Crop Water Requirement of Selected Crops and Frequency oF Irrigation on Bread Wheat

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Abstract

An experiment on crop water requirements and irrigation scheduling was conducted at Bakelo irrigation area on Vertisol from 2001-2004. . Soil water budget was used to determine the water requirements. Crop water requirement of wheat, barley, lentil, and potato were 392 mm, 356 mm, 284 mm and 448mm respectively. Out of which 236mm, 233 mm, 171 mm, 276 mm must be applied artificially and accounted as net irrigation requirements. Accordingly, the gross irrigation water required excluding pre-irrigation amounts will be 327mm, 250 mm 159 mm and 307mm for wheat, barley lentil, and potato correspondingly. As a result the number of irrigations for wheat, barley lentil and potato are four, two three and .six times during the growing season in that order. Among the tested irrigation frequencies for wheat, irrigation at early tillering + booting + milkstage, and at booting + milkstage have a better water distribution pattern over the season which in most of the periods coincided with the actual water balance in supplemental irrigation. The amount of water applied for irrigation regimes at early tillering, and booting independently was less than the net irrigation requirement of wheat.

An economical wheat yield benefit of 34 q/ha was obtained by applying water at early tillering (67mm) + booting (52mm)+ milk stages (113mm).The marginal rate of return compared to the existing farmers' irrigation practice is 435 %. It is therefore recommended to apply water at early tillering + booting + milk stages of wheat in Bakelo irrigation area.

Keywords: growth stage based irrigation, optimum yield, water management

Introduction

Access to affordable irrigation has significantly reduced poverty because it addresses critical leverage points in the livelihood strategies of the rural poor by enhancing agricultural production and creating opportunities for more active and effective market participation. Improving the productivity of crops can be achieved by looking the economic productivity of water for maximum value using rainfall, surface water, and wastewater in the form of runoff.

Focus of most irrigation projects has been on large scale irrigation schemes. But there are quite a lot of small-scale irrigation holders (0.1-0.25 ha) which have not ever been documented. Even their productivity is not well known. They can be producing a great deal which we have to focus on. It is poor farmers that we move on to the end of poverty reduction. The research and development activities have also better to focus on small-holder irrigation instead of large scale infrastructures.

Rainfall amount during the *belg* season in the area is much lower than crop water requirements for economic production. Because of unfavorable rainfall pattern, soil moisture in the root zone often does not satisfy crop needs over the whole season. Since rainfall is the principal source of moisture for rain-fed crops, supplemental irrigation (SI) is only applied when rainfall fails to provide essential moisture for improved and stabilized production. The amount and timing of SI are scheduled not to provide moisture stress-free conditions throughout the growing season, but to insure that there is a minimum amount of water available during the critical stages of crop growth that would permit optimal instead of maximum yield. Unlike full irrigation, the management of SI is dependent on the rainfall as a basic source of water for the crop.

The current irrigation method is by flooding the field or farm until water satisfied deep percolation, field capacity, or saturation level of the soil and depression storage of the clay soil. The farms irrigated in this way require a range of 7-10 days to dry the soil moisture to the level that crops need at planting – called '*nish*' (farmers' experience). The existing irrigation method (i.e. flooding) and allow free to use the limited water over the night for one field as they wish leads to water wastage and low performance in water use and obtaining optimal yield (Horst, 1998). Really this is the actual situation by which great losses of water is existing which needs immediate intervention on irrigation water scheduling. The most important considerations in good SI management are when and how much water to apply. Yet many, perhaps most, farmers apply too much water if they can get it. Evidence of the over- use of irrigation water is clear in many situations, and SI is no exception. Farmers tend to overuse water in supplemental irrigation because of the low water and irrigation costs they incur. The aim of irrigation scheduling should be to provide sufficient water to crops at the right time and also to discourage farmers from over irrigating.

One problem can be that the need for water occurs at the same time for all the planted area. Irrigation has to be applied to a large area in a short time. A large water supply rate and a large irrigation system are then needed. This conflicts with the limited water supply and the objective of minimizing the cost. To overcome this problem irrigation scheduling to specific water sensitive stages is proposed as one strategy.

