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Full Length Research Paper

Deficit irrigation practices as alternative means of improving water use efficiencies in irrigated agriculture: Case study of maize crop at Arba Minch, Ethiopia

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Deficit irrigation is becoming an important strategy to reduce agricultural water use in arid and semi-arid regions. A field experiment was conducted in 2007 to examine the effect of deficit irrigation on the yield performance of maize crop under Arba Minch (Ethiopia) condition. Based on four phonological growth stages (establishment, vegetative, flowering and grain-filling stages) of maize, the crop was subjected to water deficit during one, two or three growth stages. The highest yield obtained was 5.933 tons/ha and the lowest was 3.467 tons/ha. Treatments that were water stressed during single growth stages such as first and second as well as consecutively during two stages, that is, first and second growth stages produced yields that are not significantly different from the yield achieved under fully irrigated treatment. Compared to the maximum yield, 29 to 42% lower yields were registered under treatments that were subjected to water deficit during three growth stages. Not only frequency of water deficit periods but also its timing was found to have effect on the final yield. Treatments which were stressed during two growth stages had 2.2 (0011) to 38.5% (1010) yield reduction compared to the maximum yield. The highest yield reduction was observed under the treatment which was irrigated only during the fourth growth stage (0001), followed by treatment irrigated during first and third growth stages (1010) and then treatments irrigated only during second stage (0100). This shows that prolonged deficit over three growing stages will have more yield reduction impacts. Plots stressed during third and fourth growth stages were found to produce lower yields indicating the severe effects of water stress during flowering (tasseling and silking) and early grain-filling stages on yield. The comparison of water savings achieved under different treatments that had no significant differences in yield level from full irrigated plot (1111l) ranged from 18.2% (treatments 0111 and 1011) to 36.4% (0011). This indicates that water deficit during first and second growth stages had no significant effect on the grain yield of corn and it is worthwhile to save irrigation water under this condition. The water use efficiency increased with decreasing water supply and increasing yield level. Irrigation water use efficiency increased with decreasing water supply and related yield which may not be desirable from farmers' perspective.

Key words: Deficit irrigation, Ethiopia, growth stage, maize, water use efficiency.

INTRODUCTION

Irrigation development is increasingly implemented in Ethiopia more than ever. The main objectives are to increase agricultural productivity and diversify the production of food and raw materials for agro-industry as well as to ensure that the agriculture plays the role of driving the economic development of the country. Expansion of irrigated area combined with efficient management of water will enhance the attainment of food security and poverty alleviation goals of the country. Although the country is well known for its vast water resources potential its erratic distribution both in space and time coupled with limited capacity is the most

Table 1. Rainfall and reference evapotranspiration of the study site.

Months	Rainfall (mm/month)		ET_o (mm/day)	
	Average (1970-2006)	Study period 2007	Average (1970-2006)	Study period (2007)
January	28.0	63.4	4.5	3.91
February	27.9	35.5	5.0	4.39
March	64.0	16.3	5.8	4.82
April	181.7	129.2	4.7	4.42
May	140.5	193.4	4.4	4.17

Table 2. Soil physical characteristics in the study area (Teshome, 2006).

Soil depth (cm)	Particle composition (%)			Bulk density (gm/cm^3)	FC (%)	PWP (%)
	Sand	Silt	Clay			
0 - 30	20	26	54	1.31	39.27	21.3
30 - 60	16	14	70	1.32	34.68	19.7
60 - 90	10	18	72	1.36	31.56	17.0
90 - 120	20	24	56		31.35	16.80

challenging problem that limited the contribution of the resources to the socio-economic development of the country. Under such conditions water is sometimes not available where and when it is required. Under conventional practices of irrigated agriculture, agriculture is considered as the major consumer of water compared to other sectors. The expansion of irrigated agriculture to feed the ever-increasing population on one hand and the increasing competition for water due to the development of other water use sectors on the other hand, as well as increasing concerns for environment, necessitated the improvement of water use efficiencies in irrigated agriculture to ensure sustained production and conservation of this limited resource.

