Effect of Weed Management Methods and Nitrogen Fertilizer Rates on Grain Yield and Nitrogen Use Efficiency of Bread Wheat (*Triticum aestivum* L.) in Southern Ethiopia

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Abstract: Inefficient weed management practices and the use of inappropriate nitrogen fertilizer rates are the major causes of low yield of wheat in Ethiopia. Therefore, field experiments were conducted at Bobicho and Faate in southern Ethiopia to determine the effect of weed management practices and N fertilizer rates on grain yield, N uptake, and N use efficiency of bread wheat. The treatments consisted of a factorial combination of four rates of nitrogen (0, 60, 85, and 110 kg N ha^{-1}) and five weed management practices [two hand weeding at 2 and 5 weeks after crop emergence (WAE), application of pyroxsulam at 20 g ha^{-1}, pyroxsulam at 10 g ha^{-1} + 2,4-DEE 0.50 kg ha^{-1}, weed free and weedy check] in randomized complete block design with three replications. The interactions of location, N fertilizer rate, and weed management practices significantly ($P < 0.01$) affected grain yield, nitrogen concentration, nitrogen uptake, and N use efficiencies of the crop where weedy check had the lowest values. Under both hand weeding and use of herbicides, increasing the nitrogen rates resulted in a significant increase in grain yield, grain and straw nitrogen concentration nitrogen uptake, and apparent nitrogen recovery efficiency at both locations. The highest grain yield, grain nitrogen uptake, total nitrogen uptake and apparent nitrogen recovery efficiency were recorded in the weed free plot with the application of 110 kg N ha^{-1} at both locations. Aside from the weed free check, combined application of herbicides pyroxsulam at 10 g ha^{-1} + 2,4-DEE 0.50 kg ha^{-1} with the application of 110 kg N ha^{-1} resulted in higher grain yield of 5285 kg ha^{-1} at Bobicho and 4868 kg ha^{-1} at Faate with the highest economic advantage at both locations.

Keywords: Hand Weeding; Herbicide Combinations; Nitrogen Uptake; Pyroxsulam, 2; 4-Dichlorophenoxyethylene Ester

1. Introduction

Bread wheat (*Triticum aestivum* L.) is one of the most important cereal crops globally and is a staple food for about one third of the world's population (Hussain *et al*., 2002). It is fourth in area coverage (1.63 million ha) following *tef*, maize and sorghum and fourth in total production (3.43 million tons) following maize, *tef,* and sorghum in Ethiopia (CSA, 2013) which makes the country the largest wheat producer in sub-Saharan Africa. It is one of the major cereal crops in the Ethiopian highlands that lie between latitude of 6^{o} and 16^{o}N and longitude of 35^{o} and 42^{o} E and is widely grown from 1500 to 3000 meters above sea level. Moreover, it is one of the major cereal crops of choice in Ethiopia, dominating food habits and dietary practices, and is known to be a major source of energy and protein in the country (Tanner *et al.,* 1993).

Low soil fertility, especially nitrogen deficiency, is one of the major constraints limiting wheat production in Ethiopian highlands (Teklu and Hailemariam, 2009). Wheat is highly responsive to N fertilization, with significant amounts of supplemental N required to maximize grain yields. Application of N fertilizers has been the most direct and effective approach to increase wheat production. However, reports have shown that about 50% of applied N fertilizer remains unavailable to a crop due to temporary immobilization in soil organic matter or due to losses by leaching, erosion, nitrification or volatilization (Zafar and Muhammad, 2007). Thus, the use of appropriate rates, efficient timing and placement of nitrogen could increase recovery of applied nitrogen up to 70 or to 80% (Legg and Meisinger, 1982). These considerations make it essential to enhance N use efficiency (NUE) in order to maximize economic returns from the nitrogen application (Raun and Johnson, 1999; Hirel *et al.,* 2007).

In Ethiopia, erratic seasonal rainfall, inadequate availability of other nutrients, nitrate leaching during the short but heavy rainy seasons, ammonia volatilization and continuous removal in the cereal mono cropping systems of the highlands are the major factors that result in inefficient use of N fertilizer (Tanner *et al.,* 1993). Haile *et al.* (2012) reported N use efficiency (NUE) of bread wheat that ranged from 27.10% with the highest nitrogen rate of 120 kg N ha^{-1} to 39.27% at the lowest N rate of 30 kg N ha^{-1}. Farmers in the study area use blanket recommendation of 150 kg ha^{-1} Urea (69 kg N) and 100 kg ha^{-1} of DAP (18 kg N and 46 kg P_2O_5). However, such fertilizer rates vary with crop cultivars, soil types, climatic conditions etc. Thus, location specific recommendations are required.

Thus, the application of appropriate rate of N fertilizer is considered to be a primary means of increasing wheat grain yield, in improving N uptake and use efficiency and consequently nitrogen harvest

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ISSN 1992-0407

index (Fageria, 2014). High rates of nitrogen supply result in a higher protein content, but increased efficiency of utilization is realized when concentration in the kernels increases and grain yield remains stable (Ortiz-Monasterio *et al*., 1997). Hence, its efficient use is important for the economic sustainability of cropping systems

Weeds infestation is the main bottleneck in wheat production in Ethiopia, especially during the rainy season. Farmers in the country are aware of weed problem in their fields but often they cannot cope-up with heavy weed infestation during the peak-period of agricultural activities because of labor shortage as hand weeding is the most dominant practice, hence, most of their fields are weeded late or left un-weeded. Such ineffective weed management is considered as one of the main factors for low average yield of bread wheat resulting in average annual yield loss that ranges from 45% to 86% (Franzel *et al.,* 1987; Eshetu *et al.,* 2006). Moreover, Tran and Tremblay (2000) reported that wheat nitrogen uptake efficiency (NUPE) and nitrogen utilization efficiency (NUTE) were lower in the weed infested field than the weed free field. The amount of economic yield, therefore, increased by increasing NUPE and NUTE through effective weed management and application of optimum N fertilizer rates that decrease N losses from the soil-plant system (Muurinen, 2007).

An integrated weed management system that combines herbicides, their combinations, hand weeding and nitrogen fertilizer application is the most effective and economical way to manage weeds and increase N uptake and use efficiency in wheat (Kassim*,* 2012).

However, little research has been done to elucidate the influence of various weed management practices and N fertilizer application on the productivity and N use efficiency of wheat. Therefore, this study was conducted to determine the effect of weed management practices and nitrogen fertilizer application on grain yield, N uptake, and N use efficiency of bread wheat.

2. Materials and Methods

2.1. Description of the Study Sites

The study was conducted during the 2014 main cropping season (July to November) at Faate (06º 52' 42" N latitude, 37º 48' 25.2" E longitude, and the altitude of 2252 meters above sea level) on farmer`s fields in Wolaita Zone and at Bobicho (07˚ 34'14.6" N latitude, 37˚ 50' 06.1"E longitude, 2275 meters above sea level) on experimental site in Hadiya Zone, southern Ethiopia. Total seasonal (July to November) rainfall of 734.3 and 627.8 mm were recorded at Bobicho and Faate, respectively. Average minimum temperatures of 12.1 ˚C and 14.6 ˚C, and maximum temperatures of 21.3 ˚C and 23.1 ˚C were recorded at Bobicho and Faate, respectively.

