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Response of Wheat *(Triticum Aestivum* L) to Supplementary Irrigation and N-P Fertilizers in Mekelle, Northern Ethiopia

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Abstract

The experiment was conducted at two locations in Mekelle, Northern Ethiopia during the 2012 cropping season to study the effect of supplementary irrigation (SI), and N-P fertilizers on wheat (cv. HAR-2501) yield and yield components. The experiment was laid out as a two factorial RCBD design with each treatment replicated thrice. Three levels of SI and N-P fertilizers were used. Crop phenology, data on soil physical and chemical properties, water quality, grain yield and yield components were collected. Soil moisture was recorded every ten days. Data were subjected to statistical analysis using Genstat 12ed. statistical software. Crop water requirement and irrigation schedule, were analyzed using the FAO Cropwat8. Analysis of variance (ANOVA), mean comparison (p=0.05) of the different parameters for each treatment were analyzed. According to the ANOVA, wheat grain was significantly (p<0.05) affected by nitrogen and nitrogen fertilizers at the two sites. Application of 64-46 kg/ha N-P_2O_5 fertilizers and six SI increased wheat grain yield by 205.3 and 157.3% at the Endayesus and Ik sites respectively. Application of 32-23 kg/ha N- P_2O_5 fertilizers could be recommended for sandy soils and 64-46 kg/ha N & P_2O_5 respectively, for clay type soils under rain-fed conditions. Based on this experiment, wheat was responsive to SI and N-P fertilizers, so, further research could be important to determine the response of the wheat to higher irrigation levels, especially for clay type soils and N-P fertilizers under the Northern Ethiopia climatic conditions, and to determine the economic feasibility of the SI and N-P fertilizers application on farmers' management practices.

Keywords

Wheat; Nitrogen; Phosphorus; Supplementary irrigation; Grain yield

Introduction

Wheat (*Triticum aestivum* L.) is one of the major cereal food crops in the world. It is one of the major cereal crops growing in Ethiopia [1]. Ethiopia is the second largest wheat producer Tefera [2] in Africa. The area and production of wheat in 2011/12 cropping season was 11.89% and 13.34 % [3] respectively. Bread wheat *(Triticum aestivum* L.) and durum wheat (*Triticum turgidum* L. *var durum)* are the major wheat types dominantly growing in Ethiopia [4], with bread wheat dominantly growing [5].

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Wheat, the major source of carbohydrate and source of food for human beings and feed for animals [6], production in arid and semi-arid environments like the northern parts of Ethiopia, where late onset and early cessation of rain prevails, can be enhanced by using different technologies such as use of early maturing varieties, drought resistant varieties and use of supplementary irrigation, appropriate use of fertilizers, and application of appropriate agronomic practices.

Crop production in Ethiopia is mainly dependent on rainfall as a source of moisture for growth of crops; with irrigation contributing 1.1% of the total cultivated land in the country where amount and temporal rain fall distribution are prominent for crop production [7], particularly the northern parts of the country receives inadequate rainfall for crop production, that late onset and early cessation affect wheat production and productivity in the region. Crop production under rain-fed conditions is prone to variability in precipitation resulting in yield failure [8]. According to Yemenu and Chemeda [9], yield obtained from rain fed in Ethiopia are very low due to crop failures as a result of irregular onset, temporal and spatial distribution of rain during the crop growing season. According to Araya et al. [10], report, the rainy season in northern Ethiopia is shorter than the crops growing period, indicating that most of the crops require not less than 80 days, however, the rainy season is not often exceeding 65 days. The erratic rain fall pattern in such areas, where moisture is a limiting factor, the probability of receiving optimum rain for the growth and development of crops is limited; thus, yield failure is an important problem for farmers in the region.

According to Rockstrom et al. [11] increasing water productivity in arid and semi-arid areas and sub-humid tropics can be achieved through improving and maximizing crop water availability, maximizing water uptake of plants and use of supplementary irrigation (Figure 1).

To enhance wheat production and productivity to satisfy the increased demand of the increasing population, use of high yielding, better quality, and drought tolerant varieties [12], control insect pests and diseases, have been a big challenge in wheat producing areas. Application of supplemental and /deficit irrigation in limited amount in the moisture sensitive crop growth stages can enhance the crop yield and water productivity [13].

Efficient use of limited water and better growth under limited water supply conditions are important traits for crops in drought prone environments [12]. It is obvious that irrigation is an alternative way to increase and stabilize crop production [8]. According to Araya and Stroosnijder [14] dry spells and false starts which can result in crop failure can be tolerated by using supplementary irrigation; indicating that more than 80% of yield reductions is resulted due to water stress, and more than 50% of crop failures attributed by this stress could have been avoided by irrigation during the periods of dry spells and rain withdrawals.