Wheat sown at the beginning of the season is at early stages, and rate of root water extraction is low. This implies that little moisture stress occurs at this stage. However, plants grow faster with high rates of evapotranspiration and rapid soil moisture depletion. Thus, a stage of increasing moisture stress starts and continues until the end of the season. The most sensitive growth stages of wheat to water stress were from stem elongation to booting, followed by anthesis/flowering, and grain filling. The sensitivity index of wheat to water stress at individual growth stages were small in seedling stage, become larger from stem elongation to grain filling stage, and then become small after soft-dough stage (Zhang and Oweis, 1999). Water stress at stem elongation and ear formation increased tiller abortion significantly reduced ear number (Blum and Pnuel, 1990). The variation of sensitivity index during individual growth stages indicates that crop grain yield not only depends on the total water use during the growing season, but also on water use during individual growth stages (Zhang and Oweis, 1999). Water stress to which crop subjected depends on rainfall and its distribution during the growing season. Therefore, water stress during certain growth stages may have more effect on grain yield than similar stress at other growth stages.

Water use efficiency (WUE) is a measure of the productivity of the water consumed by the crop. In areas with limited water resources, where water is the greatest limitation to production, WUE is the main criterion for evaluating the performance of production systems. No longer is productivity per unit area the main objective, since land is not as limiting to production as is water (Oweis, 1997; Zhang and Oweis, 1999). The need for improving water-use efficiency in crop production and sustainable use of water resources are clearly urgent. Fully satisfying crop water requirements may be prohibitive in terms of sustainable utilization of limited water resources. The solution is to limit water application to specific stages, minimizing loss of yield from water stress. We need to know, therefore, at what stages of crop growth a small amount of water application results in optimal WUE and minimum reduction in yield.

Materials and methods

Study site and experiments

Supplemental irrigation experiments were carried out at Bakelo irrigation area (9.694 to 9.735 degree northing, 39.59 to 39.65 degree easting, and an altitude of 2820 to 3000m asl) from 2001 to 2004. The first year (2001) experiment was for determination of crop water requirement and monitoring of phenological stages of wheat, lentil, barley, and potato. From 2002 to 2003 an irrigation frequency experiment based on sensitive growth stages of wheat coupled with recommended fertilizer and with out fertilizer was conducted to determine the time of irrigation. In 2004 an experiment on 100 m^2 plot was conducted to verify the result obtained in the previous years. The study area, 15 km from Debre Brehan, has received the mean seasonal (February to June) rainfall and evaporation of 214 mm and 725 mm, respectively. The major soil type of irrigated farm lands is Vertisol (*mererie*) with the associated water logging problem. The soil is characterized by heavy clay soil with water content at field capacity and wilting point (crop extractable water) of 49 % and 24 % by volume and bulk density of 1.19 gm/cm^3. The area at which the study targeted is dependent on supplemental irrigation during *belg* and *amegn* production seasons. The coverage of traditional irrigation production in Bakelo-Keyit small-scale irrigation area is estimated to be about 1100-1250 ha. The major water sources are *Gunagunit* River, D*odot* and *Aba Chacha* streams (Sheno Survey Report, 2004). An estimated of 500-700 households is benefited from irrigation along the *Gunagunit River* (personal communication). Among the crops grown under irrigation, wheat takes the largest proportion followed by lentil, faba bean and small proportions of fenugreek and barley. Farmers have also started to produce vegetables like garlic under irrigation.

Phase I: Crop Water Requirement

A preliminary study to generate data on crop phenology was conducted for wheat (S*hemet*), lentil (*Tegulet*), barley (*Ferkie*) and improved potato (*Tolcha*). Water requirement for those crops was calculated using soil water budgeting based on the crop phenology and meteorological data (pan evaporation and rainfall) collected. Reference evapotranspiration (ETo) was computed using pan evaporation method (using 0.70 pan coefficient). Crop evapotranspiration was then calculated multiplying ETo by the crop coefficient values in the literature. Water requirement is defined as the quantity of water required by a crop in a given period for its normal growth under field conditions (Garg, 1989). The soil water depleted during the growing period was considered as irrigation requirement. Net irrigation requirement refers to the amount of water needed to replenish the soil water deficit in the crop field. Crop irrigation water requirement was determined for each required growth stages and for the whole growing period using the following mathematical relation.