Strategies to improve water use efficiency of irrigated crops are among others; deficit irrigation, precision irrigation technologies such as drip irrigation and soil and water conservation practices. Deficit irrigation has been practiced in different parts of the world (English and Raja, 1996; Pandey, 2000; Fabeiro et al., 2001; Oktem et al., 2003; Karam et al., 2005; Girona et al., 2005; Zhang, 2004; Payero et al., 2006; Igbadun et al., 2006; Bekele and Tilahun, 2007; Ali et al., 2007). On the contrary, traditional irrigation development paradigm aims at providing sufficient water to crops to avoid water deficits at all stages, so as to achieve maximum yields (Lorite et al., 2007), deficit irrigation is the practice of deliberately under irrigating crops (Dag'delen et al., 2006) in order to reduce water consumption while minimizing adverse effects of extreme water stress on yield. Adoption of deficit irrigation requires the knowledge of the response of different crops to water deficit at various growth stages. Reduced yield as the result of deficit irrigation,especially under water limiting situations, may be compensated by increased production from the additional irrigated area with the water saved by deficit irrigation (Ali et al., 2007). Many investigations have been carried out worldwide regarding the effect of water deficit on yield of maize (Oktem et al., 2003; Panda et al., 2004; Igbadun et al., 2006; Payero et al., 2009; Farre´ et al., 2009; Mansouri-Far et al., 2010). However, most of these studies have examined the effect of reduced water application irrespective of growth stages on grain yield. The objective of this study was to examine the effects of timing of water deficit on yield and water use efficiency of maize under Arba Minch condition.

MATERIALS AND METHODS

Description of the study area

The field experiment was conducted at Arba Minch State Farm (latitude 6°04'N, longitude 37°36'E and altitude 1218 m) which is found at the distance of 505 km southern of Addis Ababa during the period from January to June 2007. Mean annual rainfall is about 910 mm. Average maximum and minimum temperature is about 33.3 and 17.4°C respectively. The rainfall distribution has a bimodal nature with the first and second rainfall during April to May and September to October, respectively. Mean annual reference evapotranspiration is about 1644mm. Peak daily evapotranspiration rates occurred in March. The month of April was characterized by high rainfall during the study period Table 1. The soil of the study area is characterized as clay textured with average filed capacity and permanent wilting point of 34.2 and 18.7% respectively (Table 2).

Experimental design

The experiment was conducted in an intensively cultivated area of Arba Minch. It was designed to expose maize crop to water deficit during one or more of its growing stages. Considering four growing stages of the crop (FAO, 1998) there were fourteen treatments as indicated in Table 3. These treatments were replicated three times to yield a total of 42 experimental plots which were assigned in a

Table 3. Description of irrigation treatments.

Treatments	Growing stages				Explanation
	I	II	III	IV	
Days from germination	0-29	30-53	54-80	81-135	
T_1	0	I	I	I	1st stage no irrigation
T_2	I	0	I	I	2nd stage no irrigation
T_3	I	I	0	I	3rd stage no irrigation
T_4	I	I	I	0	4th stage no irrigation
T_5	0	0	I	I	1st and 2nd stage no irrigation
T_6	I	0	0	I	2nd and 3rd stage no irrigation
T_7	I	I	0	0	3rd and 4th stage no irrigation
T_8	I	0	I	0	2nd and 4th stage no irrigation
T_9	0	I	0	I	1st and 3rd stage no irrigation
T_{10}	I	0	0	0	1st stage irrigation
T_{11}	0	I	0	0	2nd stage irrigation
T_{12}	0	0	I	0	3rd stage irrigation
T_{13}	0	0	0	I	4th stage irrigation
T_{14}	I	I	I	I	All stages irrigation

randomized complete block design (RCBD). The size of each experimental plot was 4 × 4 m. The space between plots was 2 m. Each plot had four furrows of 0.50 m top width for irrigation water application and five planting rows of 0.40 m width. The furrows were regularly maintained to sustain their water storage capacities over the season. The time ranges of individual growth stages as observed and adopted for the experiment are: growing stage I: from January 11 to February 8; growth stage II: from February 9 to March 6; growth stage III: from March 7 to March 31 and growth stage IV: From April 1 to May 25.

Agronomic practices and water application

Land preparation was made using tractor driven dick plough and labour forces for finishing and seedbed preparation. Two days before sowing (that is, January 3, 2007), the land was well irrigated. The improved maize seed distributed by Ethiopian Improved Seed Corporation (RH-240) was used as seed material. After germination and establishment, thinning was carried out to maintain the spacing between plants to be 30 – 40 cm. Weeding was done manually in all plots. No fertilizer was applied throughout the growing period. This is because as some of the plots are under water stress (no irrigation) applying fertilizer may cause further drying of the roots due to osmosis effects. The sowing and harvesting dates were 5th of January and 25th of May, 2007 respectively.

Crop water requirement and irrigation scheduling was calculated using CROPWATT for Windows (FAO, 1992). The results of the output are presented in Table 4. Diverted water from the river was brought to the field using filed channel that run adjacent to experimental plots. Water is then directed to smaller supply channels that feed the furrows. Through careful opening and closure of channel banks, the water was supplied into furrows up to their storage capacity (0.10 m water depth × 0.50 m wetting perimeter × 4 m furrow length = 0.20 m^3 per furrow. Water was carefully controlled to avoid the flow of water into water deficit plots. Since the furrows are close ended all water flowing into the furrows were infiltrated over the entire length, that is, there was no runoff. The fact that the furrows are short, the stream size is large and the cut-off time is short, no significant deep percolation will be expected. Local practices were followed to apply irrigation water. That means equal amount of water was applied during each irrigation event irrespective of growth stage. Every time each furrow was filled to its full capacity. To maintain the capacity of furrows constant throughout the growing season, maintenances were done every time shortly before irrigation. Volume of water supplied is given by the cross-sectional area of the furrow (wetted perimeter × depth) multiplied by the length of the furrows.

