THE ROLE OF EARLY SOWING WITH SUPPLEMENTAL IRRIGATION IN COOL HIGHLAND ENVIRONMENTS

T. Oweis*, M. Pala*, B. Benli*1 A. Ilbeyi, A. R. Tavakkoli*****

[*1] Corresponding author. International Center for Agricultural Research in the Dry Areas (ICARDA) P.B. 5466, Aleppo, Syria, Tel.: +963-21-2213433; fax: +963-21-2213490, E-mail address: b.benli@cgiar.org

[**] Ankara Research Institute of Rural Services, P.K. 253, Bakanliklar Ankara, Turkey

[***] Dryland Agricultural Research Institute (DARI), P.O. Box 119, Maragheh, Iran

ABSTRACT – he per capita wheat consumption in the Central and West Asia and North Africa (CWANA) region is the highest in the world. Therefore, the crop occupies a major share of arable land annually in the region-as much as 70% of the land in Turkey and Iran. However, wheat yields are low and variable mainly as a result of inadequate and erratic seasonal rainfall and associated management factors, such as late sowing. ICARDA has conducted two experiments in the highlands of Iran and Turkey, in order to determine the impact of early sowing and supplementary irrigation (SI) on rainfed wheat production. Treatments included early sowing with 50 mm irrigation and normal sowing with no irrigation and four spring (SI) levels (rainfed, 1/3, 2/3 and full SI). Results indicate that, when early rain was inadequate for crop germination, SI, given at sowing substantially increased wheat yields. Early sowing with SI allowed early crop emergence and development of good stand before being subjected to the winter frost. Additional supplemental irrigation in the spring also increased yield significantly but involved a lower rate of water productivity. The reduction in grain yield with deficit irrigation of 2/3 and 1/3 of full irrigation was 3% and 5% below maximum levels respectively for Turkish highlands. Also maximum WUE has achieved with 1/3 of full SI for Iranian highlands. Thus, when limited SI is combined with appropriate management, wheat production can be substantially and consistently increased in cool highlands.

KEYWORDS: Water productivity, early sowing, supplemental irrigation, bread wheat, rainfed agriculture, deficit irrigation, highlands

Introduction

Bread wheat (*Triticum aestivum L.*) is one of the most important food crops and is extensively grown throughout the dry areas in the West Asia and North Africa (WANA) region. The crop occupies a major share of arable land annually in the region-as much as 70% of the land in Turkey and Iran.

The highlands of this region have a severely cold and rainy (mostly snow) winter, relatively cool spring and hot summer. Precipitation for most cropland is extremely variable from year to year and within season, ranging from 200 to 600 mm per year (Kassam, 1981). However, wheat yields are low and variable mainly as a result of inadequate and erratic seasonal rainfall and associated management factors, such as late sowing.

The foremost concern in arid and semi-arid areas is also water availability and its efficient use. The dominant constraint on wheat production is water shortage, especially where a high evaporative demand coincides with low rainfall. Though crop yields under dryland conditions are related to seasonal rainfall, water productivity (WP) can be substantially improved by crop management practices (Cooper and Gregory, 1987; Keatinge et al., 1986; Harris et al. 1991) and fertilizer use (Harmsen 1984; Keatinge et al. 1985; Ryan and Matar, 1992).

The introduction of supplemental irrigation to winter-grown cereals can potentially stabilize and increase yields, as well as increasing the use efficiency of water received both from rainfall and from irrigation. Results from long-term research in experimental stations and farmers' fields showed substantial increases in rainfed crop yields and water productivity in response to SI (Oweis and Hachum, 2001). Unlike in full irrigation, the timing and amount of SI can not be determined in advance, because the basic source of water to rainfed crops is rainfall, which is variable in amount and distribution and difficult to predict.

