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RESEARCH ARTICLE

Performance of bread wheat (*Triticum aestivum* L.) in response to supplemental irrigation and rate of nitrogen application in Enderta, Tigray, Northern Ethiopia

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ABSTRACT

Moisture stress and nitrogen deficiency are the most important factors which limit wheat production in the semi-arid Tigray region of Ethiopia. Therefore, a field experiment was conducted in Enderta district in the region during the 2013 and 2014 cropping seasons to elucidate the response of bread wheat to supplemental irrigation (SI) and rates of nitrogen application. The experiment was laid out as a randomized complete block design (RCBD) in a split-plot arrangement with three replications. Four levels of supplementary irrigation (SI), viz: 0, 50, 75, and 100% (full) of the crop water requirement were assigned to the main plots whilst, nitrogen levels of 0, 23, 46, 69 and 92 kg N ha^{-1} were assigned to the sub-plots. Application of 92 kg N ha^{-1} with 75% SI increased tiller production by 94% as compared to the rain-fed treatment. Similarly, plants that received 100% SI with the application of 69 kg N ha^{-1} had their heights significantly increased by about 39%, spike length by 56%, kernel per spike by 51%, TKW by 47% and aboveground biomass yield by 340% as compared to no irrigation and no nitrogen application. Maximum grain yield of 4504kg ha^{-1} and water productivity of 7.99 kg mm^{-1} ha^{-1} was recorded in response to the application of 100% SI combined with 92 kg N ha^{-1}, However, the lowest grain yield of 885 kg ha^{-1} and water productivity of 2.15 kg mm^{-1} ha^{-1} were recorded in response to the rain-fed production with no application of nitrogen fertilizer.. Based on economic analysis, the acceptable marginal rate of return of 255% and the highest net benefit (47004 ETB ha^{-1}) was obtained from the application of 92 kg N ha^{-1} with 100% supplemental irrigation. It can be concluded that the integration of 92 kg N ha^{-1} with 100% supplementary irrigation resulted in optimum grain yield and economic return of the crop.

Key words: Deficit irrigation, economic analysis, N application, water productivity yield, yield component

INTRODUCTION

Bread wheat (*Triticum aestivum* L.) one of the most important small cereal crop which ranks fourth in terms of area coverage after teff, maize and sorghum. The crop is also one of the most important cereal crops being cultivated in the mid and high land areas of Tigray region cultivated over 100,175 hectares (ha) with a total production of about 192,507 tons (CSA, 2014).

Nonetheless, the productivity of wheat in the country is low compared to other wheat producing countries of the world (Gashaw *et al.,* 2014). Moreover, its average yield in Tigray has remained by far lower than the national yield (Mesay *et al*., 2012). This explicitly shows that the production of wheat in the Region is very insufficient to meet the increasing food demand for the ever increasing population (Gain, 2014).

Though, several socio-economic, abiotic, and biotic constraints explain these yield gaps; crop production in the semi-arid highlands of Tigray is restricted by soil moisture stress and low fertility mainly nitrogen (Fassil *et al.,* 2009, Araya *et al.,* 2010a). Rainfall is erratic with intermittent drought spells (Araya *et al.,* 2010a), short length of growing period (Hadgu *et al.,* 2013). Mean annual rainfall has been estimated at 650 mm or less over the past few decades (Pender and Gebremedhin, 2004), and the coefficient of variation is four times the national level (REST 1995). However, the risk of water shortage usually happens due to late onset and early cessation of rainfall. These periods of water deficit mainly occur during the critical periods of flowering, grain set and grain filling of wheat as a result yield is consequently low(Araya *et al.,* 2010 , Alemtsehay *et al.,* 2015).

Allen *et al*. (1998) and Rockström and Barron (2007) stated that for cereals, the period between grain filling and maturity was particularly sensitive to drought stress, with greatest yield reductions occurring when stress began during or following heading or during maturation. Water deficit around anthesis may lead to a loss in yield by reducing spike and spikelet number and the fertility of surviving spikelets (Giunta *et al*., 1993), while water deficit during grain-filling period reduces grain weight (Royo *et al*., 2000).

Oweis (2014) reported that supplemental irrigation of 50–200 mm in a season is sufficient to double or more than double rain-fed yields. Similarly, Oweis and Hachum (2003) reported that wheat yields can be increased from 2 tons per hectare to more than 5 tons per hectare by the conjunctive use and timely application of only 100 to 200 mm of irrigation water. Related studies in the country have shown that more than 80% of the yield reduction and more than 50% of crop failures in tef and barley can be avoided if SI is employed during the critical growth stages of the crops (Araya and Stroosnijder, 2011). SI increased the yield of tef from less than 1 t ha^{-1} to 2 tons ha^{-1} (Yihun *et al*., 2013 and Alemtsehay *et al*., 2015). Similar results were also reported for Pearl millet (Ashraf *et al.,* 2001).

However, the most beneficial effects of supplemental irrigation were obtained in combination with soil fertility management (Rockström *et al*., 2003). Plant available nutrient supply is also essential to maximize the benefits of additional water captured or saved. This is especially true for N (Ryan *et al*., 2009). Several studies suggested that limited supplemental irrigation and fertilization during the growth season could significantly increase water productivity, fertilizer use efficiency and wheat yield (Pandey *et al*., 2002; Mintesinot *et al*., 2004; Kibe *et al*., 2006, and Tavakoli *et al.,* 2010). Furthermore, SI allows modifying crop calendars to escape climatic extremes and adapt to climate change (Oweis, 2014).

Supplemental irrigation (SI) is a key strategy, albeit it is still underused, for unlocking rain-fed yield potential and water productivity in rain-fed wheat in Tigray even in areas having perennial water sources in the study area. Conversely, no research has been conducted in the study area to elucidate the effect of application of mineral nitrogen coupled with supplementary irrigation on the productivity of wheat. The objective of the study was, therefore, to identify the optimum rates of nitrogen and supplemental irrigation that would maximize the productivity of bread wheat.

