Godebo *et al. Environ Syst Res (2021) 10:12*
https://doi.org/10.1186/s40068-020-00210-4

Environmental Systems Research

RESEARCH

Open Access

Nutrient uptake, use efficiency and productivity of bread wheat (*Triticum aestivum* L.) as affected by nitrogen and potassium fertilizer in Keddida Gamela *Woreda*, Southern Ethiopia

Temesgen Godebo[1*], Fanuel Laekemariam[2] and Gobeze Loha[3]

Abstract

Bread wheat (*Triticum aestivum* L.) is one of the most important cereal crops in Ethiopia. The productivity of wheat is markedly constrained by nutrient depletion and inadequate fertilizer application. The experiment was conducted to study the effect of nitrogen (N) and potassium (K) fertilizer rates on growth, yield, nutrient uptake and use efficiency during 2019 cropping season on Kedida Gamela *Woreda*, Kembata Tembaro Zone Southern Ethiopia. Factorial combinations of four rates of N (0, 23, 46 and 69 kg Nha^{-1}) and three rates of K_2O (0, 30 and 60 kg Nha^{-1}) in the form of urea (46–0-0) and murate of potash (KCl) (0-0-60) respectively, were laid out in a randomized complete block design with three replications. The results showed that most parameters viz yield, yield components, N uptake and use efficiency revealed significant differences ($P<0.05$) due to interaction effects of N and K. Fertilizer application at the rate of 46 N and 30 kg K ha^{-1} resulted in high grain yield of 4392 kg ha^{-1} and the lowest 1041 from control. The highest agronomic efficiency of N (52.5) obtained from the application of 46 kg N ha^{-1}. Maximum physiological efficiency of N (86.6 kg kg^{-1}) and use efficiency of K (58.6%) was recorded from the interaction of 46 and 30 kg K ha^{-1}. Hence, it could be concluded that applying 46 and 30 kg K ha^{-1}was resulted in high grain yield and economic return to wheat growing farmers of the area. Yet, in order to draw sound conclusion, repeating the experiment in over seasons and locations is recommended.

Keywords: *Economic return*, *Growth*, *Yield and nutrient use efficiency*

Background

Wheat is main staple crops in terms of both production and consumption in Ethiopia. It is one of the most important cereals cultivated in Ethiopia (Jemal et al. 2015). Ethiopia is the second largest wheat (*Triticum aestivum L.*) producer in sub-Saharan Africa, after South Africa (FAO, 2019). Wheat ranks fourth after tef (*Eragrostis teff*), maize (*Zea mays L.*) and sorghum (*Sorghum bicolor L. Moench*) in area coverage and total production (CSA 2019). Despite the long history of wheat cultivation and its importance to the Ethiopian agriculture its average productivity is still very low 2.76, 2.66 and 2.7 t ha^{-1} at national, SNNPRS and Kambata Tambaro zone, respectively (CSA 2019). In all cases this is definitely far below the world's average yield (3.52 t ha^{-1}) (USDA 2020) and 6 t ha^{-1} (at research station) (Assefa et al. 2015). The low yield of wheat may be due to soil erosion, intensive crop cultivation and inadequate application of N and P for a long time without

*Correspondence: teme.tome@gmail.com
[1] Specialization in Agronomy, Department of Plant Science, College of Agriculture, Wolaita Sodo University, Wolaita Sodo, Ethiopia
Full list of author information is available at the end of the article

considering soil fertility status and crop requirement were the major constraint in Ethiopia. In addition to this research findings showed acute crop cultivation, complete crop residue removal and high nutrient depletion contribute to low productivity of wheat (Fanuel et al 2018).

Nitrogen (N) and potassium (K) fertilizers play an important role in increasing growth and grain yield of wheat. According to Oosterhuis et al. (2014) N and K are required for plants to complete their life cycles and are the two nutrients acquired in greatest quantities by roots. Yield response to K application depends to a great extent on the level of N nutrition and the interaction is normally positive (Brennan et al., 2009). Different scholars in Ethiopia reported varied rates of N for wheat production. For instance Mesele (2007) in Ofla area obtained grain yield of 2.5 t ha^{-1} at 69 kg N ha^{-1}; Worku (2008) in Densa area achieved grain yield of 3.5 t ha^{-1} at 138 kg N ha^{-1} whereas Solomon and Anjulo (2017) in Doyo Gena area recorded 3.7 t ha^{-1} at 46 kg N ha^{-1}. Additionally, Dereje et al. (2019) reported 46–92 kg N ha^{-1} for better grain quality and nutrient use efficiency (NUE). Conversely, until recently the application of K fertilizer is not known in Ethiopian agriculture mainly due to the view that K is not a limiting nutrient in the soil. However, research findings indicated the potential of K limitation in soils of southern Ethiopia (Fanuel et al. 2018; Lelago et al. 2016). Correspondingly, positive response and grain yield increment up to 4.27 t ha^{-1} (Tigist 2017) and 4.33 t ha^{-1} (Mesele, 2019) to 30 kg K ha^{-1} in Wolaita zone, southern Ethiopia was reported.

Most of cultivated soils in Ethiopia were found at low level of N, phosphorous (P), K, Sulphur (S), cupper (Cu), zinc (Zn) and boron (B) (Ethio SIS 2014). The soil survey in Kambata Tembaro Zone, where this study was conducted also indicated the limitation of N, P and K (Lelago et al. 2016). However, Farmers in Ethiopia including the study area for long time apply N and P containing fertilizers through blanket recommendation and application of K has not been practiced. Therefore, site specific information for wheat growers found in N and K deficient soil of Kembata Tembaro zone is lacking. Hence, the study was initiated with the following objectives: to investigate the effect of N and K fertilizer rates on yield and related traits of wheat, to evaluate the nutrient uptake and use efficiency of wheat and to assess the economic feasibility of N and K fertilizer rate in wheat production and to assess the economic feasibility of N and K fertilizer rate in wheat production.

Materials and methods

Description of the study site

A field experiment was conducted at Zeto shodara *Kebele*, Kedida Gamela *Woreda* in SNNPRS Ethiopia. The site is situated at 7°14′ N latitude and 37°52′ E longitude with altitude of 2010 masl. The monthly meteorological data (amount of rainfall and maximum and minimum temperatures) for the growing year of 2019 at the experimental site is presented in (Fig. 1). The total rainfall in the cropping season was 1194.91 mm, and the mean maximum and minimum temperatures were 23.15 °C and 12.05 °C, respectively (HNMA 2019).

Treatments and experimental design

The treatment consisted of four levels of N (0, 23, 46 and 69 kg ha^{-1}) and three levels of K_2O (0, 30 and 60 kg ha^{-1}) arranged in factorial lay out in a randomized complete block design (RCBD) with three replications. Here after K_2O in the text represented by elemental form of K. The sources of N and K were urea (46–0-0) and Murate of potash (KCl) (0–0-60) fertilizers, respectively. Here after the form of K_2O in the text represented by form of K. The gross plot area was 2×3 m (6 m^2) and the net plot area 4.16 m^2. Planting was carried in mid July 2019 by drilling seeds in rows at row spacing of 20 cm. Bread wheat variety Shorma (ETBW 5483) developed and released in 2011 by Kulumsa Agricultural Research Center was used as a test crop.

Data collection and measurements

Soil data

Before planting soil samples were collected from the entire experimental field to a depth of 0–20 cm in a diagonally using soil auger after ploughing. The samples were thoroughly mixed to get a kilogram of composite sample which was air dried; ground to pass through a 2 mm sieve for analysis of selected soil physico-chemical properties such as particle size distribution, soil pH, total N, P, K, Mg and cation exchangeable capacity (CEC).

Crop data

Phenological parameters Days to heading and 90% physiological maturity.

Growth parameters plant height (cm) and flage leaf area (cm^2), at physiological maturity from 10 and 5 respectively plants were randomly selected from central eight rows.

Yield components and yield at physiological maturity from 10 plants were randomly selected from central eight rows of each treatment for measuring total tilers, effective tilers, number of grain per spike and grain weight per spike (g).

Biological (grain and straw yield) were calculated form whole plant of central eight rows of each plot.

The harvest index (%) was calculated at harvest as a ratio of grain to the total biological yield (dry matter) and expressed as a percentage.

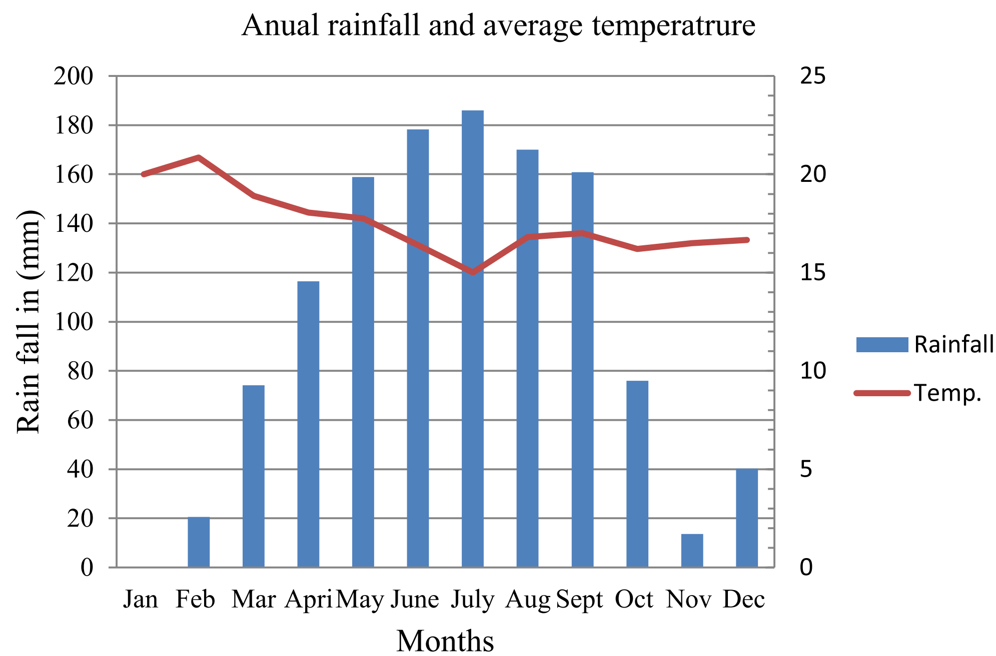

Fig. 1 Annual rainfall and average temperature of the study area

Tissue analysis at maturity representative non border wheat plant samples were randomly collected from each plot and partitioned into grain and straw and then kept in paper bags. Grain and straw samples of each treatment were oven dried at temperature of 70 °C to constant weight and thereafter ground using stainless still grinder. The powder was re-dried at 60 °C and then rubbed in muffle furnace at 550 °C for eight hours. The ash digest in 20% HNO_3 (Zarcinas et al. 1987). Total N concentrations of the samples were determined using the modified Kjeldahl method (Jackson 1958). Phosphorus concentration of the digests was measured with a spectrophotometer and the K concentration with a flame photometer.

