase in head emptiness. In Fereres *et al.* (1986) test water deficit was found to lead to fall the seed yield through reduction in seed numbers in head, dropping photosynthesis and increase in the seed emptiness percentage. Pankovic *et al.* (1999) announced that moisture deficit during budding process to end of flowering had the maximum negative effect on sunflower hybrid yields because of reduction in head diameter and seed numbers in head.

Balanced water consumption during different development processes like flowering and seeding seemed to result in improving sunflower seed yield because two important components of seed yield (seed numbers in head and 100-seed weight) would be formed during these processes, while enough irrigation in vegetative process leads to desired development of leaf area and plant photosynthesis. Desirable seed yield in conventional irrigation exhibits such due to having high durability of leaf area in reproductive process, rapid physiologic growth, transferring enough photosynthetic materials to reproductive organs and eventually good benefiting from environmental feasibilities. It could come to conclusion, therefore, that reason of desirable seed yield in conventional irrigation is to assign better and more the photosynthetic materials in favour of reproduction process and filling seed. Therefore, due to drought stress could be such justified that improper irrigation treatment accelerated leaf ageing and reduced production level, while decreased in leaf area and photosynthesis amount.

Mazaheri-laqab *et al.* (2001) in this regard stated that improper irrigation treatment caused loss to the seed yield, while reduced leaf area and their early ageing. Some researchers, of course, (Jaafarzadeh-kenarsari and Postini (1998); Kalhori *et al.,* 2002) know the main reason of seed yield loss due to drought stress as present photosynthesis reduction and retains ferrying materials during seed filling process. Kamel and Khiavi (2002) reported while considering drought stress effect on some physiological characteristics and yield components of sunflower, that water stress leads to reduce severely seed yield, biomass and length of time of vegetative process.

Human *et al.* (1990) in a test introduced also that extreme moisture stress in flowering, pollination and seeding caused the maximum seed yield loss. Bonary *et al.* (1992) stated that presence of water deficit and occurring drought stress led to reduce leaf activity and consequently reduced the yield. D'Andria *et al.* (1995) came to conclusion during separated tests that reduction in irrigation frequencies and increase in irrigation times could be helpful in making the maximum seed yield. Karam *et al.* (2004) stated, in a study, that sunflower seed yield at dry basis on the well-irrigated treatment was 5.36 t/ha. Deficit irrigation at early (WS_1) and mid (WS_2) flowering stages reduced seed yield by 25 and 14% ($P < 0.05$), respectively, in comparison with the control. However, deficit irrigation at early seed formation was found to increase slightly seed yield in WS_3 treatment (5.50 t/ha). Our findings are in agreement with the above reported results.

100-Seed Kernel Weight

Test results showed that a significant difference at the 5% level of probability was found between different irrigation treatments in the terms of 100-seed kernel weight (Table 3). According to the results, the maximum 100-seed kernel weight was related to CI treatment averaged 3.38 g and the minimum one was associated with PRD_{50} and RDI_{50} irrigation treatments averaged 2.52 and 2.56 g, respectively (Table 4). Proper water use (in conventional irrigation) and as a result good leaf area development and increase in photosynthesis led to increase in seed kernel weight.

Seed kernel desirable yield in CI treatment showed such situation because of having high leaf area durability in reproductive process, quick physiologic growth, transferring enough photosynthetic materials to reproductive organs and finally proper benefiting from environmental feasibilities. It could come to conclusion, therefore, that reproduction process and filling seed kernel was reason of seed kernel good yield in CI treatment.

100-Seed Weight

A significant difference at the 5%

probability level was found among different irrigation treatments in the terms of 100-seed weights based upon variance analysis results (Table 3).

The maximum 100-seed weight averaged 4.72 g was related to CI treatment and the minimum one averaged 3.45 and 3.62 g was associated with PRD_{50} and RDI_{50} treatments (Table 4).