Plots which are to be subjected to water deficit during particular growth stage according to schedule in Table 3 were deprived of irrigation water application and also protected from possible supply of water through rainfall using plastic shelters. The shelters were designed in such a way that they can easily be rolled-up when there is no rainfall and unrolled when rainfall occurs and during night.

Whenever irrigable plots get water from unexpected rainfall, it was accounted for while determining the time of the next irrigation. Irrigation was scheduled based on soil moisture monitoring using gravimetric method. Available moisture content was determined by taking soil samples from the effective root zone of the crop two days after irrigation. The days until next irrigation was obtained by dividing the amount of readily available moisture in the root zone by mean daily crop water evapotranspiration.

Data collection and analysis

Important data collected during the experiment includes among others: amount of water applied during the period, soil moisture levels, yield and open air dried aboveground biomass. The grain yield weight was 16% moisture content. The data collected were subjected to descriptive statistical analysis and ANOVA test to see the effects of different treatments on the yield and water use efficiency performances. The results are presented in the form of tables or figures.

RESULTS AND DISCUSSION

Amount of water applied

Amount of water required during the growing season and amount of irrigation water applied to each treatment plots is presented in Tables 5 and 6 respectively. Total number of irrigation water application varied from 11 in full irrigated plots (T_{14}) to 4 in treatments which were subjected to water deficit during three growing stages.

Table 4. Water requirement as given by CROPWATT.

Months	Decade	Growing Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Jan	1	Initial	0.3	1.38	13.8	9.2	4.7
Jan	2	Initial	0.3	1.37	13.7	8.8	4.9
Jan	3	Develop	0.46	2.15	23.7	8.9	14.8
Feb	1	Develop	0.73	3.56	35.6	7.9	27.6
Feb	2	Develop	0.99	4.98	49.8	7.4	42.3
Feb	3	Mid	1.19	6.24	50.0	11.3	38.6
Mar	1	Mid	1.21	6.76	67.6	14.5	53.2
Mar	2	Mid	1.21	7.1	71.0	17.2	53.8
Mar	3	Mid	1.21	6.61	72.7	25.8	46.9
Apr	1	Late	1.17	5.82	58.2	37.9	20.3
Apr	2	Late	0.91	4.23	42.3	47.3	0
Apr	3	Late	0.62	2.83	28.3	43.6	0
May	1	Late	0.41	1.81	9.1	19.8	0
					535.8	259.6	307.2

Table 5. Irrigation water applied (mm).

Irrigation date	T_1 0111	T_2 1011	T_3 1101	T_4 1110	T_5 0011	T_6 1001	T_7 1100	T_8 1010	T_9 0101	T_{10} 1000	T_{11} 0100	T_{12} 0010	T_{13} 0001	T_{14} 1111
Jan-04	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5
Jan-11		62.5	62.5	62.5		62.5	62.5	62.5		62.5				62.5
Jan-23		62.5	62.5	62.5		62.5	62.5	62.5		62.5				62.5
Feb-9	62.5		62.5	62.5			62.5		62.5		62.5			62.5
Feb-17	62.5		62.5	62.5			62.5		62.5		62.5			62.5
Mar-02	62.5		62.5	62.5			62.5		62.5		62.5			62.5
Mar-05		62.5			62.5			31.0				62.5		
Mar-06						31.0				31.0			62.5	
Mar-11	62.5	62.5		62.5	62.5			62.5				62.5		62.5
Mar-17	62.5	62.5		62.5	62.5			62.5				62.5		62.5
Mar-29	62.5	62.5			62.5									62.5
Apr-07	62.5	62.5	62.5		62.5	62.5			62.5				62.5	62.5
Apr-24	62.5	62.5	62.5		62.5	62.5			62.5				62.5	62.5
Total	562.5	562.5	500	500	437.5	343.5	375	343.5	375	218.5	250	250	250	687.5

62.5 mm water depth is obtained by measuring furrow wetted perimeter (wp), furrow length (L), water depths in furrows (d). Based on these measured data, volume of water supplied (V) can be calculated. Finally depth of irrigation supplied to the A ($16m^2$) can be obtained by dividing volume of water by total area (A); wp=50 cm, L=400 cm and hence, A=wp*L = 20,000 cm^2. V=A*d=1,000,000 cm^3. Then irrigation depth = V/A=62.5 mm.