Araya and Stroosnijder [14] recommended that supplementary irrigation is important for the areas Mekelle et al., as a result of rain withdrawal during late August to/or early September. It is indicated that supplemental irrigation has a paramount importance in stabilizing yield of crops in dry rain-fed areas [15]. Application of

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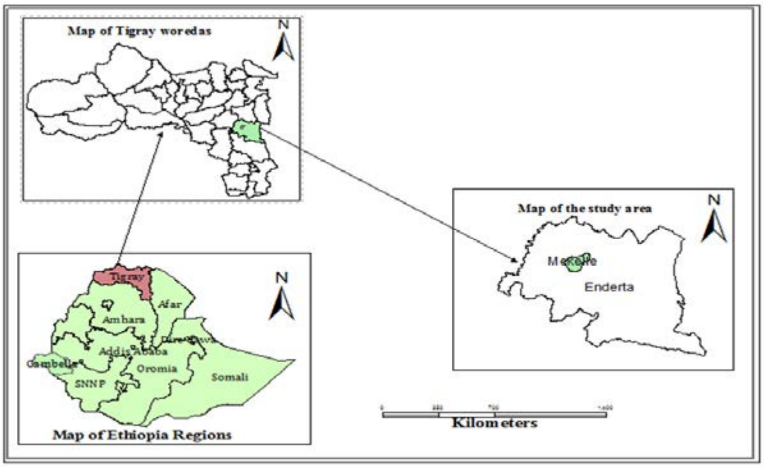

Figure 1: Map of the research site.

adequate amount of phosphorus fertilizer is necessary in addition to nitrogen and supplemental irrigation [15] for wheat growth and development. Application of deficit irrigation has a paramount importance in stabilizing grain yield, increasing water and nitrogen use efficiency in arid and semi-arid areas where, water is a limiting factor for crop growth [16]. Hence, use of supplementary irrigation at times of dry spells in the late growing season of crops including wheat, and use of appropriate rate of nitrogen and phosphorus fertilizers are of important practices for farmers to enhance production and productivity of wheat in dry areas. By doing this they can achieve their food security and self-reliance. Therefore, this experiment was conducted to determine the effect of N-P fertilizers and supplementary irrigation on yield and yield components of wheat crop in Northern Ethiopia.

Materials and Methods

Description of study area

This experiment was conducted in Northern Ethiopia at two sites in Mekelle during 2012 cropping season; one at Mekelle University Endayesus campus with latitude of 13° 29' N and long 39° 35'E and altitude of 2200 m above sea level [2,17] and the other site at the Industry kebele which is about 2 km far from the city.

The soil type at the Endayesus site ranges from Sandy Clay Loam to Sandy Loam and the average bulk density of the soil at different soil depths is 1.02, 1.56, and 1.17 g/cm³ at 0-20 cm, 20-40 cm and 40-60 cm soil depths respectively. And the soil pH ranges from 6.75 to 7.15 are shown in Table 1. The bulk density for the Industry kebele varies from 1.49 g/cm³ at the top 20 cm to 1.327 g/mc³ at the lower soil depth 80-100 cm. The soil pH ranges are from 7.72 to 8.02.

The long-term average annual precipitation of the Endayesus site is about 600 mm; of which 70 to 80% is received between the months of June and September while the other 20 to 30% is received between the months of February and May [2]. The average annual minimum, maximum and rainfall of the Industry kebele and Endayesus are 11.95°C, 27.25°C and 46.83 mm, and 11.04°C, 22.29°C and 45.43 mm respectively.

Experimental design and field management

The experiment was designed as a two factorial RCBD design with three replications. The experiment comprised of three levels of fertilizer rates: zero fertilizer (F0), 32 kg N and 23 kg P_2O_5 per hectare (F1) and 64 N and 46 kg P_2O_5 (F2); and three levels of irrigation: rain-fed (Io), two irrigations (I2), and six irrigations (I6). One variety of wheat HAR-2501(common name Hawi) was used as a test crop. Plot size was 2.5 m by 4 m, and spacing of 1 m and 1.5 m between treatments and replications respectively.

Data on physical and chemical soil properties, irrigation water quality, grain yield and yield components were collected. Thousand seeds were counted using Electronic Grain counter (Wagtech International) grain counter for measuring thousand grain weights. Harvest index (HI) for each treatment was computed.