Another factor of significance in dryland farming is sowing date. Delaying sowing after the optimum time, which coincides with the onset of seasonal rains, consistently reduce yields (O`Leary et al. 1985; French and Schultz, 1984; Batten and Khan, 1987). Farmers in the Central Anatolia Plateau (CAP) reported that when enough precipitation falls in early October to allow early sowing and germination, yields are much higher than when rain comes in late November as is the case in most seasons (Oweis and Hachum, 2001). It is logical to expect that when rain is late, applying SI early at sowing may boost an early crop growth for higher productivity. Research in Iran showed that single irrigation at planting time to winter cereals can increase yield from 500 to 1000 kg.ha^{-1} (Tavakkoli, 2001). As planting is mostly done in early October crop emergence usually occurs in early November or later depending on the occurrence of sufficient rainfall. Thus, lower temperatures in November accompanied with late or no emergence of crops is a common phenomenon. Under these conditions the crop will either emerge late and be subjected to severe winter conditions in 1-2 leaf stage or emerge in spring with slower growth rate, less green leaf area and photosynthesis, and poor competitive ability with weeds. This situation leads to lower water productivity and eventually to lower yields.

Therefore, the aim of this research is to improve wheat yield and water productivity in the cool highlands environments by using limited amount of water as SI. The specific objectives are:

i. Determine the effect of SI at sowing for early establishment on crop yield and water productivity, and

ii. Evaluate the effect of deficit and full SI on bread wheat yield and WP.

2. Materials and methods

This study was carried out in highlands of Iran and Turkey. The site in Iran consist of three cropping seasons (1999-2002) at Maragheh, main station of Dryland Agricultural Research Institute (DARI), in northwest of Iran (37°15`N; 46°15` E; elev. 1725 m). Average annual precipitation is 375 mm. The region has very cold winters with minimum air temperatures falling below -15°C and the number of days with freezing temperatures exceeding 100. The site in Turkey consists four cropping seasons (1998-2002) at the Ankara Research Institute of Rural Services (ARIRS), in central Turkey (30° 53’ N; 32° 45’ E; elev. 924 m). Ankara is placed in semi-arid climate; with mean annual rainfall of 387 mm. Frost begins between early November and early December and covers of 2-4 months is common, which protects the emerged crop as it develops before severe winter.

The soil at DARI station in Iran is deep and classified as fine clay. Soil moisture at field capacity and at wilting point was 38 and 20 vol. %, respectively. The soil at ARIRS station in Turkey is brown clay-loam soil. Soil moisture at field capacity and at wilting point was 35 and 20% vol. respectively.

Monthly weather data for max and min temperature, precipitation and evaporation are summarized for each growing season in Table 1 for Iran and Turkey.

The soil at DARI station in Iran is deep and classified as fine clay. Relevant properties were – pH: 7.7; EC: 0.61 dS/m; extractable K: 662 ppm; extractable P: 16.3 ppm; total N, organic carbon and TNV: 0.0055, 0.65 and 4.2%; sand, silt and clay: 16, 40 and 45%, respectively. Soil moisture at field capacity and at wilting point was 38 and 20 vol. %, respectively.

The soil at ARIRS station in Turkey is brown clay-loam soil. Relevant properties were – pH: 7.4 to 8.0; EC_e: 0.75-2.50 dS/m; available K and P values range from 744.9 to 1258.4 and 35.6 to 75.6 at 0-20 cm depth and 588.9 to 1092.1 and 24.4 to 71.0 at 20-40 cm depth respectively; lime : 24.97-29.70%; organic matter: 1.37-1.95%. sand, silt, clay 36, 26% and 38% respectively; Soil moisture at field capacity and at wilting point was 35 and 20% vol. respectively.