Total water supplied is the summation of effective rainfall which was determined using CROPWAT and irrigation water supplied during the growth stages of the crop. Accordingly, the total water supplied varied from 264 mm (T_{12}) to 894 mm (T_{14}). The differences in the total amount of water supplied among treatments which were subjected to deficit during two or three growing stages were mainly due to the contribution of rainfall. It varied for instance, from 264 - 354 mm in treatments which were irrigated only during one growth stage. Irrigation water supply was 687.5 mm in plots which were irrigated during all growing stages and the amount varied from 219 - 250 mm in treatments which were irrigated during only one growth stage. In April there was high rainfall which could satisfy the evaporative demand of the atmosphere in the area. Accordingly, the irrigation interval was longer compared to low rainfall months such as January, February and March which were respectively, 63, 35 and 16 mm.

Total amount of irrigation water supplied varied from 218.5 mm (in treatments which were stressed during three growth stage and irrigated during only one stage) to

Table 6. Amount of water supplied during the season (both irrigation and effective rainfall).

Treatment	Number of irrigation	Irrigation water supplied (mm)	Effective rainfall during the growing stages (mm)				Total water supplied (mm)
			I	II	III	IV	
0111	9	562.5		21.1	14.2	103.5	701.3
1011	9	562.5	67.4		14.2	103.5	747.6
1101	8	500.0	67.4	21.1		103.5	692.0
1110	8	500.0	67.4	21.1	14.2		602.7
0011	7	437.5			14.2	103.5	555.2
1001	6	343.5	67.4			103.5	514.4
1100	6	375.0	67.4	21.1			463.5
1010	6	343.5	67.4		14.2		425.1
0101	6	375.0		21.1		103.5	499.6
1000	4	218.5	67.4				285.9
0100	4	250.0		21.1			271.1
0010	4	250.0			14.2		264.2
0001	4	250.0				103.5	353.5
1111	11	687.5	67.4	21.1	14.2	103.5	893.7

Stressed treatments have not obtained rainfall as they were covered with shelters during rainfall events.

Table 7. Grain yield (moisture content 16%), aboveground biomass and harvest index for different irrigation treatments of maize.

Treatment	Label	Grain yield (t/ha)	Aboveground biomass (t/ha)	Harvest index (-)	Remarks
T_1	0111	5.933 a	17.933 a	0.33	Only one growth stage stressed
T_2	1011	5.967 a	16.733 ab	0.36	
T_3	1101	4.967 abc	15.933 ab	0.31	
T_4	1110	5.400 ab	15.167 ab	0.36	
T_5	0011	5.833 a	15.933 ab	0.37	Two growth stages stressed
T_6	1001	4.433 bcd	14.333 bc	0.31	
T_7	1100	4.567 bcd	15.267 ab	0.30	
T_8	1010	3.667 d	11.067 c	0.33	
T_9	0101	4.433 bcd	17.167 ab	0.26	
T_{10}	1000	3.467 d	14.400 bc	0.24	Three growth stages stressed
T_{11}	0100	3.700 d	13.833 bc	0.27	
T_{12}	0010	4.233 cd	11.733 c	0.36	
T_{13}	0001	4.229 cd	11.563 c	0.37	
T_{14}	1111	5.800 a	16.500 ab	0.35	No stress

Treatments with the same letter in the same column are not significantly different at P<0.05.

687.5 mm in fully irrigated treatment (T_{14}). Irrigation interval was relatively short in the month of March. This month was also characterized by low rainfall and high evapotranspiration and hence frequent irrigation was necessitated. Hence, water supplied to plot T_{14} was higher than crop water requirement which was calculated using mean climatic data. Treatments which were subjected to water deficit in March showed very often symptoms of wilting indicating critical water stress. To maintain the crop alive the plots were lightly irrigated (31 mm).

Yield parameters

The grain yield and aboveground biomass of the maize plant is presented in Table 7. ANOVA test showed that there is a significant difference between treatments in terms of grain yield and total aboveground biomass. It