The analysis of variance (ANOVA), mean comparison (p<0.05); relation and correlation were analyzed by using GenStat 12ed. Crop water requirement (ETC) and irrigation schedule were calculated for the two sites by using the CROPWATT [18] statistical software. The soil moisture balance of the experimental site was calculated as;

$$ETc = P + I - (D + Ro)\Delta SW \quad 1$$

where, Etc is crop water requirement, P is precipitation, I is irrigation, D is drainage, Ro is runoff and ΔSW is the change in soil moisture storage between soil moisture measurements (mm) over time [1]. Due to the deep water table the effect from drainage was ignored [17]. Therefore, water balance was calculated as;

$$ETc = P + I - Ro\Delta SW \quad \mathbf{2}$$

Result and Discussion

Plant height (cm)

The ANOVA for plant height at the Endayesus revealed that there was no significant (p<0.05) difference among NP fertilizers and supplementary irrigation treatments. The tallest plant (74.04 cm) was obtained from application of 64-46 kg ha^{-1} of N and P_2O_5 with six SIs, and the short plant (68.03 cm) was obtained from zero fertilizer (F0) under six irrigations (I6), which the effect might be as a result of fertilizer treatments due to the effect of rainfall is minimal, indeed, the plants reached maximum plant height before application of SI. Means not connected with same letter are significantly different.

Whereas; plant height at the Industry kebele was significantly

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affected ($p<0.05$) by NP fertilizers and supplemental irrigation application, with the highest plant height (75.5 cm) obtained by applying 64-46 N-P_2O_5 fertilizers under six irrigations; and the smallest plant height (64.73 cm) was obtained from application of zero fertilizer and rain-fed treatment. Application of NP fertilizers brought a significant difference on plant height at the IK sites on rain-fed treatments, which high NP fertilizers result in higher plant height. The variation in plant height at the two sites might be due the variation in NP fertilizers application, whereas, the effect of SI on plant height could be minimal.

Research conducted on participatory varietal selection in Northern Tigray, showed that the performance of wheat variety (HAR-2501 or Hawi, test variety in this experiment) has resulted in 80 cm plant height, which is actually higher than the average plant height obtained in this experiment under different treatments [19]. According to Zhang et al. [49] application of deficit irrigation during booting and shooting stages resulted in higher plant height 79.8-81 cm, which is in par with the result 82.37 cm obtained by Ghobadi et al. [20]. Shamsi et al. [21] reported that the highest plant height 89.46 cm was obtained with application of full irrigation application at all growth stages when compared to the shortest plant height 58.44 cm. This was obtained from treatments receiving no supplemental irrigation. Report by Chauhan and Yadav [22] showed that plant height was increasing (92.13 to 97.46 cm) with increasing irrigation water from 310.47 to 463.5 mm with a slight decrease to 96.92 and 96.63 cm from 493.43 to 497.25 mm increase. Kabir et al. [13] also reported that higher plant height 82.33 cm was obtained under treatment received single irrigation application at crown root initiation, and the smaller plant height 77.07 cm was obtained with no irritation.

Ali et al. [23]; Guarda et al. [24]; Naseri et al. [25]; Shehzad et al. [26] and [27] stated that wheat plant height was increased with increase in nitrogen levels, whereas, [28] reported that increasing phosphorus levels increased average wheat plant height, which is in agreement with results observed in this experiment. Means not connected with same letter are significantly different.

Number of tillers per meter square

Fertilizer and supplementary irrigation application did not bring significant effect ($P<0.05$) on number of tillers per meter square at the Industry Kebele. The highest number of tillers per meter square (157.3) was obtained from application of 64 kg N and 46 P_2O_5 and six irrigations; whereas, the smallest number (81.3) were obtained from application of zero fertilizer and six irrigations. Similarly, application of N & P fertilizers and supplemental irrigation did not result in a significant ($p<0.05$) effected on number of tillers per meter square at the Endayesus site. The highest number of tillers per meter square (160) was recorded from application of 64 kg N and 46 kg per hectare P_2O_5 and six supplementary irrigation; while the smallest number (84) was obtained from application of 32 kg N and 23 P_2O_5 kg per hectare.

Application of nitrogen and phosphorus 128 kg/ha each (1:1) resulted in the highest number of tillers per square meter (355 and 310) in 2002/03 and 2003/04 respectively [6]. Experimental results in Pakistan by Chauhan and Yadav [22] revealed that number of fertile tillers per square meter increassed with increasing irrigation water (104 fertile tillers per square meter) by applying 493.43 mm of water except (102 tillers) with application of 497.25 mm (Table 2).

Spike length (cm)

Nitrogen-phosphorus fertilizers and supplementary irrigation significantly affected wheat spike length at the Endayesus site. The analysis of variance for spike length at the Endayesus site revealed that there was a significant difference ($p<0.05$) with supplementary irrigation and NP treatments, which the highest spike length (8.58 cm) was obtained from application of six SI and 64 kg N and 46 kg P_2O_5 ha^{-1}. On the contrary, the smallest spike length (7.64cm) was obtained from application of zero fertilizer and to irrigations. Spike length at the Endayesus showed an increase with NP fertilizers. Means not connected with same letter are significantly different (Table 2).