Nutrient use efficiency computed as:

Nutrient use efficiency The nutrient use efficiencies computed were.

1. *Nutrient uptake* It was calculated by multiplying the grain and straw yield (kg ha^{-1})with the nutrient concentration %) of each treatment as follows

a. Nutrient (N, P or K)uptake by grain or straw (kg ha−1) = [Yield of grain or straw (kg ha−1 × Nutrient (N, P or K)concentration of grain or straw (%) × 10−2
b. Total uptake (kg ha−1) = Nutrient uptake grain + Nutrient uptake straw

2. *Physiological Efficiency (PE)* is the biological production per unit of nutrient absorbed$PE\left(\frac{kg}{ha}\right) = \frac{Byf(kg) - Byu(kg)}{Nf(kg) - Nu(Kg)}$ where; PE stands for physiological efficiency, B*yf* is the biological yield (grain plus straw) of fertilized plot (kg), B*yu* is the biological yield of the unfertilized plot(kg), N*f* is the total N uptake of the fertilized plot (kg), Nu is the total N uptake of unfertilized plot (kg).
3. *Recovery Efficiency (RE)* the quantity of nutrient absorbed per unit of nutrient applied $RE\% = \frac{Un - Uo}{n} \times 100$ Where*; Un* nutrient uptake by the rate of N and K fertilizer *Uo* nutrient uptake by unfertilized and n for quantity of fertilizer applied.
4. *Agronomic Efficiency (AE)* the economic production obtained per unit of nutrient applied $AE\left(\frac{kg}{kg}\right) = \frac{[Gf - Gu]}{QA}$ Where; Gf and Gu stand for Grain yield of fertilized plots at 'n' rates of fertilizer and grain yield of unfertilized plots, respectively, and QA stands for nutrient applied.
5. *Nutrient Use Efficiency (NUE)* the product of Physiological Efficiency and Recovery Efficiency $NUE(\%) = PhysiologicalEfficiency(PE) \times RecoveryEfficiency(RE)$

Partial budget analysis

The mean grain yields of the treatments were used in partial budget analysis as described by CIMMYT (1988). For each pair of ranked treatments, MRR (%) was calculated using the formula $MRR\ (\%) = \frac{\text{Change in NB (NBb}-\text{NBa)}}{\text{Change in TCV (TCVb}-\text{TCVa)}} \times 100$ Where, N_{Ba} = NB with the immediate lower TCV, NB_b = NB with the next higher TCV, TCV_a = the immediate lower TCV and TCV_b = the next highest TCV.

Results and discussion

Physio-chemical properties of the soil of experimental site

The laboratory analysis result of selected physical and chemical properties experimental site is presented in Table 1. The site has clay loam textural class with a particle size distribution of 40% clay, 32% silt and 28% sand. Soil pH was 5.8 which is under moderate acidity (5.5–6.5) (Landon 1991) and suitable for wheat (Mengel and Kirkby 2001). The OC content was 1.7% which was low (< 4%) (Landon 1991). The total nitrogen (TN) was 0.14% and categorized under low level (0.1–0.2%) (Landon 1991). Olsen available P was 20 mg kg^{-1} which is medium (10–20 mg kg^{-1}) (Landon 1991). The available K was 0.17 Cmolc kg^{-1}which is under low category (Ethio SIS, 2013). The ratio of K: Mg is 0.06:1 which indicated the potential of Mg induced K deficiency (Loide 2004; Fanuel et al. 2018). The CEC of the experimental soil was 14.4 Cmolc kg^{-1}which is low (5–15 Cmolc kg^{-1}) (Landon 1991).

In general, the soil analysis result demonstrated the low level of OC and TN, and the potential of Mg induced K deficiency that may be ascribed due to inadequate soil fertility management practices. Thus, application of N and K containing fertilizers are justifiable to satisfy the wheat crop.

Table 1 Some physical and chemical properties of soils of experimental site

Parameter	Value	Rating
Particle size distribution (%)		
Sand	28	
Silt	32	
Clay	40	
Textural class	Clay loam	
pH_{-H2O}	5.78	Moderately acidic
CEC [Cmolc kg^{-1}]	14.4	Low
Organic carbon (%)	1.67	Low
Total N (%)	0.14	Low
Available P (mgkg^{-1})	20.54	Medium
Available K [Cmolc kg^{-1}]	0.17	Low
Mg [Cmolc kg^{-1}]	2.86	Medium
K:Mg ratio	0.06	Low

Crop phenology

Days to heading

Analysis of variance showed that the main effect of N was significant however; the main effect of K and the interaction effects of N and K were resulted insignificant differences on days to heading. It ranged from 54 to 57.78 days (Table 2) where the longest day 57.78 was recorded at 69 kg N ha^{-1} and the shortest days 54 was seen at 0 kg ha^{-1} N fertilizer. Days to heading showed an increasing trend with increasing from 0 to 69 kg N ha^{-1}. The results agreed with Muhammad et al. (2016) who reported that days to heading increased gradually with increasing levels of nitrogen. This might be due to fact that increasing N rates extended vegetative growth which prolong days to heading.

Days to physiological maturity

Days to physiological maturity was significantly affected due to interaction effect of N and K fertilizer. The longest days were observed at 69 kg N ha^{-1} without K fertilizer. However, 69 kg N ha^{-1} was statistically at par with 30 and 60 kg K ha^{-1}. On the other hand, unfertilized plots followed by K without N fertilizer shortened days to physiological maturity (Table 3). In general, combined application of N and K fertilizers at increasing rates relatively prolonged maturity by two weeks as compared to non-fertilized plots. Comparatively, it is also noted that increasing rates of N at all levels of K rates prolonged days to physiological maturity. This might be suggested that N fertilization is associated with extended vegetative growth. However, the

Table 2 Days to heading as affected by the interaction of N and K fertilizer rates

N rates(kg ha^{-1})	Days to heading
0	54^{c}
23	55.11^{bc}
46	56^{b}
69	57.78^{a}
$LSD_{0.05}$	1.23
K rates(kg ha^{-1})	
0	56.08
30	55.25
60	55.83
$LSD_{0.05}$	1.07
CV(%)	2.27
S	1.26

Means followed by the same letters within a column are not significantly different at 5% probability level * and **, significant at 5 and 1% level of significance, respectively, *ns* nonsignificant difference, *CV (%)* coefficient of variation in percent, *S* standard deviation

Table 3 Growth parameters, yield and yield components as affected by interaction of N and K fertilizer rates

Treatment		Days	Plant height (cm$^{2)}$	Flag LA (cm$^{2)}$	Productive tilers (m^2)	Total tilers (m^2)	No. kernel/spike	TSW (g)	AGB (Kg)	GY (Kg)
N	K	Phys maturity								
0	0	91.67^{e}	45.71^{f}	12.18^{e}	121.7^{h}	205.33^{h}	24.53^{e}	28.40^{f}	4326.2^{e}	1040.8^{e}
	30	101.00^{cd}	71.80^{de}	21.72^{d}	255^{fg}	396.67^{fg}	42.63^{d}	38.07^{de}	5141.9^{de}	1788.5^{cd}
	60	99.00^{d}	66.82^{e}	21.45^{d}	228.3^{g}	370.33^{g}	45.30^{cd}	36.06^{e}	5081.2^{cd}	1692.0^{d}
23	0	102.33^{bcd}	72.73^{de}	23.41^{cd}	278.3^{efg}	416.67^{efg}	43.37^{cd}	40.70^{cd}	5717.9^{cd}	2198.4^{cd}
	30	101.00^{cd}	73.65^{d}	23.49^{cd}	310.7^{cdef}	441.67^{defg}	43.53^{cd}	42.50^{c}	6034.4^{c}	2255.2 ^{c}
	60	101.33^{cd}	73.09^{de}	23.18^{cd}	290d^{ef}	423.33^{efg}	44.54^{cd}	41.13^{cd}	5610.^{cd}	2250.1^{c}
46	0	105.33^{ab}	75.09^{cd}	24.04 ^{cd}	345b^{cd}	466.67^{cdef}	44.67^{cd}	46.57^{b}	7819.9^{b}	3270.0 ^{b}
	30	103.67^{bc}	80.37^{bc}	28.59^{ab}	453.33^{a}	548.33^{ab}	51.03^{a}	49.83^{ab}	9384^{a}	4392.4^{a}
	60	103.33^{bc}	77.91^{bcd}	23.93^{cd}	391.67^{b}	476.67^{bcde}	47.73^{abc}	47.57^{ab}	8338.9^{b}	3500.4^{b}
69	0	108.00^{a}	74.36^{cd}	25.85^{bc}	330c^{de}	525.0^{abc}	46.10^{bcd}	48.67^{ab}	7954.4^{b}	3229.0 ^{b}
	30	105.67^{ab}	90.57^{a}	30.83^{a}	398.67^{ab}	595.0^{a}	50.50^{a}	50.69^{a}	9775.9^{a}	4277.8^{a}
	60	105.67^{ab}	84.18^{ab}	27.18^{abc}	356.67^{bc}	513.33^{bcd}	49.20^{ab}	49.32^{ab}	9493.9^{ab}	3326^{b}
LSD 0.05		3.48	6.67	4.01	56.33	73.26	4.36	3.24	839.96	521
CV(%)		2.01	5.33	9.96	10.62	9.95	5.81	4.44	7.17	11.13
S		2.06	3.93	2.37	33.27	43.27	2.58	1.91	496.05	308.25

Means followed by the same letters within a column are not significantly different at 5% probability level * and **, significant at 5 and 1% level of significance, respectively, *ns*nonsignificant difference, *CV (%)* coefficient of variation in percent, *S* standard deviation combined application of N and K fertilization regulated the extreme cases maturity of wheat (i.e. too early and too late).