100-seed weight reduction reason in stress treatment seems possibly to be reducing in water absorption and solutes by plant and reduced in making and transferring photosynthesis materials and processed sap to the seeds, in other words, moisture stress led to reduce the characteristic (100-seed weight) through dropping in leaf area. Continuation of drought stress in irrigation stress treatments is likely to negatively affect transferring photosynthetic materials of shrubs and eventually transferred materials to seeds would be reduced and this results in wrinkling and reducing in seed weights.

Our findings support the previous work of Gimenez and Fereres (1986) D'Andria *et al.* (1995) and Razi and Asad (1998) who reported cause of this lower photosynthetic materials production affected by moisture stress and seeds remained half filled.

Mozafari *et al.* (1996) drew to conclusion, in their study, that 100-seed weights had more reliability for drought stresses among other characteristics related to yield. Shobeiri (2004) and Weerathaworn *et al.* (1992) reported similar results as well. Rafiae *et al.* (2002) considered effect of irrigation process and applied nitrogen on the yield and some morphological characteristics of sunflower hybrid of Golshid. They came to conclusion that deficit irrigation had the maximum effect on 100-seed weights among seed yield components. 100-seed weight was affected by seed filling process.

Irrigation affects increase in food supplies and seed filling and consequently their weight increased in head. Kalhori *et al.* (2002) test results showed, in this regard, that stopping irrigation and drought stress in seeding had the maximal negative effect on 100 seeds and the minimal seed weights were obtained due to stress during this process. Jana *et al.* (1982) and Karaata (1991) reported that 100-seed weight would be increased applying irrigation in flowering and seed sap processed. Goksoy *et al.* (2002) reported that the 100-seed weight generally increased as the number of irrigations increased. The highest mean values were obtained from the irrigations applied at two or three growth stages (6.06-6.42 g) and the lowest from the control (5.25 g).

Kernel to Total Seed Percentage

In these tests, effect of different irrigation treatments on characteristic of kernel to total seed percentage was not significant and did not show a significant effect (Table 3). With respect to Table 4 results the maximum kernel to total seed percentage was related to PRD_{50} irrigation treatment averaged 71.47% and the minimum one belonged to CI and RDI_{70} treatments averaged 69.64 and 69.86%. Because seed number in head has been reduced in deficit irrigation treatments, reduction in competition for receiving photosynthetic materials is likely to lead to transfer more materials to each of seeds, thus, seed weighs of these treatments increase. Roath and Miller (1982) stated, in their study, in order to consider environmental effects on oil sunflower seeding, that a compensative state between the yield components was found in sunflower and reduction in seed numbers in head could lead to increase in seed kernel weight which is in line with this study results. Ravishankar *et al.* (1990) drew to conclusion that drought stress led to enhance seed husk weights and decrease in kernel to total seed percentage. Jaafarzadeh-kenarsari and Postini (1998) announced, in this regard, that moisture stress occurrence in flowering and pollination process led to smaller seeds and increased seed husk percentage (reading kernel of seeds percentage) which do not correspond to our findings.

Number of Seeds/Head

The test results indicated that a significant difference was found at 1% probability level between different irrigation treatments in the terms of number of seeds per head (Table 3). According to the results obtained CI and RDI_{50} treatments averaged seed numbers of 1038.67 and 750.33 were related to the maximum and minimum number of seeds per head, respectively (Table

4). Water stress and moisture deficit herein are likely to reduction seed numbers in head, and no difference was found between number of seeds per head in deficit irrigation treatments. Lowering seed numbers in head is thought to be resulted from reducion in the head area due to stress and or increase in seed emptiness percentage (which results from not completing reproduction process) and or mixed effect of both of which reason of seed numbers per head. In other words, drought stress occurrence leads to reduce the plant photosynthetic supply and loss of enzyme activities affecting this process by means of reducing leaf area and their falling. Water deficit gives rise in drying pollen grains and stigma in flowering and pollination process which this leads to disorder in pollination by insects. All the mentioned factors, finally, result in loss of fertilized little flowers of head surface and eventually seed numbers in head. Villalobos *et al.* (1996) test results showed that number of seeds per head would be varied affected by environmental factors present over the period before start of pollination and sometime after this.