Similarly, spike length at the Industry kebele was significantly ($p<0.05$) influenced by application of NP fertilizers and supplementary irrigation. The smallest and highest spike lengths (7.2 and 8.83 cm respectively) were obtained from the control (F0I0), and 32 kg N and 23 kg ha^{-1} P_2O_5 and application of two irrigations respectively, with the coefficient of variation 4.4%.

This result was in par with the data reported by Zhang et al. [29]. However, the average spike length obtained in this experiment under the different treatments is higher than the spike length (6.6 cm) of same variety under farmers management practice [19]. According to Waraich et al. [30] spike length was increasing irrigation 9.44 cm with one irrigation at tillering to 11.36 cm with four irrigations at tillering, stem elongation, anthesis and grain development stages, which is in a similar trend with the data obtained in this experiment that spike length increased from rain-fed 7.65 cm to 8.457 cm at full irrigation that is six irrigations in the late growth stages. According to the report by Mahamed et al. [31] soil moisture depletion at 50% , 60% and 75% of available water resulted 7.71, 7.25 and 7.32 cm spike length with no significant difference ($p<0.05$), indicating that spike length was higher at 50% soil moisture deficit. Similarly, data reported by Chauhan and Yadav [30] showed that spike length was icreasing with amount of irrigation water, with maximum spike length obtained 9.50 cm by applying 497.25 mm. Waraich et al. [30] observed that spike length was increased with increase in nitrogen levels which is in line with the data observed in this experiment at both sites. According to Tafere et al. [27] wheat spike length was increased with increase in N levels with no significant difference at 46 and 69 kg N ha^{-1} (Table 3).

Above ground biomass (kg ha^{-1})

The ANOVA for aboveground biomass at the Endayesus site showed that there was a significant ($p<0.05$) effect on the performance of wheat under the different NP fertilizers application, whereas, applications of SI after cessation of rain did not bring significant ($p<0.05$) effect. The highest and smallest aboveground biomasses (4417 and 2083 kg ha^{-1}) were obtained from application of 32 kg N and 23 kg $ha^{-1}P_2O_5$ and irrigations, and the control respectively. Application of NP fertilizers in the form of Urea and DAP, and SI increased aboveground biomass by 84% with coefficient of variation 25.5%.

Aboveground biomass (AB) at the IK was highly significantly ($p<0.01$) with NP fertilizers, while supplementary irrigation application did not result in a significant effect. The highest aboveground biomass (8500 kg/ha) and the smallest AB (3167 kg/ha) were observed from application of 64 kg N and 46 P_2O_5 kg ha^{-1} and six irrigations, and zero fertilizer and two irrigation treatments respectively. Application of SI and NP fertilizers application increased AB by 168.39% at the site. The highest above ground biomass at the Industry Kebele from application of NP fertilizers and supplementary irrigation, might be due to the clay soil type when compared with the Sandy Clay Loam soil at the Endayesus site. Application of high NP

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Table 1: Means for plant height for Endayesus and IK sites. Number of Tillers per meter square.

Endayesus site				**IK site**		
	Io	I2	I6	Io	I2	I6
F0	70.3ª	68.07ª	68.03ª	64.73ª	69.53ᵃᵇ	68.5ᵃᵇ
F1	71.23ª	68.07ª	71.3a	65.6ª	73.9ᵃᵇ	71.6ᵃᵇ
F2	70.73ª	70.2ª	74.07ª	73.7ᵇ	73.03ᵃᵇ	75.5ᵃᵇ
LSD (5%)	8.25			8.89		

Table 2: Means for number of tillers per meter square.

Endayesus site				**IK site**		
	Io	**I2**	**I6**	**Io**	**I2**	**I6**
F0	92.0a	98.7a	101.3a	86.7a	101.3a	81.3a
F1	120.0a	138.7a	84.0a	116.0a	110.7a	116.0a
F2	126.7a	105.3a	160.0a	133.3a	137.3a	157.3a
LSD (5%)	56.07			66.93		

Table 3: Mean SL (cm) for Endayesus and IK.

Endayesus site				**IK site**		
	Io	**I2**	**I6**	**Io**	**I2**	**I6**
F0	7.81a	7.64a	7.87ab	7.2a	7.46ab	8.18cde
F1	8.34ab	7.82ab	8.4ab	7.7abc	8.56de	8.55de
F2	8.33ab	7.9ab	8.58b	8.06bcd	8.83e	8.64de
LSD (5%)	0.67			0.62		

Table 4: Means of grain yield (kg ha^{-1}) for Endayesus and IK sites.

