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SOIL & CROP SCIENCES | RESEARCH ARTICLE

Optimum potassium fertilization level for growth, yield and nutrient uptake of wheat (*Triticum aestivum*) in Vertisols of Northern Ethiopia

Hagos Brhane^{1*}, Tekalign Mamo² and Kassa Teka³

Abstract: Potassium fertilization was started in 2014 using K containing blended fertilizers in Ethiopia. However, there was no evidence whether the recommended rates of K in the blended formula (which is between 7 and 12 kg/ha in the form of K₂O) meets the crop demand on different soil reference groups or not. So, a field experiments were conducted to determine the optimum rate of potassium for yield and nutrient uptake of wheat in Vertisols of northern Ethiopia. The experiments were laid out in Randomized Complete Block Design with 4 levels of potassium (0, 30, 60, 90, of kg/ha K₂O) in three replications. Results depicted that the highest biological yield (straw + grain) and grain yields of wheat were increased with K rates. But, the partial budget analysis revealed that 60 K₂O kg/ha is economically feasible rate for wheat in Vertisols of the area. On the other hand, the highest apparent K recovery and agronomic use efficiencies were found at 30 kg/ha K₂O. Then it is concluded that the level of K in the blended formula was not enough to meet the yield requirement of wheat. Therefore, K should be applied independently rather than in blended for Vertisols of the area studied.

Subjects: Agriculture & Environmental Sciences; Soil Sciences; Soil Science; African Studies

Keywords: potassium; blended fertilizer; Vertisol; wheat; uptake; yield

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PUBLIC INTEREST STATEMENT

Wheat (*Triticum aestivum* L.) is an important food crop in Ethiopia, which accounts for 15.65% of the total cereal output. The role of potassium on crop production was not prioritized in Ethiopia for many years due to the view that potassium was not deficient. In contrast, out of the assessed Vertisols of Tigray region northern Ethiopia, 76% were deficient in potassium. As a result, potassium fertilization was started in 2014 as blended fertilizers in the region. However, there was no evidence which justifies whether the recommended rates of K in the blended formula (between 7 and 12 kg/ha K₂O) meets the crop demand on different soil reference groups or not. Hence, in this study we found that K improved yield and yield components of wheat in Vertisols of the area studied. Moreover, the level of K in the blended formula was not enough to meet the yield requirement of wheat.

1. Introduction

Wheat (*Triticum aestivum* L.) is an important food crop in Ethiopia, which accounts for 15.65% of the total cereal output (Central Statistical Authority of Ethiopia [CSA], 2015). However, the country is forced to import wheat every year since its productivity is minimal due to depletion of nutrients and poor management practices (Gebreselassie, 2002). As a result, for the past several years, farmers in the country had used blanket recommendation of only Urea and DAP (Di Ammonium Phosphate) as an input to improve soil fertility and increase crop production including wheat.

The role of potassium fertilizer on crop production in Ethiopia was not prioritized for many years due to the view that potassium was not deficient in Ethiopian soils. In contrast, recent research findings such as Tena and Beyene (2011) indicated that potassium was deficient in different parts of the country. In line with this, out of the assessed Vertisol dominated soil reference groups of Tigray region in northern Ethiopia, 76% were deficient in Potassium (Kebede & Yamoah, 2009). Similarly, the soil fertility atlas of Tigray, which was developed by Ethiopian Soil Information System (EthioSIS) indicated a potassium deficiency in various districts of the region, including Enderta, where this study took place (Ethiopian Soil Information System [EthioSIS], 2014).