Reduction in seed numbers was achieved affected by moisture stress in D'Andria *et al.* (1995) research as well. Zaffroni and Schneiter (1989) considerations showed that number of seeds per head was the most important sunflower component and should be regarded to increase the yield. Goksoy *et al.* (2002) reported that the full and limited irrigation at three growth periods (HFM, H60FM, H40FM, HF60M, HF40M, HFM60, HFM40) produced more seeds per head. The mean values varied from 1143 to 1224 seeds per head. The lowest number of seeds per head was obtained from the non-irrigated treatment (803 seeds per head). Madan doost (2004) in a research studied tillage systems and deficit irrigation effects on the sunflower yield and water use efficiency. The results showed that the fixed and alternative PRD irrigations had lower number of seeds per head than control, but no difference was found statistically in 100-seed weight displacing furrows.

Oil Percentage

No significant difference was observed among different irrigation treatments in oil percentage based on results of variance analysis table (Table 3). Based on average comparison test table (Table 4), the maximum oil percentage averaged 53% was related to CI treatment, the minimum oil percentage average 40.67% was associated with RDI_{50} one.

The results showed that there was more seed oil stability to the seed yield in water deficit conditions. Seed oil is much affected by the plant genetics, while the seed yield is much affected by the environmental factors (Mozafari *et al.,* 1996).

Mozafari *et al.* (1996) stated, on drought stress effects on sunflower oil percentage, that oil percentage would not be lost much due to drought stress because oil of seed is a quantitative feature, which is governed by a great number of genes.

Unger and Paul (1982) announced that drought stress occurrence led to loss of oil in 1-2% during seed filling process. In this study also increase in irrigation water resulted in improving seed oil percentage.

Karaata (1991) reported that oil percentage did not significantly increase as the amount of irrigation water increased, but increased with irrigation applied at flowering and milk ripening stages. Since oil percentage is determined by several environmental factors (especially temperature) as well as genotypic structure (Fick and Zimmerman, 1973; Harris *et al.,* 1978), it is likely that the differences between the various studies are mainly due to environmental conditions. Sing and Bhunia (1997) came to conclusion, in their study over 1993-95, that seed oil per cent would not be affected by irrigation treatments applied, while the seed yield showed a significant increase in complete irrigation treatment. Goksoy *et al.* (2002) stated that oil percentage, an important quality component in sunflower, was not affected by irrigation treatments applied at different growth stages. They reported that mean oil percentages varied from 43.7 to 45.8 in all treatments.

Demir *et al.* (2006) showed, in a research on deficit irrigation for sunflower plant, that there was no significant difference between irrigation treatments about oil percentage according to variance analysis results. Our results are nearly in agreement with those of Tan *et al.* (2000) and Flagella *et al.* (2002) who reported that oil percentage would not vary as irrigation is increased.

Oil Yield

In these tests, effects of different irrigation treatments on oil yield characteristic showed a significant difference at the 1% level of probability (Table 3). With respect to results (Table 4) the maximum oil yield percentage was associated with CI treatment averaged 3553 kg/ha. After that, the RDI_{70} and PRD_{70} irrigation treatments averaged 2153.5 and 2119 kg/ha, respectively, were found the next rank. PRD_{50} averaged 1584.7 kg/ha was found the third rank and the minimum oil yield was related to RDI_{50} irrigation treatment averaged 1464.3 kg/ha.

Since the oil yield is determined by multiplying the seed yield by oil percentage (particularly the seed yield which showed a meaningful difference in this study), difference between the oil yield of different irrigation treatments seemed to be due to the seed yield difference in different irrigation treatments (because no significant difference was observed in oil percentage and treatments in oil percentage are approximately equal). The oil yield reduced herein as water consumption was reduced and drought stress was applied in different irrigation levels depending upon stress severances. Enough irrigation particularly during sunflower seed filling can be helpful to increase seed weights (seed yield) and enough oil supply herein. Jafarzadeh-kenarsari and Postini (1998) drew to conclusion that negative effect of drought stress on the oil yield during reproductive process was more severe than the vegetative one. Hamoodi *et al.* (2000) concluded also that applying drought stress led to significant reduction in sunflower seed oil amount. Goksoy *et al.* (2002) stated that, the highest oil yield (1841 kg/ha) was obtained from HFM treatment (Irrigation at all the periods. No water stress), followed by the 60% deficit-irrigation treatments (H40FM, HF40M and HFM40). The lowest mean oil yield (979 kg/ha) was obtained from the non-irrigated treatment. Roshdi *et al.* (2003) observed a significant difference while considering water deficit on sunflower oil yield. They stated that Hysun variety was of high capability to produce seed yield under favourite moisture conditions. Therefore, this would appear in the oil yield as well. The previous researchers' results satisfy with the study results.