Endayesus site				**IK site**		
	Io	**I2**	**I6**	**Io**	**I2**	**I6**
F0	754ª	1341ᵃᵇ	1389ᵇ	1047ª	1113ª	1439ᵃᵇ
F1	1695ᵇᶜ	1662ᵇᶜ	1798ᵇᶜ	1473ᵃᵇ	2278ᵇᶜ	2081ᵇᶜ
F2	1590ᵇ	1679ᵇᶜ	2302ᶜ	1986ᵃᵇᶜ	2692ᶜ	2688ᶜ
LSD (5%)	592.3			864.4		

fertilizers followed by application of six supplementary irrigations during the midcrop growth stage resulted in high AB at the two sites.

According to the data reported by Gebru et al. [19] the biomass obtained by the variety HAR-2501 5.6 ton/ha, is less than the highest above ground biomass obtained at the IK site from 32-23 NP, and full irrigation 7681 and 6167 kg/ha (7.68 and 6.16 ton/ha). Research finding reported by Shamsi et al. [21] indicated that application of full irrigation produced highest biological yield 13690 kg/ha, however, the least was 10600 kg/ha, which actually is higher than the yield obtained from full irrigation in this experiment. And similarly, a report by Zhang et al. [29] shows higher biomass production was obtained in growth stages free of water deficit at the booting, shoot elongation, grain filling and physiological maturity with 20.3 and 20.4 ton/ha in 2003 and 2004 growing seasons respectively. Similaryl, Ghanbari-Malidarreh et al. [32] an increase in biomass was obtained with increasing supplementary irrigation from 50 to 150 mm from heading to early grain filling stages. Accoriding to Mahamed et al. [31] above goudnd biomass was increasing significantly ($p<0.05$) with decreasing soil moisture depletion from 24.9 t/ha to 27.0 t/ha at soil moisture depletion of 75 and 50% of available water respectively, with no significant difference between 60% and 75% soil moisture deficit. A research data reported by Galavi and Moghaddam [33] was in agreement with this results that above ground biomass or biological yield increased with increasing irrigation application 3236 kg/ha obtained with irrigatio applicatied before planting to 10470 kg/ha obtained with deficit irrigation applied at all growth stages (Table 4).

Grain yield (kg ha^{-1})

The mean grain yield of wheat at the Endayesus with sandy type soils varied from 754 to 2302 kg/ha; and 1047 to 2692 kg/ha at the IK under clay type soils. Application of nitrogen and phosphorus fertilizers and supplementary irrigation influenced wheat grain yield significantly ($p<0.05$). The highest grain yield (2692 kg ha^{-1}) was obtained from application 32 kg N and 23 kg P_2O_5 ha^{-1} and application of two supplementary irrigation after cessation of rain, whereas, the lowest grain yield (1047 $kgha^{-1}$) respectively) was obtained from the control treatment. Application of 64 kg N and 46 P_2O_5 kg ha^{-1} at the Endayesus increased wheat grain yield by 205.7%, whereas, the increase in grain yield at the IK through application of 32 kg N and 23 kg P_2O_5 ha^{-1} and two SI applications was 157.1%. Grain yield at the two sites revealed a positive correlation with all the yield components, especially, with high degree of correlation with aboveground biomass.

Hawi (HAR-2501) the variety used in this experiment as a test crop, was indicated as adaptable to the climatic conditions of the northern Ethiopia with a grain yield of 2040 kg ha^{-1} [19] which is less than highest grain yield obtained at the Endayesus and IK sites. Results observed in this experiment are consistent with the data reported by Korkmaz et al., [34] which grain yield was increased with increasing phosphorus fertilizer. Similarly, Guarda et al. [24] and Shehzad et al. [26] observed that grain yield was affected with application of nitrogen levels. Ali et al. [35] reported that maximum grain yield was observed with 150 kg N ha^{-1}, which is higher than the amount used in this experiment.

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Results in this experiment are in agreement with Sandhu and Sidhu which wheat grain yield was significantly ($p<0.05$) affected with application of supplementary irrigation. Similarly, full irrigation applied throughout the crop's growing season gave higher grain yield 45.4 Qtha^{-1} [36]. Application of irrigation in the middle and late growth stages produced higher grain yield 7.95 and 7.26 ton ha^{-1} in 2003 and 2004 respectively [29]. An increase in grain yield from 4032 to 5670 kg ha^{-1} was obtained with increasing supplemental irrigation from zero to 150mm [32]. Similarly, grain yield reported by Galavi and Moghaddam [37], Waraich et al. [30] showed that grain yield (kg ha^{-1}) increased with increasing application of irrigation levels. An experiment conducted in Turkey in 2009 and 2010 on four wheat varieties and four supplementary irrigation levels, the highest average grain yield 5511 and 4799 kg ha^{-1} was obtained in 2009 and 2010 respectively, from application of 80mm of water as supplementary irrigation, Sagittario variety with the highest grain yield 6021 kg ha^{-1} in 2009 from application of 80mm of irrigation water [38].