Growth parameters

Plant height

Plant height of wheat was significantly influenced due to interaction effects of N by K rates. The tallest plant height (90.57 cm) was obtained from the combination of 69 kg N ha^{-1} with 30 kg K ha^{-1} followed (84.18 cm) by the same N rate combined with 60 kg K ha^{-1}. The shortest plant height (45.71 cm) was recorded from unfertilized plots. The result further demonstrated that combining N at increasing rate with K up to 30 kg ha^{-1} improved plant height of wheat (Table 3). This could probably due to major role of N towards cell division, elongation and enhancing the vegetative growth of plants, and the role of K in promoting vigorous plant growth through efficient photosynthesis. This result is in agreement with Sharma et al. (2005); Amare et al. (2013) and Muhammad et al. (2016) who reported that N and K fertilization significantly increased plant height of wheat. According to Liangwei et al. (2004) and Tiwari (2002) nitrogen enhances vegetative growth of wheat, while K positively affects the root growth. Therefore, when N and K fertilizers applied together enhance vigorous vegetative growth and resulted in increasing plant height of wheat.

Flag leaf area

Data regarding leaf area shows that it was significantly affected by the interactions of N and K fertilizer rates. Leaf area ranged from 12.18 cm2 (non-fertilized plot) to 30.83 cm2 (69 kg ha^{-1} and30 kg ha^{-1} K) (Table 3). Wheat plant received 69 kg N ha^{-1} and 30 kg K ha^{-1} attained 153.12% more leaf area as compared to unfertilized. This result agreed with those obtained by Marschner (2012); Ara et al. (2014) and Tisdale et al. (2000) who reported that N enhanced leaf area and K application enhanced productive life of flag leaves respectively. In general, combined application of N and K consistently increased leaf area with increasing rate of N and K up to 30 kg ha^{-1}. This indicated that the higher amount of N seems to have more effect over K.

The interaction effects of N and K indicated that significant relationship with the flag leaf area. The interaction of 46 and 69 N with 30 kg ha^{-1} had justified the maximum of flag leaf area = 0.9903x + 17.262 with (R^2 = 0.63) (Fig. 2). Therefore, combined application of N and K could have synergistic effect to improve the growth and development of wheat and consequently contributed to the higher leaf area of wheat.

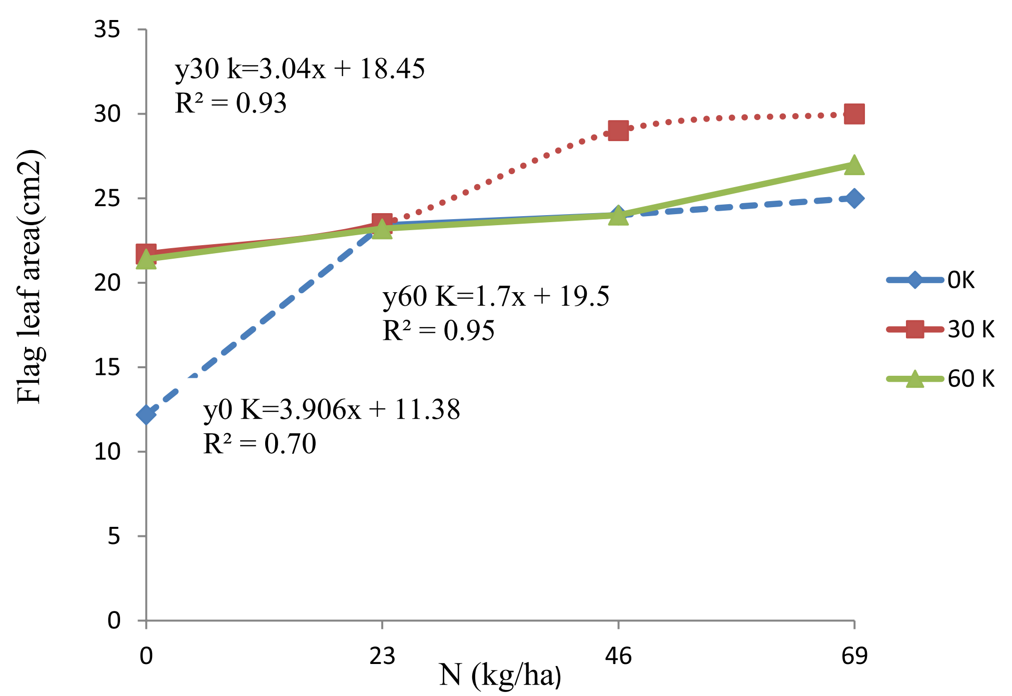

Fig. 2 Relationship between interaction effects of N x K and flag leaf area

Yield components and yield

Total tiller number

Total number of tiller per m2 was significantly affected by the interactions of N and K rates. The highest number of total tillers (595.00) was seen at 69 kg N ha^{-1} and 30 kg K ha^{-1} followed by (548.33) the same K rate combination with 46 kg N ha^{-1}. The lowest number of total tillers (205.33) was obtained from plots without fertilization (Table 3). Total number of tillers tended to increase as N rates increased across all levels of K rate, but peaked up at 30 kg ha^{-1} (Table 3). Similarly, Hussain and Shah (2002) and Amare et al. (2013) individual effects of N and K respectively, have positive effects of the nutrients for increased number of tillers per unit area. Furthermore, Bundy and Andraski (2004) also reported that the combined application of N and K increased tiller production. Therefore, strong effects on total number of tillers when both are applied together were observed.

Productive tillers

Number of productive tiller was significantly affected by the interactions of N and K fertilizer rates. The maximum value (453) was achieved from 46 kg N ha^{-1} and 30 kg K ha^{-1}. The lowest value (121.7) was obtained from non-fertilized plots. It is clear that combined application increased the productive tillers. Overall, combination of K at 30 kg K ha^{-1} and N up to 46 kg ha^{-1} linearly increased number of productive tiller. Meanwhile, higher doses of N and K beyond 30 kg K ha^{-1} and46 kg N ha^{-1} reduced tiller number as it might be toxic for tiller formation.

The increased number of productive tillers might be ascribed due to combined role of N and K in which N availability initiated cell division and elongation leading to proper vegetative and reproductive growth. The result agreed with Ejaz et al. (2002) who reported that increasing N application increased the number of productive tillers. On the other hand, Tahir et al. (2003) showed that production of productive tillers was promoted with increasing K fertilization. Therefore, combined application of N and K fertilizer may have created synergetic effect and improved the number of productive tillers.

Number of kernel per spike

Analysis of variance indicated that number of kernels per spike was significantly affected by the interactions of N and K fertilizer rates. Number of kernels per spike increased with increasing N rates across all levels of K rate. Similarly, it was also increased with increasing K rates for all levels N rates. Generally, number of kernels per spike ranged from 24.53 to 51.03 (Table 3). The greatest number of kernels per spike (51.03) was achieved from 46 kg N ha^{-1} and 30 kg K ha^{-1} followed (50.50) by 69 kg N ha^{-1} with 30 kg ha^{-1}. The least number of kernels per spike (24.53) was observed on non-fertilized plots (Table 3).This result in contrast to Wogane (2017) who reported that increased application of N was associated with proportional increase in the number of kernels per spike.

The utilization of K increased grain spike^{-1} as material transition in phloem increased cell division and growth (Tabatabaii et al. 2011). Potassium application may have a stimulatory effect on number of kernals per spike (Bahmanyer and Ranjo bar 2008). The findings are in line with the data reported by Mirza et al. (2018) who observed that K application helps to increase the number of grains. As these investigation showed that application of N and K rates promoted the number of kernels per spike. Similarly, Elkholy (2004) and Muhammad et al. (2016) conforming that number of grains per spike increased with the increase in NK levels.

Thousand seed weight

Data regarding thousand seed weight (TSW) was significantly responded to the interactions of N and K fertilizer rates. The highest TSW (50.69 g) was obtained from combination of 69 kg N ha^{-1} with 30 kg K ha^{-1} followed (49.83 g) by the same K rate combined with 46 kg N ha^{-1}. The lowest TSW (28.40 g) was recorded from unfertilized plots. Thousand seed weight significantly and positively correlated with productive tiler ($r = 0.98^{**}$), total tillers, ($r = 0.99^{*}$) and number of kernel per spike($r = 0.99^{*}$) (Table 3).