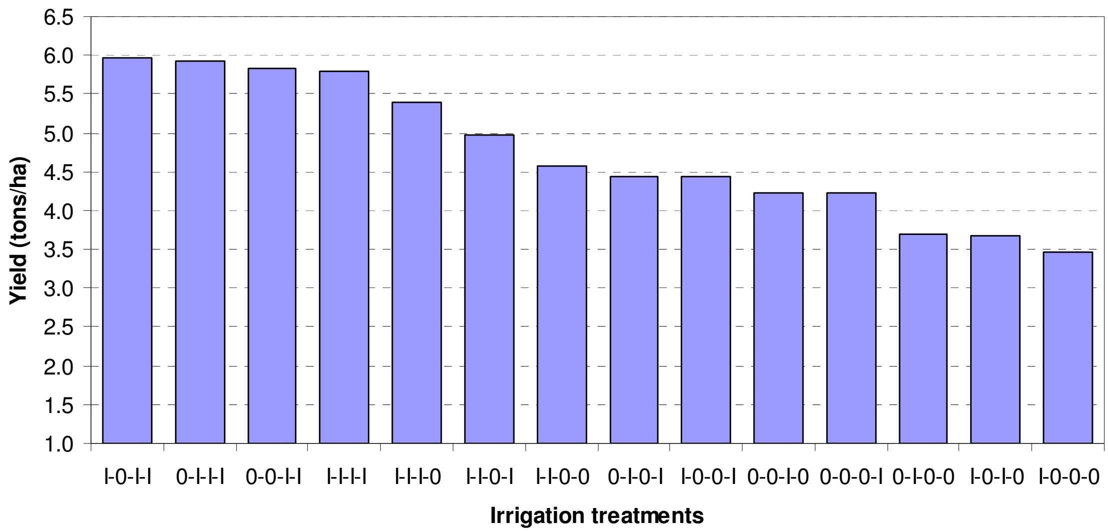

Figure 1. Variation of yield as affected by timing and frequency of water deficit.

was also evidenced that there is no significant difference between full irrigation T_{14}, and plots stressed during first and second growing stages (T_1 and T_2) as well as stressed plots during both first and second growth stages (T_5) in terms of yield. The grain yield varied from 5.967 - 3.467 tons/ha. Whereas the the aboveground biomass ranged from 17.933 - 11.067 tons/ha. The maximum yield was obtained from the treatment which was water stressed during second growth stage (early vegetative stage).

Relatively lower yield was registered under the treatment which was irrigated during first growth stage and stressed during other stages (T_{10}). However it is not significantly different from the yields of T_8 which was irrigated during two growing stages.

For further comparison, it is important to classify the results into four as indicated in the remark column of Table 7. Relatively higher yield was obtained from the plots subjected to water stress during only one growth stage (0111 and 1011). The effect of water stress at flowering or reproductive stage (no irrigation during third stage, 1101) had more yield reduction effect compared to stress during establishment (0111), vegetative stage (1011) and grain filling stage (1110). Stress during vegetative and/or grain-filling stages had more impact on yield.

The lowest yield was obtained from plots which were stressed during three growth stages. The fact that significant differences was observed between plots stressed only during one growth stage (T_1 - T_4), indicate that not only the frequency of water stress but also the timing had effect on the yield. However the difference between T_1 and T_2 was not significant indicating that stress during first and second growth stage produced more yield compared to the treatment T_3 and T_4. Moreover no significant difference was observed in the yields of T_1 and T_2 as well as full irrigated treatment T_{14}. The yield obtained under treatment T_5 (consecutive stress during first and second stages) is also not significantly different from the maximum yield obtained from treatment T_2 as well as fully irrigated treatment T_{14}. Shifting the stress to consecutive second and third (T_6) as well as to third and fourth growth stages (T_7) had a yield reduction of about 24 and 22% respectively, compared to the yield obtained under T_5. Plots stressed during three growth stages, like T_{10} - T_{13}, produced comparatively lower yield followed by those stressed during two growing stages (Figure 1). Igbadun et al. (2007) found that skipping of irrigation at flowering growth stage has only impacted more severely on yield compared to skipping irrigation at vegetative or grain-filling growth stage. Moreso, they found out that the impact of the deficit was more on those treatments in which irrigation was skipped in two or more growth stages than those in which irrigation events were skipped in one growth stage only.

The aboveground biomass was different among treatments. However, there was no significant difference in aboveground biomass among most plots water stressed during only one growth stage. Relatively lower aboveground biomass was observed under plots which were subjected to water deficit during two or more growth stages starting from second growth stages. Water deficit during first growth stage has no significant influence on both grain yield and aboveground biomass. The harvest index (HI) which refers to the percentage dry matter allocated to grain yield, decreased with increasing frequency of deficit from all except under T_{13}. The lowest HI is 0.24 and the highest is 0.37. These values are relatively lower than the values of 0.31 – 0.55 reported by Farre and Faci (2009).