$$\mathbf{TWR} = \mathbf{IRR_{net} + RF_{eff} + Losses = ET_{crop} + Losses}$$

$$\mathbf{IRR_{net}} = \mathbf{\Sigma(ETcrop - RFeff)}$$

$$\mathbf{IRR_{gross}} = \mathbf{IRR_{net} + Losses}$$

Where,

IRR_{net} = Net irrigation requirement

IRR_{gross} = Gross irrigation requirement

ET_{crop} = Crop evapotranspiration/net crop water requirement

RF_{eff} = Effective rainfall

TWR = Total water requirement

Losses = Amount of water lost through deep percolation, application and distribution

Irrigation water amount at each stage was estimated to replenish soil water in the root zone to the field capacity when the available soil water dropped below a fraction of total available water (TAW). The fraction of TAW (p) that a crop can extract from the root zone without suffering water stress is the readily available water (RAW). The quantity of RAW is commonly taken as p=0.50 of the total available water (TAW) between field capacity (FC) and crop extractable water (CEW) for many crops (Figure 1).

$$\textbf{TAW}\ (\text{mm}) = \textbf{FC - CEW} = (\theta_{FC} - \theta_{CEW})*D_r*1000$$

$$\textbf{RAW}\ (\text{mm}) = p * TAW$$

IF (RAW-ETc+RFeff) < 0, apply water
0 < Water Balance < RAW

Where, θ_{FC} = the water content at field capacity, %
θ_{CEW}) = the water content at crop extractable water, %
D_r = the rooting depth, m
p = depletion factor

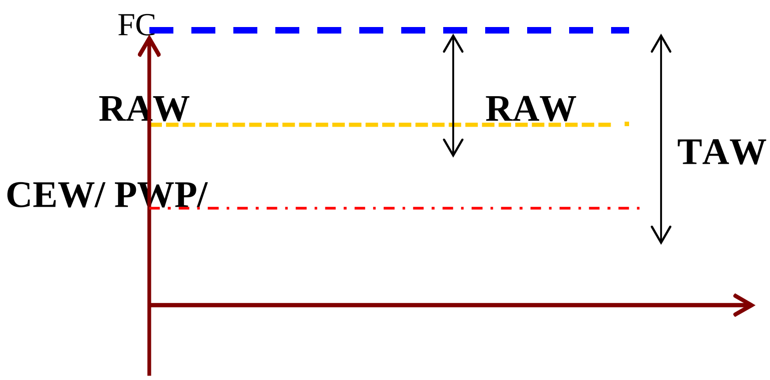

Fig. 1. Schematic illustration of available soil water in soil water budget

Phase II: Irrigation Frequency for Wheat

When to irrigate

Phenological and crop water requirement information based on farmers planting practice without moisture stress condition for local wheat variety called *shemet* were collected and determined in the first year experiment. Taking this information as a datum, an experiment on wheat irrigation frequency was conducted for two years. To evaluate watering frequency for wheat, split plot arrangement of five irrigation regimes with three replications was used. Main plot being fertilized (60\60 kg/ha N/P2O5) and unfertilized, and subplots being irrigation frequency at critical water requirement growth stages of local wheat, *shemet*.

Irrigation frequency periods

1.	Early tillering + booting + milk stage	(1	1	1)
2.	Early tillering	(1	0	0)
3.	Early tillering + milk stage	(1	0	1)
4.	Booting	(0	1	0)
5.	Booting + milk stage	(0	1	1)

Finally, in 2004 a trial was conducted using only the most promising irrigation frequency periods of wheat (or critical water requirement stages) identified in the previous experiment. Those irrigation frequency periods were:

a. Early tillering + booting + milk stage (1 1 1)

b. Early tillering + milk stage (1 0 1)

c. Booting + milk stage (0 1 1)