Thus, synergistic effects by combining N and K have significant effect on TSW of wheat. In agreement, Bundy and Andraski (2004) and Muhammad et al. (2016) reported significant improvement of TSW with the increasing trend of N and K (Bundy and Andraski 2004 and Muhammad et al., 2016).

Yield

Biomass yield

Analysis of variance revealed that above ground biomass yield was significantly affected by the interactions of N and K fertilizer rates. Above ground biomass yield ranged from 4326 to 9776 kg ha^{-1}. The highest biomass yield (9776 kg ha^{-1}) was recorded at 69 kg N ha^{-1} combined with 30 kg K ha^{-1} followed (9494 kg ha^{-1}) by 46 N with the same K rate. The lowest biomass yield (4326 kg ha^{-1}) was achieved from unfertilized plots. All fertilized plots out yielded the unfertilized plots (Table 3). Above ground biomass yield of wheat is significantly and positively correlated with number of seeds per kernel ($r = 0.98^{**}$), TSW ($r = 0.99^{**}$), productive tillers ($r = 0.99^{**}$) and total number of tillers ($r = 0.99^{**}$) (Table 4). In the present study,

Table 4 Correlation coefficients between selected mean yield and yield components of wheat

	GY Kgha^{-1}	AGB Kgha^{-1}	SY Kgha^{-1}	HI %	TSW Gm	NKS No	TT No.m^2	PT No.m^2
GY	1							
AGB	0.99**	1						
SY	0.97*	0.99**	1					
HI	0.97*	0.98**	0.98**	1				
TSW	0.97**	0.99**	0.99**	0.99**	1			
NKS	0.96**	0.98**	0.98**	0.99**	0.99**	1		
TT	0.98**	0.99**	0.99**	0.99**	0.99**	0.99**	1	
PT	0.97**	0.99**	0.98**	0.97**	0.99*	0.98**	0.99**	1

* and **, significant at 5% and 1% level of significance, respectively

GY grain yield, *AGB* above ground biomass, *SY* straw yield, *HI* harvest index, *TSW* thousand seed weight, *NKS* No. of kernel per spike, *TT* total tiler, *PT* productive tilers

increasing N fertilizer rates across all levels of K rates led an increase in biomass yield and it was also higher at the highest N rates for all K fertilizer. The above ground biomass yield peaked at K rate of 30 kg ha^{-1} across all levels of N fertilizer rate.

As this investigation clearly indicated that biomass yield of wheat responded differently to variable combination rate of N and K fertilizer. Biomass yield changed with increasing N rates at respective K rates. At K rate 0 kg ha^{-1} gain of biomass was for N rate change from 0–23 (32.18%), 23–46 (36.76%) and 46–69 (1.71%). Increasing N rates from 0 to 46 kg ha^{-1} across all levels of K associated with increasing dry matter accumulation in relation to N increment. The rate of N increases from 23–46 kg ha^{-1} resulted 38%, 56% and 38% at all levels of K respectively. Similarly, N increases from 46–69 kg ha^{-1} resulted in biomass yield gain of 1.71%, 30.1% and 10.3% across all respective K rates. Based on this evidence, N rate above 46 kg ha^{-1} at all levels of K rate in increment of biomass yield gain was declined and negligible.

On the other hand, K rate above 30 kg ha^{-1} led to decline in dry matter accumulation at all levels of N rates. From a view point of total biomass, K rate 30 kg ha^{-1} performed superior at all levels of N rates. Regarding N rates, 46 kg ha^{-1} N showed superiority of dry matter accumulation gain at all levels of K rates. This strongly suggests that N rate above 46 kg ha^{-1} the utilization by plants were very little or nearly negligible and exposed to different losses of N such as leaching, volatilization and immobilization. This illustrated that combination of 46 kg ha^{-1} N with 30 kg ha^{-1} K increased the ability of plants for capturing resources which was reflected as evident in their increased dry matter accumulation. Biomass yield had increased with increase in N rate from control to the highest level.

The interaction result shows that highest biological yield was produced when 30 kg K ha^{-1} interacted with 46 and 69 kg ha^{-1} N levels. This result is in line with Allam (2003) and Solomon and Anjulo (2017) who reported that N application enhanced the vegetative growth of wheat crop, which ultimately increased biological yield with increase in straw yield. However, N rate beyond 46 kg ha^{-1} showed the tendency of declining dry matter accumulation. With increased level of N and K, increase in number of total tillers m^{-2} results in biological yield of wheat.

Grain yield

The result showed that grain yield was significantly affected by the interactions of N and K fertilizer. Grain yield as affected by interaction of N by K rates ranged from 1041 to 4392 kg ha^{-1}. All fertilized plots had higher grain yield as compared to plots without fertilization. Grain yield tended to increase with increasing N rate up to 46 kg ha^{-1} and then declined above that rate of N across all levels of K rates (Table 3). Regarding the effect K rates, higher grain yield was recorded at K rate of 30 kg ha^{-1} and then grain yield declined above that rate of K across all levels of N rates. The highest grain yield (4392 kg ha^{-1}) was achieved from combination of 46 kg N ha^{-1} with 30 kg K ha^{-1} followed by the N rate 69 kg ha^{-1} with the same K rate with mean grain yield of 4278 kg ha^{-1}. The lowest grain yield (1041 kg ha^{-1}) was achieved from unfertilized plots. This result was agreed by Inamullah and Muhammad (2014) who reported that on average, the plots where N and K nutrients were applied produced higher grain yields as compared to the plots where no N and K nutrients. Increasing N rates across all levels of K rates led variability in response to N as reflected on grain yield of wheat. In the presence of K, wheat showed greater than 100% yield gain over unfertilized plots of N. With respect of N rate at 46 kg ha^{-1} it was recorded a yield gain of 48.77%, 94.77% and 55.56% across all levels of K rates. The grain yield was from 46 kg N ha^{-1} with 30 kg K ha^{-1} yield gain 322% over unfertilized plots.

Table 5 Straw yield (kg/ha) and Harvest index as affected by N and K fertilizer rates

N rates(kg ha^{-1})	Straw yield (kg ha^{-1})	Harvest index (HI %)
0	3342.7^c	31^c
23	3552.9^c	39^b
46	4600.8^b	44^a
69	5118.4^a	41^{ab}
$LSD_{0.05}$	424.81	4.00
K rates(kg ha^{-1})		
0	4020	36^b
30	4379.9	41 ^{a}
60	4061.1	39^{ab}
$LSD_{0.05}$	NS	3.00
CV (%)	12.52	11.6
S	519.8	4.5

Means followed by the same letters within a column are not significantly different at 5% probability level * and **, significant at 5 and 1% level of significance, respectively, *ns* nonsignificant difference, *CV (%)* coefficient of variation in percent, *S* standard deviation

The correlation of selected agronomic traits with grain yield, irrespective of N and K fertilizer rates, is presented in Table 4. The association of the parameters with grain yield was highly positively correlated with r (Correlation coefficient) values ranged 0.96 to 0.99 (Table 5). The association of total number of tillers (r = 0.98) and productive tillers (r = 0.97) with grain yield was highly positively correlated ($P \leq 0.01$) which suggests that increasing both parameters tended with positive impact on grain yield. Number of kernels per spike (r = 0.96) and TSW (r = 0.97)(Table 4) were highly positively associated with grain yield suggesting that both yield components are important traits for selection in improving wheat grain yield. Moreover, straw yield (r = 0.97), HI (r = 0.97) and biomass yield (r = 0.99) were highly positively associated with grain yield probably an indication that increasing the parameters led to an increase in grain yield. This result was supported by the findings by Firehiwot (2014) and Bekalu and Mamo (2016) who reported significantly positive correlation of grain yield with number of seeds per spikes, biological yield and harvest index.

Generally optimization of N and K fertilizer combination resulted in positive effect for the parameters correlated with grain yield suggesting that their increase led to increment in grain yield to a certain optimum level. Moreover, the linear multiple regression $Y = 1469.98 + 33.90X_1$ (N rates) $+ 4.29X_2$ (K rates) with $R^2 = 0.75$ indicated that was very responsive to both N and K fertilization at significant level (Fig. 3). As this analysis indicated that grain yield was increased at rate of 33.90 for within N rates of 0 to 69 kg ha^{-1} for all levels of from 0 to 60 kg ha^{-1}. In line with this, grain yield was

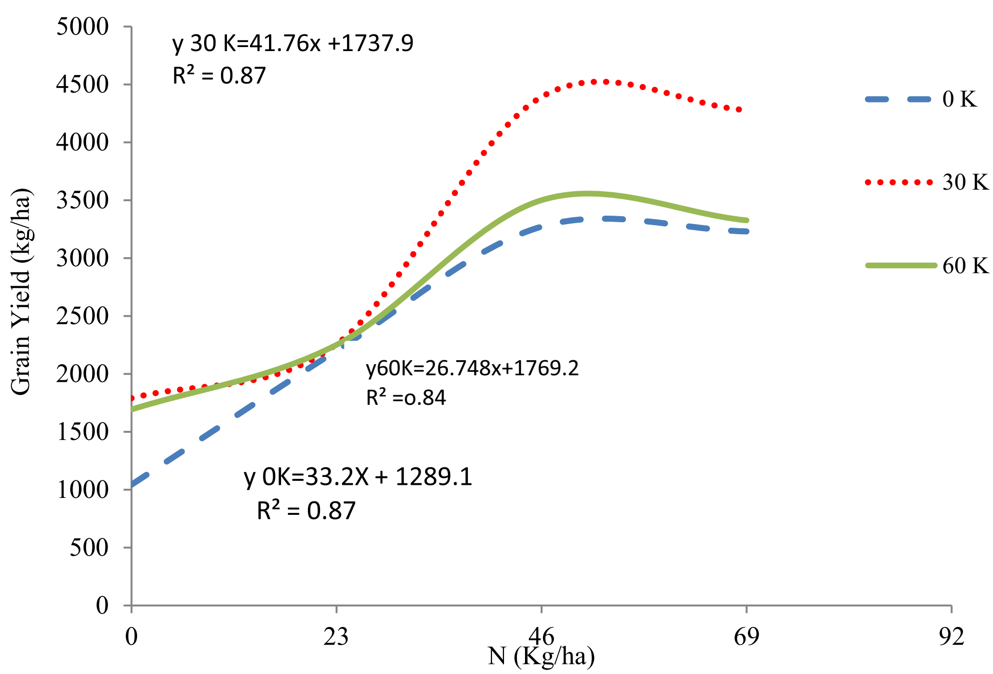

Fig. 3 Relationship between interaction effects of N x K on grain yield

Table 6 N, P and K uptake (kg ha^{-1}) on straw and grain of wheat as affected by interaction effect of N and K