2.2. Experimental Materials

The bread wheat variety 'Kakaba' was used for the experiment. It was released by Kulumssa Agricultural Research Center in 2010 and it is widely grown in the study areas. The variety takes 90-120 days to maturity and has grain yields ranging from 3.3-5.2 t ha^{-1} (MoARD, 2010). Pyroxsulam and 2, 4–DEE (2, 4-dichlorophenoxy ethylene ester) were used as a post-emergence herbicide. Urea (46% N) and triple super phosphate (46% P_2O_5) were used as a source of nitrogen and phosphorus respectively.

2.3. Treatments and Experimental Design

The treatments consisted of factorial combinations of four rates of nitrogen (0, 60, 85 and 110 kg N ha^{-1}) and five weed management methods [two hand weeding at two and five weeks after crop emergence (WAE), application of pyroxsulam at the rate of 20 g ha^{-1}, pyroxsulam at the rate of 10 g ha^{-1} + 2,4-DEE 0.50 kg ha^{-1}, weed free, and weedy check]. The treatments were laid out in a randomized complete block design in a factorial arrangement and replicated three times per treatment. A gross plot size of 3.0 m × 3.0 m (9 m^2) and a net plot size of 2.60 m × 2.50 m (6.5m^2) were used.

2.4. Experimental Procedure

The land was prepared to a fine tilth using an oxen plough in the month of June 2014. The plots were prepared as per the layout and leveled manually. Wheat was sown at the seed rate of 150 kg ha^{-1} by drilling in furrows of 20 cm apart manually on July 8, 2014. One third of the nitrogen fertilizer as per the treatment and a uniform dose of phosphorus at the rate of 46 kg P_2O_5 ha^{-1} in the form of triple super phosphate were applied within the rows at sowing and the remaining nitrogen in the form of urea was side-dressed in two equal splits at tillering and panicle initiation stages.

The herbicides were applied as per the treatment in the assigned plots at tillering stage of wheat. The amount of herbicides as per the treatment was calculated and measured using a sensitive digital balance and a measuring cylinder. Herbicide spray volume with water as carrier was 500 L ha^{-1}. Spraying was done with a manually operated Knapsack sprayer (15 L capacity) using flat-fan nozzle. Hand weeding and hoeing as per the treatment were done in the assigned plots at an appropriate time. The weeds in weed free plots were removed by hand frequently to keep the plots free of weeds. Plot-wise harvesting was done when the crop matured on 12th and 13th of November 2014 at Bobicho and Faate, respectively. The harvested crop was sun-dried for eight days and threshed.

2.5. Plant Sampling and Analysis

At crop maturity, representative samples of non-grain aboveground plant parts (stems, leaves and chaff) were taken to determine straw nitrogen concentration. The plant samples were rinsed with distilled water to remove soil dirt, and oven-dried at 65°C to a constant weight. The dry weight was measured using an electronic balance. The samples were ground by a rotor mill and allowed to pass through a 0.5 mm sieve to prepare a sample of 10 g. One gram of the ground sample of each treatment was subjected to digestion with H_2SO_4 (0.1 N) containing digestion mixture (10 parts potassium sulphate and 1 part copper sulphate). The nitrogen concentration in the plant tissue was determined by the Micro- Kjeldahl digestion method as described in the guide for plant nutrient analysis (FAO, 2008). Likewise, grain N concentrations were estimated from 1 g dry samples by the digestion method of Micro-Kjeldahl's apparatus. The laboratory analysis was done at Soil Laboratory Department of the Bureau of Agricultural at Hawassa, Southern Nations, Nationalities and People's Regional State.

2.6. Data Collection

The grain yield (kg ha^{-1}) was determined after threshing the sun-dried plants harvested from each net plot area and the yield was adjusted at 12.5% moisture content.

Then, the nitrogen uptake, recovery and use efficiency by the crop were determined using the formulae described by Fageria *et al.* (2011):

$$Grain\ N\ uptake\ (\frac{kg}{ha}) = \frac{N(\%)\ in\ grain\ \times grain\ yield\left(\frac{kg}{ha}\right)}{100}$$

$$Straw\ N\ uptake\ (\frac{kg}{ha}) = \frac{N(\%)\ in\ straw \times straw\ yield\left(\frac{kg}{ha}\right)}{100}$$

$$\text{Total N uptake}\left(\frac{\text{kg}}{\text{ha}}\right) = \text{N uptake of grain} + \text{N uptake of straw}$$

Apparent fertilizer N recovery efficiency (%): It indicates the quantity of nutrient uptake per unit of nutrient applied and was calculated as: $ARE(\%) = \frac{Nf - Nu}{Na} \times 100$ where, Nf is the total N uptake of the fertilized plot (kg), Nu is the total N uptake of unfertilized plot (kg), and Na is the quantity of N applied (kg).

N Agronomic efficiency (kg kg^{-1}): It is defined as the economic production obtained per unit of nitrogen applied and was calculated as: $AE\left(\frac{kg}{kg}\right) = \frac{Gf\ (kg) - Gu\ (kg)}{Na\ (kg)}$ where, AE stands for agronomic efficiency, Gf and Gu for grain yield in fertilized and unfertilized plots, respectively, and Na for quantity of fertilizer applied

Nitrogen physiological efficiencies (kg kg^{-1}): It represents the ability of a plant to transform N acquired from fertilizer into economic yield (grain). It was calculated as: $PE\left(\frac{kg}{kg}\right) = \frac{Byf\ (kg) - Byu\ (kg)}{Nf\ (kg) - Nu\ (kg)}$ where, PE stands for physiological efficiency, Byf is the biological yield (grain plus straw) of fertilized plot (kg), Byu is the biological yield of the unfertilized plot (kg), Nf is the total N uptake of the fertilized plot (kg), Nu is the total N uptake of unfertilized plot (kg).

Finally, the nitrogen harvest index (NHI) was determined as the ratio of nitrogen uptake by grain and nitrogen uptake by grain plus straw as described by Fageria (2014).

2.7. Statistical Data Analysis

The data were subjected to analysis of variance appropriate to the design using SAS version 9.2 (SAS, 2008). As the F-test for homogeneity of variances showed non-significant differences for the parameters between the locations, combined analysis of variance was done. Mean separation was done using Fisher's protected Least Significance Difference (LSD) test at 5% level of significance.

2.8. Partial Budget Analysis

The partial budget analysis was done to determine the economic feasibility of the treatments. It was calculated by taking into account the variable input cost involved and the gross returns obtained from different treatments. The variable cost also included the labor cost involved for harvesting, threshing and winnowing (ETB 100/100 kg) as their cost varied according to the yield obtained in a particular treatment. Actual yield was adjusted downwards to 10% of the experimental yield to represents the farmer`s yield as described by CIMMYT (1988). For determining gross returns, the prevailing local market price ETB 750 /100 kg of wheat at the harvest of wheat was considered. The net returns were calculated by subtracting the cost of treatment from the gross returns as RNR = GR-VC, where, RNR = Relative net returns, GR = Gross returns, and VC = Variable cost.