The trial treatments are summarized for both sites as following:

DARI Station Trial (Iran)	ARIRS Station Trial (Turkey)
*Split plot design	*Split block design
*Main plots: Full SI = 100% 2/3 = 2/3 of I1 1/3 = 1/3 of I1 0 = rainfed	*Main plots : NIS : No irrigation at sowing SIS : 50 mm irrigation at sowing
*Sub-plots : N1 : 0 kg N/ha N2 : 30 kg N/ha N3 : 60 kg N/ha N4 :120 kg N/ha	*Subplots : Full SI (full) = 100% 2/3 = 2/3 of full 1/3 = 1/3 of full 0 = rainfed
P_2O_5 :???	At sowing, 75 kg N/ha and of 75 kg P_2O_5/ha of fertilizers were applied

Soil moisture was measured weekly, before and after water application. Irrigation was applied simultaneously in small basins when 50% of the available soil water was depleted in the full SI treatment to all treatments (except the rainfed plots) for both trials. The amount of water that was given was calculated to restore root-zone moisture to near field capacity for the full irrigation treatment. Other treatments automatically received fixed proportions (1/3 and 2/3) of the full SI amount. The root zone depth was estimated before each irrigation application based on the depletion pattern of the soil profile.

Evapotranspiration was calculated by the mass balance equation given in Raats and Warrick (1983)

$$ET = P + NI \pm \Delta S \qquad (1)$$

where P is precipitation, NI is the depth of water needed to refill the root zone for the full SI treatment using the current root zone depth with 50% allowable depletion. Two thirds and one third of this depth is used with the 2/3 and 1/3 SI treatments and ΔS is the change in soil water storage during the measurement period. Water productivity (WP), kg/m^3, was calculated as the crop yield (kg/ha) to the actual amount of water used (ET) m^3/ha. Precipitation water productivity was determined as the ratio of average rainfed yield to the amount of seasonal precipitation. It is assumed that all precipitation is used in ET. Since no runoff was allowed and the amount of precipitation is smaller than the antecedent

Table 1. Weather parameters at highlands of Iran and Turkey

Season		Oct.	Nov	Dec.	Jan.	Feb.	Mar.	April	May	June	July
Weather parameters at DARI station (northwest Iran)											
1999/2000	P (mm)	18.2	32.2	29.0	44.0	35.3	55.4	46.7	15.5	0.0	0.4
	T_{max} (C^o)	21.9	9.3	5.2	3.9	3.6	8.5	16.4	22.2	28.2	31.9
	T_{min} (C^o)	4.4	-3.3	-6.4	-8.4	-10.8	-5.2	3.5	7.4	11.6	17.0
2000/2001	P (mm)	21.9	22.6	28.6	4.5	14.5	48.9	21.8	32.8	0.0	31.6
	T_{max} (C^o)	15.7	8.4	3.9	2.6	2.6	13.8	16.4	21.9	30.4	30.0
	T_{min} (C^o)	4.1	-1.4	-4.3	-10.4	-5.6	-0.9	2.8	6.4	12.1	14.6
2001/2002	P (mm)	9.4	35.5	50.5	74.0	13.2	39.0	109.5	49.5	1.2	0.0
	T_{max} (C^o)	18.0	11.6	4.1	2.4	4.6	10.2	11.8	21.7	27.1	30.8
	T_{min} (C^o)	6.4	-2.4	-2.5	-11.2	-8.8	-4.2	2.3	4.7	9.6	15.9
Weather parameters at ARIRS station (Central Anatolia Plateau, Turkey)											
1998/1999	P (mm)	24.8	30.5	40.8	33.1	74.1	41.4	16.5	16.3	39.6	50.9
	T_{max} (C^o)	21.6	13.1	7.1	6.3	6.9	11.5	17.0	22.8	25.9	30.6
	T_{min} (C^o)	8.5	4.8	1.8	-0.2	-0.6	1.2	5.8	9.2	13.5	16.5
1999/2000	P (mm)	36.3	27.5	38.8	46.5	53.6	36.0	78.8	51.0	33.2	-
	T_{max} (C^o)	19.6	12.2	10.0	-0.4	2.0	9.0	17.8	20.7	25.5	33.3
	T_{min} (C^o)	8.5	2.0	0.7	-6.6	-4.9	1.4	7.4	9.0	12.2	17.4
2000/2001	P (mm)	23.4	17.1	35.5	2.2	37.1	26.9	28.8	91.3	0.1	8.2
	T_{max} (C^o)	18.1	15.3	5.0	6.6	8.4	16.5	17.8	20.0	28.2	32.8
	T_{min} (C^o)	6.6	3.2	-1.3	-0.6	-0.6	5.6	6.1	8.5	13.2	18.1