MATERIALS AND METHODS

Description of the Experimental Site

A field experiment was carried out for two successive seasons (2013/ – 2014) under farmers field at Enderta. The site is geographically located in the southeast of Tigray at 13^0 5′N latitude, 39^0 5′ E longitudes and an altitude of 1970 masl. The area receives an average annual rainfall of 392 mm of which 317 mm were received in the 2013 cropping season. For 2014, the average annual rainfall was 790 mm of which 537 mm were received in the growing season. The average yearly minimum and maximum temperatures are 11 and 27 for 2013 and 11 and 26 ° C for 2014, respectively (Mekelle research Meteorological service*)*. The study site has a one-season rainfall pattern with extended rainy season from March to November with the peak season in August. The main rain season falls from June to September, during which about 83% of the annual rainfall occurs. The area is characterized by heavy and erratic rainfall distribution.

Experimental Materials

A bread wheat variety named Mekelle I which was released by Mekelle Agricultural Research Centre (MARC) in 2011 was used as a test crop. It is a semi-dwarf variety known for its moisture stress resistance but can perform better under good rainfall. It needs 300- 500 mm rainfall and grows at an altitude of 1980-2500 meters above sea level. The variety needs 90-95 days to reach maturity (Hintsa *et al*. 2011).

Treatments and Experimental Design

The experiment was conducted in 2013 and 2014 cropping seasons. The experimental field was laid out in a randomized complete block design with split plot arrangement having three replications. Four levels of supplemental irrigation:(full irrigation or 100 %, 75 % , 50 % of the crop water requirement as well as rain-fed condition(control) were assigned to main plots, while nitrogen levels (0, 23, 46, 69 and 92 kg ha^{-1}) were maintained in subplots.. The size of each plot was 3 m x 2 m (6m^2) and plots and blocks were at the distances of 0.5 m and 1.5 m apart, respectively. Soil bunds were constructed around each plot and around the entire experimental field to minimize nutrient and water movement from plot to plot. Seeds were sown into rows of 0.20 m apart and 3 m long. Each plot consisted of 10 rows. Wheat plants in the two outer most rows on both sides of a plot as well as 0.2 m on each end of central rows were considered border plants and not considered for data collection. The net plot area that was used for data collection consisted of 6 rows (1.2 m) each 2.6 m in length.

Experimental Procedures

Prior to planting, surface (0 - 20 cm) soil samples, from twelve spots across the experimental field, were collected in a zigzag pattern, composited, and analyzed at Mekelle soil laboratory research center for pH, texture, soil OC, total N, available P, CEC. for bulk density, field capacity, permanent wilting point, Soil bulk density was determined from undisturbed soil sample taken using a metal cylinder (core sampler) of known volume (100 cm^3) that was driven into the soil of desired depth and calculated as the ratio of oven dry weight of soil to a known cylinder core sampler volume. The water content at field capacity was determined in the laboratory by using a pressure (porous) plate apparatus by applying -1/3 bar to a saturated soil sample. When water is no longer leaving the soil sample, the soil moisture was taken as field capacity. Permanent wilting point was also determined by using pressure membrane apparatus by applying -15 bars to a saturated soil sample. When water is no longer leaving the soil sample, the soil moisture was taken as permanent wilting point. The improved recommended wheat variety known as Mekelle I was seeded on 19th July in 2013 and 12th July in 2014 by hand drilling with a row spacing of 20cm at a seeding rate of 150 kg ha^{-1}.

The full dose of P fertilizer (20 P) was applied as triple super phosphate (46% P_2O_5) at planting, while N was split applied (half of the dose at planting and half at 30 days after emergence) as Urea: 46% N) according to the treatments. The improved wheat variety (Mekelle I) used as test crop which was hand drilled at 150 kg ha^{-1} rate with a row spacing of 20 cm was planted on July 19th and 12th of 2013 and 2014 cropping seasons, respectively. The size of each plot was 3 m x 2 m (6m^2). Weeds were removed by hand weeding two times at 30 and 55 days after crop emergence. The crop was harvested on 29th October and 2th November, 2013 and 2014 respectively.

Determination of Irrigation Water Requirement

The field was irrigated based on the water requirement (CWR) of the crop after the rain stopped (Clarke *et al*., 1988). To estimate the CWR, irrigation scheduling and irrigation water requirement (IWR) of the crop the CropWat 8 for windows was used. Modified FAO Penman-monteith method (Allen *et al.,* 1998) was used for calculating reference crop evapo-transpiration (ETO). For the computation of ETo, meteorological data such as rainfall, Tmax, Tmin, relative humidity, sunshine hours and wind speed were used from nearby weather station.

The respective crop coefficient for initial, middle and late growth stages were adopted from the FAO Penman-monteith method for wheat. Soil data like total available water (194 mm/m), maximum rain infiltration rate (30mm/day), rooting depth (3m), initial soil moisture depletion (45%) and initial available soil moisture (106 mm/m) were used to calculate crop irrigation schedule.

Seventy percent of application efficiency was considered as surface method of water application was used. Irrigation scheduling of the crop was computed using FAO CROPWAT program (Allen *et al*., 1998) by considering soil type with fixed interval and variable depth (refill to field capacity). Ten days fixed interval and refill to field capacity irrigation scheduling criteria was adopted. Since there was no rainfall received during the later growth stage net irrigation requirement was taken to be equal to Etc. The depth applied to other treatments was taken simply as percentage of the optimal irrigation.

Based on CROPWAT computer program the total amount of supplemental irrigation water for 0%, 50%, 75% and 100% SI treatments were 0, 93, 140, 187 mm, respectively. The computed depth of irrigation water was applied through a partial flume (7.0 cm height) as per the treatment. First irrigation was applied on 21 September based on the irrigation regimes. The second and third irrigation was applied on 29 September and 09 October 2013. The equivalent values for the aforementioned treatments in 2014 were 0, 52, 71, 95 mm and applied on 1 October and 10 October.

Data Collection and Measurements

Days to maturity (DM): Physiological maturity was calculated by counting the number of days from 50 % emergence to the stage when 90% of the plant reaches physiological maturity. Data on productive tillers and plant stand of the plots at harvest were recorded from randomly selected area of 0.25 m^2 (0.5 x 0.5m) at four sites and expressed as tiller population per meter square. Plant height (PHT), spikes length (SPL), Number of seeds per spike (NSPS) was determined from 10 random sampled plants per plot during physiological maturity. Grain yield and biomass yield per plot was determined from the middle 6 rows of each plot to avoid border effects. Total biomass was determined by weighing the shoots along with the seeds using Salter balance. Grain yield was recorded after cautiously separating the grain from the straw, cleaned and adjusted to 12.5% seed moisture content using a hand seed moisture tester instrument. The thousand grain weights was determined by counting the number of seeds randomly taken from each plot and recorded on 12.5 % moisture basis. Harvest index (HI) was calculated as the ratio of grain to above ground biomass yield.