3. Results and Discussion

3.1. Soil Physico-chemical Properties of the Experimental Sites

Selected physico-chemical properties were analyzed for composite surface soil (0-30 cm) before wheat sowing. The results indicated that soils of the experimental sites were found to be silty clay in texture at both sites. Thus, the soil texture is suitable for wheat production as it has better water and nutrient holding capacity. Analysis of soil samples from planting depth indicated moderate level of total N (0.23%) and (0.21%) at Bobicho and Faate, respectively (Tekalign, 1991), indicating that the nutrient to be a limiting factor for wheat production in the study sites. According to the rating of Tekalign (1991), the organic matter content of the soil was low at Bobicho (1.1%) and medium (3.41%) at Faate (Table 1). The low and medium amount of organic matter in the soil might be due to low addition of crop residue as smallholder farmers use the biomass of wheat for animal feed in the study area. Similarly, the soil of the experimental sites was very low in available P according to the rating by Olsen *et al.* (1954). In agreement with this result, Kelsa *et al.* (1996) reported that available P content of most soils in southern Ethiopia is less than 5 ppm which is in the range of low P content.

Table 1. Physio-chemical properties of the experimental soils (0-30 cm depth) before sowing of bread wheat.

Soil property	Values		Rating	Reference
	BobichoFaate			
Sand (%)	11	10	-	-
Silt (%)	40	42	-	-
Clay (%)	49	48	-	-
Textural class	Silty clay	Silty clay	Silty clay	
pH 1:2.5 (H_2O)	4.5	5.2	Strongly acidic	Tekalign (1991)
Organic matter (%)	1.1	3.41	Low-Medium	Tekalign (1991)
Total N (%)	0.23	0.21	Moderate	Tekalign (1991)
Ava. P (ppm)	1.53	2.31	Very low	Olsen *et al.* (1954)

The main effects of weed management practices and nitrogen rates, the two way interaction of weed management practices and nitrogen rates and the three way interaction of location, weed management practices and nitrogen rates were significant ($P<0.01$) on all parameters measured, while the main effect of location was significant only on grain yield (Table 2). Thus, the discussions of the results are made based on the three way interactions.

3.2. Effect on Grain Yield of Wheat

The interaction effect of location, nitrogen rate, and weed management practices was significant ($P<0.01$) on grain yield (Table 2). Weed free treatment with 110 kg N ha^{-1} at Bobicho had the highest grain yield which was in statistical parity with the yield obtained in plots treated with pyroxsulam 10 g ha^{-1} + 2,4-DEE 0.5 kg ha^{-1} at 110 kg N ha^{-1} at the same place (Table 3). Similarly, the above treatments gave the highest yield at Faate. The crop grown under these treatments were less affected by the weed competition and might have effectively utilized the available resources in a better way resulting in increased grain yield. Higher grain yield obtained with the combined use of herbicides might also be attributed to broader spectrum effect thus resulting in more efficient weed control. Similarly, Baghestani *et al.* (2008) reported, increased yield of wheat with the use of herbicide mixtures than the use of single herbicides alone. On the other hand, the lowest grain yields were obtained in the weedy check plots with no nitrogen application at both locations. The presence of weeds and lack of N fertilizer application might have exacerbated nitrogen deficiency in the crop due to the stiff competition of the weed for the nutrient, resulting in a concomitant severe reduction in yield.

In agreement with this result, Nano (2012) reported the lowest grain yield (909 kg ha^{-1}) of bread wheat in weedy check at no nitrogen application as compared to the other treatments.

Under all the weed management practices, grain yield increased with increasing nitrogen rate at both locations since the addition of N may have improved early season wheat growth, which might have enhanced the competitive ability of wheat against weeds. However, the magnitude of increase was lowest at the weedy check indicating that competition due to weeds may have reduced the nitrogen use efficiency of the crop.

In general, the yield was comparatively higher at Bobicho than at Faate which might be due to lower seasonal rainfall (627.8 mm compared to 734.3 mm), higher average temperature (18.85 °C compared to 16.7 °C) and higher weed infestation at the later site as wheat is a cool season crop that requires lower average temperature for optimum production. Moreover, the grain yield (5285 kg ha^{-1}) obtained in response to the application of pyroxsulam 10 g ha^{-1} + 2,4-DEE 0.5 kg ha^{-1} at 110 kg N ha^{-1} was twice as much as that commonly obtained in the study Zone (Hadiya) (CSA, 2013), indicating the importance of proper weed management practices and the application of higher rate of nitrogen to maximize grain yield of wheat as farmers in the study area use sub-optimal rate of nitrogen (87 kg N ha^{-1}) and weed the crop late due to shortage of labour during peak cropping season (personal communication with the head of Zonal department of agriculture).

Table 2. Mean squares of combined analysis of variance for the effects of location, weed management practices and nitrogen rates on grain yield, nitrogen uptake, and efficiency of bread wheat in southern Ethiopia.

	Mean squares for sources of variation with respective degrees of freedom in parenthesis								
Parameters	L(1)	R in L(4)	W(4)	N(3)	L×W(4)	L×N(3)	W×N(12)	L×W×N (12)	Error (76)
Grain yield	3175578**	1298ns	26826406.4**	548056.1**	12836362**	25655790**	1397209.8**	719105**	911.7
Grain N concentration	0.032ns	0.0085ns	0.172**	3.0696**	0.013ns	0.00899ns	0.043**	0.0895**	0.0083
Straw N concentration	0.00001ns	0.00217ns	0.0094**	0.0408**	0.0005**	0.0024**	0.0031**	0.0071**	0.0004
Grain N uptake	1268.6ns	12.95ns	9968.0**	31092.6**	4992.2**	15575.8**	721.6**	3741.1**	6.52
Straw N uptake	2.34ns	0.37ns	132.4**	585.5**	66.9**	295.34**	22.2**	68.1**	1.55
Total N uptake	1380.0ns	9.59ns	11992.6**	39650.9**	6001.8**	19874.2**	809.4**	4661.0**	7.35
Agronomic use efficiency	48.8ns	1.96ns	1505**	6337.6**	745.2**	2925.4**	178.3**	675.7**	2.74
Apparent recovery efficiency	549.7ns	2.49ns	6349**	35409.5**	1915.4**	17738.7**	817.1**	31.9**	3.54
Physiological efficiency	42.8ns	16.21ns	1544**	22454.2**	541.01*	11225.6**	772.3**	18.7*	5.86
Nitrogen harvest index	0.145ns	1.16ns	886**	1566.0**	443.42**	783.36**	23.4**	5.3**	1.51

*L = Location, R in L = replication within location, W = weed management, N = Nitrogen rate, L×W = location and weed management interaction, L×N = location and nitrogen rate interaction, W×N = weed management and nitrogen rate interaction, L×W×N = Location, weed management and nitrogen rate interaction; *, ** = Significant at p = 0.05 and p = 0.05, respectively, and ns = Non - significant*

Table 3. Interaction effect of location, weed management methods and nitrogen application on grain yield (kg ha^{-1}) of bread wheat in southern Ethiopia