2001/2002	P (mm)	0.7	56.8	114.1	25.7	15.3	27.8	61.9	41.8	16.8	23.6
	Tmax (C^o)	19.8	11.1	5.2	-0.9	7.5	14.3	15.2	22.1	26.9	31.6
	Tmin (C^o)	9.8	2.3	-1.2	-7.7	-0.9	3.0	5.3	9.2	12.6	16.8

water holding capacity of the soil profile, no deep percolation can occur from precipitation alone(Oweis et al., 2000), however, due to the inefficiency of irrigation system, some deep percolation occurred, but only net amount was used in ET and WP calculations. Grain yields were measured and variance analysis was performed by MSTAT-C statistical software.

3. Results

3.1. Weather

In DARI station, the first season's rainfall (276.7 mm) was below the long term average of 298 mm, with the first rain fell on 31 October-1 November; subsequent rain was well distributed over the period until April, when the last significant rainfall occurred. In May only 15.5 mm of rainfall contributed little to soil moisture crop water needs. The total rainfall (227.2 mm) in the second growing season was also below the long-term average; with the first 17.4 mm rain fell on 23-25 October. This amount was enough for seed germination and good stand establishment before the frost period. The rainfall in the third season (381.8 mm) was above average but the first rainfall was late (5 November). As a result rainfed treatment was unable to germinate before the winter frost period. However 49.5 mm rainfall in May contributed substantially to improved crop yield. Lower temperatures in the spring of the third season inversely affected the crop.

In ARIRS station, the annual rainfall amount was variable during the four growing seasons. In the seasons of 1998/99 and 1999/2000, adequate rainfall fell in October immediately after sowing with a total seasonal amount of 383.0 and 421.8 mm, respectively. In the seasons 2000/01 and 2001/02, inadequate rainfall for emergence occurred after sowing in October. The 2000/2001 season was extremely dry with a total amount of 275.6 mm. The 2001/2002 season received 396.8 mm with poor distribution. For example, after an extremely dry month in October, 57 mm of rain fell in November and 114 mm in December, when the temperature dropped and negatively affected the crop development.

In the first two seasons (1998/1999 and 1999/2000), wheat received 19 and 36 mm of rainfall respectively after sowing in October. This was followed by rain of 31 and 28 mm in November, respectively. This rainfall was sufficient for early emergence of the crop. In the third year (2000/2001), wheat received 5 mm rainfall after sowing in September and 23 mm rainfall in late October. In the fourth year (2001/2002), wheat received 5 mm of rainfall after sowing. Thus, in the second and third seasons (2000/2001 and 2001/2002) rainfall was not adequate for crop emergence in October.

3.2. Grain yield

In DARI station trials, the main production factor in dryland cropping is water, whether from rainfall or added as supplemental irrigation. The addition of supplemental irrigation increased crop yields in each season, but the effect varied with the season. Thus the highest yields were obtained in the 3rd season (2001-2002) and the lowest yields in 2nd season (2000-2001) (Table 2).

Yields from non-irrigated plots alone were poorly related to seasonal rainfall. Regardless of season, the pattern of response to supplemental irrigation was similar, with the addition of the first increment of water having the greatest effect. Increases occurred in water use efficiency at 2/3 SI and full SI levels, were significant, however they were non-significant regarding yield increases at these levels.