Figure 1 depicts the effects of deficit frequency on the grain yield. It indicates that not only the frequency of

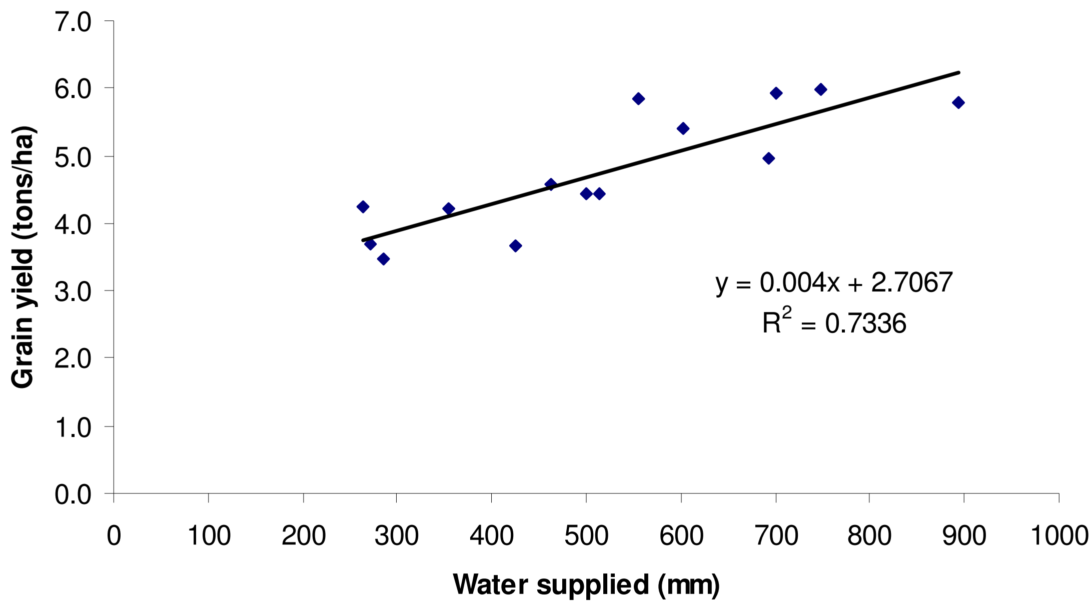

Figure 2. Irrigation water supplied versus yield.

irrigation but also its timing has an effect on yield. Treatment which was stressed during third growth stage (1101) has shown 15% yield reduction compared to treatment plot stressed during both first and second stages (0011). Treatments under water stress during single growth stage have yielded more followed by treatments plots stressed during two and three growth stages. Appropriate timing of the stress can minimize this loss of yield.

The fact that the yield of treatment 1100 is inferior to the yield of treatment 0011 by 22% indicates that the timing of both irrigation and water deficit are important. Similarly the yield of treatment 1010 is 17.3% less than the yield of treatment 0101 and also significantly different. Mansouri-Far et al. (2010) also found that deficit irrigation of maize during reproductive stage has resulted in more yield reduction than during vegetative stage.

Water supply–yield relationship

Water supply-yield relationship is also known as water production function. It was obtained by plotting yield on Y-axis and water supplied on X-axis (Figure 2). Irrigation water and effective rainfall were considered to quantify the amount of seasonal water supplied. The comparison in Figure 3 shows that there is a linear relationship between amounts of water supplied and grain yield obtained (R^2 = 0.7336). The slope of the regression line which indicates the increment of grain yield for unit increase of irrigation water supply is very low. The correlation coefficient obtained by some researchers vary from 0.81 to 0.96 (Farre' and Faci, 2006; Dag'delen et al., 2006; Oktem et al., 2003; Igbadun et al., 2007). Obviously, this relationship depends on rainfall, crop characteristics and weather conditions.

The least yielded treatment was not the one that obtained the lowest amount of water. Similarly, treatment that obtained highest amount of water during the season has not necessarily produced the highest yield. This shows that trying to improve crop water production by adopting deficit irrigation without due consideration of its timing might not be beneficial.

It is not only the total amount of water applied that matters but the timing of its application. Zwart et al. (2004) found out that crop-water productivity under rainfed system is low, but increase rapidly when a little irrigation is applied. Moreover, water stress during different growth stages affected crop-water production differently.

The highest yield reduction was observed under the treatments T_{10} followed by T_8 and T_{11} (Figure 3).

This shows that prolonged stress over three growing stages like in T_{10} will have definitely more yield reduction impacts. None or lower yield reduction were registered under treatments 1011, 0111, 0011 and 1111. This is not only due to the application of more water but also the timing of stress was arranged such that the crop was imposed to water stress during less sensitive growth stages (establishment and vegetative) and irrigated during high sensitive stages (flowering, silking and early grain-filling stages). Average yield response factor was found to be 1.03 and slightly less than values given by FAO which is 1.25 (Allen et al., 1998).