Weed management Method	Nitrogen (kg N ha^{-1})							
	0	60	85	110	0	60	85	110
	Bobicho				Faate			
Weedy check	930^{q}	1454^{p}	1724^{l}	2181^{k}	813^{r}	1140^{q}	1608^{l}	1851^{m}
Weed free check	1785^{o}	3778^{i}	5171^{b}	5369^{a}	1475^{p}	3489^{ij}	4796^{e}	5052^{bc}
Pyroxsulam 20 g ha^{-1}	1876^{l-n}	3885^{h}	4750^{g}	5196^{b}	1581^{m}	3492^{i}	4400^{h}	4719^{f}
Pyroxsulam 10 g ha^{-1} + 2,4-DEE 0.5 kg ha^{-1}	1866^{mn}	3644^{j}	4899^{f}	5285^{a}	1666^{op}	3323^{kl}	4398^{h}	4868^{f}
Two hand weeding at 2 and 5 WAE	1844^{l-n}	3698^{j}	4934^{e}	5173^{b}	1553^{op}	3368^{m}	4536^{g}	$4806e^{ef}$
LSD (5%)	96.0							
CV (%)	7.7							

Means followed by the same letter are not significantly different from each other at P = 0.05 level of significance; CV= Coefficient of variation; LSD =Least significant difference; WAE = weeks after crop emergence.

3.3. Nitrogen Concentration in Grain and Straw

3.3.1. Nitrogen concentration in grains

The nitrogen concentration in grain was significantly ($P < 0.01$) affected by the interaction of location, weed management practices and nitrogen rates (Table 2). The highest amount of nitrogen concentration in grain (2.24%) was recorded for the weed free plot in combination with 110 kg N ha^{-1} at Bobicho followed by the same treatment (2.23%) at Faate (Table 4). However, the lowest nitrogen concentration in grain (1.11%) was recorded for the weedy check with 0 kg N ha^{-1} at Faate (Table 4).

Table 4. Interaction effect of location, weed management method, and nitrogen application rate on nitrogen concentration (%) of grain and straw of bread wheat in southern Ethiopia.

Weed management Method	Nitrogen concentration in grain (%)							
	Nitrogen (kg N ha^{-1})							
	0	60	85	110	0	60	85	110
	Bobicho				Faate			
Weedy check	1.12^{p}	1.62^{i}	1.61^{l}	2.08^{ab}	1.11^{p}	1.61^{i}	1.63^{i}	2.07^{b}
Weed free check	1.46^{m}	1.78^{h}	1.85^{e}	2.24^{ab}	1.45^{mn}	1.75^{h}	1.84^{e}	2.23^{ab}
Pyroxsulam 20 g ha^{-1}	1.42^{m}	1.62^{i}	1.82^{fg}	2.18^{ab}	1.41^{m}	1.62^{j}	1.81^{fg}	2.18^{ab}
Pyroxsulam 10 g ha^{-1} + 2,4-DEE 0.5 kg ha^{-1}	1.44^{m}	1.57^{j}	1.85^{e}	2.17^{ab}	1.42^{m}	1.57^{j}	1.82^{fg}	2.06^{b}
Two hand weeding at 2 and 5 WAE	1.42^{m}	1.61^{i}	1.82^{fg}	2.21^{ab}	1.62^{i}	1.54^{jk}	1.72^{gh}	2.22^{ab}
LSD (5%)	0.07							
CV (%)	2.7							
	Nitrogen concentration in straw (%)							
Weedy check	0.18^{m}	0.26^{g}	0.27^{g}	0.32^{bc}	0.17^{m}	0.25^{gh}	0.28^{fg}	0.29^{f}
Weed free check	0.24^{jkl}	0.27^{fg}	0.33^{b}	0.36^{a}	0.27^{fg}	0.28^{fg}	0.31^{c}	0.34^{ab}
Pyroxsulam 20 g ha^{-1}	0.26^{g}	0.25^{gh}	0.25^{gh}	0.32^{bc}	0.29^{f}	0.26^{g}	0.24^{jkl}	0.29^{f}
Pyroxsulam 10 g ha^{-1} + 2,4-DEE 0.5 kg ha^{-1}	0.23^{jkl}	0.25^{gh}	0.27^{fg}	0.33^{b}	0.26^{g}	0.24^{jkl}	0.27^{fg}	0.32^{b}
Two hand weeding at 2 and 5 WAE	0.24^{jkl}	0.27^{fg}	0.31^{c}	0.35^{a}	0.27^{fg}	0.27^{fg}	0.31^{c}	0.34^{ab}
LSD (5%)	0.02							
CV (%)	1.9							

Means followed by the same letter are not significantly different from each other at P = 0.05 level of significance; CV= Coefficient of variation; LSD = Least significant difference; WAE = weeks after crop emergence.

The highest nitrogen concentration of grains in the weed free plots in combination with 110 kg N ha^{-1} might be due to sufficient availability of nitrogen for the crop in the absence of weed competition. The result showed significantly higher concentration in grains with the combination of weed management practices and N fertilizer over the combination of weedy check with N application rates. Availability and effective absorption of nitrogen in these treatments might have resulted in increased N concentration compared to treatment combinations involving weedy check (Table 4). Similarly, Nano (2012) reported that weed management method with increased nitrogen application rates (60- 120 kg N ha^{-1}) resulted in the highest grain nitrogen concentration (1.52-2.28%) in wheat at Kulumsa, Southeastern Ethiopia

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3.3.2. Nitrogen concentration in straw

Nitrogen concentration in straw was significantly (P<0.01) affected by the interaction of location, weed management practices and nitrogen rates (Table 2). Like the N concentration in grain, straw N concentration was significantly higher for weed free check with 110 kg N ha^{-1} at Bobicho and for the treatments with the combination of two hand weeding at 2 and 5 WAE and application of 110 kg N ha^{-1}at both locations (Table 4). A perusal of data (Table 3) further revealed that in the unweeded plots the N concentration in straw was significantly lower under all N application rates than the other weed management practices and N application rates at both locations. In line with this result, Julie *et al.* (2008) stated that controlling weeds leads to more vigorous plants, which may increase N concentration in biological yield especially in straw because of healthier roots and greater density of root hairs. Similarly, Kumbhar *et al.* (2007) reported that the combination of weed management methods with zero N fertilizer rates gave lower straw N concentration as compared to N-applied plots of wheat.