Water productivity

The productivity of total applied water (WP) is defined as crop yield per unit volume of total water supplied (Molden, 1997).

$$\text{WP} = \frac{\text{Crop yield kg}^{-1}}{\text{Water supplied (P+I mm)}}$$

Where,
I = irrigation water (mm),
P = the precipitation (mm) during the growing season.

Economic analysis was performed following the CIMMYT partial budget methodology (CIMMYT, 1988). Economic analysis was done using the prevailing average market prices for inputs at planting and for outputs at the time of crop harvest. The average local market price of wheat was 11.29 Birr kg^{-1}, straw 0.68 Birr kg^{-1}, the cost of urea was 12.48 Birr kg^{-1}, and application cost was 2 Birr kg^{-1}. Labor cost for irrigation was 16.97, 12.75 and 8.51 man-days per hectare for 100%, 75% and 50% SI treatments, respectively. One man-day cost was Birr 100. Fuel cost was Birr 14.08 $liter^{-1}$. All costs and benefits were based on the average of the two years. Percent MRR was calculated as changes in NB (raised benefit) divided by changes in cost (raised cost).

Finally all data were analyzed following statistical procedures of SAS version 9.2. Whenever treatment effects were significant, the means were separated using the least significant difference (LSD) and LSD fisher procedures at the probability level of($p < 0.05$).

Homogeneity of variances was also evaluated using the F-test as described by Gomez and Gomez (1984). Since the F-test has showed homogeneity of the variances of the two years for most of the agronomic parameters, combined analysis was used.

RESULTS AND DISCUSSION

Soil physico-chemical properties

The soil in the study area is vertisol with clay texture (Rowell, 1994) with a particle size distribution of 45% clay, 30% silt and 25% sand. High clay content may indicate the better water and nutrient holding capacity of the soil in the experimental site. The soil reaction is almost neutral to slightly neutral according to the rating of (Tekalign , 1991) indicating that it is suitable for growing most crops (FAO, 2008).Wheat grows under a wide range of soil pH, with permissible ranges of 5.5-7.0 (Gooding and Davies, 1997). Based on the limit set by Hazelton and Murphy (2007), the soil had high CEC. The data further revealed that the soil is low in available P (Cottenie, 1980) and low total N content and organic matter (Tekalign , 1991), which indicating that NP is inadequate for maximum crop production in this soil, causing an important constraint to wheat production. Therefore, the soils need amendment for successful crop production. The soil falls in category of non saline soils (Hazelton and Murphy (2007).

Phenological and Morphological Attributes

Days to maturity was significantly (P<0.01) influenced by the main effects of supplemental irrigation, N fertilization and their interaction, year of cultivation and nitrogen rates by year of cultivation interaction (Appendix Table I). Table 1 showed that the treatment that received 100% SI level at application rates of 69 kg N ha^{-1} delayed maturity by 23% as compared to no irrigation and no nitrogen was applied. But differences were not significant with the treatment that received 100% SI at application rates of 92 kg N ha^{-1}and 46 kg N ha^{-1}.

Table 1. Mean values of days to maturity and plant height of bread wheat as influenced by the interaction effect of nitrogen rates by supplemental Irrigation levels.

Supplemental irrigation	N rate (kg ha^{-1})	Days to maturity	Plant height (cm)
Control (no irrigation)	0	83.50^{k}	64.71^{m}
	23	84.67^{jk}	67.10^{l}
	46	85.67^{ij}	67.53^{kl}
	69	86.33^{hi}	69.57^{jk}
	92	86.17^{i}	69.83j
50% CWR	0	87.67^{h}	72.48^{i}
	23	91.00^{ef}	74.22^{ghi}
	46	91.83^{rf}	83.05^{cde}
	69	90.67^{f}	81.95^{de}
	92	92.33^{e}	81.12^{e}
75% CWR	0	89.17^{g}	73.17^{hi}
	23	90.67^{f}	75.37^{fgh}
	46	100.50^{c}	82.92^{cde}
	69	102.00^{ab}	84.53^{bc}
	92	101.17^{bc}	83.47^{cd}
100% CWR	0	96.17^{d}	75.87^{fg}
	23	100.50^{c}	76.73^{f}
	46	102.83^{a}	86.77^{b}
	69	103.00^{a}	89.47^{a}
	92	102.83^{a}	83.81^{cd}
LSD (0.05)		1.40	2.29
CV (%)		2.58	1.26
Year			
2013		76.21^{b}	92.33^{b}
2014		78.14^{a}	94.53^{a}
LSD (0.05)		0.72	0.43

Means of the same parameter in a column followed by the same letter are not significantly different at P = 0.05 according to LSD Fishers Protected Test. CWR= crop water requirement

Table 2. Mean values of days to maturity and productive tiller production of Bread wheat as influenced by the interaction of nitrogen rate and growing Season.

	Days to maturity		Productive Tillers m^{-2}	
N rate(kg ha^{-1})	2013	2014	2013	2014
0	88.4^{e}	89.0^{d}	161^{g}	184^{ef}
23	90.7^{d}	92.8^{c}	187^{de}	226^{b}
46	94.2^{b}	96.2^{a}	194^{cd}	222^{b}
69	94.1^{b}	96.9^{a}	176^{f}	223^{b}
92	94.2^{b}	97.0^{a}	200^{c}	258^{a}
LSD (0.05)	1.01		9.00	
CV(%)	1.26		5.50	

Means of the same parameter in a column followed by the same letter are not significantly different at P = 0.05 according to LSD Fishers Protected Test.

