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# The role of limited irrigation and advanced management on improving water productivity of rainfed wheat at semi-cold region of upper Karkheh River Basin, Iran

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**ABSTRACT:** In order to evaluate the role of a limited irrigation (LI) and agronomic management on improving rain water productivity, a field study was conducted during 2005-08 winter cropping seasons of wheat at multiple farms across benchmark watershed of Honam (Lorestan Province) in the upper Karkheh River Basin (KRB), Iran. limited irrigation consist of four treatments; single irrigation (SI) at planting time, single irrigation at spring time, two times irrigation (planting time and spring) and Rainfed, and so agronomic management practices consist of two treatments: traditional and advanced management (TM and AM), were evaluated. The results of this study showed that under rainfed conditions, wheat grain yield of AM (2321 kg ha$^{-1}$) increased by 34.5% as compared to TM (1726 kg ha$^{-1}$). At Honam site, the optimum program was obtained by a combination of advanced agronomic management package with SI options (irrigation at planting time/spring time), in which the maximum water productivity and net benefit were obtained. The advanced agronomic management (AM) had better performance as compared to traditional management. At rainfed conditions, WP of traditional management (0.35 kg m$^{-3}$) increased by 28.6% as compared to advanced management (0.45 kg m$^{-3}$). The results of this study showed that a single irrigation application at sowing or spring time (during heading to flowering stage) increased total water productivity (TWP) of wheat to a range of 0.57 to 0.63 kg m$^{-3}$ during average three seasons. The average irrigation water productivity (IWP) of wheat reached a range of 2.15-3.26 kg m$^{-3}$ by using single irrigation at sowing or spring time. Low WP (and yield) in farmers' practices of rainfed conditions, were mainly due to suboptimal agronomic management practices. These preliminary results confirm the potential of single irrigation and early/normal planting as an effective method to enhance productivity.

***Keywords***: Karkheh River Basin, Water productivity, Rainfed, Wheat, Traditional and Advanced management, Supplemental / Single irrigation

## INTRODUCTION

Rainfed agriculture in Iran covers large areas of land where wheat (*Tritium aestivum L.)* and barley (*Hordum vulgare L.*) are the major crops. Nearly 10% of the country's total agricultural products are derived from rainfed agriculture. Areas under rainfed wheat and barley were 3.95 and 1.11 million ha in 1997-98, 4.032 and 0.87 million ha in 2003-04 and 4.44 and 1.05 million ha in 2007-08, respectively. According to the official documents of Ministry of Jihad-e-Agriculture, the total production of rainfed wheat and barley were 4.72 and 0.82 million ton in 2003-04 and 5.31 and 1.22 million ton in 2007-08, respectively. Low and variable rainfall, high evaporation rates, long dry periods, relatively low soil fertility, poor seed quality and inappropriate agronomic practices contribute to low yields of the rainfed areas. Presently, National average yield of wheat and barley under rainfed condition in 2003-08 were 1114 and 1019 kg ha$^{-1}$, respectively.

In some rainfed areas of Iran where natural rainfall do not match crop water requirements, supplemental irrigation is practiced to increase yields. In the rainfed areas of Iran, groundwater, seasonal rivers, springs and small dams are the main source of water for supplemental irrigation (Tavakoli et al., 2008). However, excessive-use of surface and groundwater resources has caused severe environmental problems.

Supplemental irrigation and single irrigation have been described as techniques used for those crops that do not received enough water during the rainfall season (Oweis *et al.,* 1999; Perrier and Salinki 1987; Tavakoli and Oweis, 2004; Caliandro and Boari, 1992).

In highland rainfed regions of Iran, which total annual precipitation is directly influenced by the land topography and elevation, especially by the great mountain ranges, application of single irrigation at planting time or at heading-flowering growth stage for winter cereals increased yield from 500 to 2500 kg $ha^{-1}$ and from 500 to 1000 kg $ha^{-1}$, respectively (Tavakoli, 2001; Tavakoli *et al.,* 2000). Four-year trials, conducted at the central Anatolia plateau of Turkey, showed that applying 50 mm of SI to early sowing wheat increased grain yields by more than 60%, adding more than 2 t/ha to the average rainfed yield of 3.2 t/ha (ICARDA, 2003). Water productivity reached 5.25 kg.grain/$m^3$ of applied irrigation water and rainfall, with an average of 4.4 kg $m^{-3}$. The study also revealed that SI at later in the spring also increased yield, but resulted in lower water productivity. Similar results were obtained in the highlands of Iran at Maragheh (Tavakoli and Oweis, 2004).
Among agronomic practices, application of nitrogen, SI and early sowing are widely recognized the means of increasing wheat yield in the dry areas (Cooper *et al.,* 1987; Siddique *et al.,* 1990; Anderson and Smith, 1990; Oweis *et al.,* 1998). The results of studies conducted by ICARDA and Iraq showed that substantial improvement can be made in yield and WP by using SI in conjunction with proper production inputs and system management (Adary *et al.,* 2002). The response of wheat to irrigation water is dependent on the cultivar (Fischer and Maurer, 1978; Sojka *et al.,* 1981; Nachit *et al.,* 1992).