3.4. Effect on Nitrogen Uptake of Wheat

3.4.1. Nitrogen uptake by grains

The nitrogen uptake by the grain was significantly (P < 0.01) affected by the interaction of location, weed management practices and nitrogen rates (Table 2). The highest amount of nitrogen uptake by grain (120.4 kg ha^{-1}) was recorded for the weed free plot plus 110 kg N ha^{-1} at Bobicho, followed by the treatment in which pyroxsulam 10 g ha^{-1} + 2,4-DEE 0.5 kg ha^{-1} and 110 kg N ha^{-1} (115.1 kg ha^{-1}) was applied at the same place (Table 5). However, the lowest nitrogen uptake by grain (9.1 kg ha^{-1}) was recorded for the weedy check plus 0 kg N ha^{-1} treatment at Faate (Table 5). The highest nitrogen uptake by grain at both locations in the weed free plots to which 110 kg N ha^{-1} was applied might be due to sufficient availability of nitrogen for the crop in the absence of weed competition. The result also showed significantly higher N uptake by grains with both hand weeding and application of herbicides over the combination of weedy check with N application rates. Higher grain yield and grain N concentration in these treatments resulted in increased N uptake compared to treatments combinations containing the weedy check. In conformity with this result, Tesfaye *et al.* (2014) reported that two hand weeding, 25 and 35 days after crop emergence, with 85 kg N ha^{-1} resulted in the highest grain N uptake (101.7 kg N ha^{-1}) in wheat. Similarly, Gholamereza *et al.* (2011) reported high nitrogen uptake by the grain from higher rate of nitrogen (131 kg ha^{-1}) application combined with improved weed management practices due to enhanced N absorption in winter wheat. On the other hand, uncontrolled weed growth throughout the crop growth period, coupled with absence of nitrogen application, resulted in the lowest N uptake in grain perhaps due to severe competition for growth resources like nutrients, moisture, light and space. This competition might have also restricted the crop root growth and development, thus resulting in lower grain yield, and may have deprived the crop from accumulating more N in the grains. Likewise, Muhammad *et al.* (2006) reported the lowest N uptake of 14.5 kg ha^{-1} from weedy checks with no N fertilizer application.

In general, similar to the grain yield, the nitrogen uptake was comparatively higher for Bobicho than Faate which might be due to lower weed infestation at the former site than the later.

Table 5. Interaction effect of location, weed management methods, and nitrogen application on nitrogen uptake of grain (kg ha^{-1}) of bread wheat in southern Ethiopia.

Weed management Method	Nitrogen (kg N ha^{-1})							
	0	60	85	110	0	60	85	110
	Bobicho				Faate			
Weedy check	10.5^{p}	23.6^{no}	27.9^{l}	45.5^{k}	9.1^{p}	18.4^{o}	26.3^{m}	38.4^{l}
Weed free check	26.2^{m}	67.3^{h}	95.7^{d}	120.4^{a}	21.5^{mn}	61.2^{h}	88.4^{d}	112.8^{c}
Pyroxsulam 20 g ha^{-1}	26.7^{m}	63.3^{i}	86.7^{fg}	113.7^{c}	22.4^{m}	56.7^{j}	79.8^{ef}	103.2^{d}
Pyroxsulam 10 g ha^{-1} + 2,4-DEE 0.5 kg ha^{-1}	26.9^{m}	57.5^{j}	90.8^{e}	115.1^{b}	23.7^{m}	52.4^{j}	80.4^{ef}	100.3^{de}
Two hand weeding at 2 and 5 WAE	26.3^{m}	59.5^{j}	90.2^{e}	114.4^{b}	25.7^{m}	52.1^{j}	78.6^{ef}	107.0^{cd}
LSD (5%)	4.15							
CV (%)	4.7							

Means followed by the same letter are not significantly different from each other at P = 0.05 level of significance; CV= Coefficient of variation; LSD = Least significant difference; WAE = weeks after crop emergence..

3.4.2. Nitrogen uptake by straw

Nitrogen uptake by straw was significantly (P<0.01) affected by the interaction of location, weed management practices, and nitrogen rates (Table 2). Like the N uptake by grain, the N uptake by straw was also highest for the weed free check with 110 kg N ha^{-1} at Bobicho, which was in statistical parity with the treatment in which combination of two hand weeding at 2 and 5 WAE plus 110 kg N ha^{-1} was applied at both locations (Table 6).

Table 6. Interaction effect of location, weed management methods, and nitrogen application on nitrogen uptake of straw (kg ha^{-1}) of bread wheat in southern Ethiopia.

Weed management Method	Nitrogen (kg N ha^{-1})							
	Bobicho				Faate			
	0	60	85	110	0	60	85	110
Weedy check	8.5^{m}	12.3^{g}	12.9^{g}	16.8^{d}	7.2^{m}	12.1^{h-k}	12.6^{de}	15.8^{de}
Weed free check	10.8^{jkl}	16.5^{d}	18.9^{c}	25.4^{a}	11.7^{j-l}	15.8^{de}	17.5^{c}	24.2^{a}
Pyroxsulam 20 g ha^{-1}	12.9^{fg}	10.2^{kl}	14.1^{j}	21.7^{b}	14.5^{gh}	10.1^{kl}	14.1^{f}	20.5^{b}
Pyroxsulam 10 g ha^{-1} + 2,4-DEE 0.5 kg ha^{-1}	11.7^{g-i}	10.6^{kl}	15.8^{de}	21.5^{b}	14.0^{hi}	9.7^{l}	16.2^{d}	21.8^{b}
Two hand weeding at 2 and 5 WAE	12.5^{f-g}	16.6^{d}	19.3^{c}	25.2^{a}	13.8^{gi}	16.9^{cd}	16.9^{cd}	23.9^{a}
LSD (5%)	2.02							
CV (%)	7.9							

Means followed by the same letter are not significantly different from each other at P = 0.05 level of significance; CV = Coefficient of variation, LSD = Least significant difference; WAE = weeks after crop emergence.

A perusal of data (Table 6) further revealed that in the unweeded plots, the N uptake by straw was significantly lower under all N application rates than the other weed management practices and N application rates at both locations. In agreement with this result, Julie *et al.* (2008) stated that controlling weeds leads to more vigorous plants, which may increase N uptake in biological yield especially by straw. On the other hand, there was inconsistent trend in N uptake with the increase in N application rates in herbicide treated plots. Similarly, Kumbhar *et al.* (2007) reported that the combination of weed management methods with zero N fertilizer rates resulted in the lowest straw N uptake as compared to plots treated with nitrogen.

In general, the nitrogen concentration (Table 4) and uptake by the grain (Table 5) were higher than the nitrogen concentration and uptake by straw, indicating the high partitioning of nitrogen to the grain. Likewise, Kiniry *et al.* (2001) and Fageria *et al.* (2010) reported higher nitrogen concentration in grain of rice compared to the straw of the crop.

3.4.3. Total nitrogen uptake

Interaction of location, weed management practices and nitrogen rates showed significant (P<0.01) effect on the total (grain + straw) nitrogen uptake (Table 2). The highest total nitrogen uptake (145.8 kg ha^{-1}) was recorded for the weed free plus 110 kg N ha^{-1} treatment at Bobicho followed by two hand weeding at 2 and 5 WAE plus 110 kg N ha^{-1} treatment at same location while the lowest total nitrogen uptake (16.3 kg ha^{-1}) was recorded for the weedy check with 0 kg N ha^{-1} at Faate (Table 7).