Interaction effects among nitrogen rates and year were significant. In both seasons, days to maturity was prolonged with the increase in nitrogen rates. Significantly longest maturity (97) and 94 days was recorded with application of 92 kg N ha^{-1} for 2014 and 2013 seasons respectively. The possible reason for long maturity in 2014 might be attributed to the better moisture condition and nitrogen fertilizer that favored the growth of the crop, delayed senescence and extended grain filling duration. While, the shortest maturity in 2013 might be due to the moisture stress that accelerated senescence. The results are in agreement with Westage (2003) and Akram *et al.* (2004) who stated that water stress-induced accelerated senescence after anthesis and shorten the duration of grain filling by causing premature desiccation of the endosperm. A similar result on cotton has been reported by Owen *et al.* (2011).

Plant height of bread wheat was significantly ($P < 0.01$) varied in response to supplemental irrigation, N fertilization and their interaction and cropping season (Appendix Table I). Table 1 showed that the treatment that received 100%SI with nitrogen application rates of 69 kg N ha^{-1} increased plant height by about 39 % as compared to no irrigation and no nitrogen was applied. The increase in plant height in response to this treatment might be primarily due to the contribution of higher N rates and supplementary irrigation which improved vegetative growth, cell expansion and enlargement. This result is in agreement with Ayoub *et al.* (1994); and Muhammad *et al.* (2012) who have reported direct relationship of nitrogen application to plant height through elongation of internodes.

Plant height has significantly (P<0.01) varied across years. The highest plant height (89.47cm) was recorded during 2014 cropping season as compared (83.80cm) to 2013. The highest plant height of wheat plant in 2014 might be attributed to relatively adequate water which helps the plant to utilize the available nutrient to grow fast and taller, produce more vegetative and reproductive growth than in 2013 with lower rainfall.

Yield components

Productive tiller:

The number of productive tillers m^{-2} was significantly ($P < 0.01$) influenced by supplemental irrigation, N fertilization rates and their interaction as well as year of cultivation and its interaction by nitrogen rates (Appendix Table 1).

Application of 92 kg N ha^{-1} with 75% SI or 100% SI level increased tiller production by 94% and 92% as compared to the control treatment (Table 3). This result is in line with Kibe *et al.* (2006) and Malhi *et al.* (2006) who stated that increasing irrigation water during heading to flowering stages of wheat and nitrogen uptake increased tiller production of wheat. They also noted that stimulatory effects of N on tillering through cytokinin synthesis are known to result into more number of effective tillers of wheat. In contrast, plants in control (140 m^{-2}) recorded the lowest number of fertile tillers which might be attributed to relatively low soil moisture content at the growth stages of anthesis and booting, which may have stressed the crop, thereby reducing survival of productive tillers (Kibe *et al.*, 2006).

Nitrogen rate and year of cultivation interact significantly to affect number of productive tillers (Table 2). The highest rate of nitrogen application (92 kg ha^{-1}) increased tiller production by 24% during the 2013 cropping season and by 40% during 2014 cropping season compared to the control treatment.

Spike length: Spike length of bread wheat was significantly ($P>0.001$) influenced by supplemental irrigation levels, N fertilization rates and their interaction as well as cropping season and its interaction with supplemental irrigation (Appendix Table I).

Spike length of wheat was significantly ($P<0.01$) affected by the interaction effect of nitrogen rates and supplemental irrigation levels. The treatment where nitrogen was applied at the rate of 69 kg N ha^{-1} and irrigated with 100 % SI level increased spike length by about 36% in comparison with no irrigation and no nitrogen treatment (Table 3).

Spike length has significantly ($P<0.01$) affected due to supplemental irrigation and this also varied across years. In this regard, the highest supplemental irrigation level increased spike length by 46 % during the 2014 cropping season and by 28 % during 2013 cropping season as compared to their respective control (Table 4). The increase in spike length in 2014 might be associated to the better utilization of nutrients using the adequate moisture of the season which helps the crop to better utilize the nutrient and made the plant more efficient to express its potential in photosynthetic activity and influence to increase length of spike. Attia and Barsoum (2013); and Shirazi *et al.* (2014) also indicated that irrigation resulted in increased spike lengths of wheat compared with non-irrigated treatment.

Table 3. Mean values of productive tiller, spike length, seeds per spike, 1000 kernel weight and harvest index as influenced by nitrogen rates and Supplemental Irrigation levels interaction

Supplemental irrigation Levels	N levels kg ha^{-1}	Productive Tiller m^{-2}	Spike length (cm)	Seeds per Spike(no)	Thousand seed weight (g)
Control (no irrigation)	0	140.00^{k}	7.23^{i}	31.13^{m}	28.56^{j}
	23	150.00^{k}	7.37^{i}	33.63^{l}	29.52^{j}
	46	177.67^{h}	7.73^{ghi}	36.31^{ij}	31.32^{i}
	69	164.33^{ij}	7.73^{ghi}	35.27^{jk}	29.1^{6j}
	92	177.10^{hi}	7.77^{ghi}	34.01^{kl}	29.32^{j}
50% CWR	0	163.33^{j}	7.61^{hi}	35.01^{jkl}	32.91^{h}
	23	206.67^{de}	8.51^{ef}	38.73^{gh}	34.92^{g}
	46	211.67^{de}	9.17^{d}	39.81^{fg}	35.93^{fg}
	69	228.34^{c}	8.81^{de}	41.67^{de}	36.42^{ef}
	92	236.65^{bc}	8.93^{de}	41.91^{de}	36.07^{fg}
75%CWR	0	203.33^{def}	7.98^{fgh}	37.28^{hi}	36.03^{fg}
	23	200.00^{ef}	8.95^{de}	39.58^{g}	37.67^{de}
	46	201.65^{def}	9.85^{c}	41.62^{de}	39.05^{cd}
	69	191.64^{fg}	9.95^{bc}	42.91^{cd}	40.11^{bc}
	92	275.00^{a}	10.15^{bc}	43.47^{c}	39.98^{bc}
100%CWR	0	183.00^{gh}	8.25^{fg}	38.97^{g}	37.47^{e}
	23	227.00^{c}	10.45^{b}	41.21^{ef}	39.73^{bc}
	46	241.76^{b}	11.25^{a}	43.91^{c}	41.82^{a}
	69	213.33^{d}	11.58^{a}	45.96^{b}	41082^{a}
	92	270.00^{a}	10.42^{b}	47.59^{a}	42.02^{a}
LSD(0.05)		13	0.54	1.53	1.38
CV%		5.50	4.52	3.01	2.84
Year					
2013		183.46^{b}	8.09^{b}	38.09^{b}	34.86^{b}
2014		222.76^{a}	9.87^{a}	40.89^{a}	40.89^{a}
LSD(0.05)		4.06	0.15	0.43	0.37