The scattered points in Figure 4 also show the effect of timing of water stress on the extent of the resulting yield reduction. Treatments that obtained almost equal amount of irrigation water during the season had different

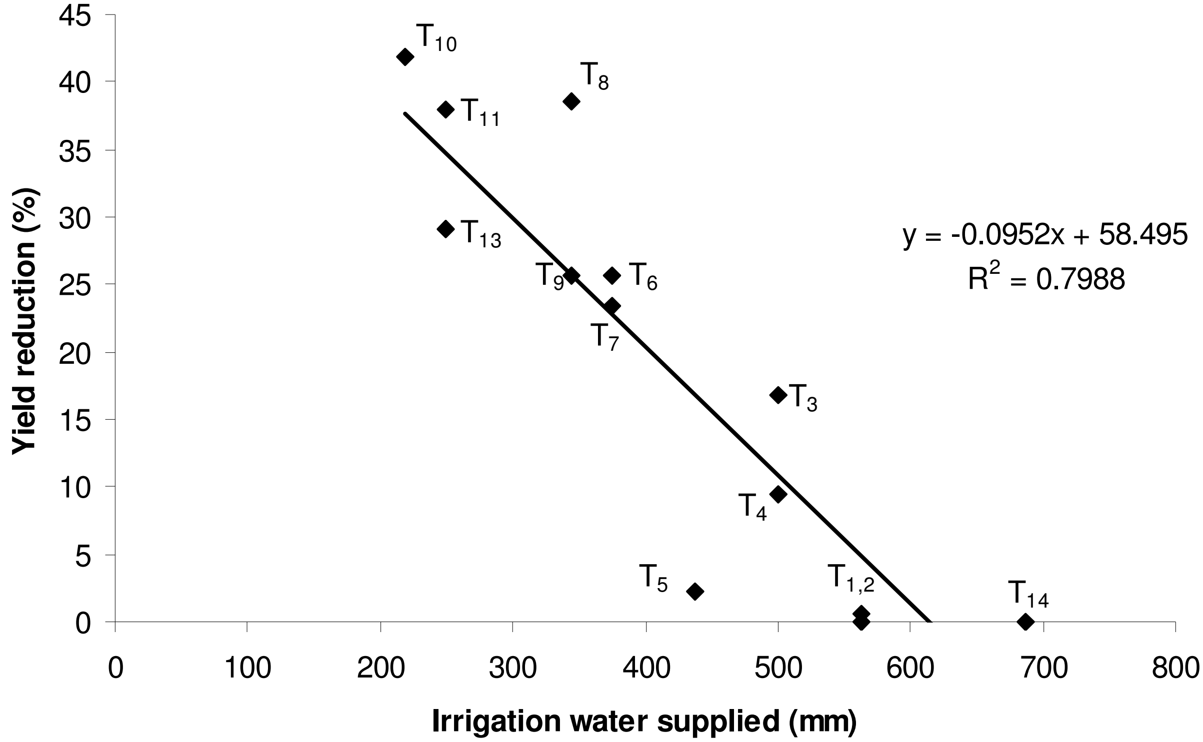

Figure 3. Yield reduction versus irrigation water applied.

responses in terms of yield reduction (for instance T_5, T_3, T_4, and T_8). Stress during flowering, silking and early grain filling stage had the highest effect on yield reduction than stress during establishment and vegetative stages. The results of Pandey et al. (2000) indicated also that water stress during vegetative growth stage of maize had no significant yield reduction.

Irrigation operator should know when it is worthwhile to save water. As can be seen from Figure 4, the amount of water saved under treatment T_5 and T_8 is almost close to each other but the resulted yield reduction under both treatments is 2.2 and 39% respectively. This reveals that timing of stress imposition is important to save water without much effect on yield.

Zwart et al. (2004) argued that maximum water productivity will often not coincide with farmers' interest, whose aim is a maximum land productivity or economic profitability. Hence, it requires a shift in irrigation science, irrigation water management and basin water allocation to move away from 'maximum irrigation-maximum yield' strategies to 'less irrigation-maximum CWP' polices. Besides the total amount of irrigation water applied, the timing of irrigation is important. Water stress during different growth stages affects water productivity differently.

The difference between yield obtained under treatments T_1, T_2, T_5, and T_{14} are statistically not significant. However, the water saved was 18% under the first two treatments and 36% under treatment T_5. Even treatments T_3 and T_4 which were irrigated more saving less water than T_5 produced significantly lesser yield than T_5. This indicates that water stress during third and fourth growth stage affected the yield compared to stress during first and second growth stages.

Water use efficiency

Irrigation water use efficiency (IWUE), which refers to the ratio of grain yield to total irrigation water supplied, varied from 0.84 to 1.69 (Figure 4). With increasing amount of water supply, the water use efficiency decreases.

Treatments with lower yield due to less water application had higher water use efficiency. The result indicated that higher yield treatments had low water use efficiencies.

Zwart et al. (2004) reviewed more than 27 literatures from 10 countries and found out that the crop-water-productivity of maize ranges between 0.22 and 3.99 kg/m^3. Zhang et al. (2004) reported water use efficiency of corn that varied from 1.39 to 1.72 kg/m^3. The findings of this study are in line with the results from elsewhere.