Rainfall variability and unreliability prevent farming community from larger investments into the production system. The prevailing high risk in rainfed agriculture needs to be addressed given the increase in food demand for a burgeoning population. New ways and methods of production are needed for increasing and stabilizing crop production in these areas. Optimized supplemental irrigation techniques have shown promising results to overcome low level and unstable yield levels.

As this research, it is assumed that water productivity in the KRB could be substantially increased by improving on-farm management, introducing optimizing SI and integrating appropriate agronomic practices in the crop production system. It is believed that the key to the realization of this hypothesis is the involvement and participation of farmers and local communities as well as the full cooperation of the official organizations and authorities responsible for water and agricultural development of the basin.

The main objective of this research was enhancing water productivity through limited irrigation (amount and time) in combination with and advanced agronomic management package (including crop variety, sowing date, land preparation, planting machinery, rotation, fertility, weed and disease control) and compare to traditional agronomic management.

## MATERIALS AND METHODS

### *Research Site*

The site of water productivity studies carried out in Karkheh River Basin (KRB), Iran. Karkheh River Basin (KRB) is located in the western parts of Iran and represents semi-arid and arid areas of the region. Two major agricultural production systems prevail in the KRB: rainfed cropping in the upstream of the newly built Karkheh dam and the fully irrigated cropping in areas located mainly in the downstream of the dam.

The research pilot site and community was selected for the project; in Lorestan Province. The pilot site in Lorestan, Province (Honam) is located at about 45 km north of Khorram-Abad, the Provincial Capital of Lorestan. The coordinates are 33˚49' N; 48˚15' E; and has an average elevation of 1567m a.s.l., with a long-term annual rainfall of 457 mm, but more than falls the winter season. This site is drained by the Honam River. It is a sub-catchment of the KRB and covers an area of about 3400 km² (Fig. 1). According to the 2005 population census, Honam sub-catchment (HSC) and Aleshtar city have a population of about 10000 and 67000 inhabitants, respectively with an average annual growth rate of 1.9%. Honam site is a semi-cold region having a 10-year average annual precipitation of 457 mm, mostly falling as snow (Fig 2).

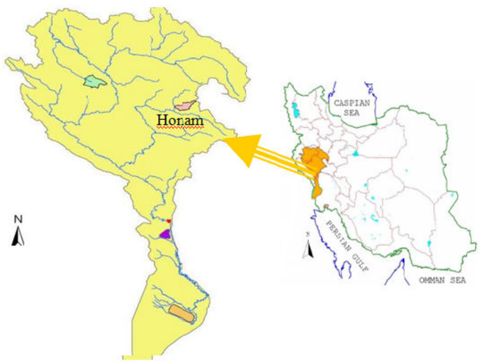


Figure 1. Location map of the research site

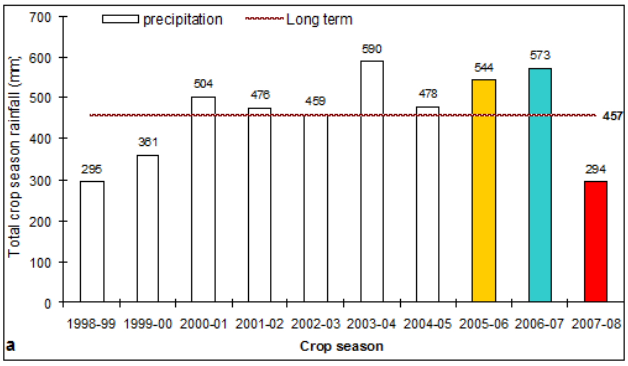


Figure 2. Year to year variation of crop season precipitation in study site from 1998-99 to 2007-08

***SI and agronomic treatments***

The field trials were conducted at farmers' fields for three crop seasons during 2005-2008 at the Honam site. According to crop rotation (cereals-legumes), farmer fields changed in all years during field trials. At agronomic management package, crop cultivars were a local winter bread wheat cultivar (Sardari) and an advanced wheat cultivar (Azar2) in all years. Irrigation treatments based on soil moisture content, were as follows:

1. single irrigation of 75 mm at planting time only,
2. single irrigation at spring time (during heading to flowering stage) of 50 mm only,
3. no irrigation (rainfed),

The average single irrigation amount applied at the planting time and in the spring were 75 and 50 mm, respectively.