Treatment										
N	K	Straw N	Grain N	Total N	Straw P	Grain P	Total P	Straw K	Grain K	Total K
	0	6.8h	22.7e	29.6e	0.37f	2.7f	3.4f	10.2h	2.6e	12.8g
0	30	7.5fgh	37.5cd	45d	1.3bc	4.9e	6.25e	14.8fg	6.7d	21.57f
	60	8.8efg	35.3d	44.2d	1.1c	5.8de	6.28e	12gh	6.5d	19.16f
	0	10cde	47.1c	57.4c	0.59e	6.4cd	7.02de	12.6gh	7.4cd	20.09f
23	30	9.52de	44.6cd	54.1cd	0.8d	6.8c	7.7d	21.9d	8.55c	30.5de
	60	7.4gh	45.7cd	53.17cd	0.7de	5.8de	5.72e	19.2de	7.8cd	26.99e
	0	9.17ef	70.5b	79.7b	1.4b	8.8b	10.0bc	16.5ef	11.5b	28de
46	30	13.8b	101a	115.18a	1.3bc	9.7b	10.95b	29.23c	15.4a	44.63c
	60	11.2cd	67.8b	79.04b	1.3bc	9.2 b	10.97b	19.4de	12.b	31.5d
	0	10.1cd	69b	79.5b	1.2c	8.4b	9.5c	39.3b	11.3b	50.65b
69	30	17.2a	95.5a	112.76a	1.8a	13.2a	15.1a	44.3a	14.9a	59.3a
	60	11.9bc	70b	81.9b	1.3bc	8.9b	10.3bc	36.1b	10.6b	46.8c
LSD $_{0.05}$		2.13	11.31	10.77	0.26	1.36	1.28	4.48	1.81	4.31
CV%		12.23	11.35	9.19	10.9	11.1	9.12	11.51	11.2	7.81
S		1.02	6.49	6.16	0.12	0.83	0.79	2.28	1.06	2.23

Means followed by the same letters within a column are not significantly different at 5% probability level * and **, significant at 5 and 1% level of significance, respectively, *ns* nonsignificant difference, *CV (%)* coefficient of variation in percent, *S* standard deviation

increased at rate of 4.29 for K rates from 0 to 60 kg ha^{-1} for all levels of N fertilizer rates. As this finding clearly indicated that both fertilizer elements were essential for wheat grain yield. However, grain yield showed greater response to N than K (Table 6).

From the above discussion, it is clear that N at 46 kg ha^{-1} and K at 30 kg ha^{-1} would be optimal for wheat production. The result in line with Solomon and Anjulo (2017) who reported that increasing N levels to 46 kg ha^{-1} increased grain yield. In contrast to Beyenesh et al. (2017) who reported that application of N 69 kg N ha^{-1} was produced a high grain yield reported by. Therefore, the increase in grain yield might be attributed due to the collective role of N and K where N is a major constituent of chlorophyll and dry matter accumulation while K aids in water and nutrient uptake, photosynthesis and food formation.

Straw yield

Data on straw yield shows that it was significantly affected by main effect of N but not by K and the interactions of N and K. The highest straw yield (5118.4 kg ha^{-1}) was recorded at 69 kg ha^{-1} N followed (4600 kg ha^{-1}) by the 46 N rate whereas the lowest straw yield (3342.7 kg ha^{-1}) was seen on unfertilized plots (Table 5). Similarly, Gul et al. (2011) and Tilahun et al. (2017) reported that N application has more contribution towards production of higher straw yield. Though the straw yield was not statistically significant due to K application, relatively higher straw yield was observed at 30 kg K ha^{-1} then declined.

Harvest index

Significant differences on harvest index (HI) by the main effect of N and K fertilizer rates were recorded. The HI ranged from 31 to 44% (Table 5) that was recorded at 0 kg ha^{-1} and 46 kg N ha^{-1}, respectively. The finding are similar to Solomon and Anjulo (2017) who reported an increasing trend of HI up to 46 kg N ha^{-1} and a decreasing HI with further increase in its rate of application.

Nutrient uptake and use efficiency

N, P and K uptake

Nutrient uptake by wheat was significantly influenced by interaction effect of N and K fertilizer (Table 6). Overall, the amount of nutrient uptake was in the order of N > K > P. Grain was found to have higher content of N and P than the straw. Conversely, straw of wheat contained higher K than grain yield. The maximum N uptake by the straw (17.2 kg ha^{-1}) that was recorded from 69 kg N ha^{-1} and 30 kg K ha^{-1} had 153% more N than the lowest (6.8 kg ha^{-1}) from unfertilized plots.

The result further displayed that combined application of N and K at increasing rates resulted in higher uptake of N, P and K (straw and grain). On the other hand, interaction of 46 kg ha^{-1} N and 30 kg ha^{-1} K gave 344.9% and 288.5% higher grain and total N uptake respectively, over unfertilized plot. The results from interaction of N and K indicated that significant effect on grain N up take which is supported with coefficient ($R^2 = 0.80$) (Fig. 4). The grain N uptake increased with the interaction of 46 N and 30 kg ha^{-1} K, beyond it the grain N uptake decreased. This result was supported by the findings by Hailu et al. (2012) who reported that N uptake by wheat was significantly improved by integrated application of N, P and K. It is observed that N and K fertilizers had positive response on P uptake. It was supported by the findings by Amare et al. (2013) who reported that P uptake by grain of wheat increased by increasing N level and in the presence of K at 50 kg than in its absence.

Application of 69 kg N ha^{-1} with 30 kg K ha^{-1} result highest K uptake by straw and total and the lowest K uptake on straw and total were recorded from unfertilized plot (Fig. 4). The maximum K uptake by grain (15.4 kg ha^{-1}) was obtained from 46 kg of N and 30 kg ha^{-1} of K. Overall, the maximum K uptake with N and K application resulted 333.3% (straw), 477% (grain) and 283% (total) more K uptake than unfertilized plots. The interaction of 46 kg N ha^{-1} and 30 kg K ha^{-1} fertilizer rate has significant effect on grain K uptake which was best expressed $y = 57.1x + 211.5$ with a significant ($R^2 = 0.70$) (Fig. 5). The result was agreed with Mesele (2019) who reported that the highest K uptake of straw, grain and total at 30 kg K ha^{-1} and the lowest from the control.

Nutrient use efficiency

Agronomic efficiency

Agronomic efficiency (AE) of N significantly influenced by the main effect of N and K fertilizers. Supplying 46 kg ha^{-1} N produced maximum AE (52.53 kg grain per kg N) whereas lowest AE (41.132 kg grain per kg N) was observed at high N levels i.e. 69 kg ha^{-1} (Table 7). This study showed that AE increases up to 46 kg N ha^{-1} and beyond this it decreased. This result is in line with those of Solomon and Anjulo (2017) and Fageria and Baligar (2005) who reported that the highest AE of N at the lower rate because of reduced losses. At the lower rate of N, the wheat plant utilized most of the supplied N for grain yield. The AE result in this study was close to the findings of Dereje et al. (2019) who indicated AE of 50.48 kg kg^{-1} and Birke et al. (2019) who showed 57.1 kg kg^{-1} at 46 kg ha^{-1} of N.

The AE of K was significantly affected by the interaction effect of N and K (Appendix Table A6). The maximum AE (29.9 kgkg^{-1}) was recorded from 46 kg N ha^{-1} and 30 kg K ha^{-1} and the lowest (10.8 kg kg^{-1}) from 60 kg K ha^{-1}without N. The result had shown that AE of K decreases with the increasing rate of N and K (Table 8). This result is in line with those of Tariq et al.(2011); Hagos et al. (2017) and Mesele (2019) who reported that AE of K decreased when the rate of K increase. The higher AE from this study was recorded from the lower rates of N and K. As reported by Singh (2004) if a unit of