Table.4. Mean values of spike length, number of seeds per spike and biological yield of bread wheat as influenced by the interaction of supplemental irrigation by year of cultivation, Enderta

	Spike length (cm)	
Supplemental irrigation	2013	2014
0 (rain-fed)	7.07^{f}	8.06^{de}
50% CWR	7.93^{e}	9.27^{c}
75% CWR	8.33^{d}	10.43^{b}
100% CWR	9.04^{c}	11.74^{a}
LSD (0.05)	0.29	
CV(%)	4.40	
	Number of kernels per spike	
0 (rain-fed)	32.47^{e}	36.80^{d}
50% CWR	38.09^{cd}	42.74^{b}
75% CWR	39.21^{c}	44.23^{ab}
100% CWR	44.04^{b}	46.47^{a}
LSD (0.05)	2.27	
CV(%)	3.10	
	Thousand kernel weight (g)	
0(rain-fed)	28.07^{g}	31.07^{f}
50% CWR	33.99^{e}	36.50^{d}
75% CWR	37.56^{c}	39.57^{b}
100% CWR	39.83^{b}	40.99^{a}
LSD (0.05)	0.87	
CV(%)	6.00	
	Aboveground biomass yield (kg ha^{-1})	
0(rain-fed)	3045.7^{f}	3681.1^{e}
50%CWR	5187.6^{d}	6493.5^{c}
75%CWR	7534.3^{b}	8654.7^{a}
100%CWR	7940.0^{b}	9002.7^{a}
LSD (0.05)	494.78	
CV(%)	9.34	

Means of the same parameter in a column followed by he same letter are not significantly different at P = 0.05 according to LSD Fishers Protected Test. CWR= crop water requirement

Number of Seeds per Spike (NSPS):

Number of seeds per spike of bread wheat was significantly ($P<0.01$) influenced by supplemental irrigation levels, N fertilization rates and their interaction as well as cropping season and its interaction with supplemental irrigation (Appendix Table I).

The number of seeds per spike were significantly ($P<0.01$) affected by the interaction effect of nitrogen rates and supplemental irrigation levels. The treatment where nitrogen was applied at the rate of 92 kg N ha^{-1} and irrigated with 100 % SI level increased seeds per spike by 51 % as compared to no irrigation and no nitrogen was applied (Table 3). The increase in number of grains per spike might be due to availability of both nitrogen and water in the soil which may have increased floret endurance whilst the reduction in the control plots might be attributed to deficiency of assimilates due to water stress during grain filling (Ferrante *et al.,* 2010), reduced number of grains per unit area due to flower abortion (Acevedo *et al.*, 2002) and reduces pollination Shraf (1999).

Kernel per spike were significantly ($P<0.01$) affected by supplemental irrigation, which also varied across years. In this regard, the highest number of kernels per spike increased kernels per spike by 46% during the 2014 cropping season and by 35% during 2013 cropping season as compared to their respective control (Table 4). The result are in agreement with the findings of Madani *et al.* (2010) ; and Passioura and

Angus (2010) who reported that stress after anthesis reduced pollination, size of the individual grains and the grain number through abortion of the developing grains which resulted in the reduction in grain yields.

Thousand Kernel Weight (TKW):

The TKW of bread wheat was significantly ($P < 0.01$) influenced by supplemental irrigation levels, N fertilization rates and their interaction as well as cropping season and its interaction with supplemental irrigation (Appendix Table1).

The treatment where nitrogen was applied at the rate of 92 kg N ha^{-1} and irrigated with 100% SI level, increased TKW by 47% as compared to no irrigation and nitrogen application but this treatment was in statistical parity with the treatment that received 69 kg N ha^{-1} of the same SI level (Table 1). The increase in thousand kernels weight could be attributed to higher grain weight of well-watered plants which could be associated with longer grain filling duration and faster grain filling rate as reported by Li *et al.* (2000). These results are in agreement with the findings of Zhang *et al.* (1998) who also reported that adequate water at anthesis not only allowed the plant to increase photosynthesis rate but also gave extra time to translocate the carbohydrate to grains which improved grain size and yield.

The reduction in thousand kernel weight in response to decreased irrigation may be attributed to water shortage effects in seed filling period which cause to the reduction of absorption and translocation of water and nutrients in plant and reduction of nutrients translocation rapidity to seeds. This suggestion is consistent with the findings of Begdelo *et al*. (2011) who stated that thousand kernels weight was reduced under moisture stress conditions. Thousand kernel weight has significantly ($P<0.01$) influenced by the interaction of supplemental irrigation levels and year of cultivation. The highest TKW (41g) was recorded during 2014 cropping season with the application of 100% SI level as compared (39.8g) to 2013. In this regard, the year explained 3 % total variability on thousand kernel weight of wheat (Table 4).In both seasons, thousand kernels weight progressively increased with increasing the level of supplemental irrigation. The lowest TKW was recorded in 2013 than that of 2014 cropping season. The treatment that received 100% SI level increased TKW by 31 % and 42% as compared to no irrigation and no nitrogen was applied in 2014 and 2013 cropping season, respectively. The highest thousand kernel weight of wheat in 2014 might be attributed to relatively adequate water which helps the plant to give extra time to translocate the carbohydrate to grains which improves grain size than in 2013 with lower rainfall (Zhang and Oweis, 1998).

Aboveground biomass and Grain Yields

Total aboveground biomass responded significantly ($P < 0.01$) to supplemental irrigation, N fertilization rates and their interaction as well as cropping season and its interaction with supplemental irrigation (Appendix Table 1). Table 5 showed that increasing the rate of nitrogen application from 0 to 92 kg N ha^{-1} and supplemental irrigation from zero to 100% had increased aboveground biomass yield of the wheat plants consistently. The increases in the aboveground biomass yield obtained in response to application of 100%, 75% and 50%, SI irrigation combined and 92 kg N ha^{-1} over the control treatment were 340%, 58% and 7%, respectively. However, the aboveground biomass yield obtained in response to application of 100% irrigation and 92 kg N ha^{-1} were in statistical parity with the aboveground biomass yield obtained in response to the application of 100% irrigation and 69 kg N ha^{-1}. Similar findings were reported by Tavakoli *et al.* (2010) who found that irrigation and nitrogen significantly enhanced biomass yield of wheat, in which case no significant differences were observed in biomass production between 66% and 100% irrigation levels and between nitrogen fertilizer rates of 60 and 90 kg N ha^{-1}.