There were two agronomic management package treatments:

1. Traditional management (TM)
2. Advanced management (AM)

Comparison of traditional and advanced management showed that in Table 1. The experiment treatments were randomly assigned to each block and replicated two times (two farmer’s field) and there was at least three samples of each farmer's field. It should be known that, according to the size of each field, carrying out such a field experiment in three separate farms in practical condition is very hard and needs a lot of field work and logistics. So, it was considered to prepare two separate fields each year in order to carry out this project.

Table 1. Comparison between advanced and traditional management

| Management practices | Sub activity | TM | AM |
|---|---|---|---|
| Preparation land | Tillage | √ | √ |
| | Disk Harrow | | √ |
| Planting Machinery | Row planter | | √ |
| | Plot | | √ |
| | 6 Plow (shesh Khish) | √ | |
| | Broadcasting | √ | |
| Fertilizer | Machinery | | √ |
| | Labor | √ | |
| Crop variety | Local variety | √ | |
| | New cultivar | | √ |
| | Labor for fertilizer spring time) | √ | |
| Seed | 160 kg/ha | | √ |
| | 200 kg/ha | √ | |
| | Labor for seed | √ | |
| Weed and decease control | - | √ | √ |
| Harvest | Combine | √ | √ |

Wheat crop was sown for three seasons in October over the three years (2005-2008) at 20 cm row spacing. The plot sizes of farmers' fields under SI treatments varied from 1000 to 5000 $m^2$, of which 3 $m^2$ (3* $1m^2$) were used for grain yield and yield components measurements and finally harvested all plots with combine.

Water for irrigation was from different sources including: pumping from rivers, groundwater, springs, traditional canals and qanat. Spring irrigation was done based on crop stage during heading to flowering stage, when more than 50% of the soil moisture content was depleted. This strategy allowed the crop to grow until maturity. Irrigation method was according to farmers practices: they were often border and basin surface irrigation.

***Crop agronomy***

Fertilizer requirements based on soil sample analyzing were splited into two doses, first dose was given at planting time and the second dose was applied at early spring time (early stem elongation stage). During the preparation of the land, ammonium sulfate and triple super phosphate of fertilizers were applied. Additional nitrogen was given as top dressing in March-April. The growing stages including emergence, tillering, stem elongation, heading, flowering, maturity and harvest, were observed and recorded during the seasons.
Among the three years of study, the 2007/2008 season was the worst condition in terms of drought and frost, which resulted in the lowest yields. In this season, some farmers at Honam site applied two or three irrigations at spring time.

***Weather***

Daily meteorological data; rainfall, Class A pan evaporation, relative humidity (maximum and minimum), maximum and minimum temperatures, wind speed and sunshine were recorded at the nearest meteorological station (Aleshtar Station). Monthly variation of crop season precipitation, maximum and minimum values of air temperature in study site are shown in Table 2.

Although total annual precipitation is highly effective in determining the success of dry-farming, but distribution of rainfall throughout the year is also of great importance. The total precipitation amounts in Honam site during the 2005/06, 2006/07 and 2007/08 crop seasons were 544, 573 and 294 mm, respectively (Fig 2).

Table 2. Summary of climate data at research site

| climate data* | | Oct. | Nov. | Dec. | Jan. | Feb. | March | April | May | June | July | Aug. | Sep. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $T_{max}$(°C) | 25.1 | 16.2 | 14.1 | 6.3 | 11.2 | 17 | 20.5 | 26.5 | 34.3 | 36.8 | 36.3 | 31.5 |
| 2005-06 | $T_{min}$(°C) | 3.7 | 0.6 | -1.8 | -4.3 | -1.1 | -1 | 3.6 | 6 | 8.4 | 12.3 | 14.1 | 7 |
| | P(mm) | 7.6 | 55.2 | 86.2 | 97.6 | 176.2 | 37.8 | 75.8 | 7.2 | 0.3 | 0 | 0 | 0 |
| | $T_{max}$(°C) | 23 | 14.2 | 6.7 | 6.4 | 10.3 | 12.1 | 17.3 | 26.9 | 32.7 | 35.4 | 35.3 | 32.4 |
| 2006-07 | $T_{min}$(°C) | 7.1 | 0.6 | -5.4 | -6.5 | -1.6 | -0.8 | 4.2 | 8.1 | 9.4 | 12.6 | 12.2 | 7.9 |
| | P(mm) | 84.3 | 82 | 33.9 | 39.1 | 97.2 | 90.6 | 109.6 | 36.5 | 0 | 0 | 0 | 0 |
| | $T_{max}$(°C) | 25.5 | 18.3 | 9.9 | 3.3 | 8.7 | 19.7 | 23.3 | 24.8 | 32.2 | 35.4 | 36.4 | 32.1 |
| 2007-08 | $T_{min}$(°C) | 4.3 | -0.9 | -2.7 | -10.6 | -5.9 | 1.1 | 3 | 5.8 | 8.3 | 12.6 | 13.4 | 9.8 |
| | P(mm) | 0.7 | 45.4 | 103.7 | 50.1 | 59.7 | 3.8 | 9.1 | 21.3 | 0.1 | 0 | 0 | 0 |