Farre' and Faci (2009) reported that under water deficit conditions, maize fully irrigated around flowering was able to produce more grain yield per unit of irrigation water applied than maize subject to deficit irrigation around flowering. This has important economical implications because it means that under water limited conditions, maize fully irrigated around flowering can

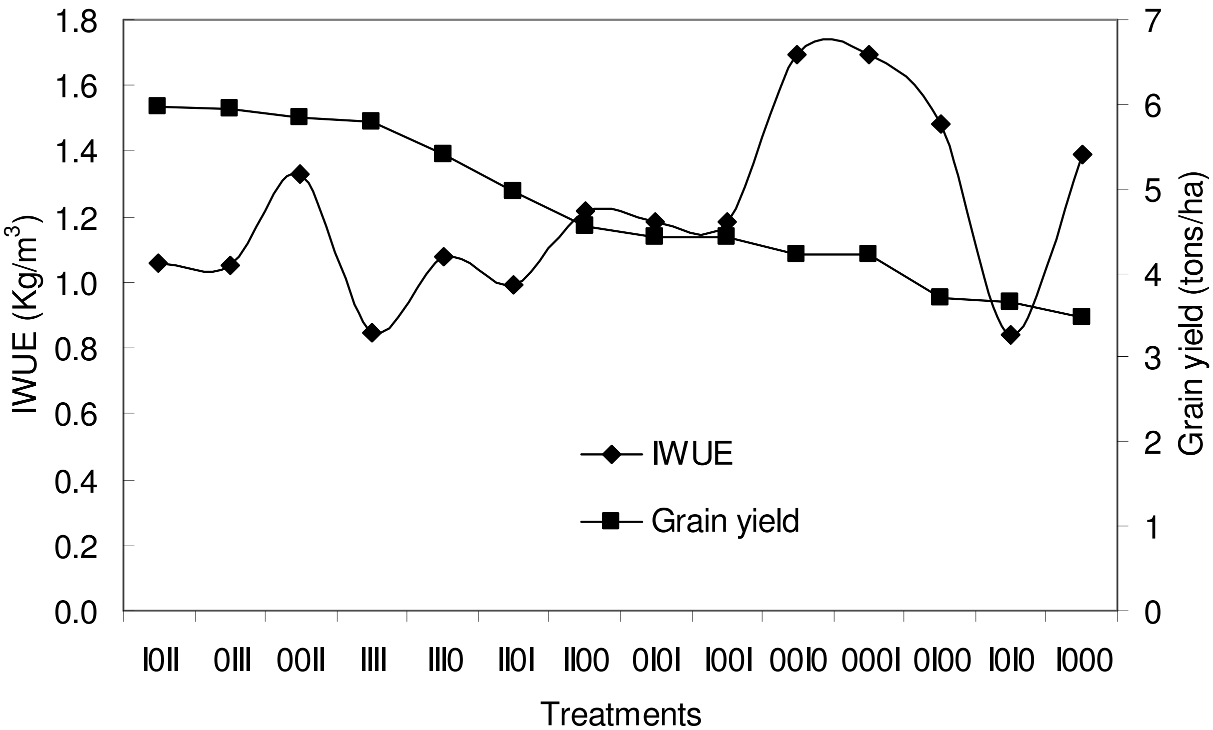

Figure 4. Comparison of Irrigation water use efficiency (IWUE) and grain yield as affected by deficit irrigation.

produce more yields per monetary unit spent in irrigation water than maize subject to deficit irrigation around flowering.

Conclusions

The advantage of deficit irrigation lies in saving water while maintaining optimum yield as close to fully irrigated farm. The study indicated that no significant difference as observed between the yields of treatments which were irrigated during all growth stages (full irrigation) and those stressed during first and second growth stages as well as treatment which were consecutively subjected to water deficit during first and second growth stages. This indicates that water deficit at establishment and vegetative stages have not significantly affected the yield. That means during these growth stages, water and other irrigation expenses can be saved. By doing so more land can be irrigated with the saved water to enhance more production.

The highest yield reduction was observed under the treatments which was irrigated only during fourth growth stage (0001), followed by treatment irrigated during first and third growth stages (1010) and plot irrigated only during second stage (0100). This shows that prolonged stress over three growing stages will have definitely more yield reduction impacts. Plots stressed during third and fourth growth stages were found to produce lower yields indicating the severe effects of water stress during tasseling, silking and early grain-filling stages on yield. IWUE has increased with decreasing water application which, however is also related to decreased grain yield and hence may not be desirable from the farmers' perspective. Other agricultural inputs need to be appropriately used to enhance productivity by maintaining improved IWUE.

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