Grain weight per spike (g)

Grain weigh per spike was significantly ($p<0.05$) affected by fertilizer and supplementary irrigation applications at both sites. The highest grain weight (1.657 g) at the Endayesus site was obtained from application of full fertilizer (64-46 P_2O_5) and six irrigations, and the lowest grain weight per spike (1.147 g) was obtained from the control treatments. The mean comparison showed that grain weight per spike increased with increasing supplementary irrigation, except in the case of 32 kg N and 23 kg P_2O_5 per hectare fertilizer and two deficit irrigation treatments. Similarly, grain weight per spike at the Industry Kebele was significantly influenced with NP fertilizer rates and deficit supplementary irrigation applications. The highest grain weight (1.41 g) and the lowest grain weight (0.85 g) were obtained from full fertilizer (64-46 P_2O_5) and two deficit irrigations, and control treatments respectively

According to the research report by Zhang et al. [29], highest grain weight per spike 2.22 g was obtained from application of irrigation in the late growth stages in 2004. A research conducted on different seed rates of wheat varieties revealed that the highest grain weight per spike (2.6 g) was obtained at a seed rate of 125 kg/ha; and the lowest seed rate was obtained at seed rate of 200 kg/ha, however, the grain weight (2.3 g) obtained at same seed rate (150 kg/ha) [39] with this experiment is higher than the highest grain yield observed in this experiment from the various treatments a both sites.

Harvest index was calculated as the total grain yield divided by the total above ground biomass. Due to the lower above ground biomass yield at the Endayesus site, HI was greater than at the Industry Kebele for the same treatments. HI was not influenced significantly ($p<0.05$) by application of NP fertilizers rates and deficit supplementary irrigation application, though the highest (52.5%) and the lowest (37.23%) HI were obtained from application of full fertilizer (64-46 N-P_2O_5) and full irrigation (six deficit irrigations), and control treatments respectively. However, as a result of the higher above ground biomass production at the Industry Kebele, HI was relatively lower than the record obtained at the Endayesus site. The highest HI (36.44%) was obtained from 32-23 N-P_2O_5 fertilizer and two deficit irrigation application; on the contrary, the lowest HI was obtained from application of zero fertilizer and full irrigation treatments.

The harvest index for the Industry kebele has shown no significant difference among the treatments. A higher harvest index percentage 34.98% and 34.84% were obtained from treatments grown under no fertilizer applications and supplied with full irrigation; and the standard error and coefficient of variation were recorded 6.37 and 19.3% respectively. The analysis of variance showed that there was no interaction between the factors used in this experiment. The highest HI at the Endayesus site from fertilizer and supplementary irrigation applications might be due to the high N-P and high moisture from full irrigation in the soil; however, the highest HI at IK from 50% (32-23 N-P_2O_5) might be due to the higher total N (%) available in the soil, and the biomass produced from deficit irrigation is less than the amount produced from full irrigation treatments resulting in high HI ratio. The difference in soil type might be the factor for the difference in harvest index at the two sites.

Maqsood et al. [35] reported that harvest index was significantly affected by nitrogen and irrigation levels, with higher HI 36.53% was obtained from treatments subjected to full irrigation; similarly, irrigation levels resulted significant effect on HI on wheat crop [37] which is in agreement with this data. Karam et al.13] found similar HI at higher nitrogen fertilizer rates, and different irrigation regimes from 2000-2004 that HI varied from 34 to 48% in both irrigation and nitrogen fertilizer regimes which in most of the years the data was more similar to the results obtained at the Endayesus site. Mohammad et al. [40] reported that supplementary irrigation at anthesis resulted 32.29% HI, which is smaller than the maximum harvest index 50.59% obtained in this experiment. Application of deficit irrigation at 75% depletion of available soil moisture produced the highest HI when compared with the irrigation applications at 50 and 60% soil moisture deficit [31], agrees with the data obtained at the IK site in this experiment indicating HI was decreased with increased irrigation levels. A research conducted in the northern Ethiopia during 2008 and 2009 on a participatory variety selection, the performance of the variety HAR-2501 was superior when compared with the other varieties with HI of 34.5%, which is in par with the results obtained at the IK site [19] (Table 6).

Thousand grain weight (g)

Thousand grain weight at the Endayesus site showed that application of NP fertilizers and deficit irrigation significantly ($p<0.05$) affected thousand grain weight. The highest (42.01 g) and lowest (35.99 g) were obtained from application of 32-23 Kg/ha of N-P_2O_5 and six SI applications, and full fertilizer and rain-fed treatments, respectively. The mean comparison for the various treatments showed that there was no significant ($p<0.05$) different under fertilizer treatments and rain-fed treatments. However, the combined effect of fertilizer rates and SI application brought significant difference between treatments.