* $T_{max}$: maximum temperature, $T_{max}$: minimum temperature, P: precipitation

***Air temperature***

The average annual air temperature of the Honam site ranges from 12 to 15° C. Most of the rainfed farm territories in this site are assigned as a class of semi-cold climate region, although there are some areas with very cold winter and warm summer temperature. The range of temperature from the highest in summer to the lowest in winter is considerable, but not widely different from other similar parts of the rainfed areas of Iran.
Mean temperatures (maximum, minimum and average) at Honam site and during the three years of study (2005/2006/2007) were as follow; the annual average temperatures were 12.5°C, 13°C and 12.9°C, the maximum temperatures were 38.8°C, 39.8°C and 37.4°C, and the minimum temperatures were -19.6°C, -17.4°C and -14.2°C, respectively (Table 2).

***Growing degree days (GDD)***

Estimation of GDD is commonly based on daily average air temperature using the following equations (Ojeda-Bustamante et al., 2004):

$$GDD = T_a - T_{c-\min} \qquad T_a < T_{c-\max} \qquad (1)$$

$$GDD = T_{c-\max} - T_{c-\min} \qquad T_a \geq T_{c-\max} \qquad (2)$$

$$GDD = 0 \qquad T_a < T_{c-\min} \qquad (3)$$

Where Ta is the daily average air temperature, Tc-min is the minimum air temperature for growth of the particular species and Tc-max is the maximum air temperature above which growth ceases for the particular species.

The GDD values for growing period of the 3-year study were 1677, 1496 and 1530, respectively.

***Relative humidity***

The annual average relative humidity at Honam site and during the three years (2005/2006/2007) is 55.2, 56.4 and 55.6%, respectively.

### *Evaporation*

Potential evaporation varies considerably within the KRB. There is a tendency for decreasing evaporation with increasing altitude. The pan evaporation during three years, April-November (2005/2006/2007) are 1682, 1432 and 1151 mm/year, respectively. The lowest evaporation corresponds to February (during the wet season) and increases during the dry season (from June to December), reaching a maximum in July/August. The rainfall deficits relative to evaporation are great in spring and summer. Significant rainfall deficits are evident in the months of May to October. At Honam site, the annual total rainfall deficit for three years (2005, 2006 and 2007) was 1194, 837 and 896 mm, respectively.

### *Soil*

Soil samples were taken from the study site for analysis. Average soil properties from two layers, 0-20 and 20-100 cm are shown in Table 3. Soil samples of field experiments analyzed at laboratory and soil moisture content at field capacity (-33kpa) and at wilting point (-1500kpa) was about 301 and 134 $mL.L^{-1}$, respectively.

Table 3.Summary of soil samples properties at Honam site

| Soil depth | Sand | Clay | Silt | W.P (-1500) | F.C (-33) | bulk density | Available water | Saturation hyd. cond. | Water content at Saturation |
|---|---|---|---|---|---|---|---|---|---|
| cm | % | % | % | $m^3/m^3$ | $m^3/m^3$ | $gr/cm^3$ | $m^3/m^3$ | m/day | $m^3/m^3$ |
| 0-20 | 22.5 | 18.7 | 58.8 | 0.118 | 0.289 | 1.38 | 0.171 | 0.297 | 0.478 |
| 20-100 | 22.5 | 24.0 | 53.5 | 0.138 | 0.304 | 1.35 | 0.166 | 0.181 | 0.492 |

## RESULTS

The mean grain yield (GY), straw yield, total aboveground dry biomass (BY), harvest index (HI), thousand kernel weight (TKW), and water productivity indices (WP, TWP and IWP) under rainfed and various SI treatments for all cropping seasons were analyzed and are discussed in following sections.