The highest aboveground biomass yield obtained at 100% irrigation combined with 69 and 92 kg N ha^{-1} might be attributed to the synergistic effect of improved N nutrition and enhanced moisture content of the soil on growth and photosynthetic efficiency of the plants, enhanced tillering and delayed senescence of leaves of the crop which may have resulted in higher production of dry matter. Moreover, there were no further statistical yield increases beyond 46 kg ha^{-1} under non-irrigated plots and 50% SI plots. This could be possibly due to supra-optimal rates of nitrogen supply to the plant that was above optimum under moisture stressed condition.

Aboveground biomass yield varied significantly in response to supplemental irrigation as well as across the years (Table 5). In both years, aboveground biomass yields increased with the increase in SI level.

A higher aboveground biomass yield was recorded during the 2014 cropping year than during the 2013 possibly due to the favorable moisture conditions during growing period that may have improved the efficiency of nutrient utilization, and thus the yield attributing characters and yield of the crop.

The magnitudes of increase in response to 100% irrigation over the rain-fed, 50% and 75% SI treatments were 160%, 53%, and 5%, respectively, in 2013. The equivalent values for the 2014 cropping year were 144%, 39% and 4%, respectively. This may be attributed to the differences in the amount of rainfall received during the growing season. Thus, the rainfall of only 317 mm during the growing season of 2013, which was as much as 537 during the growing season of 2014, may have made the crop respond to irrigation more vigorously in the former than the latter growing seasons.

Grain Yield (kg ha^{-1}):

The grain yield of wheat responded significantly ($P < 0.01$) to the supplemental irrigation levels, N fertilization rates and their interaction and year of cultivation (Appendix Table1). Grain yield increased significantly ($P < 0.01$) with the increased level of irrigation and nitrogen being the highest in plots that received 100% SI with 92 kg N ha^{-1} and the lowest in plots that received no irrigation and nitrogen (Table 5). Keeping the N fertilization at 69 kg ha^{-1} and applying 100%, 75% and 50% irrigation levels increased grain yield by 408%, 75% and 9%, respectively over none irrigated control. However, there was no significant difference between the treatment that received 69 kgN ha^{-1} and 92 kg N ha^{-1} at 100% SI which increased the grain yield by about 385% over the control treatment.

Table 5. Mean values of biological yield , grain yield and water productivity of wheat as influenced by nitrogen rates by Supplemental Irrigation levels interaction.

Supplemental Irrigation	N levels kg ha^{-1}	Biological yield (kg ha^{-1})	Grain yield kg ha^{-1})	W P kg ha^{-1} mm^{-1}
Control	0	2505.11^{j}	885.91^{l}	2.15^{j}
	23	3046.10^{ij}	1087.81^{kl}	2.67^{hij}
	46	3774.10^{ghi}	1367.10^{ijk}	3.39^{efg}
	69	3987.85^{fgh}	1461.61^{hij}	3.58^{ef}
	92	3504.75^{ghi}	1253.62^{ijk}	3.06^{fgh}
50% CWR	0	3343.42^{hi}	1189.61^{jkl}	2.39^{ij}
	23	5110.01^{e}	1886.42^{g}	3.80^{e}
	46	6593.24^{d}	2478.56^{f}	5.03^{cd}
	69	7171.01^{d}	2715.01^{f}	5.50^{c}
	92	6985.33^{d}	2595.91^{f}	5.24^{cd}
75% CWR	0	4221.71^{fg}	1543.65^{hi}	2.90^{ghi}
	23	6937.81^{d}	2596.71^{f}	4.97^{cd}
	46	8274.22^{c}	3228.01^{e}	6.17^{b}
	69	9831.05^{b}	3987.52^{cd}	7.42^{a}
	92	10209.42^{b}	4119.31^{bc}	7.60^{a}
100%CWR	0	4751.11^{ef}	1713.11^{gh}	3.00^{fghi}
	23	7009.32^{d}	2643.56^{f}	4.68^{d}
	46	9010.91^{c}	3630.01^{d}	6.42^{b}
	69	10563.56^{ab}	4297.03^{ab}	7.60^{a}
	92	11023.65^{a}	4505.85^{a}	7.99^{a}
LSD(0.05)		765.80	322.70	0.63
CV%		9.34	10.39	10.64
Year				
2013		5976.90^{b}	2306.00^{b}	5.26^{a}
2014		6808.02^{a}	2602.04^{a}	4.32^{b}
LSD(0.05)		217.36	92.87	0.18

Means of the same parameter in a column followed by the same letter are not significantly different at P = 0.05 according to LSD Fishers Protected Test. TKW=thousand kernel weight, CWR= crop water requirement, PAW = Productivity of available water .

This suggests that the extra N levels greater than 69 kg N ha^{-1} had little influence on increasing yield. The possible reason of increased yield at 100% supplemental irrigation and nitrogen rates at 69 kg N ha^{-1} might be largely attributed to the effect of nitrogen in sustaining leaf photosynthesis activity, delaying leaf senescence during grain filling period and extended duration of grain filling when moisture supply was not limited. Likewise, supplementary irrigation upon the cessation of rains may have allowed remobilization of photoassimilates from source to sink as was evidenced by Abderrazzak *et al.* (2013). The results are in conformity with the findings of other researchers (Abbas, 2010; Tsegay *et al*., 2015; Yihun *et al*., 2013) who reported supplemental irrigation at heading; anthesis and early grain filling period resulted in maximum wheat and *tef* yields. This finding is also supported by Tadayon *et al*. (2012) who showed that supplemental irrigation at jointing stage produced greater grain yield and higher water productivity with application of 100 kg N ha^{-1}.

The lowest grain yield obtained in the control treatment (885 kg ha^{-1}) might be attributed to reduced production of photosythate because of deficiencies of both nitrogen and moisture, which may have resulted in stomatal closure and early senescence that could have ultimately affected grain development processes. Similar results were reported by Akram *et al.* (2004) who stated that water stress-induced accelerated senescence after anthesis shortening the duration of grain filling and causing premature desiccation of the endosperm and reducing embryo volume, grain yield, and kernel weight.