The analysis of variance for thousand grain weight at the IK revealed that there was significant difference ($p< 0.05$) with irrigation application, which maximum test weight was obtained 39.49 gm with treatments received full fertilizer and six irrigations, and a minimum of 33.28 g was obtained from the control treatments. The coefficient of variation for the site was 6.2%.

This result is similar to the data reported by Maqsood et al. [35]; and Mohammad et al. [40], which SI resulted in a significant difference ($p<0.05$). Tahir et al. [6] observed the highest thousand grain weight under 128 kg of nitrogen and phosphorus fertilizers each, which is considerably higher than the highest record obtained in this experiment (38.54 g at a rate of 64-46 kg/ha of N-P_2O_5 each respectively). This research agrees with the report by Waraich et al. [30] that 1000 grain weight increased with increasing irrigation levels that 45.5 gm was obtained with four irrigations from tillering

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Table 5: Means of grain weight (g) per spike for Endayesus and IK.

Endayesus site				**IK site**		
	Io	**I2**	**I6**	**Io**	**I2**	**I6**
F0	1.147[a]	1.257[ab]	1.34[abc]	0.85[a]	1.07[ab]	1.21[bc]
F1	1.46b[c]	1.38[abc]	1.65[c]	1.34[bc]	1.24[bc]	1.2[bc]
F2	1.467b[c]	1.5[bc]	1.657[c]	1.13[bc]	1.41[c]	1.34[bc]
LSD (5%)	0.285			0.256		

Table 6: Means comparison of HI (%) for Endayesus and IK. Means not connected with same letter are significantly different.

Endayesus site				**IK site**		
	Io	**I2**	**I6**	**Io**	**I2**	**I6**
F0	37.23[a]	47.34[a]	47.31[a]	34.96[b]	39.01[b]	30.98[ab]
F1	49.47[a]	51.2[a]	51.97[a]	33.99[b]	36.44[b]	35.4[b]
F2	43.51[a]	52.03[a]	52.5[a]	35.56[b]	3012[ab]	20.49[a]
LSD (5%)	15.93			11.02		

Table 7: Mean comparison of AB (kg/ha) for Endayesus and IK. Means not connected with same letter are significantly different.

Endayesus site				**IK site**		
	Io	**I2**	**I6**	**Io**	**I2**	**I6**
F0	2083[a]	2833[ab]	2646[ab]	3542[ab]	3167[a]	4833[abc]
F1	3229[abc]	3833[bc]	3500[abc]	4333[abc]	6167[bcd]	5167[abc]
F2	3083[abc]	3250[abc]	4417[c]	6500[cd]	8042[d]	8500[d]
LSD (5%)	1416.8			2547.4		

Table 8: Means of 1000 Grain weight (g) for Endayesus and IK.

Endayesus site				**IK site**		
	Io	**I2**	**I6**	**Io**	**I2**	**I6**
F0	36.47[a]	37.22[ab]	39.21[abc]	33.28[a]	35.48[ab]	38.27[b]
F1	36.04[a]	37.55[ab]	42.01[c]	37.56[ab]	37.86[b]	39.11[b]
F2	35.99[a]	40.40[bc]	39.24[abc]	36.98[ab]	37.74[b]	39.49[b]
LSD (5%)	3.38			4.0		

Table 9: Means of No. Grains per spike for Endayesus and IK sites. Means not connected with same letter are significantly different.

Endayesus site				**IK site**		
	Io	**I2**	**I6**	**Io**	**I2**	**I6**
F0	30.0[a]	32.67[ab]	34.33[abc]	25.6[a]	28.67[ab]	29.67[abc]
F1	37.0[bc]	33.33[ab]c	38.67[c]	35.0[cd]	31.33[bc]	32.33[bc]
F2	37.67[bc]	36.33[bc]	33.0[abc]	29.67[abc]	38.67[d]	38.33[d]
LSD (5%)	5.217			5.045		

to grain development. Supplementary irrigation during flowering and grain filling stages resulted better 1000 grain weight 30.6 and 36.7 g respectively when compared with 26.6 and 28.8 g obtained without application of irrigation and application at stem elongation [25]. Application of irrigation water at 50% of available soil moisture resuled higher thousand grain weight 35.97 g which is significantly ($p<0.05$) higher than the result obtained from the 60 and 75% Soil moisture deficit [31] (Table 7).