### *Statistical analysis*

Statistical analysis (t-Test) was performed for the grain yield of wheat under different treatments of supplemental irrigation and agronomic management practices. The results indicate that there are statistically significant differences between rainfed, SI planting (75 mm) and SI spring (50 mm) treatments and two agronomic managements at 5%, 1% and 1% level, respectively (Table 4).

For all years, the effect of irrigation time and management type on grain yield and biomass were consistent and highly significant ($P$<0.01). Combined statistical analysis was performed for grain and straw yields. Results indicate that there are statistically significant differences (at 1% level) on yields of the years at irrigation and managements treatments. As already explained, depending on the amount of rainfall coming during the sowing period of different seasons, irrigation at sowing period had a significant effect (1% level) on both grain and straw yields, particularly in the seasons where late crop emergence occurred because of insufficient rainfall after sowing. Irrigation in the spring has a significant effect (1% level) on both grain yield and thousand kernel weight.

Table 4. Statistical analysis (t-Test) of wheat grain yield values under different SI and agronomic managements treatments, average three crop seasons at Honam site

| | | | Mean grain yield (kg $ha^{-1}$) | Standard Deviation (kg) | F value | t or t′ value | SD[¥¥¥] of differences |
|---|---|---|---|---|---|---|---|
| Rainfed | TM[¥] | N=24 | 1928 | 374 | 1.5 | -2.89* | 109.1 |
| | AM[¥¥] | N=45 | 2243 | 459 | | | |
| SI planting | TM | N=22 | 2344 | 223 | -12.6 | -6.57** | 136.8 |
| | AM | N=38 | 3244 | 791 | | | |
| SI spring | TM | N=21 | 2279 | 317 | 1.45 | -15.04** | 75.45 |
| | AM | N=42 | 3414 | 264 | | | |

* and ** : significant at the 1 and 5% levels of probability respectively

¥: TM: Traditional management ¥¥: AM: Advanced management ¥¥¥: Standard Deviation

### *Grain yield producing*

Average rainfed grain yield production under traditional management (TM) and advanced management (AM) was 1726 and 2289 kg $ha^{-1}$, respectively (Fig. 3). Compared to the long-term average rainfall (455 mm), the 2005/2006 season had higher rainfall (544 mm) with a good distribution over spring supporting such high yield. The 2006/2007 season had an average rainfall of 573 mm, inadequate for emergence in October.

Emergence was delayed, but favorable conditions later in the spring provided the second highest rainfed yield. The 2007/2008 season was the poorest for rainfed grain yield because of lowest rainfall (294 mm) and delay emergence consequently. In this year, the grain yield was 1050 kg $ha^{-1}$ under traditional management and 1740 kg $ha^{-1}$ under advanced management. Low rainfall amounts in the spring of 2007/2008 was suddenly and non predictable that caused physical damages to crops and drop the yield. The rainfall amount from March to maturity was 34.3 mm or 11.7% of total annual rainfall. Rainfed straw yield was affected similarly.

The average grain yields for the SI planting treatments and under traditional management (TM) for the three seasons were 2484, 2303 and 1590 kg $ha^{-1}$, respectively, but under SI-planting and AM, those were 4108, 3359 and 2635 kg $ha^{-1}$, respectively.

The average grain yields for the SI spring treatment and under traditional management (TM) for the three seasons were 2458, 2314 and 1640 kg $ha^{-1}$, respectively, but average grain yield under SI-spring and AM, those were 3297, 3534 and 3325 kg $ha^{-1}$, respectively. Early emergence of crop under advanced management produced higher straw yields; 7083, 6028 and 5426 kg $ha^{-1}$ in the three seasons, respectively. But, 2005/2006 season provided higher straw yield (7083 kg $ha^{-1}$) like grain yield due to good distribution of rainfall in spring that boosted both grain and straw yield under rainfed conditions.

According to the three crop seasons field experiments, at Honam site and under rainfed condition, wheat grain yield of AM (2289 kg $ha^{-1}$) increased by 33% compared to TM (1726 kg $ha^{-1}$). Under SI planting/spring scenarios, grain yield of AM (3426 kg $ha^{-1}$) increased by 47%, 60.9% and 94% as compared to the rainfed-AM, SI planting/spring-TM (2129 kg $ha^{-1}$) and rainfed-TM, respectively.