The magnitude of decrease in grain yield in response to increasing nitrogen from 69 kg N ha^{-1} to 92 kg N ha^{-1} under non-irrigated treatment was 14%. A similar result was reported by Tavakoli *et al*. (2010) who described that the lowest response to N was under rainfed conditions and the highest level (120 kg.N.ha^{-1}) tended to decrease yields more. While, response to N were not limited by available water at the 2/3 of full irrigation level, as they were similar to those at full irrigation.

The results of this study are also corroborated by the findings of Thomson and Whitney (1998) who showed that the most important factors controlling the effect of nitrogen on crops is water supply. Corbeels *et al.* (1998) showed that when water supply was insufficient, fertilizer nitrogen was inadequately taken by the plant and some of it may have been lost by denitrification in an experiment involving a wheat/sunflower cropping sequence.

The grain yield produced in response to the application of 69 kg N ha^{-1} combined with 100% irrigation, which was agronomically optimum in this experiment, was five-fold higher than the grain yield produced in response to the rainfed treatment. Similarly, this yield was 4-fold, 3-fold, 3-fold, and 3.4-fold higher than the grain yield produced without irrigation but with combined applications of 23, 46, 69, and 93 kg N ha^{-1} in order mention here. In this connection, the blanket recommended rate of N fertilizer in the study area is about 41 kg N ha^{-1}and 46 kg P_2O_5 (100 kg DAP and 50 kg Urea per hectare) (Elias, 2002). However, farmers may be applying much less than even the blanket recommended rate of the fertilizers possibly because of escalating fertilizers prices (Bekunda *et al*., 2010), uncertainty of response to fertilizers because of frequent moisture stress during the growing season (Morris *et al*., 2007). As a result, the average grain yield of bread wheat obtained by smallholder farmers under rain-fed condition in the study area is about 1.5 t ha^{-1} (TBOARD, 2013), which is almost equal to the yield obtained under rain-fed condition (no irrigation), combined with the application of 69 kg N ha^{-1} in this study. Thus, the average grain yield obtained by smallholder farmers in the study area is only about 1/3rd of the grain yield obtained in this experiment in response to the application of 100% supplementary irrigation combined with 69 kg N ha^{-1}. This result reveals that farmers in the study area are losing about 66% wheat grain yield to moisture stress under the rain-fed production system although the blanket recommended rate of fertilizer they apply on average to the crop seems adequate.

The results are in line with the findings of Alemtsehay *et al.* (2015) who reported that uptake of N and P by tef [*Eragrostis tef* (Zucc.) Trotter] was enhanced in response to increasing the rates of the fertilizers in the presence of supplemental irrigation. Araya and Stroosnijder (2011) also reported that more than 80% of the yield reduction and more than 50% of crop failures in tef and barley can be avoided if SI is employed during the critical growth stages of the crops.

Similarly, Oweis and Hachum (2003) found that wheat yields increased from 2 tons per hectare to more than 5 tons per hectare in response to the use and timely application of only 100 to 200 mm of irrigation water. SI increased the yield of tef from less than 1 t ha^{-1} to 2 tons ha^{-1} (Alemtsehay *et al.*, 2015). Similarly, Ashraf *et al.* (2001) reported that when water was applied at mid grain fill pearl millet produced 10 % more grain yields than with no irrigation.

Water Productivity (WP)

The productivity of total applied water (PAW) responded significantly ($P \leq 0.01$) to supplemental irrigation levels , N fertilization rates and their interaction, year of cultivation and the interaction effect of supplemental irrigation levels by year and nitrogen rates by year of cultivation(Appendix Table I). Table 5 showed that increasing the rate of nitrogen application from 0 to 92 kg N ha^{-1} with supplemental irrigation from zero to 100 % SI significantly ($P < 0.001$) increased water productivity (7.99 kg ha^{-1} mm^{-1}) of the crop. Thus, increasing the rate of nitrogen from 0 N ha^{-1} to 92 kg N ha^{-1} and no irrigation to 100 % SI increased WP of the crop by 271% over control. There was however, no statistical difference with plots that received 100 % SI level with 69 kg N ha^{-1} (7.60 kg ha^{-1} mm^{-1}) , 75% SI level at application rates of 92 kg N ha^{-1} (7.84 kg ha^{-1} mm^{-1}) and 75% SI level at application rates of 69 kg N ha^{-1} (7.41 kg ha^{-1} mm^{-1}). The findings of this research indicated that water and nitrogen use efficiency was greatly increased by supplemental irrigation. Similar results were reported by (Zhang *et al*. 2004; Ali *et al*. 2007; Oweis *et al*. 2010).

In both seasons, water productivity decreased with the increase in SI level up to 100 % SI. Significantly higher water productivity was observed during 2013 cropping season (6.54 kg ha^{-1} mm^{-1}) when the crop was supplemented with 75% SI level as compared to (5.58 kg ha^{-1} mm^{-1}) during 2014 crop season (Table 6). In this regard, 75% SI level increased WP by 161% during 2013 cropping season as compared to 129 % in 2014 cropping season. However, increasing the rate of supplemental irrigation from 75% to 100% levels decreased the water productivity by 4 % during the 2013 cropping season and by about 7 % during the 2014 cropping season, respectively.

The results showed a more significant improvement in SI water productivity at ¾ SI level application rates than at full SI level. The increase in water productivity might be attributed to the effectiveness of a small amount of water in alleviating severe moisture stress during the crop development and grain filling. While, the decrease in water productivity at the high SI levels might be due to increase grain yield is less than proportional increase in ET. Similar results were reported by (Maliheh and Aliasghar, 2011).