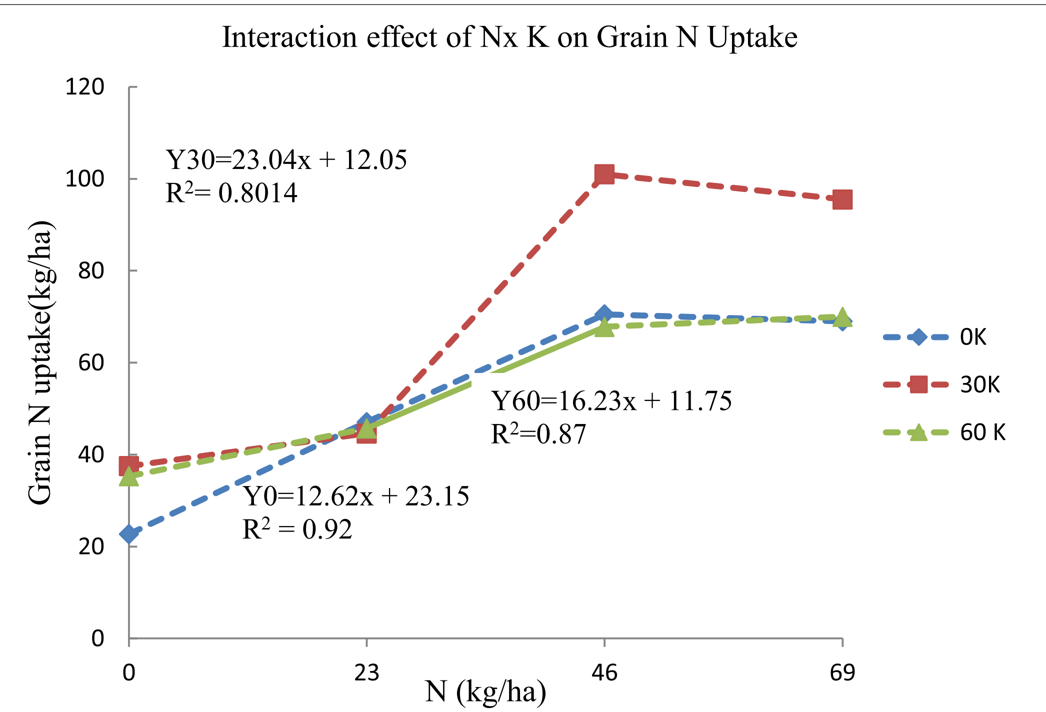

Fig. 4 Interaction effects of N and K on Grain N Uptake

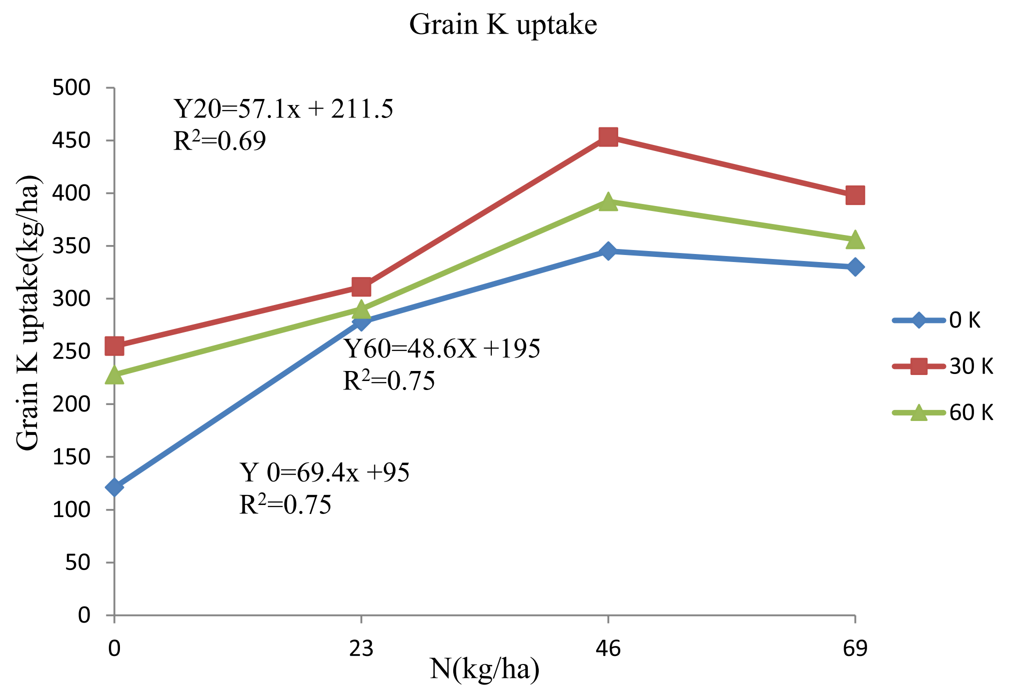

Fig. 5 Interaction effects of N and K on Grain N and K Uptake

fertilizer does not increase the yield enough to pay for its cost, its application will not be economical.

Physiological efficiency

Physiological efficiency (PE) of N and K was significantly influenced by interaction effects of N and K fertilizers. The maximum PE of N (86.6 kg kg^{-1}) was recorded from 46 N and 30 kg ha^{-1} and the lowest (53.294 kg kg^{-1}) from 23 kg N ha^{-1} and without K (Table 8). Similarly, Brar et al. (2011) who reported application of K greatly influenced PE of N in maize. The highest (83.1 kg kg^{-1}) PE of K was recorded from 46 and 60 kg K ha^{-1} fertilizer. The lowest (29.31 kg kg^{1}) PE of K was obtained from 60 kg K ha^{1} and 0 kg N ha^{1} level.

On the other hand, K rate above 30 kg ha^{-1} led to decline in PE of K at all levels of N rates.. This illustrated that combination of 46 kg ha^{-1} N with 30 kg ha^{-1} K increased the ability of wheat to absorb applied nutrients which was reflected as increased PE of N and K. This result is in line with those of Beyenesh et al. (2017) and Mesele (2017) who reported that the highest physiological efficiency recorded with the application of 46 kg N ha^{-1} and K up to 30 kg K ha^{-1} respectively.

Crop recovery

Data regarding, RE of N was significantly affected by main effect of N and K fertilizer but not by their interaction. The highest RE of N (116.66%) was obtained from 46 kg N ha^{-1}and lowest (100.38%) with application of 69 kg N ha^{-1}(Table 7). The RE of N increases up to 46 kg ha^{-1} and then showed declining trend. The RE of N obtained in this study is comparable with those obtained 89% by (Beyenesh et al. 2017); 68% by (Fresew et al. 2019) and (224.17%) by (Birke et al. 2019), 160% by (Dereje et al. 2019).

Table 7 Agronomic, crop recovery and TUE of N affected by the rate of N and K fertilizers

Treatment	AE(kg kg^{-1})	RE(%)	TUE(%)
N rates	N	N	N
0	–	–	–
23	51.9^{a}	109.8^{a}	63.5^{b}
46	52.5^{a}	116.6^{a}	79.3^{a}
69	42.1^{b}	100.4^{a}	68.8^{ab}
$LSD_{0.05}$	7.87	17.9	15.2
K rates			
0	43.5^{b}	100.6^{b}	63.0^{b}
30	53.3^{a}	122.4^{a}	75.9^{a}
60	49.7^{ab}	103.8^{b}	72.6^{a}
$LSD_{0.05}$	7.8	17.89	15.2
CV(%)	16.1	20.43	21.6
S	7.88	20.58	15.23

Means followed by the same letters within a column are not significantly different at 5% probability level *S* standard deviation

The crop recovery of K was significantly affected by the interaction effect of N and K fertilizer rates (Table 7). The highest apparent recovery efficiency of K (56.6%) was obtained with application of 46 and 30 kg K ha^{-1} and the lowest (10.51%) with application of K 60 kg ha^{-1} and without N fertilizer. Potassium application rates had influenced apparent potassium recovery. The results had shown decreasing trend with increasing N and K rates consistently. Similar result was indicated by Jackson (2018) who reported that RE decreased when the rate of N and K increases. The same result was obtained by Brar et al. (2011) who reported that the recovery efficiencies of K increased with the application of N and K fertilizer in maize.

Nutrient use efficiency

Nitrogen use efficiency (NUE) of wheat was significantly affected by main effect of N and K fertilizer whereas potassium use efficiency (KUE) was significantly influenced by interaction effects of N and K fertilizers. The highest NUE (79.28%) due to N fertilizer was recorded from 46 kg N ha^{-1} and the lowest (63.53%) was from 23 kg N ha^{-1} (Table 7). Increasing the rate of N from 23 to 46 kg N ha^{-1} increased the N use efficiency by 24.78% and increasing N from 46 to 69 kg N ha^{-1} decreases the efficiency by 15.2%.

Potassium fertilizer also significantly influenced NUE (Table 8). Application of K up to 30 kg/ha increased NUE. The maximum KUE (58.6%) was recorded from 46 kg N ha^{-1} and 30 kg Kha^{-1} and the lowest (14.9%) was from 0 kg N ha^{-1} and 60 kg K ha^{-1}. The result agrees with Amer (2005) who reported that NUE of wheat was increased in the presence of 50 kg K ha^{-1} than in itsabsence.