***Water productivity***

***The concept of water productivity (WP)***

The productivity of applied water is defined as crop yield per unit volume of water use. Volume of water use refers to irrigation, rainfall or the summation of irrigation and rainfall amounts. Total water productivity (TWP) defined as grain yield divided by the sum of total crop season annual rainfall plus irrigation water. The irrigation water productivity (IWP) defined as the ratio of increase in grain yield by supplemental irrigation to the applied irrigation water. These indices are defined by the following equations:

$$RWP = \frac{Yield}{rain} \tag{4}$$

$$IWP = \frac{\Delta\, Yield}{Irr.\ water\ \ use} \tag{5}$$

$$TWP = \frac{Yield}{rain + Irr.\ water\ \ use} \tag{6}$$

***Water productivity evaluation***

For the rainfed treatment, the WP-TM and WP-AM were 0.35 and 0.45 kg $m^{-3}$, respectively. The TWP under combination of sowing irrigation and traditional management treatment were 0.40, 0.36 and 0.38 kg $m^{-3}$, while the TWP under combination of sowing irrigation and advanced management treatment were 0.66, 0.52 and 0.58 kg $m^{-3}$ for three seasons, respectively. TWP under combination of spring irrigation and traditional management treatment were 0.41, 0.40 and 0.42 kg $m^{-3}$, while the TWP under combination of planting irrigation and advanced management treatment were 0.55, 0.52 and 0.77 kg $m^{-3}$ for three seasons, respectively.

The IWP under combination of sowing irrigation and traditional management treatment were 0.45, 0.42 and 0.72 kg $m^{-3}$, while the IWP under combination of planting irrigation and advanced management treatment were 2.62, 1.83 and 2.12 kg $m^{-3}$ for the three seasons, respectively. The IWP values under combination of spring irrigation and traditional management treatment were 0.63, 0.66 and 1.18 kg $m^{-3}$, while the IWP under combination of spring irrigation and advanced management treatment were 2.30, 3.10 and 4.55 kg $m^{-3}$ for three seasons, respectively (Fig. 4).

The overall mean WP for the rainfed treatments of advanced management was 0.47 kg $m^{-3}$. Corresponding lowest and highest TWP values for the irrigated treatments were 0.36 kg $m^{-3}$ (TM) and 0.77 kg $m^{-3}$ (AM), respectively. The lowest rainfed WP was 0.31 kg $m^{-3}$ (TM, 2007/2008 season), while the highest value was 0.47 kg $m^{-3}$ (AM, 2006/2007 season). The corresponding lowest and highest IWP values for the irrigated treatments were 0.42 kg $m^{-3}$ (SI at planting time and TM, 2006/2007) and 4.55 kg $m^{-3}$ (SI at spring time and advanced management, 2007/2008). Figure 4 shows that the IWP generally increases with the type of field management and irrigation timing. From the management point of view, advance management has significant impact on WP compare to traditional management, irrespective to planting or spring irrigation. From the irrigation timing point of view, results shown that SI at spring improves WP compare to SI at planting.

Figure 5 shows the observed ranges (high, low and average value) of TWP under rainfed, SI and type of field management treatments. According to the proposed crop seasons at the field experiments, irrespective of type of field management, the average value of TWP at the rainfed treatments were the lowest compare to other irrigation treatments. Considering type of field management under rainfed condition, TWP of AM (0.45 kg $m^{-3}$) increased by about 29% compared to TM (0.33 kg $m^{-3}$). Under SI planting scenarios, TWP of TM (0.39 kg $m^{-3}$) increased by about 50% as compared to SI planting-AM (0.57 kg $m^{-3}$). Under SI spring scenarios, TWP of TM (0.41 kg $m^{-3}$) increased by about 78% as compared to SI spring-AM (0.72 kg $m^{-3}$) .

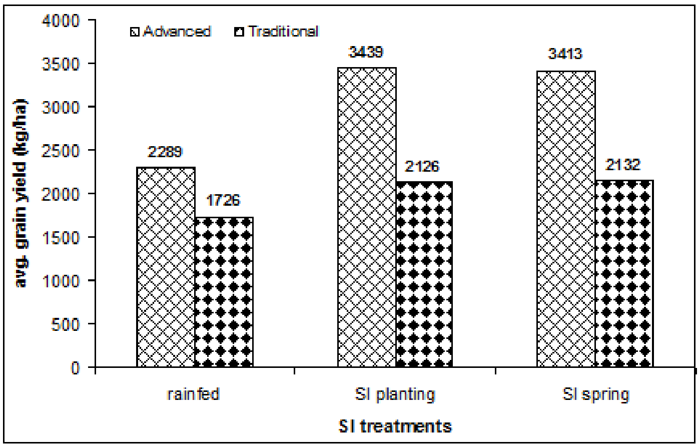


Figure 3.Average wheat grain yield under SI and agronomic management treatments, 2005/08