Table 6. Interaction effect of supplemental irrigation and year and nitrogen rate and year on water productivity in Enderta , Tigray

	WP (kg ha^{-1} mm^{-1})	
Supplemental irrigation	2013	2014
0 (rain-fed)	2.50^{f}	2.43^{g}
50% CWR	4.69^{d}	4.09^{e}
75% CWR	6.54^{a}	5.58^{b}
100% CWR	6.30^{a}	5.18^{c}
LSD (0.05)	0.40	
Nitrogen (kg N ha^{-1})		
0	2.70^{f}	2.51^{f}
23	4.48^{d}	3.58^{e}
46	5.85^{b}	4.65^{d}
69	6.63^{a}	5.45^{bc}
92	6.61^{a}	5.41^{bc}
LSD (0.05)	0.41	
CV(%)	10.64	

Means of the same parameter in a column followed by the same letter are not significantly different at P = 0.05 according to LSD Fishers Protected, PAW = Productivity of available water, CWR= crop water requirement

Table 7. Mean marginal rate of return on the effect of nitrogen and supplemental irrigation levels on wheat in Enderta district, Tigray

Supplemental irrigation (CWR %)	Applied N kg ha^{-1}	TCV (ETB)ha^{-1}	Net benefit (ETB ha^{-1})	Raised cost (ETB ha^{-1})	Raised benefit (ETB ha^{-1})	MRR%
0	0	0.00	10495.0	0.0	0.00	0.00
0	23	724	12144.5	1649.5	724.0	227.83
50	0	1291	12789.3	644.8	567.0	113.72
75	0	1935	16264.3	3475.0	644.0	539.60
50	23	2015	20195.4	3931.1	80.0	4913.88
75	23	2659	27855.3	7659.9	644.0	1189.43
75	46	3333	30732.3	2877.0	674.0	426.85
100	46	3975	38260.9	7528.6	642.0	1172.68
75	69	4007	43658.9	5398.0	32.0	16868.70
100	69	4649	45284.7	1625.8	642.0	253.24
100	92	5323	47004.7	1720.0	674.0	255.19

CWR= crop water requirement, TCV= total cost that vary, MRR= marginal rate of return, ETB= Ethiopian Birr

In general higher water productivity was observed in 2013 compared to 2014 cropping season. The results are in close collaboration with Magombeyi *et al.* (2009) who found large yield responses to supplementary irrigation of maize, ranging from 67 to 314 %, with the highest responses in the driest years. They also signify that the significant response of supplementary irrigation even in the wettest year reflects the erratic rainfall pattern typical of the semi - arid tropics, and the potential for supplementary irrigation to bridge dry spells at critical stages .This study is also in line with Rahman *et al.* (2000) who reported that WP is the highest in low rainfall season and gradually decreased with increasing irrigation levels in good season.

In both seasons, water productivity decreased when nitrogen level was increased from 69 to 92 kg N ha^{-1}. Significantly higher water productivity was obtained in 2013 (6.63 kg ha^{-1} mm^{-1}) at application rates of 69 N kg ha^{-1} as compared to (5.45 kg ha^{-1} mm^{-1}) in 2014. In this regard, the increasing rate of application from 69 N kg ha^{-1} to 92 N kg ha^{-1} decreased water productivity by 4 % during the 2013 cropping season and by about 7 % during the 2014 cropping season, respectively. Decreased productivity at higher rates was also reported by Oweis and Hachum, 2003. Moreover, the application of 69 kg N ha^{-1} increased water productivity by 145 % during the 2013 cropping season and by 117% during 2014 cropping season as compared to control.

Partial Budget Analysis

Treatments having marginal rates of return (MRR) below 100% were considered low and unacceptable to farmers, thus, eliminated (CIMMYT, 1988). This was because such a return would not offset the cost of capital and other related costs while still giving an attractive profit margin to serve as an incentive. The maximum net benefit of 47004 ETB ha^{-1} with optimum marginal rate of return was recorded at the rate of 92 kg N ha^{-1} supplemented with 100% irrigation, followed by nitrogen application rates of 69 kg N ha^{-1} supplemented with 100% irrigation (Table 7).

CONCLUSION

The results of this study have demonstrated that grain yield, yield components and water productivity of bread wheat were strongly influenced by supplemental irrigation and nitrogen application. Maximum bread wheat grain yield of 4504 kg ha^{-1} the highest water productivity 7.99 kg mm^{-1} ha^{-1} was recorded in response to the application of 100%SI combined with 92 kg N ha^{-1}. However, the lowest grain yield of 885 kg ha^{-1} and the lowest water productivity of 2.15 kg mm^{-1} ha^{-1} were recorded in response to the rain-fed production with no application of any nitrogen fertilizer. Based on economic analysis, the acceptable marginal rate of return of 255% and the highest net benefit (47004 ETB ha^{-1}) was obtained from the application of 92 kg N ha^{-1} with 100%

supplemental irrigation. The results of the study indicated that in order to improve the grain yield and yield components of wheat grown in the clay soils of Enderta farmers should adopt supplementary irrigation and adequate fertilization.

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Appendix Table I. Analysis of variance for phonology, growth characteristics, yield and yield components and water productivity of wheat as affected by , supplemental irrigation and nitrogen rates at Enderta, 2013 and 2014 cropping seasons.

					MSE of agronomic variables			
Source of variation	DF	DM	PHT	PTM	SPL	NSPS	TKW	BYLD
Replication	2	15.108	32.85	312.93	2.98	59.8	37.63	224802
SI	3	1431.04**	1268.14**	24419.41**	42.87**	478.6**	678.85**	160575812**
Error1	6	2.7194	3.9176	89.38	0.875	6.115	6.196	1491320
NL	4	202.57**	467.19**	9903.13**	13.02**	158.05**	45.265	77079680**
SI.NL	12	36.86**	27.34**	3288.58**	1.53**	7.94**	4.0391	5632169**
Error 2	32	2.3792	8.90525	249.89	0.309	2.9044	2.33877	293751
Year	1	145.2**	111.16**	46334.7**	95.40**	233.80**	140.83**	20722115**
SI.year	3	1.6222	0.05764	15.14	4.39**	1.30**	4.58**	1445703*
NL.year	4	2.1**	0.0125	1212.2**	0.033	0.300	0.113	201833
SI.NL.year	12	0.0389	0.0125	28.76	0.033	0.300	1.432	156353
Error 3	40	0.60	0.0271	24.70	0.050	0.229	1.042	406979
Total	119							

DM= days to maturity, PHT= plant height ,PTM= productive tiller m2 , SPL=spike length ,NSPS= number of seeds per spike , BYLD=biological yield, GYLD= grain yield ,HI= harvest index, PAW= productivity of available water.