Table 8 Agronomic, physiological, crop recovery and total use efficiency affected by the rate of N and K fertilizers

Treatment	Agronomic efficiency	Physiological efficiency		Recovery efficiency	Nutrient use efficiency
N + K	K	N	K	K	K
0.0	–	–	–	–	–
0,30	13.2^{d}	54.6^{bc}	48.4^{d}	29^{b}	21.5^{de}
0,60	10.1^{e}	53.7^{bc}	29.3^{e}	10.5^{c}	14.9^{e}
23,0	–	53.3^{c}	53.1^{cd}	–	–
23,30	14.1^{d}	72.9^{abc}	62^{abcd}	45.4^{ab}	31.6^{cd}
23,60	16.8^{cd}	57.7^{bc}	54.1^{cd}	23.5^{bc}	23.1^{de}
46,0	–	77.8^{ab}	52.5^{cd}	–	–
46,30	29.9^{a}	86.6^{a}	79^{ab}	56.6^{a}	58.6^{a}
46,60	21.7^{bc}	54.3^{bc}	83.1^{a}	31.1^{b}	42.6^{bc}
69,0	–	73.5^{abc}	57.9^{bcd}	–	–
69,30	26.38^{ab}	63.8^{abc}	71.6^{abc}	54.7^{a}	44.9^{b}
69,60	22.9^{b}	71.8^{abc}	64.5^{abcd}	55.9^{a}	48.2^{ab}
$LSD_{0.05}$	5.2	24.3	22.4	12.4	11.25
CV(%)	21.91	21.83	21.8	18.4	18
S	10.72	13.1	13.37	7.07	5.42

Means followed by the same letters within a column are not significantly different at 5% probability level *S* standard deviation

Partial budget analysis

The partial budget analysis was carried out by using the methodology described in CIMMYT (1988) in which

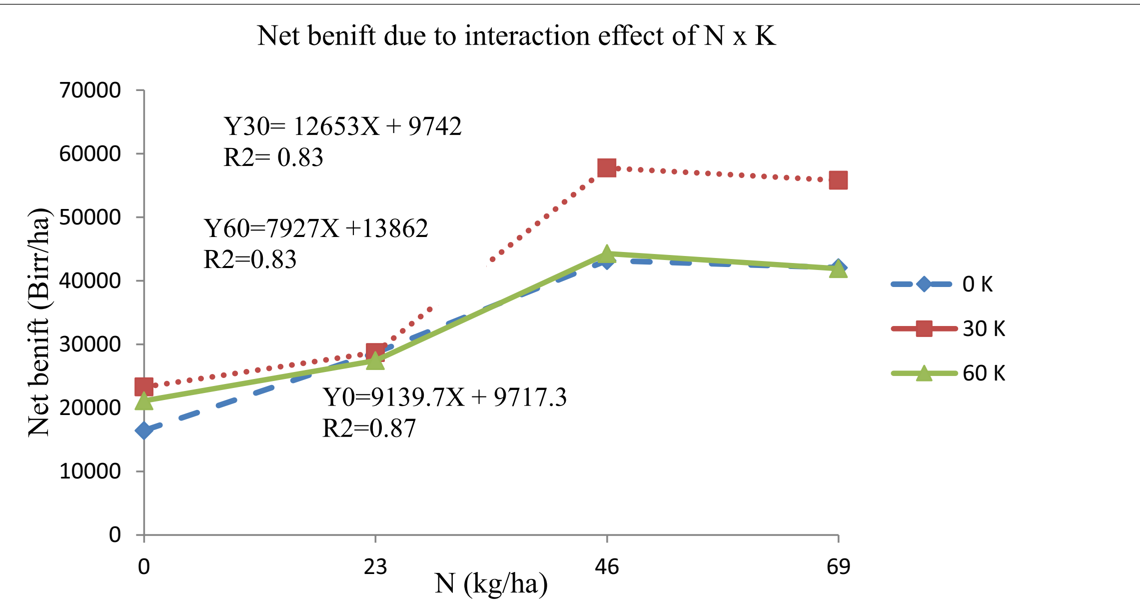

Fig. 6 Regression analyses of interaction effects of N and K on net benefit

Table 9 Profitability as affected by N and K fertilizer rates

Treatments		Wheat yield kg ha^{-1}		Adjusted dawn10% kg ha^{-1}		Income ETB ha^{-1}		GFB	TVC	NB	MRR
N	K	GY	SY	GY	SY	Grain	Straw	ETB	ETB ha^{-1}	ETB ha^{-1}	(%)
0	0	1041	3285	936.7	2957	14,051	2365	16,416	–	–	–
	30	1789	3353	1610	3018	24,145	2414	26,559	3275	23,284	309.7
	60	1692	3389	1523	3050	22,842	2440	25,282	4175	21,107	D
23	0	2198	3519	1979	3167	29,678	2534	32,212	3567	28,645	D
	30	2255	3779	2030	3401	30,445	2721	33,166	4467	28,699	106
	60	2250	3360	2025	3024	30,376	2419	32,795	5367	27,429	D
46	0	3270	4550	2943	4095	44,145	3276	47,421	4259	43,162	D
	30	4392	4992	3953	4493	59,297	3594	62,891	5159	57,733	1719
	60	3500	4261	3150	3835	47,255	3068	50,323	6059	44,264	D
69	0	3229	4726	2906	4253	43,592	3402	46,994	4951	42,043	D
	30	4278	5395	3850	4856	57,750	3885	61,635	5851	55,784	1627
	60	3326	5235	2993	4711	44,901	3769	48,670	6751	41,919	D

Urea cost = 14.54 Birr kg^{-1}, Kcl, cost = 18 Birr kg^{-1}, UREA cost = 13.84birr Birr kg^{-1} of N, wheat grain per ha = 15 Birr kg^{-1}, straw = 0.8 Birr kg^{-1} application cost = 500 Birr ha^{-1}, *MRR (%)* Marginal rate of return, *D* Dominant, *GFB* Gross field benefit, *TVC* Total Variable Cost, *NB* Net Benefit

considering all variable costs and all benefits of grain yield. Variable cost includes cost of fertilizer during experimental period. All costs and benefits were calculated on ha basis in Birr. The price of potassium was (18.00 birr kg^{-1}) and urea (13.84birr kg^{-1}). The average price of wheat grain and straw at local market were 15 and 0.8 ETB kg^{-1} respectively.

The relationship of interaction of N and K with net benefit was best expressed $y = 12653x + 9742$ with a significant ($R^2 = 0.87$) in (Fig. 6). The results from interaction effects of 46 and 30 kg K ha^{-1} indicated that significant effect on grain yield of wheat correspondingly increases the net benefit. Economic analysis showed that the highest net benefit (57,732.5.5 birr ha^{-1}) was obtained from wheat plot that received 46 and 30 kg K ha^{-1}; whereas the lowest net benefit (16,416 birr ha^{-1}) was obtained from unfertilized treatment (Table 9).

Conclusion

The results of this experiment indicated increase in grain yield, nutrient uptake, agronomic, recover and use efficiency with mineral N and K fertilization. The amount of nutrient uptake was in the order of N > K > P. Nitrogen and P are largely stored on grain than straw whereas, K is more on straw. Based on this study agronomic, economic and nutrient use efficiency application of 46 N with 30 kg K ha^{-1} is suggested for farmers in the study area. Yet, repeating the experiment over seasons and locations is also suggested for strong recommendation.

Abbreviations

AE: Agronomic Efficiency; HI: Harvest Index; MRR: Marginal Rate of Return; NUE: Nutrient Use Efficiency; PE: Physiological Efficiency; RE: Recovery Efficiency; SNNPRS: Southern Nation Nationality Peoples' Regional State; TSW: Thousand Seed Weight.

Acknowledgements

We would like to thank SNNPRS public service Birro for financial support, Kedida Gamela District for their facilitation and providing farm area for the research.

Authors' contributions

Temesgen contribute to design of the research proposal, field work, data collection, analysis and interpretation of the data using SAS software version 9.20 and writing the manuscript. Dr. Fanuel and Dr. Gobeze assisted in analysis and interpretation of the data and also in writing the manuscript. All authors read and approved the final manuscript.

Funding

This research was conducted with the financial support of Southern Nations, Nationality and Peoples' Regional State Public service Biro, Ethiopia (SNNPRS).

Availability of data and materials

We declare that the data and materials presented in this manuscript can be made available as per the editorial policy of the journal.

Ethics approval and consent to participate

Not applicable to this manuscript.

Consent for publication

Not applicable to this manuscript.

Competing interests

There is no competing interest.

Author details

[1] Specialization in Agronomy, Department of Plant Science, College of Agriculture, Wolaita Sodo University, Wolaita Sodo, Ethiopia. [2] Department of Plant Science, College of Agriculture, Wolaita Sodo University, Wolaita Sodo, Ethiopia. [3] Department of Plant Science, College of Agriculture, Wolaita Sodo University, Wolaita Sodo, Ethiopia.

Received: 2 October 2020 Accepted: 14 December 2020
Published online: 29 January 2021

References

Allam AY (2003) Response of three wheat (*Triticum aestivum* L.) Cultivars to split application nitrogen fertilization application on crop yield. Experimental Agriculture rates in sandy soils. J Agri Sci 40(03):369–379

Amare TA, Terefe YG, Selassie B, Yitaferu BW, Hurni H (2013) Soil properties and crop yields along the terraces and topo sequece of Anjeni Watershed, Central Highlands of Ethiopia. J Agric Sci 5(2):134–144. https://doi.org/10.5539/jas.v5n2p134

Ara J, Mahmud JA, Ryad MS, Nur F, Sarkar S, Islam MM (2014) Response of seed yieldcontributing characters and seed quality of rapeseed (Brassica campestris L.) to nitrogenand boron. Appl. Sci. Reports 1:5–10

Assefa W, Yemane N, Dawit H (2015) Planting density and nitrogen and phosphorus fertilization effect on different bread wheat (*Triticum aestivum* L.) genotypes in South Tigray, Ethiopia. World J Med Med Sci Res 3(2):020–028

Bahmanyar MA, Ranjbar GA (2008) The role of potassium in improving growth indices and increasing amount of grain nutrient elements of wheat cultivar. J Appld Sci 8:1280–1285

Bekalu A, Mamo M (2016) Effect of the rate of N-fertilizer application growth and yield of wheat (*Triticum aestivum* L.) at Chencha, Southern Ethiopia. Int J Plant Animal Environ Sci 6(3):168–175

Beyenesh Z, Nigussie D, Fetien A (2017) Yield and nutrient use efficiency of bread wheat (*Triticum Aestivum* L.) as influenced by time and rate of nitrogen application in enderta, Tigray Northern Ethiopia. Open Agri 2(1):611–624

Birke B, Habtamu A, Mihratu A (2019) Nitrogen uptake and use efficiency of irrigated bread wheat (*Triticum aestivum* L.) as influenced by seed and nitrogen fertilizer rates at werer, Afar National Regional StateB Ethiopia. Adv Crop Sci Tech 7:418. https://doi.org/10.4172/2329-8863.100041