It was also found that the total nitrogen uptake by the crop increased significantly with the increase in nitrogen application rate under all the weed management practices at both locations. Thus, the results clearly indicated increments in the total N uptake in wheat due to weed management and increasing the rate of nitrogen application. The higher uptake of nitrogen by the wheat plants under the weed free condition might be due to a significant reduction in weed biomass as a result of better control of weeds with the weed management practices, resulting in enhanced uptake of the nutrient and its concentration in the grain and straw tissues. In addition to the effective weed control, congenial growth environment for development of wheat root hairs and growth might have led to enhanced N uptake by the roots of the plant. In agreement with this result, Kumbhar *et al.* (2007) reported the highest plant N uptake of 131.2 kg N ha^{-1} in wheat at the rate of 100 kg N ha^{-1} with herbicide combinations. On the other hand, weedy check with N fertilizer showed lower N uptake than other weed control methods. This might be due to stiffer competition from the weeds for uptake of nitrogen, which may have resulted in lower N concentration in weedy check plots. Similarly, Amanullah (2013) reported that 120 kg N ha^{-1} in weedy check plots resulted in lower N uptake by maize than under the weed managed treatments.

Nitrogen uptake at Faate was in general lower than that at Bobicho. This might be due to lower nitrogen concentration that was recorded from treatments which might have been taken up by the high weed density present at Faate.

Table 7. Interaction effect of location, weed management methods, and nitrogen application on total nitrogen uptake (kg ha^{-1}) by bread wheat in southern Ethiopia.

Weed management Method	Nitrogen (kg N ha^{-1})							
	0	60	85	110	0	60	85	110
	Bobicho				Faate			
Weedy check	18.9^{u}	35.8^{rs}	40.9^{o}	62.2^{n}	16.3^{u}	30.4^{t}	38.8^{p}	54.2^{o}
Weed free check	36.9st	83.7^{k}	114.6^{f}	145.8^{a}	33.3^{q-t}	77.1^{k}	105.9^{f}	136.8^{bc}
Pyroxsulam 20 g ha^{-1}	39.7^{p}	73.5^{l}	100.8^{j}	135.5^{de}	36.8^{pq}	66.8^{l}	93.8^{j}	125.1^{e}
Pyroxsulam 10 g ha^{-1} + 2,4-DEE 0.5 kg ha^{-1}	38.6^{p-r}	68.2^{m}	106.6^{hi}	136.6^{bc}	37.7^{pq}	62.1^{mn}	96.6^{i}	120.8^{cd}
Two hand weeding at 2 and 5 WAE	38.8^{p}	76.1^{l}	109.3^{g}	139.6^{b}	39.3^{m}	68.7^{l}	95.6^{g}	131.2^{bc}
LSD (5%)	4.41							
CV (%)	3.5							

Means followed by the same letter are not significantly different from each other at P = 0.05 level of significance; CV= Coefficient of variation; LSD = Least significant difference; WAE = weeks after crop emergence.

3.5. Effect on Nitrogen Use Efficiency

3.5.1. Agronomic nitrogen efficiency

Agronomic nitrogen efficiency was significantly ($P<0.01$) affected by the interaction of location, weed management practices, and nitrogen rate (Table 2). The highest agronomic efficiency values of 39.8 kg kg^{-1} and 37.1 kg kg^{-1} were recorded in the weed free plots to which 85 kg N ha^{-1} was applied at Bobicho and Faate, respectively. However, the lowest agronomic efficiency values of 5.4 kg kg^{-1} and 8.4 kg kg^{-1} were recorded for the weedy check plots supplied with 60 kg N ha^{-1} at Faate and Bobicho, respectively (Table 8).

Table 8. Interaction effect of location, weed management methods, and nitrogen application on N agronomic efficiency (kg kg^{-1}) of bread wheat in southern Ethiopia.

Weed management Method	Nitrogen (kg N ha^{-1})					
	60	85	110	60	85	110
	Bobicho			Faate		
Weedy check	8.7^{j}	9.3^{i}	12.5^{o}	5.4^{j}	8.8^{i}	9.4^{i}
Weed free check	33.2^{c}	39.8^{a}	32.6^{e}	31.7^{ef}	37.1^{a}	30.5^{g}
Pyroxsulam 20 g ha^{-1}	33.4^{c}	33.8^{c}	30.2^{g}	27.1^{h}	33.2^{c}	28.5^{h}
Pyroxsulam 10 g ha^{-1} + 2,4-DEE 0.5 kg ha^{-1}	29.6^{g}	35.6^{b}	31.1^{f}	27.6^{gh}	32.2^{ef}	9.2^{g}
Two hand weeding at 2 and 5 WAE	31.9^{ef}	36.3^{b}	30.3^{g}	30.3^{g}	35.1^{b}	28.8^{g}
LSD (5%)	2.9					
CV (%)	7.9					

Means followed by the same letter are not significantly different from each other at P = 0.05 level of significance; CV= Coefficient of variation; LSD = Least significant difference; WAE = weeks after crop emergence.

The agronomic efficiency of applied N increased with the increase in N application rates in weedy check at both locations, but when the weeds were controlled it increased up to 85 kg N ha^{-1} and then showed a decline which might be due to higher aboveground dry biomass accumulation rather than grain yield at higher N rates. This result is in agreement with the finding of Amir *et al*. (2012) who reported that increase in N fertilizer rates resulted in a decline in agronomic efficiency.

Similarly, Craswell and Godwin (1984) reported that high agronomic efficiency could be obtained if the yield increment per unit applied nutrient was high. Dobbermann (2005) indicated that an agronomic efficiency value ranging from 10 to 30 is common, and values higher than 30 indicate efficiently managed systems. Consistent with the foregoing suggestion, in the study, management of weeds in combination with N application resulted in good agronomic efficiency of applied N that ranged from 27.1 to 39.8 kg kg^{-1} (Table 8). Moreover, higher agronomic efficiency at 85 kg N ha^{-1} than 60 kg N ha^{-1} could be due to a combined effect of applied N and optimum weed management practice resulting in higher grain yield. On the other hand, agronomic efficiency values of 5.4 to 12.5 kg kg^{-1} were obtained under weedy checks even with the application of N as high as 110 kg N ha^{-1} showing the importance of appropriate weed management in wheat production.

3.5.2. Nitrogen apparent recovery efficiency

Nitrogen apparent recovery (NAR) efficiency depends on the congruence between plant N demand and the quantity of N released from applied N (Fageria *et al.*, 2011). NAR was significantly (P<0.01) affected by the interaction of location, weed management practices and nitrogen (Table 2). The highest apparent nitrogen recovery (NAR) efficiency of 98.2% was recorded in weed free with 110 kg N ha^{-1} at Faate followed by the treatment to which two hand weeding at 2 and 5 WAE plus 110 kg N ha^{-1} was applied at Faate (92.5%) while the lowest apparent recovery efficiency of 21.3% was recorded in weedy check plot to which 60 kg N ha^{-1} was applied at Bobicho (Table 9). Unlike other values such as yield, the nitrogen recovery efficiency of wheat at Faate was comparatively higher than that at Bobicho. This might be due to lower total nitrogen in the soil before sowing the crop at Faate (Table 1), thus the crop had used the applied nitrogen more efficiently.

The apparent nitrogen recovery efficiency increased with the increase in N application from 60 kg to 85 kg N ha^{-1} then showed a decrease at 110 kg N ha^{-1} under the weedy checks. However, when the weeds were controlled it increased with the increase in N application rate. The decrease in apparent nitrogen recovery efficiency at 110 kg N ha^{-1} under the weedy check could be due to more competitiveness of the weeds at the highest nitrogen rate, using most of the N resource that otherwise could be taken up the crop.