Table 2: Effects of SI and nitrogen on grain yield (mg/ha) at Maragheh, DARI, Iran.[a]

Irrigation	N_0	N_{30}	N_{60}	N_{90}	N_{120}	Mean
Rainfed	1.154 g	1.021 gh	0.940 hi	0.813 ij	0.701 j	0.926 D
SI1/3	2.296 f	2.531 e	2.848 d	2.647 de	2.625 e	2.589 C
SI2/3	2.534 e	2.750 de	3.237 c	3.350 c	3.248 c	3.024 B
SIfull	2.562 e	3.137 c	3.566 b	3.857 a	3.619 b	3.348 A
Mean	2.136 D	2.360 C	2.648 AB	2.667 A	2.548 B	

[a] Significance at 5% level of probability

The response to N was associated with water application levels. As expected, the lowest response to N was under rainfed conditions, with no increase beyond the 30 kg/ha. When the year was dry or when the first effective rain was late in the autumn, the highest N levels (more 90 kg/ha) tended to decrease the yield. As the N application rate increased, the effect on yield was limited by water (at 1/3, the lowest irrigation rate). Response to N was not limited by available water at the 2/3 SI level, as they were similar to those at full irrigation. However, the highest N level (120 kg/ha), tended to decrease yields. Under any soil water condition, a delay in crop emergence at autumn, on rainfed treatments, reduced the extent of a yield response to added N.

In ARIRS station trials, the mean grain yields under rainfed and various SI treatments are shown in Table 3. The best rainfed seasons for grain yields were 1999/00 and 2001/02 with 3.56 and 3.46 t/ha, respectively. The season of 1999/2000 had the highest rainfall (401.7 mm) with a good distribution across spring supporting such high yield. The 2001/02 season had an average rainfall of 385 mm, inadequate rainfall for emergence in October and sufficient but late rainfall in November. Emergence was late but favourable conditions later in the spring provided the second highest rainfed yield. The 1998/99 and 2000/01 seasons were the poorest for rainfed grain yield (2.85 and 2.81 t/ha, respectively), because of lowest rainfall (271 mm) associated with late emergence in 2000/01. Lower rainfall amounts obtained in the spring of 1998/99 associated with physical damages on crops by the unexpected rainfall in July (51 mm) caused the drop in yield.

In the experiment the full gross SI amount applied during the spring for the four years (1998/99, 1999/00, 2000/01, 2001/02) were 644, 368, 556, 460 mm respectively. For the deficit irrigation treatments, the irrigation amounts were 1/3 and 2/3 of the values above and given at the same time.

Table 3: Mean grain (kg/ha) yields of bread wheat for four growing seasons at Ankara with different water levels.

Treatments	1998/1999	1999/2000	2000/2001	2001/2002	Mean
NIS_0	2810	3560	2850	3465	3170 *E*
$NIS_{1/3}$	4475	4905	4615	4365	4590 *C*
$NIS_{2/3}$	4625	4945	4745	4745	4765 *C*
NIS_{FULL}	4890	4840	4885	4870	4870 *BC*
SIS_0	3165	3680	4430	5315	4150 *D*
$SIS_{1/3}$	4130	5095	5360	5905	5120 *AB*
$SIS_{2/3}$	4585	4910	5205	5985	5170 *AB*
SIS_{FULL}	4660	5080	5455	6215	5350 *A*