How much water to irrigate

In water-scarce areas, unlike in full irrigation, the amount of supplemental irrigation (SI) cannot be determined in advance. This is due to the fact that the basic source of water to rain-fed crops is rainfall, which being available in amount and distribution, is difficult to predict. Since SI water is best given when soil moisture drops to a critical level, the amount of irrigation applied at critical stages can be best determined by measuring soil moisture on regular basis. Different water levels were estimated at each growth stages based on the soil water budget using long-term average rainfall and evaporation records and soil water holding capacity. The irrigation water applied was estimated to replenish soil water in the root zone to the field capacity when the available soil water dropped below 50 % of total available water. The amount of total irrigation water applied at different critical stages was 75 % (T1, T3 and T5), 45 % (T4) and 31 % (T2) of the soil water amount required in the full supplemental irrigation condition.

Results and Discussion

Crop Water Requirement

Taking sowing date during late January for belg production season the crop water requirement (ET_{crop}) of wheat, barley, lentil and potato were found to be 392.08mm (3920.80 m^3/ha), 355.95mm (3559.50 m^3/ha), 283.65mm (2836.50 m^3/ha), and 447.57mm (4475.70 m^3/ha), respectively. Out of which 236.45mm (2364.50 m^3/ha), 232.51mm (2325.10 m^3/ha), 171.43mm (1714.30 m^3/ha), and 276.18mm (2761.80 m^3/ha) must be applied artificially and accounted as net irrigation requirements. The remaining amount of the net crop water requirement was supplied by rainfall. Therefore, the gross irrigation water should account for the losses due to percolation, and application and distribution inefficiencies probably field irrigation application inefficiency (flooding heavy clay soils) contributed a lot. Accordingly, the gross irrigation water required including pre-irrigation amounts to 377.16mm, 324.61mm, 208.88mm and 357.37mm for wheat, barley, lentil and potato, respectively. But excluding pre-irrigation the gross irrigation water requirement of wheat, barley, lentil and potato is 327.16mm, 249.61mm, 158.88mm and 307.37mm respectively. The corresponding overall irrigation efficiency is therefore 0.63, 0.72, 0.77 and 0.82 (Table 1). As a result the number of irrigations for wheat, barley, lentil and potato are four, two, three and six times during the growing season, respectively. This shows frequent application demands small amount of water and vise versa. The choice of crops under irrigation relies on the comparative benefit (or opportunity cost) of each crop. Looking the water demand of the crops in an irrigation area one can select either of the crops based on the supply of water and economic benefit. On the other hand, if the water-demanding periods for different crops vary, the potential yield is likely to increase and the potential productivity of water can be realized. For instance, the water demanding period of wheat and barley coincides during 50^{th} to 52^{nd}, and 90^{th} to 96^{th} growing days; wheat and potato during 128^{th} to 130^{th} days; lentil and potato during 38^{th} to

40th (Table 2 and Fig. 4). This simultaneous requirement can result in water shortage in a specific area.

Table 1: Crop water requirement, gross and net irrigation requirement and irrigation efficiency of the different crops at Bakelo, N. Shewa

Crop type	**Growing days**	**ETo, mm**	**ET_{crop}, mm**	**RF_{eff}, mm**	**IRR_{net}, mm**	**Gross irrigation Req't, mm [1]**	**Total water requirement, mm**	**Irrig. Efficiency[2]**
Wheat	147	498.87	392.08	155.63	236.45	**327.16** (377.16)	532.79	**0.72** (0.63)
Barley	135	455.94	355.95	123.44	232.51	**249.61** (324.61)	448.05	**0.93** (0.72)
Potato	150	507.27	447.57	171.39	276.18	**307.37** (357.37)	528.76	**0.90** (0.77)
Lentil	110	370.23	283.65	112.21	171.43	**158.88** (208.88)	321.09	**0.99** (0.82)

[1] & [2] --- Values in parenthesis represent gross irrigation requirement including pre-irrigation and its irrigation efficiency
Bold values are water requirement excluding pre-irrigation

Table 2: Irrigation frequency and amount of irrigation required at each application at Bakelo