Number of grains per spike

Wheat crop was responsive to application of NP fertilizers and SI at the two sites. Application of 32-23 N-P_2O_5 fertilizers and full irrigation resulted in the highest number of grains per spike (38.64), however, the smallest number of grains per spike was obtained from the control treatments at the Endayesus site. There was an increasing trend on number of grains with increasing NP fertilizer rates. The number of grains per spike at the Industry Kebele was also affected with application NP fertilizer rates and SI. The highest number of grains (38) was obtained from application of full fertilizer and two irrigations, but, on the other hand, the smallest number of grains per spike (25.6) was resulted from the control treatments. Number of grains per spike at the Industry Kebele showed progress in counts with increasing NP fertilizer rates, which application of 64-46 kg/ha of N-P_2O_5 under two, and six irrigation conditions increased number of grains per spike by 34.88 and 29.19% when compared with the control (zero fertilizer-rainfed (Table 8).

Akbari et al. [37] reported that the highest number of grains (31 grains per spike) was obtained from application of full irrigation which is in agreement with the results obtained in this experiment, though number of grains was not significantly ($p<0.05$) affected with application of supplementary irrigation. Similarly, Maqsood et al. [35] found similar results from application of irrigation and nitrogen fertilizer levels, with this data. Mohammad et al. [40] reported 22.76 as the maximum number of grains per spike through application of supplementary irrigation at anthesis, which is lower than the record obtained in this experiment. Number of grains per spike reported by Waraich et al. [30] was increasing with increasing irrigation levels with maximum number of grains per spike. According to Erekul et al. [38] report, application of 80 mm of water applied as supplemental irrigation on four wheat varieties in 2009 and 2010 produced the highest mean grain number spike about 25 and 23 respectively when compared with the mean value obtained from application of 0, 40 and 120 mm of water (Table 9).

The results obtained at the IK are consistent with the en levels. Research finding reported by Abbas et al. [41] is similar to the results obtained from the IK, which the highest number of grains per spike 42.8 was obtained from variety Inqlab-91at a rate of 150-100 kg/ha of nitrogen and N-P_2O_5 respectively, indicating that number of grains was increasing with increasing nitrogen and phosphorus fertilizers [42,43]. The application of nitrogen and phosphorus showed an increasing trend on the findings carried out in results observed by Fallahi et al. [28] which number of grains was increasing with application nitrogen 2002/03 and 2003/04 from the smallest number 48 in 2002/03 and 40 in 2003/04 to the maximum number of grains 53.84 in 2002/03 and 52.5 in 2003/04 at a rate of 128:32 to 128:128 kg/ha of N and P respectively [6,44,45].

Conclusions and Recommendations

In the dryland areas, application of supplementary irrigation has not yet got priority and not made supportive to agricultural production. The northern part of Ethiopia is usually prone to late onset and early cessation of rainfall. As a result of repeated cultivation and erosion, the soil fertility is highly declined, which crop production can be reduced [46,47]. Application of supplementary irrigation and NP fertilizers in this experiment has profoundly affected the performance of wheat crop. Plant height and number of tillers per meter square at IK; spike length, grain yield, grain weight per spike, number of grains per spike and aboveground biomass at the two sites were significantly ($p<0.05$) influenced by application of NP fertilizers. Application of 64 kg ha^{-1} and 46 kg P_2O_5 ha^{-1} and six SI increased wheat grain yield by 205.3 and 157.1% at the Endayesus and IK sites respectively [48]. Therefore, the combined effect of NP fertilizers and SI during the mid-growth stages of wheat crop can be important in sustaining the growth of wheat crop, especially, during flower initiation and grain filling stages [49].

In addition to application of N-P fertilizers, application of supplementary irrigation in moisture stress areas, like the northern Ethiopia, where late onset and early cessation of rain occurs, is advisable for farmers to enhance production and productivity of wheat through stabilizing growth and development of the crop. Hence, application of N-P fertilizers 64 kg N and 46 kg P_2O_5 ha^{-1} respectively, on two split application to N in combination with two SI are recommended for wheat crop in clay type soils, whereas, six SI applications are important when combined with the 64-46 kg N-P_2O_5 ha^{-1} fertilizers respectively under sandy soil types.

Agronomically, wheat crop performed well under 64 kg and 46 kg Nitrogen and P_2O_5 ha^{-1}; and six SI applications under sandy type soils, and two irrigations on clay type soils respectively. Enhancing this grain yield through application of N-P fertilizers and supplementary irrigation can contribute paramount importance in ensuring food security and food self-sufficiency of subsistence farmers in the Northern Ethiopia where, soil fertility and, late onset and early cessation of rainfall are detrimental for crop production. However, further research works can be conducted on NP fertilizers, SI application and economic feasibility on wheat production in the study area. The economic importance of the specified fertilizer rates and SI applications has to be studied across locations and season.

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