LSD (5%) for grain yield is 304 kg/ha

Combined statistical analysis was performed for grain yields. Results indicate that there are statistically significant differences (at 1% level) on yields of the years, main-plots and sub-plots. Depending on the amount of rainfall received in the sowing period of different seasons as explained above, irrigation at sowing had a significant effect (1% level) on grain yields both, particularly in the last two seasons where late crop emergence occurred because of insufficient rainfall after sowing. Wheat grain yield was increased by 50 mm sowing irrigation as 1.58 and 1.85 t/ha over purely rainfed plots in 2000/01 and 2001/02 seasons, respectively. Irrigation in the spring has a significant effect (1% level) on grain yields as well. The Duncan test was applied on the four-year mean irrigation levels in order to determine the effect on the grain yield (Table 3). Mean wheat grain yields over four years showed that the amount of irrigation water in the spring do not differ from each other but all are very effective over the rainfed plots with a range of increases from 1.20 to 1.45 t/ha in grain yields. Because of interaction between the main and sub-plots for grain yield, that full ($SISI_{full}$), 67% ($SIS_{2/3}$), and 33% ($SIS_{1/3}$) in the main plots of 50 mm at sowing provided the highest yields under the same statistical group (A), followed by full (NIS_{full}), 67% ($NIS_{2/3}$) and 33% ($NIS_{1/3}$) in the main plots of no irrigation at sowing in the second statistical group (C). NIS_{full} is in the same statistical group with $SIS_{1/3}$ and $SIS_{2/3}$. All are superior to both SIS_0 (D) and NIS_0 (E).

3.3. Water Productivity

Water productivity (WP) is calculated as the rate of crop production to the amount of water used by the crop (Kg/m^3). Precipitation water productivity was determined as the ratio of average rainfed yield (Kg/ha) to the seasonal precipitation (mm).

Resulted values of WP under rainfed and irrigated treatments for DARI station trials are presented in figure 1. In the 2001/2002 season, although the total precipitation was much higher than the 2001/2002 season, there was a sever drought in the spring which reduced the yield and WP substantially. The frequent occurrence of such drought emphasizes the role of rainfall distribution in addition to amount on rainfed production. In the same season when the crop was given a small amount of irrigation water, the yield was dramatically increased and WP at 1/3 SI treatment reached 2.958 kg/m^3.

In ARIRS station trials WP values for grain under rainfed and irrigated treatments are given in Figure 2. In the 2001/02 season, grain WP reached to 3.70 at the SI at sowing (SIS_0) treatment. Meanwhile, in the first two seasons, due to the adequate rainfall in October, WP was low (0.24 kg/m^3 in 1999/2000) at the SIS_0 treatment.

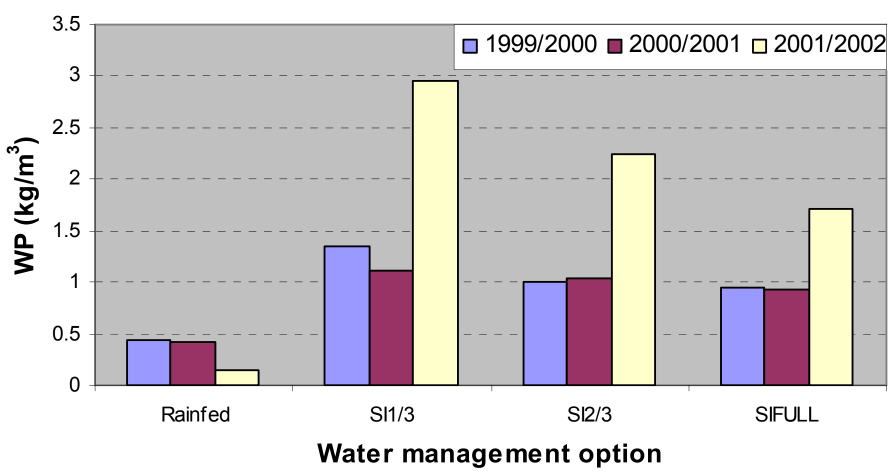

Figure 1. Precipitation and irrigation water use efficiency in producing wheat grains under various management options in Maragheh, Iran.