Crop type	**Depletion factor**	**Irrigation period/frequency starting from planting**	**Amount of irrigation water required at each period, mm**
Wheat	0.50	(Pre-irrigation, 22nd, 52nd, 90th, 130th)	(50, 41.78, 94.34, 96.78, 94.26)
Barley	0.50	(Pre-irrigation, 50th, 96th)	(75, 110.03, 139.58)
Potato	0.40	(Pre-irrigation, 10th, 40th, 59th, 84 th, 108th, 128th)	(50, 20.46, 40.48, 62.51, 60.32, 61.63, 61.98)
Lentil	0.50	(Pre-irrigation, 38th, 69th)	(50, 76.89, 82.00)

The gross irrigation water required and the corresponding irrigation periods using soil water budget is indicated in Table 2 including pre-irrigation at planting time. This depicts the critical periods at which strategic scheduling will base on and considered as frequency of irrigation in the full supplemental irrigation. Fig. 2 indicates there is water deficit requiring supplemental irrigation during February to mid June and water surplus starts in mid June when the main season rainfall starts. Seasonal evapotranspiration (ET) starts to increase after one month of planting for wheat and lentil and 35th day for barley and potato. It continues until some days before maturity (Fig. 3). Similarly Zhang, et al, (1998) indicated that ET is less in the early stages because of the effect of only soil evaporation and increases later during vegetative growth to reproductive growth via transpiration**.**