Crop Water Production Functions

Water production functions for sunflower were obtained by plotting observed seed yield and oil yield on the Y-axis and the irrigation on the X-axis in 2010 (Figs. 1 and 2). A linear relationship was found between irrigation (mm) and seed yield and oil yield (kg/ha) at 99% level of confidence (R^2=0.99 and R^2=0.98, respectively). Seed and oil yield responded linearly to applied water i. e. the

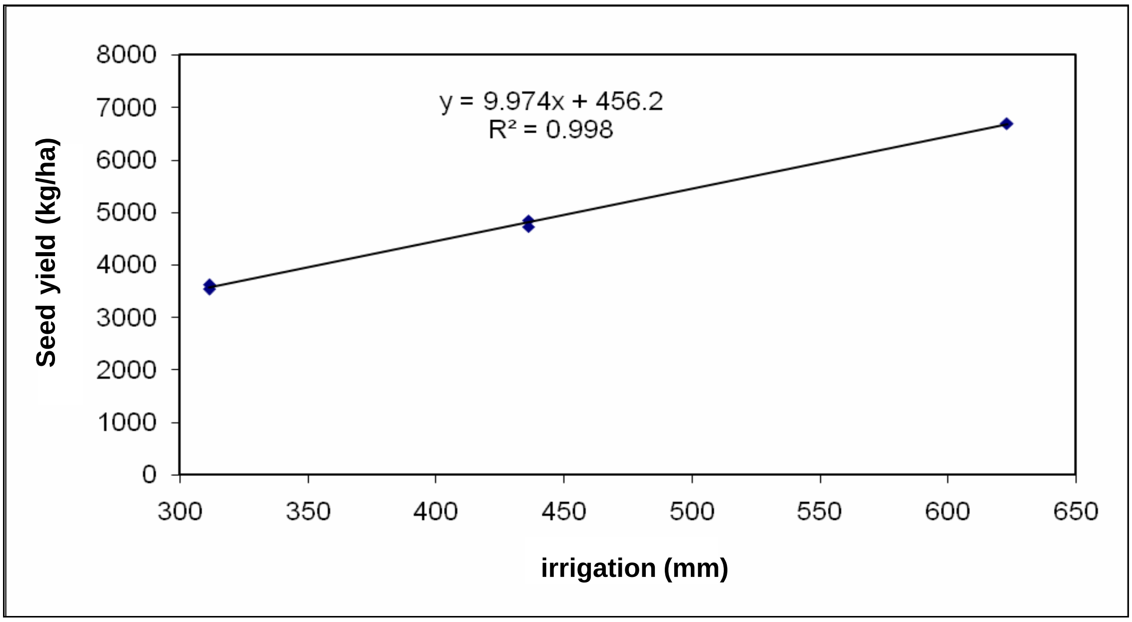

Fig. 1. Relationship between seed yield and irrigation for sunflower during 2010 season.