4. Discussion

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 supplemental irrigation. The high return for limited irrigation water is another advantage of supplemental irrigation. Obtained WP values with deficit SI of 2.96 and 3.70 kg/m^3 are not attainable in conventional irrigated wheat. Based on water availability, a relatively small amount of irrigation water applied at strategic times could achieve substantial increases in yield and water productivity of rainfed wheat. In ARIRS station trial, when early rain was inadequate for crop germination, SI, given at sowing, substantially increased wheat yield by more than 65%, adding about 2.0 t/ha to the average rainfed yield of 3.2 t/ha. Plants, which emerge earlier in the autumn, grow more vigorously and develop faster in the following spring

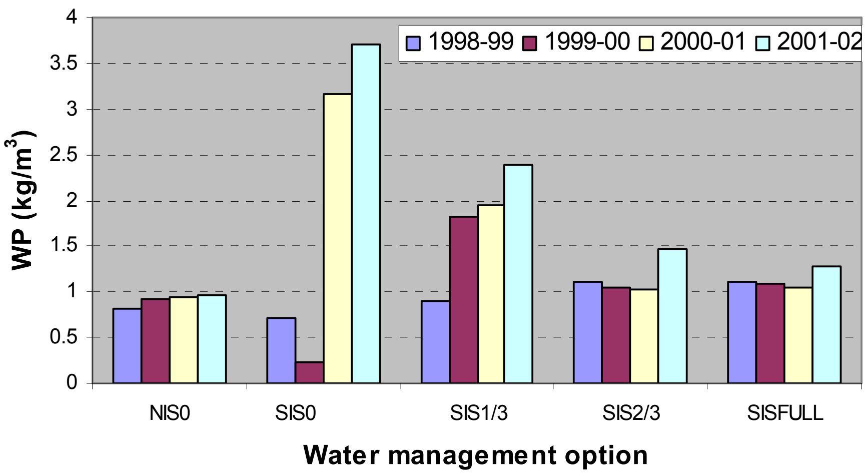

Figure 2. Precipitation and irrigation water use efficiency in producing wheat grains under various management options in Ankara, Turkey.

than plants which emerge later, this is reflected in higher yields with higher water productivity. In most years, the first rainfall sufficient to germinate the seeds occurs later than October. 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 growth in early December. In the first two seasons (1998/1999; 1999/2000) of the trial, adequate early rain in October allowed emergence and enough crop establishments with optimum growth before the winter cold in December. In these two seasons, SI treatment at sowing did not have additional impact on crop growth and yield of the rainfed treatments. Therefore, high plant vigour combined with relatively higher rainfall in these two growing seasons rendered 50 mm irrigation at planting not effective.

The third and fourth seasons (2000/2001 and 2001/2002) of the study, however, experienced different conditions in which rain was late in November. Irrigation at sowing (50 mm) had a significant effect on the rainfed grain yield which was increased from 2.90 t/ha to 4.43 t/ha and from 3.47 t/ha to 5.32 t/ha for the 3rd and 4th seasons, respectively. Large gains in yield in 2001/2002 when 50 mm irrigation were given at sowing were due to the fact that non-irrigated plots only germinated on the 6 of December while 50 mm irrigation provided the emergence 8 days after the planting on 3rd of October. A very good stand was established for the later case before the winter frost. The growth of the well established crop was boosted in early spring when the temperature became favourable again. In 2000/2001 season, the yield gains of early sowing with irrigation was about 1.2 t/ha resulting from about one month earliness in emergence (5 October with irrigation vs. 6 November without). Rainfall of 23 mm which fell in late October 2000 was too late for crop emergence after planting on 21st of September. Late October rain was able to emerge wheat on 6th November. Gains in rainfed yield in this season were lower than the 2001/2002 season where emergence occurred only in early December. Similar impact of early sowing with SI was also reported in DARI station trials as early germination and emergence can be ensured by applying small (30-40 mm) irrigation after sowing. Gains in yield and water productivity, however, were relatively lower.