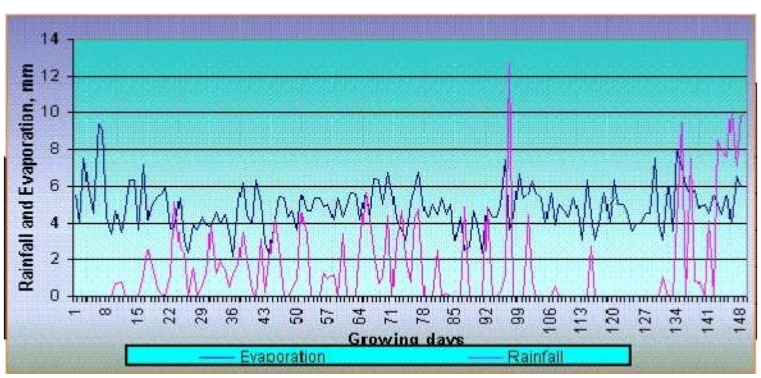

Figure 2: Seasonal distribution of rainfall and evaporation

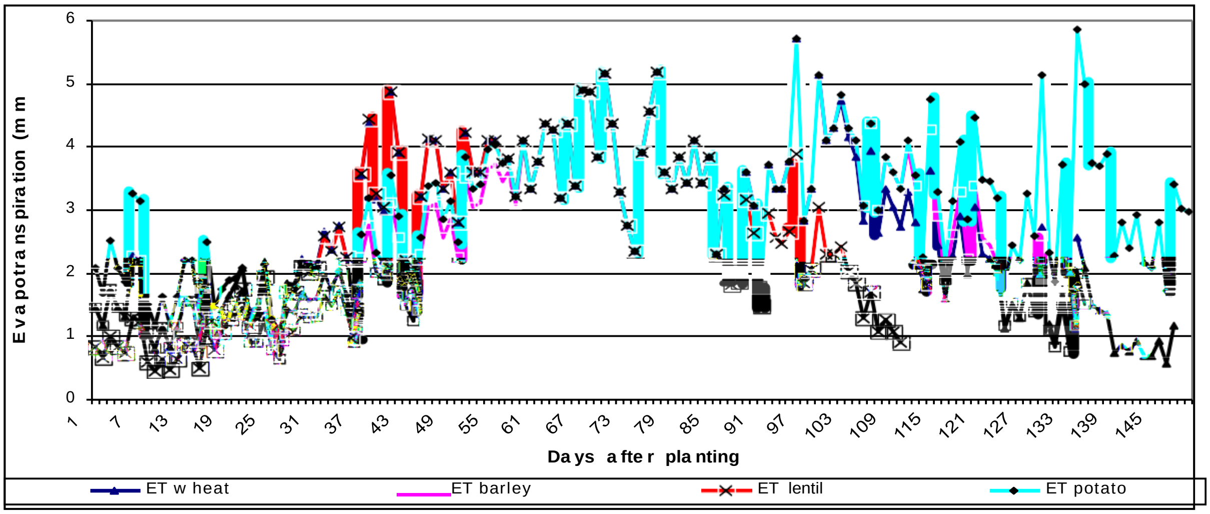

Figure 3: Daily ET of wheat, barley, lentil and potato over the growing period

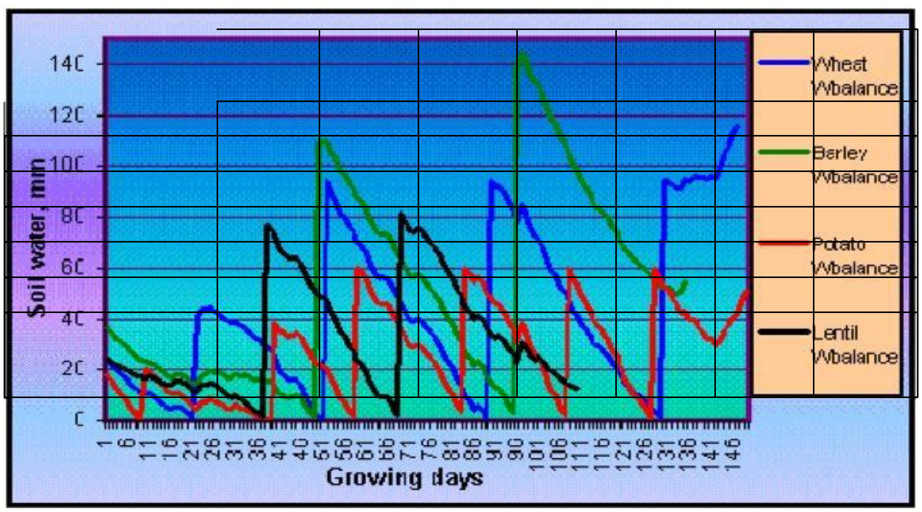

Figure 4: Seasonal water balance and distribution pattern for wheat, barley, lentil and potato

Irrigation Frequency of Wheat

Amount and number of irrigations

The number of irrigations and corresponding amount of irrigation water is compared at different application regimes using soil water balance. The number of irrigations needed for wheat in full supplemental irrigation was four, on 22 nd, 52nd, 90th, and 130 th days after planting, (Fig. 5) compared to one to three irrigations at predetermined critical water requirement stages. The number of irrigations and amount of irrigation differ if there was no rainfall at all during the season. Periods of irrigation when there is no rainfall for wheat is at 19th, 37th, 61st, 86th, and 114th days after planting (Fig. 5) with a corresponding amount of 35.38, 85.29, 97.72, 96.07, 94.74 mm water, respectively. It shows that an additional one irrigation is required when there is no rainfall in the season. The amount of irrigation applied at each sensitive growth stages of wheat are given in Table 4 that reduced 25-70 % of the amount of irrigation needed in full supplemental irrigation. Water balance of wheat in the five critical growth stages is given in figures 6 & 7. As it is indicated, irrigation at T1= early tillering, booting and at milk stage; and at T5 = booting and milk stage have a better water distribution pattern which in most points coinciding with the actual water balance in full supplemental irrigation. Irrigation at T3 = early tillering and milk stage has shown deficit of soil water after the first irrigation until the next irrigation. The amount of water applied for irrigation regimes at T2 = early tillering and T4 = booting was less than the net irrigation requirement of wheat (1172 and 1695 m^3/ha, respectively). Their relative amount against net irrigation (2365 m^3/ha) was less than 1(0.50 and 0.72, respectively). Hence the soil water distribution has indicated shortage of soil water in the tillering and immediately after heading for T4 and starting from booting for T2.