The higher apparent N efficiency recorded in response to the combination of 110 kg N ha^{-1} under weed free treatment might be due to high utilization of nitrogen by the crop in absence of competition from the weeds. This increased trend of NAR efficiency due to increased rate of N with weed management could also be due to higher total N uptake from 110 kg N ha^{-1}. Furthermore, NAR efficiency of a nutrient is mainly a function of indigenous nutrients supply and the amount of fertilizer that can be expected in situations where sink potential is large (e.g. favorable climatic condition, sufficient water supply and mainly low weed pressure) (Fageria and Baligar, 2005). Similarly, Delogu *et al.* (1998) reported increased in apparent nitrogen recovery efficiency at the rate of 150 kg N ha^{-1} for wheat and barley. In contrast, Haile *et al.* (2012) reported lower N use efficiency (27.10%) with the highest nitrogen rate of 120 kg N ha^{-1} and the highest value (39.27%) at the lowest N rate of 30 kg N ha^{-1} on bread wheat.

The weedy check plots had the lowest N apparent recovery efficiency of nitrogen that ranged from 21.3% to 37.9% while the apparent recovery efficiency of nitrogen efficiency obtained in this study under weed management practices ranged from 51% to 98.2% (Table 9).

Table 9. Interaction effect of location, weed management methods, and nitrogen application on apparent nitrogen recovery efficiency (%) of bread wheat in southern Ethiopia.

Weed management Method	Nitrogen level (kg N ha^{-1})					
	60	85	110	60	85	110
	Bobicho			Faate		
Weedy check	21.3^{q}	30.0^{p}	23.5^{q}	27.6^{p}	37.9^{o}	29.0^{p}
Weed free check	69.2^{j}	81.5^{de}	86.4^{c}	76.3^{fg}	90.3^{b}	98.2^{a}
Pyroxsulam 20 g ha^{-1}	60.9^{kl}	71.3^{ij}	78.1^{f}	57.9^{l}	73.1^{i}	86.9^{c}
Pyroxsulam 10 g ha^{-1} + 2,4-DEE 0.5 kg ha^{-1}	53.2^{m}	75.7^{gh}	82.5^{d}	51.0^{n}	78.8^{ef}	90.4^{b}
Two hand weeding at 2 and 5 WAE	54.7^{m}	75.3^{gh}	81.2^{de}	62.8^{k}	82.6^{d}	92.5^{b}
LSD (5%)	3.06					
CV (%)	3.8					

Means followed by the same letter are not significantly different from each other at P = 0.05 level of significance; CV= Coefficient of variation; LSD = Least significant difference; WAE = weeks after crop emergence.

This suggested that the presence of weeds adversely affected the apparent nitrogen recovery efficiency. However, nitrogen recovery may vary with the location, soil type, crop variety and the environmental conditions prevailing during the crop growth (Sinebo *et al.*, 2004). In conformity with this result, studies from Ethiopia reported highest apparent nitrogen recovery efficiency of 46.8% (Amsal and Tanner, 2001), 65.8% (Selamyihun *et al.*, 2000) and 39.27% (Haile *et al.,* 2012) on wheat in Ethiopia. However, the common apparent recovery N efficiency values ranging between 30 and 50%, and 50 and 80% indicate well managed system (Dobbermann, 2005). The high NAR values obtained in this study especially under the weed management treatments and higher nitrogen rates might be due to the synergistic effect between proper weed management practices and the nitrogen fertilizer applied. In line with this result, Legg and Meisinger (1982) reported that the use of appropriate rates, efficient timing and placement of nitrogen could increase recovery of applied nitrogen up to 80%. Similarly, Nano (2012) reported the highest apparent recovery of 80.8% with the combination of 60 kg N ha^{-1} with hand weeding and hoeing at tillering of bread wheat. However, the NAR values obtained in this study especially under weed free treatment at higher rates of nitrogen are higher than that reported in most literature and thus, there is a need for further investigation to verify the results.

3.5.3. Physiological nitrogen efficiency

Physiological nitrogen efficiency was significantly (P<0.05) influenced by the interaction of location, weed management practices, and nitrogen rate (Table 2). Except for the weed free check and hand-weeded plots which showed decreasing trend, the physiological efficiency of applied N increased up to 85 kg N ha^{-1}and then declined at 110 kg N ha^{-2} (Table 10). The highest nitrogen physiological efficiency (NPE) of 84.7 kg kg^{-1} was recorded in weed free combined with the application of 60 kg N ha^{-1} at Faate, while the lowest physiological efficiency of 26.2 kg kg^{-1} was recorded in pyroxsulam 10 g ha^{-1} + 2,4-DEE 0.50 kg ha^{-1} applied with 60 kg N ha^{-1} at Bobicho (Table 10). The higher NPE in the weed free condition might be attributed to adequately available nutrient during grain development stage that might have increased the assimilation and redistribution of N from the vegetative plant components to wheat grain.

Table 10. Interaction effect of location, weed management methods and nitrogen application on N physiological efficiency (kg kg^{-1}) of bread wheat in southern Ethiopia.

Weed management method	Nitrogen (kg N ha^{-1})					
	60	85	110	60	85	110
	Bobicho			Faate		
Weedy check	49.9^{gk}	51.6^{e-k}	45.7^{k}	54.0^{d-i}	55.1^{d-j}	41.5^{jk}
Weed free check	80.3^{ab}	69.2^{c}	56.5^{c-g}	84.7^{a}	77.0^{b}	57.6^{c-f}
Pyroxsulam 20 g ha^{-1}	35.0^{l}	56.2^{c-h}	53.8^{d-i}	31.3^{l}	52.6^{c-i}	50.5^{d-h}
Pyroxsulam 10 g ha^{-1} + 2,4-DEE 0.5 kg ha^{-1}	29.0^{l}	52.9^{d-k}	48.8^{i-k}	26.2^{l}	48.4^{d-i}	45.2^{h-k}
Two hand weeding at 2 and 5 WAE	74.8^{b}	59.0^{cd}	51.2^{f-k}	71.4^{b}	54.7^{cde}	47.6^{f-k}
LSD (5%)	7.24					
CV (%)	10.8					

Means followed by the same letter are not significantly different from each other at P = 0.05 level of significance; CV= Coefficient of variation; LSD = Least significant difference; WAE = weeks after crop emergence.

The highest physiological nitrogen efficiency of the crop at 85 kg N ha^{-1} with weed management practices over the rate of 110 kg N ha^{-1} might indicate efficient utilization of nitrogen for biomass and grain production. In conformity with this result, Roberts (2008) reported higher N physiological efficiency under the application of lower levels (80 kg N ha^{-1}) of nitrogen in wheat than 110 kg N ha^{-1}. The combination of two hand weeding at 2 and 5 WAE with N fertilizer rate showed higher NPE over herbicides with N fertilizer rate. This might be due to improved soil environment under hand weeding especially soil aeration which might have also contributed to higher total N and water uptake compared to herbicide treatments.