In Central Anatolia Plateau, the optimal sowing period extends from the last week of September to mid-October. The Weibull formula (US. Water Resources Council, 1981) was used to determine the probabilities of the cumulative rainfall storage amount in the soil for the wheat sowing periods of the years 1963-2001. The results show that the probability of accumulating 50 mm rainfall before mid-October is only 3.4% increasing to 7, 15 and 20%, by the 20th, 25th and 30th of October respectively (Fig. 3). It also shows the probabilities of having rainfall amounts of 30 to 50 mm during the optimal sowing season. The amount needed for germination depends on the effectiveness of the rain which is mainly related to the rain duration. The amount of 30 mm may be enough for germination if falls in a short duration. This absolute minimum amount has a probability of occurrence of only 10% before mid-October and 27% and 35% by October 20 and 25 respectively. This analysis shows that at least in three out of four years the expected rainfall will not be early enough or sufficient enough to achieve optimal crop germination and yield. This also means that SI can be effective at sowing in most years. The impact of SI at sowing on yield and water productivity, however, depends on how early and how much rain falls in a specific year.

The study also revealed that SI applied later in the spring and early summer increased grain yield, but involved a lower rate of water productivity. DARI station trial showed that, 1 t/ha of rainfed yield would be increased to 2.5, 3.0 and 3.5 t/ha by 1/3, 2/3 and full SI, respectively Such yield increase clearly supports the findings of Stewart and Musick (1982) and Oweis et al. (1999) in favour of the potential for conjunctive use of irrigation and rainfall in semiarid regions. Also in ARIRS station trial, applying enough water to fully satisfy the crops requirements increased the yield by 1 t/ha from 4.15 t/ha under SIS_0 to 5.35 t/ha under SIS_{full} (Table 5). The reduction in grain yield with deficit irrigation of 2/3 and 1/3 of full irrigation was 3% and 5% below maximum levels respectively. This confirms the result of Oweis et al. (1998, 1999 and 2001), Oweis and Hachum (2001) which showed that deficit SI on wheat provides higher water productivity.

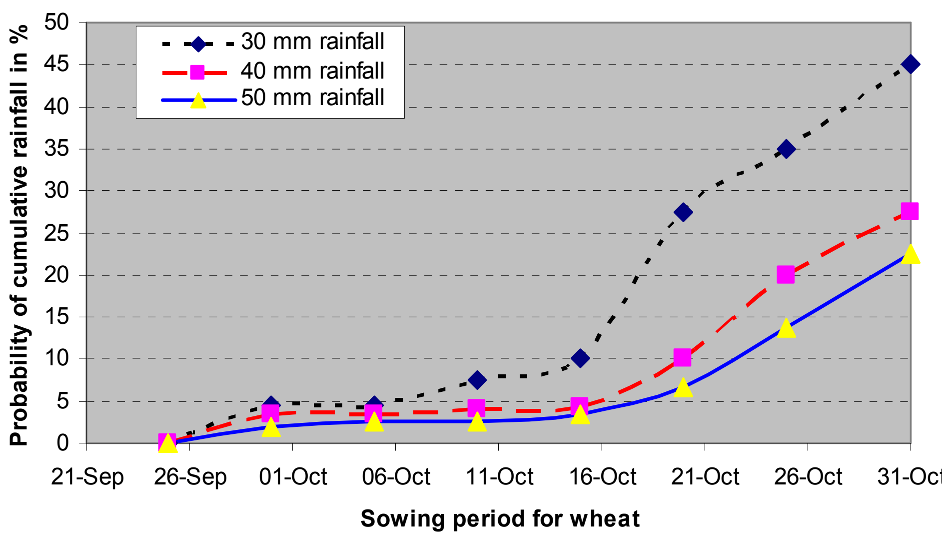

Figure 3. Probability of having 30, 40 and 50 mm of precipitation during the sowing period of wheat in Central Anatolia for the years 1963-2001.

The strategy of applying small amounts of water when soil moisture is low at critical crop growth stages to maximize rainfed crop yields seem to also maximize water productivity as well

(Zhang and Oweis, 1999). Moreover, in areas where water resources are scarce and more limiting than land, the water saved as a result of deficit SI can be used to irrigate new lands increasing total crop production. Adopting such a strategy in areas where water is more limiting than land can help farmers cope with increased water scarcity and improved income.

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