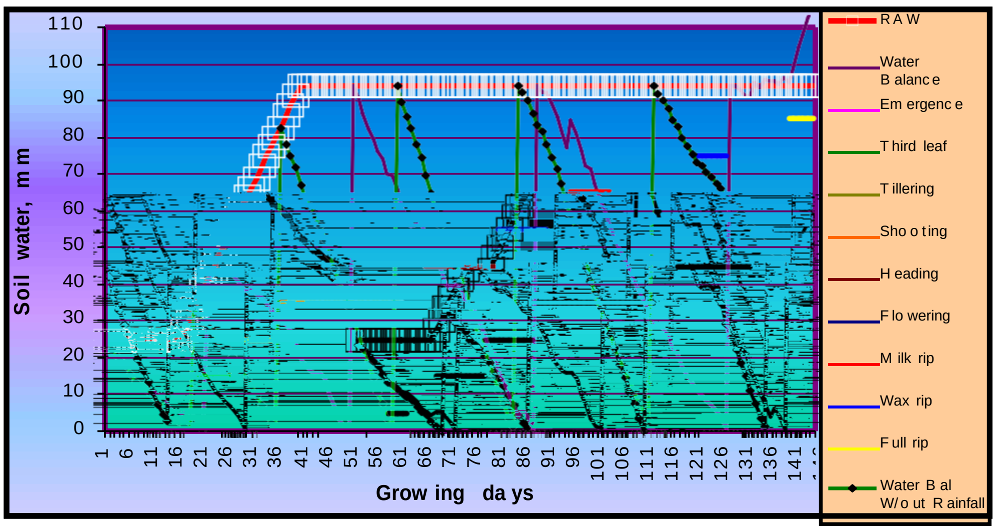

Figure 5: Seasonal water balance with and without rainfall condition in relation to wheat growth stages

Table 3: Amount of irrigation water applied (mm) at each growth stage of wheat for each treatment

Treatments	**Pre-irrigation**	**Early Tillering stage**	**Booting stage**	**Milk stage**	**Total irrigation applied**
Early tillering + booting + milk stage (T1)	50	67.21	52.28	113.11	**282.60**
Early tillering (T2)	50	67.21	---	---	**117.21**
Early tillering + milk stage (T3)	50	67.21	---	165.39	**282.60**
Booting (T4)	50	---	119.49	---	**169.49**
Booting + milk stage (T5)	50	---	119.49	113.11	**282.60**

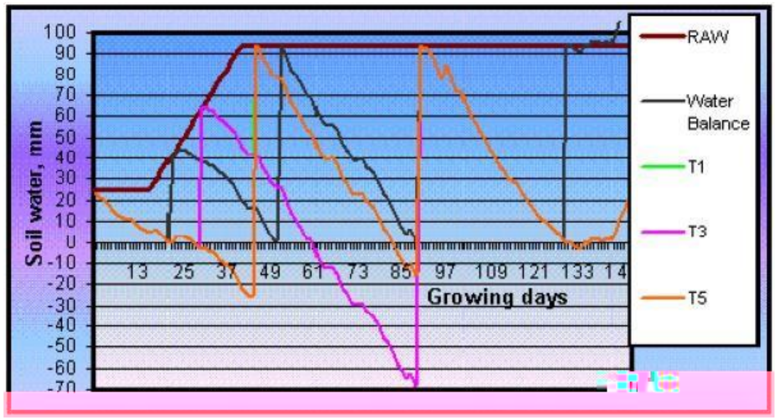

Figure 6: Comparison of actual water balance pattern for wheat with T1, T3 and T5

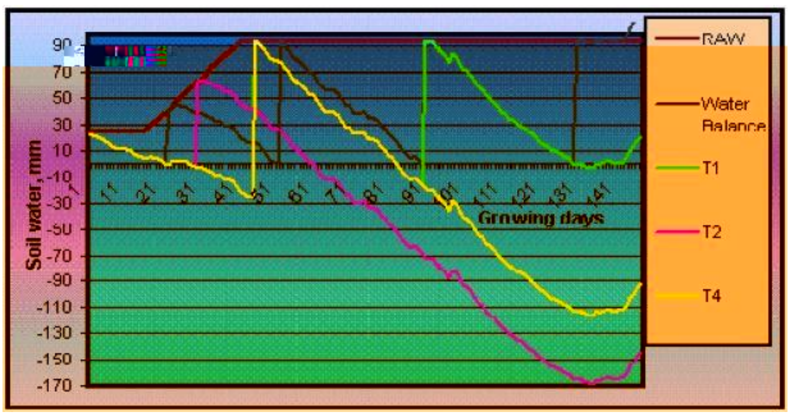

Figure 7: Comparison of actual water balance pattern for wheat with T1, T3 and T5