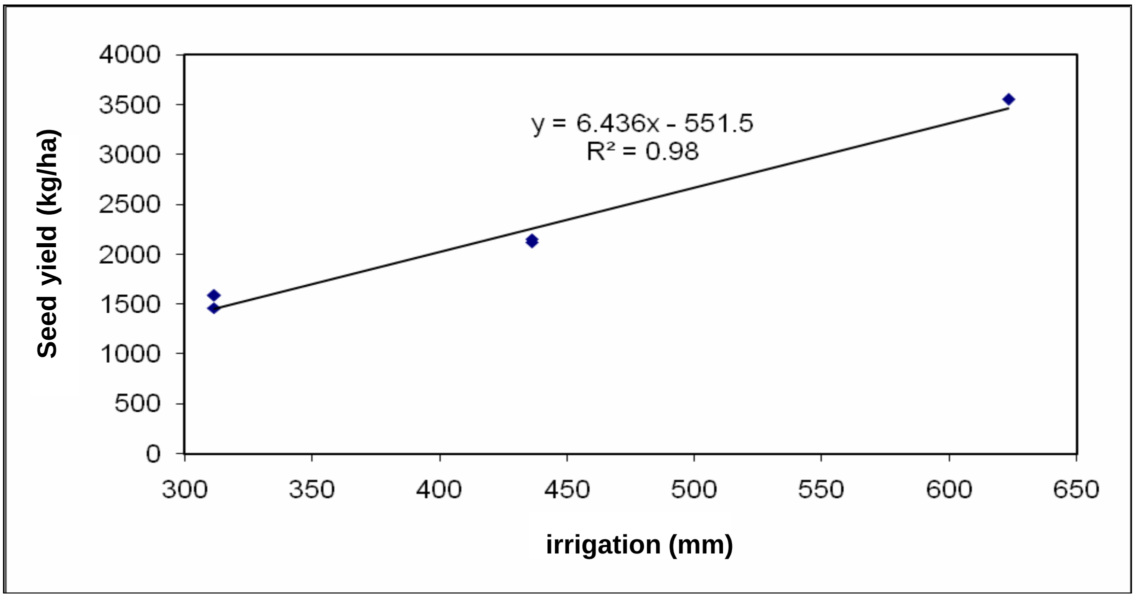

Fig. 2. Relationship between oil yield and irrigation for sunflower during 2010 season.

seed and oil yield increased as irrigation amount was increased. Our results support the previous work of Demir *et al.* (2006) who reported that a linear relationship was found between irrigation and sunflower seed yield (R^2=0.94). Also, Karam *et al.* (2004) studied the relationships between sunflower seed yield and irrigation during 2003 and 2004 growing seasons. There was poor linear relationship in 2003 between seed yield and evapotranspiration, which resulted in R^2= 0.40, while in 2004 the relationship resulted in a better correlation (R^2=0.71). The poor relationship obtained in 2003 could be due to the higher amount of rainfall and more particularly to its variable distribution in time with comparison to 2004.

CONCLUSIONS

This study was carried out to investigate the yield and yield components response of sunflower to conventional and limited irrigation and to determine the irrigation method which gives the greatest production per unit irrigation water in the Ahwaz Plain of Iran. Seed yield was significantly affected by treatments of conventional and limited irrigation. When considering the seed yield, it was concluded that the seed yield increased with irrigation amount, and the highest seed yield was obtained from a treatment of CI irrigation (6687.7 kg/ha), whereas the lowest seed yield was produced from the PRD_{50} and RDI_{50} irrigation treatments (3537.3 and 3615.3 kg/ha, respectively). Oil percentage was not significantly affected by conventional and limited irrigation treatments. However, oil yield was significantly affected by treatments as occurred in seed yield. In this study, the highest oil yield was obtained by the CI treatment (3553 kg/ha), and the lowest oil yield was obtained from the RDI_{50} and PRD_{50} irrigation treatments (1464.3 and 1584.7 kg/ha, respectively). The greatest amount of irrigation water was applied to the CI treatment (623 mm), and the lowest of irrigation amount was applied to the RDI_{50} and PRD_{50} irrigation treatments (311.5 mm). A linear relationship was found between irrigation (mm) and seed and oil yield (kg/ha) at 99% level of confidence (R^2=0.99 and R^2=0.98, respectively). Seed and oil yield responded linearly to applied water i. e. the seed and oil yield increased as irrigation amount was increased. It was concluded that the CI treatment was the best choice for maximum yield under the local conditions, but this irrigation scheme must be re-considered in areas where water resources are more limited.

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