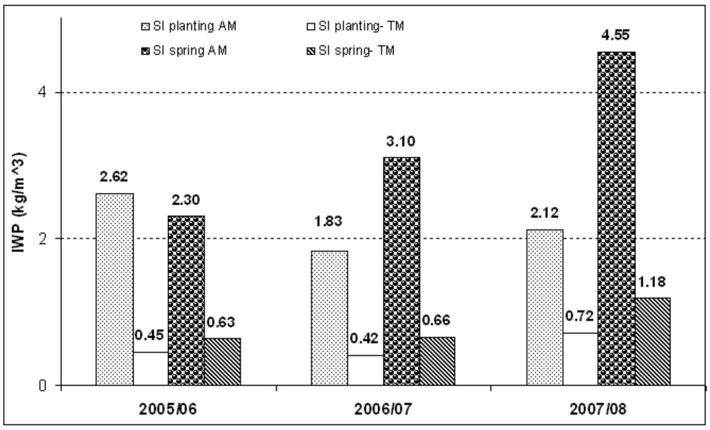


Figure 4. IWP index under combination of planting irrigation, spring irrigation with tradition and Advanced management treatments for wheat, 2005/08

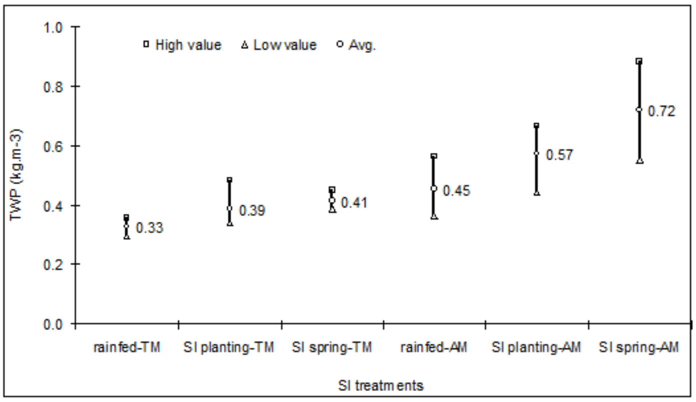


Figure 5. Observed ranges of TWP of wheat under rainfed, SI and Type of field management, 2005/08

## DISCUSSION

At Honam site, the rainfall at sowing time is not adequate to compensate crop water requirements for germination. Therefore, sowing irrigation (October) greatly benefits grain yield and water productivity. Under rainfed conditions, an early sowing date does not influence water productivity. Late sowing steadily resulted, the lowest WP under all situations of water availability (i.e., SI). Early/normal sowing under a combination of limited irrigation at sowing time and advanced management consistently resulted, higher water productivity than the late sowing dates (Tavakoli et al., 2005). Traditional management always resulted, the lowest WP. The optimum sowing date for wheat in this region is from mid until end of October, since later sowing dates decrease WP and earlier sowing dates are not recommend, because the time interval between application of SI and the first effective rainfall (in November) can be 30 days to maximum 45 days (Tavakoli et al., 2010).

The coefficient of variation for grain yield decreased from 50-100% under rainfed conditions to 20-30% under limited irrigation (Tavakoli et al., 2005). This study indicated when early rain is inadequate for crop germination, SI, given at sowing, substantially increases wheat grain yield by about 1500-2500 kg $ha^{-1}$ above the average rainfed yield (800-2000 kg $ha^{-1}$). Plants emerging earlier in the autumn, grow more vigorously and develop faster in the following spring than plants emerging later, which is reflected in higher yields with higher water productivity. In most years, the first sufficient rainfall for germination of seeds occurs later than November. This is not an optimal time for emergence in the highlands environment because the crop stand of non-irrigated wheat remains small when the first frost stops plant growth in mid November. Although in the second season (2006/2007) of the trial, adequate normal rain in October allowed emergence and enough crop establishments with optimum growth before the winter cold in November. In the first and third seasons (2005/2006 and 2007/2008) of the trials, inadequate early rain in October, didn't allow emergence and enough crop establishments with optimum growth before the winter cold in November. In this season, SI treatment at sowing had additional impact on crop growth and yield of the rainfed treatments, because crop went into tillering stage, which had maximum tolerance to cold. Therefore, high plant vigor combined with relatively higher rainfall during the growing season rendered 50 mm irrigation at planting was quite effective.