Yield of wheat

From 2002 to 2003: The crop yield data in year 2002 is given in Table 4. The third year data was not a good estimate of the reality. This was because the crop had an aphid and later bird attack. There was technical adjustment while harvesting the yield however the error could not be avoided. It had a comparable straw yield but not grain. As a result the data was not considered valid. Looking at the respective grain yields of the irrigation regimes, we observe that irrigation applied at T1 = early tillering + booting + milk stage, and T3 = early tillering + milk stage have the highest yields (2133.33 and 2100 kg/ha respectively) significantly ($p<0.05$) different from T2 = early tillering. Irrigation at T3 that depicts water shortage at booting showed good yield probably due to the rainfall occurred in the heading stage. On the other hand the grain yields of T4 and T5 were not significantly different from T1 and T2. This is because T5 has suffered from water deficit over the tillering stage. Similarly, irrigation during booting stage alone made the crop to suffer from water deficit over tillering and grain formation stages. Irrigating wheat only during early tillering is also causing serious water stress starting from vegetative stage (Fig. 6 & 7). The water deficit at these stages is reflected on their respective grain yield (Table 4).

Table 4: Biomass, grain and straw yield of the irrigation regimes, 2002

Treatments	**Grain yield (kg/ha)**	**Biomass yield (kg/ha)**	**Straw yield (kg/ha)**
Fertilized	2270.00	5233.33	2963.33
Unfertilized	1653.33	3923.33	2336.67
LSD (0.05)	NS	NS	*NS*
SE	206.73	471.03	256.14
CV (%)	10.41	12.28	14.50
Early tillering + booting + milk stage, T1	2133.33[a]	4875.00	2741.67
Early tillering, T2	1775.00[b]	4400.00	2625.00
Early tillering + milk stage, T3	2100.00[a]	5041.67	2941.67
Booting, T4	1916.67[ab]	4400.00	2483.33
Booting + milk stage, T5	1883.33[ab]	4175.00	2458.33
LSD (0.05)	***250***	***NS***	***NS***
SE	***83.37***	***229.47***	***156.87***
CV (%)	***10.41***	***12.28***	***14.50***

Although the yield (grain) difference was high between irrigation regimes both in the fertilized and unfertilized main plots, due to large standard error there was no significant difference. Though the grain yield was not significantly different, better yield increment of 2 to 2.5 quintals was observed for irrigations at early tillering + milk stage (T3) and early tillering + booting + milk stage (T1) compared to the farmers irrigation practice represented by T5.

Year 2004: Yield of wheat only for selected irrigation application stages (T1, T3 and T5) was evaluated. Observation of wheat's vigorous condition obtained just two months after planting indicates that the two sites had similar growth condition. However, relative comparison of the irrigation application stages in its growth condition had the order of early tillering + booting + milk stages > booting + milk stages > early tillering + milk stages. The application regimes, which were not irrigated in the early tillering stage and booting stage, have showed stress condition over the next irrigation period.

Table 5: Yield of wheat obtained from supplemental irrigation application at Bakelo, 2004

Stages of Irrigation Application	**Biomass yield, kg/ha**	**Straw yield, kg/ha**	**Grain yield, kg/ha**	**Supplemental irrigation use efficiency, kg/ha mm***
Early tillering + Booting + Milk stage • Three irrigations with net irrigation = **160.38** mm; when including pre-irrigation and loss = **282.60** mm	9611.102 [a]	6184.988 [a]	3426.125 [a]	**59.93**
Early tillering + Milk stage • Three irrigations with net irrigation = **163.47**				

efficiency, and marginal rate of return. Thus irrigation application at these growth stages can be used for wheat irrigation scheduling in the area.

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