3.5.4. Nitrogen harvest index (%)

Nitrogen harvest index (NHI) is defined as the amount of N accumulated in grain divided by the amount of N accumulated in grain plus straw. Nitrogen harvest index indicates the level of efficiency of plants to use acquired nitrogen for grain formation (Fageria, 2014). A high NHI indicates efficient utilization of N. Nitrogen harvest index was significantly (P<0.01) influenced by the interaction of location, weed management practices and nitrogen rate (Table 2).

The highest nitrogen harvest indices (NHI) of 86.2% and 86.1% were recorded from pyroxsulam 20 g ha^{-1} with 85 kg N ha^{-1} at Bobicho and at Faate, while the lowest nitrogen harvest index of 51.3% was recorded for weedy check plots at the rate of 60 kg N ha^{-1} at Faate (Table 11). Except for the weedy check plots, which showed an increasing trend with the increase in the rate of nitrogen rate, the nitrogen harvest index in general was increased up to 85 kg N ha^{-1} and then showed a declining trend at 110 kg N ha^{-1}.The decline in NHI at the highest N rate in combination with weed management practices could be due to partitioning of total nitrogen content more to the vegetative part of the crop and increased total above ground biomass yield. Similarly, Mohammad *et al.* (2010) reported the highest nitrogen harvest index of 81% in wheat at the rate of 100 kg N ha^{-1}. In contrast, Mahdi *et al.* (2014) reported that higher nitrogen rates in combination with herbicide application resulted in declining nitrogen harvest indices.

Table 11. Interaction effect of location, weed management methods, and nitrogen application nitrogen harvest index (%) of bread wheat in southern Ethiopia.

Weed management Method	Nitrogen (kg N ha^{-1})							
	0	60	85	110	0	60	85	110
	Bobicho				Faate			
Weedy check	56.9^{p}	65.5^{o}	71.2^{jk}	71.8^{jk}	51.3^{p}	69.3^{no}	70.9^{jk}	72.0^{j}
Weed free check	72.2^{j}	80.2^{hij}	83.1^{cde}	82.8^{de}	69.9^{kl}	80.6^{gf}	83.5^{b-e}	82.9^{cde}
Pyroxsulam 20 g ha^{-1}	67.1^{mno}	85.8^{a}	86.2^{a}	83.6^{b-e}	67.6^{mn}	85.8^{a}	86.1^{a}	83.7^{b-e}
Pyroxsulam 10 g ha^{-1} + 2,4-DEE 0.5 kg ha^{-1}	68.6^{m}	84.9^{ab}	85.3^{ab}	84.4^{a-e}	68.8^{lm}	85.2^{ab}	85.2^{ab}	84.5^{a-d}
Two hand weeding at 2 and 5 WAE	67.6^{mn}	77.9^{i}	82.6^{de}	82.4^{ef}	67.9^{mn}	78.4^{hi}	82.7^{de}	82.8^{de}
LSD (5%)	2.01							
CV (%)	1.9							

Means followed by the same letter are not significantly different from each other at P = 0.05 level of significance; CV= Coefficient of variation; LSD = Least significant difference; WAE = weeks after crop emergence.

3.6. Partial Budget Analysis

In this study, the highest net return of 28534 Birr ha^{-1} at Bobicho and 25736 Birr ha^{-1} at Faate were recorded from pyroxsulam 10 g ha^{-1} + 2,4-DEE 0.50 kg ha^{-1} with 110 kg N ha^{-1} (Table 12). Further, the relative net returns increased with increasing N fertilizer rate application with weed management practices most probably due to better control of weeds that consequently resulted in increased grain yield. Further, interaction of higher N rate with weed management practices showed better relative returns over lower rates with weed management.

Table 12. Gross return, total variable cost and net return from weed management practices and nitrogen fertilizer application rates in bread wheat at Bobicho and Faate, southern Ethiopia.

Weed management method	Gross return from adjusted grain yield (ETB ha^{-1})							
	Nitrogen level (kg N ha^{-1})							
	Bobicho				Faate			
	0	60	85	110	0	60	85	110
Weedy check	6277	9817	11640	14722	5490	7695	10852	12495
Pyroxsulam 20 g ha^{-1}	12660	26227	32062	35070	10672	23572	29700	31852
Pyroxsulam 10 g ha^{-1} + 2,4-DEE 0.5 kg ha^{-1}	12592	24592	33067	35677	11242	22432	29685	32857
Two hand weeding at 2 and 5 WAE	12442	24960	33307	34920	10485	22732	30622	32437
Total variable cost (ETB ha^{-1})								
Weedy check	841	2227	3089	3170	828	2217	3080	3158
Pyroxsulam 20 g ha^{-1}	3054	5816	6901	7500	3046	5808	6894	7489
Pyroxsulam 10 g ha^{-1} + 2,4-DEE 0.5 kg ha^{-1}	2466	5071	6429	7143	2456	5063	6421	121
Two hand weeding at 2 and 5 WAE	2861	5438	6856	7383	2849	5431	6835	7356
Net return (ETB ha^{-1})								
Weedy check	5436	7590	8550	11552	4661	5478	7772	9336
Pyroxsulam 20 g ha^{-1}	9605	20410	25160	27569	7625	17764	22805	24362
Pyroxsulam 10 g ha^{-1} + 2,4-DEE 0.5 kg ha^{-1}	10126	19521	26637	28534	8195	17368	23263	25736
Two hand weeding at 2 and 5 WAE	580	19522	26451	27536	635	17301	23787	25081

Cost of pyroxsulam 2650 ETB/kg; cost of 2,4-DEE 300 ETB/kg; Spraying ETB 60/ ha; cost of Urea 1090 ETB/100 kg, cost of hand weeding and hoeing 2 and 5 WAE 40 persons @ETB 30 / person /ha, Field price of wheat ETB 100 per 100 kg including transportation, Local market price of bread wheat was 750 ETB/100 kg, net income was the product of market price and adjusted grain yield; WAE = Weeks after crop emergence.

In line with this result, Muhammad *et al.* (2013) reported that herbicide combinations and N fertilizer levels effectively controlled weed infestation on bread wheat and gave higher yield that resulted directly to high relative net return. All combinations of weed management practices and N fertilizer rates gave higher net benefit over weedy check with N application rates.

4. Conclusion

The results of this study indicated significant interaction effects of location, N fertilizer rate and weed management methods on grain yield, grain and straw nitrogen concentration, nitrogen uptake, and N use efficiency of bread wheat. Among the treatments evaluated, the combined application of pyroxsulam 10 g ha^{-1} + 2,4-DEE 0.50 kg ha^{-1} with 110 kg N ha^{-1} gave the highest yield advantage of 4355 kg ha^{-1} at Bobicho and 4055 kg ha^{-1} at Faate as compared to the control and provided the highest economic advantage at both locations followed by two hand weeding at Faate. Thus, wheat growers in the study area can apply herbicide combination of 10 g of pyroxsulam ha^{-1} and 2,4-DEE 0.50 kg ha^{-1} especially when there is labour shortage with 110 kg N ha^{-1} to manage the weeds efficiently and thereby to improve the productivity of the crop. Moreover, as the NAR values obtained in this study are higher there is a need for further investigation to verify the results.

5. Acknowledgements

The authors thank the Ethiopian Ministry of Education for providing the budget for this research and Areka Agricultural Research Center for providing the necessary research facilities and materials.

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