The third season (2007/2008) of the study, however, experienced different conditions in which rain came late in November. Irrigation at sowing (50 mm) had a significant effect on the rainfed grain yield, but was coming drought conditions adversely affected crop growth and damaged rainfed treatments.

In most cases, applying single irrigation with new advanced varieties double yield as compared with rainfed conditions (Tavakoli 2004 and 2005). Such yield increase clearly supports the findings of Stewart and Musick (1982), Tavakoli and Oweis (2004) and Oweis et al. (1999) in favor of the potential for conjunctive use of irrigation and rainfall in semi-arid regions.

The strategy of applying restricted amounts of water at critical growth stages based on available soil moisture, as practiced in this experiment, is the essence of the concept of single irrigation. The high return for limited irrigation water is another advantage of single irrigation. Obtained WP values with SI of over 1.5 kg $m^{-3}$ are not attainable in conventional rainfed wheat. Based on water availability, a relatively small amount of irrigation water applied at strategic times could achieve substantial increases in yield and WP of rainfed wheat and barley (Zhang and Oweis, 1999; Tavakoli, 2004).

The management parameter, date of sowing, is more problematic under rainfed conditions. In this cold winter environment (such Honam condition), an adequate plant stand before the dormant frost period (end of November and March) is essential for a high crop yield. This may not be attained in the growing seasons when the first adequate rainfall occurs later than November. However, where irrigation water is available, early germination and emergence can be ensured by applying a small (30–40 mm) irrigation after sowing (Tavakoli and Oweis, 2004; Ilbeyi et al., 2006; Tavakoli, 2004 and 2005; Tavakoli et al., 2005). An experiment carried out by Taoshih (2002) at Ghamloo station located in the Kordestan province (west of Iran), reported that the single irrigation strategy in mid October improved the yield of rainfed wheat cultivar (Sabalan). Oweis et al. (2001) reported substantial increases in wheat yield, in a similar highland environment in the Central Anatolian Plateau of Turkey, as a result of a 50 mm irrigation at sowing time. Limit of benefitability for optimum level of supplemental irrigation was determined as 2857 Rials/$m^3$ water.

Supplemental irrigation and single irrigation are a highly efficient practice with great potential for increasing agricultural production and improving livelihoods in the dry rainfed areas (Tavakoli and Oweis, 2004, 2006). Average rainwater productivity of wheat grains in West Asia and North Africa (WANA) is about 0.35 kg $m^{-3}$ (Oweis and Hachum, 2003 and 2004). However, it may increase to as high as 1.0 kg $m^{-3}$ with improved management and favorable rainfall distribution. It was found that one cubic meter of water applied as SI at the proper time might produce more than 2.0 kg of wheat grain over that of rainfed (Oweis and Hachum, 2003 and 2004).

Similar impact of sowing SI was also reported in the highland environment of northwest Iran (Tavakkoli and Oweis, 2004). In Central Anatolia Plateau, the optimal sowing period extends from the last week of September to mid-October. Sayadyan and Tallie (2000) for Kermanshah condition, located in the west of Iran, reported that single irrigation at seed development stage had the highest effect on increasing grain yield and irrigation water productivity was 0.59 kg $m^{-3}$. This confirms the result of Oweis et al. (1998, 1999 and 2001), Oweis and Hachum (2003) and Tavakkoli and Oweis (2004), which showed that deficit SI on wheat provides higher water productivity.

## CONCLUSION

At Honam site, the optimum program (in producing yield and improving WP) was a combination of advanced agronomic management with SI option (single irrigation at planting and/or spring time). Based on WP and economical aspects, more than one time irrigation at rainfed areas, not recommended. At rainfed farming (i.e., without SI), advanced agronomic management had preference to traditional management. At these preferential programs, maximum water productivity and net benefit were obtained. At rainfed condition, WP under AM (0.45 kg $m^{-3}$) increased by about 28.6% as compared to TM (0.35 kg $m^{-3}$). The results of this study showed that a single irrigation application at sowing or spring time (during heading to flowering stage) and advanced agronomic management increased total water productivity (TWP) of wheat to a range of 0.57 to 0.63 kg $m^{-3}$ during three seasons. The irrigation water productivity (IWP) of wheat under advanced agronomic management reached a range of 2.15-3.26 kg $m^{-3}$ by using single irrigation at sowing or spring time. Low WP (and yield) in rainfed farmers' practices were mainly due to suboptimal agronomic management practices. These preliminary results confirm the potential of single irrigation and agronomic management practices as an effective method to enhance water productivity.

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