Brar MS, Bijay-Singh, Bansal SK, Srinivasarao Ch. (2011) Role of potassium nutrition in Nitrogen use efficiency in cereals. Research Findings: e-ifc No. 29, December 2011

Brennan RF, Bolland MDA (2009) Comparing the nitrogen and potassium requirements of canola and wheat for yield and grain quality. J. Plant Nutr. 32(12):20082026

Bundy LG, Andraski TW (2004) Diagnostic tests for site-specific nitrogen recommendation for winter wheat. Agron J 96:608–614

CIMMYT (Centro International de Mejoramiento de Maiz y Trigo/International Maize and Wheat Improvement Center) (1988) From agronomic data to farmer recommendation: an Economic work Book. D.F. CIMMYT, Mexico

CSA (Central Statistical Agency) (2019) Agricultural sample survey Report on area and production for major crops. Central Statistical Agency, Ethiopia

Dereje D, Girma A, Wegayehu W (2019) Grain quality and nitrogen use efficiency of bread wheat (*Triticum aestivum* L.) varieties in response to nitrogen fertilizer in Arsi highlands, southeastern Ethiopia. Afr J Agric Res 14(32):1544–1552

EthioSIS (Ethiopia Soil Information System) (2014) Soil fertility status and fertilizer recommendation Atlas for Tigray regional state, Ethiopia. Ethiopia Soil Information System, Ethiopia

El Kholy MA (2000) Response of wheat growth and yield to plant density and methods ofnitrogen and potassium fertilizers application. Egypt. J. Agron. 22:1–18 Components inWheat Genotypes under Post-Anthesis Drought Stress. JWSS-Isfahan University of Technology, 11; 317–328

Egilla JN, Davies FT, Boutton TW (2005) Drought stress influences leaf water content photosynthesis, and water use efficiency of hibiscusros asinensis at three potassium concentrations. Photosynthetic 43:135–140

Ejaz A, Waraich R, Ahmad S, Shamim A, Ahmad A (2010) Impact of water and nutrient management on the nutritional quality of wheat. J Plant Nutrition 33:640–653

Fageria NK, Barbosa F (2005) Dry matter and grain yield, nutrient uptake, and phosphorus use efficiency of lowland rice as influenced by phosphorus fertilization. Commun Soil Sci Plant Anal 38:1289–1297

Fanuel L, Kibebew K, Hailu S (2018) Potassium (K) to Magnesium (Mg) ratio, its spatial variability and implications to potential mg-induced k deficiency in nitisols of Southern Ethiopia. Agric Food Secur 7:13. https://doi.org/10.1186/s40066-018-0165-5

FAO (Food and Agriculture Organization) (2019) Strategic analysis and intervention plan for wheat and wheat products in the Agro-Commodities Procurement Zone of the pilot Integrated Agro-Industrial Park in Central-Eastern Oromia, Ethiopia. FAO, Addis Ababa

Firehiwot Getachew. 2014. Effect of vermi compost and inorganic N and P fertilizers ongrowth, yield, and quality of bread wheat (Triticum aestivum l.) in eastern EthiopiaM.Sc. Thesis, Haramaya University, Haramaya, Ethiopia.

Fresew B, Nigussie D, Adamu M, Tamado T (2019) Effect of nitrogen fertilizerrates on grain yield and nitrogen uptake and use efficiency of bread wheat (*Triticum aestivum* L). varieties on the Vertisols of central highlands of Ethiopia. Agric Food Secur. https://doi.org/10.1186/s40066-018-0231-z

Gul H, Said A, Saeed B, Ahmad I, Ali K (2011) Response of yield and yield components of wheat towards foliar spray of nitrogen, potassium and zinc. ARPN J Agric Biol Sci 6:23–25

Hagos B, Tekalign M, Kassa T (2017) Optimum potassium fertilization level for growth, yield and nutrient uptake of wheat (*Triticum aestivum*) in Vertisols of Northern Ethiopia. Soil & Crop Sciences Research Article. Cogent Food Agric. https://doi.org/10.1080/23311932.2017.1347022

Haile D, Nigussie D, Amsalu A (2012) Nitrogen use efficiency of breadwheat: Effects of nitrogen rate and time of application. J Soil Sci Plant Nutr 12(3):389–409

HNMA (Hawassa National Meteorology Agency) (2019) Mean monthly annual total rainfall and minimum and maximum temperatures of ten years. National Meteorological Agency, Hawassa Branch

Hussain MM, Ibrahim SA, Zaitoon MI (2002) Effect of nitrogen levels on the growth, yieldand mineral composition of wheat crop under different seed rates. Egypt J Sci. 24(1):7–18

Inamullah KA, Muhammad TJ (2014) Impact of various nitrogen and potassium levels and application methods on grain yield and yield attributes of wheat. Sarhad J Agric 30(1):35–46

Jackson ML (1958) Soil chemical analysis. Prentice Hall Inc. Engle Wood Cliffs, New Jersey

Jackson NH (2018) Evaluation of nitrogen and potassium interactions in corn. Iowa State University

Jemal A, Tamado T, Firdissa E (2015) Response of Bread Wheat (Triticum aestivum L.) Varieties to Seeding Rates. Asian J Plant Sci 14(2):50–58

Landon JR (1991) Booker tropical soil manual: a handbook for soil survey and agricultural land evaluation in the tropics and sub-tropics. Longman Scientific and Technical, Essex , p 474

Lelago A, Mamo T, Haile W, Shiferaw H (2016) Assessment and Mapping of Status and Spatial Distribution of Soil Macronutrients in Kambata Tembaro Zone. Southern Ethiopia. Adv Plants Agric Res 4(4):00144. https://doi.org/10.15406/apar.2016.04.00144

Liangwei D, Xiaoqin T, Jian Zi'ai Yuzhen Hui LCTZ (2004) Treatment and reuse of piggery wastewater by composting process of straw. Trans Chin Soc Agric Eng 20(20):255–258

Loide V (2004) About the effect of the contents and ratios of soil's available calcium, potassium and magnesium in liming of acid soils. Agron Res 2:71–82

Marschner P (2012) Mineral Nutrition of Higher Plants, 3rd edn. Academic Press, London, pp 178–189

Mengel K, Kirkby EA (2001) Principles of Plant Nutrition, 5th edn. Kluwer Academic Publishers, Dordrecht, p 849

Mesele H (2017) Response of bread wheat (*Triticum aestivum L.*) varieties to N and P fertilizer rates in Ofla district, Southern Tigray Ethiopia. Afr J Agric 12(19):1646–1660

Mesele A (2019) Productivity, nutrient uptake and use efficiency of wheat as affected by Pan K level. M.Sc. Thesis Wolaita Sodo University Ethiopia

Mirza H, Borhannuddin BM, Kamrun N (2018) Potassium: a vital regulator of plant responses and tolerance to abiotic stresses. Agronomy. 8(3):31

Muhammad A, Zahir S, Hidayat U, Bushra K (2016) Yield response of wheat to nitrogen and potassium fertilization. Pure Appl Biol 5(4):868–875

Oosterhuis DM, Loka DA, Kawakami EM, Pettigrew WT (2014) The physiology of potassium in crop production. Adv Agron 126:203–233

Sharma S, Duveiller E, Basnet R, Karki CB, Sharma RC (2005) Effects of potash fertilization on Helminthosporium leaf blight severity in wheat and associated increases in grain yield and kernel weight. Field Crop Res 93:142–150

Singh SS (2004) Soil fertility and nutrient management, 2nd edn. Kalyani Publishers, New Delhi

Solomon W, Anjulo A (2017) Response of bread wheat varieties to different levels of nitrogen at Doyogena, Southern Ethiopia. Int J Sci Res Pub 7(2):452–459
Tabatabaii ES, Yarni M, Khorshidi MB, Farajzadeh MTE (2011) Effect of potassium fertilizer on corn yield under drought stress condition. Am Eur J Agric Environ Sci 10(2):257–263
Tahir MA, Rahmatullah MA, Gill T Aziz, Imran M (2003) Response of wheat and oat crops to potassium application and artificial irrigation with canal water. Pak J. Agric. Sci. 40(3–4):114–118
Tariq M, Saeed A, Nisar M, Mian IA, Afzal M (2011) Effect of potassium rates and sources on the growth performance and on chloride accumulation of maize in two different textured soils of Haripur, Hazara division. Sarhad J Agric 27:415–422
Tigist T (2017) Growth and yield response of bread wheat (*Triticum* aestivum L.) to Potassium and blended Nitrogen Phosphorus Bulfur fertilizer rates. Wolaita Sodo University, Ethiopia
Tilahun C, Gebrekidan H, Kibebew- KT, Tolessa- DD (2017) Effect of rate and time of nitrogen fertilizer application on durum wheat (*Triticum turgidum* L. Var. durum) grown on Vertisolsof Bale highlands, south eastern Ethiopia. Am J Res Commun 5(1):39–56
Tisdale SL, Nelson J, Beaton D, Havlin JL (2002) Soil and fertilizer potassium. 230–265
Tiwari KN (2002) Phosphorus and potassium fertilization reduces dry weather and late harvest risks. Fertilizer Knowledge 2:1–2
USDA (2020) The Foreign Agricultural Service (FAS) updates its production, supply and distribution (PSD) database for cotton, oilseeds, and grains Foreign Agricultural Service/Global Market Analysis. USDA, Washington
Worku A (2008) Effect of nitrogen and seed rate on yield and yield component of bread wheat. Alemaya University, Ethiopia
Zarcinas BA, Cartwright B, Spouncer LR (1987) Nitric acid digestion and multi-element analysis of plant material by inductively coupled plasma spectrometry. Commun Soil Sci Plant Anal 18(1):131–146

Publisher's Note