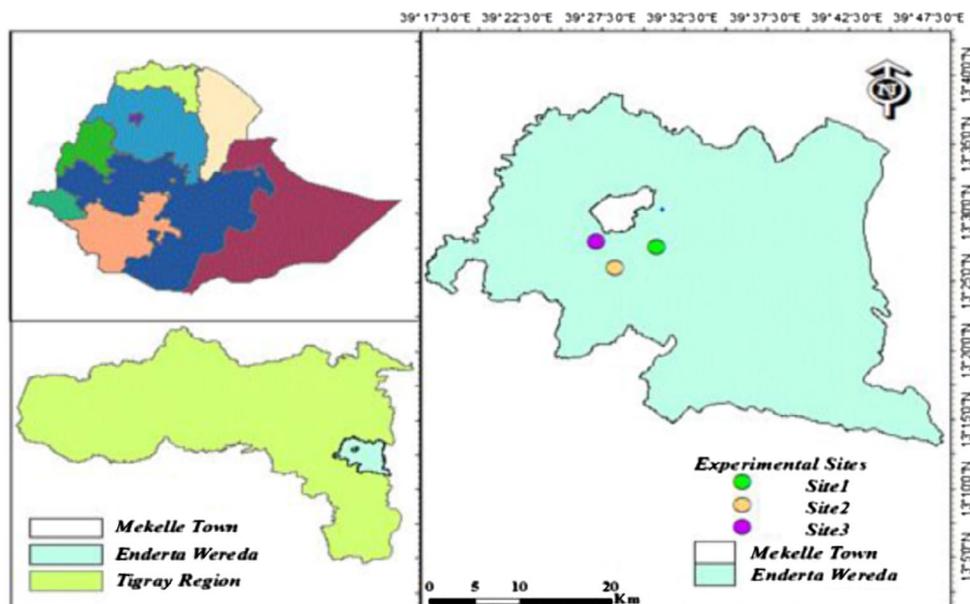
Based on the recent findings various efforts were made to include K fertilizer in 2014 through the introduction of K containing blended fertilizers produced in the country. However, there was no adequate evidence which justifies whether the recommended rates of K in the blended formula (which is between 7 and 12 kg/ha K_2O) meets the crops K demand or not. Moreover, the optimum level of K for wheat on specific soil condition was not studied. Thus, this study was designed to investigate the optimum level of potassium fertilizer for growth, yield and nutrient uptake of wheat in the Vertisols of northern Ethiopia.

2. Materials and methods

2.1. Study area

The experiment was conducted on Vertisols of Enderta district, northern Ethiopia. Geographically, the district is located between 13°12'55" and 13°38'38" N latitude and 39°16'43" and 39°48'08" E longitudes. The average elevation of the district is about 2,200 m above sea level (Gebre, Kibru, Tesfaye, & Taye, 2015, Figure 1).

Figure 1. Location of the study area in Tigray and Ethiopia.



Based on meteorological data collected from the nearest meteorological station (Mekelle airport), annual rainfall of the last six years ranged between 258 and 756 mm. The growing season of 2015 had received a relatively lower rainfall compared to the long term average, since the area was among those affected by El-Nino. The mean annual temperature ranges between 11.5 and 24.4°C. The most common soils of the study area are: Vertisols, Calcisols, Cambisol, Kastanozems, Leptosols, Luvisols, Phaozems, Regosols and Fluvisols (Gebre et al., 2015). According to same authors 58% of the soil in the area is covered by Vertisols.

2.2. Experimental design and procedures

The experiment comprised 4 levels of potassium (0, 30, 60 and 90 kg/ha K₂O) as treatments on top of recommended blended fertilizers (NPKSZn). These treatments were laid out in Randomized Complete Block Design (RCBD) with three replications. The plot size was 3 m by 3 m with spacing of 1 m between blocks and 0.5 m between plots based on recommendations set by Mekelle soil research center. On top of the blended fertilizer which contains 15.2% N, 48.8% Nitrogen was added to satisfy N wheat requirements (64 N kg/ha.) in the area. The blended fertilizer was applied at planting, while the nitrogen and K fertilizers were applied twice during the crop growth stage that is 1/3 of the full dose at planting and the other 2/3 at the full tillering stage. In the trial, picaflour (Kakaba) bread wheat variety was used as a test crop.

The initial soils of the experimental field were analyzed for texture, pH, organic matter, cation exchange capacity (CEC), total nitrogen, available phosphorus and exchangeable K. The methods used for soil physical and chemical analysis were: Soil pH (Rhoades, 1982), Organic carbon % (Walkley & Black, 1934), soil texture by hydrometer (Bouyoucos, 1962), available Phosphorus (Olsen, 1954), total nitrogen by Kjeldhal method (Bremner & Mulvaney, 1982), Neutral Ammonium acetate method (Landon, 1991) for cation exchange capacity and Exchangeable K⁺. Field monitoring and data recording were made during the wheat growth in the fields. After maturity, wheat crop samples were collected and partitioned into grain and straw parts. The grain and straw samples were analyzed for total nitrogen and potassium. Plant total nitrogen was analyzed using Kjeldhal method (Bremner & Mulvaney, 1982) whereas potassium using dry ashing method (Chapman, 1965). Data on plant height, spike length, biological yield, grain yield and 1,000 seed weight were collected. In addition, Partial budget analysis was made to investigate the economic feasibility of the treatments. Marginal Rate of Return, which refers to net income obtained by incurring a unit cost of fertilizer, was calculated as the change in net revenue divided by the change in total variable cost levels (CIMMYT Economics Program, 1988).

The K and N-uptake by straw or grain was calculated by multiplying K and N concentration (%) by respective straw or grain yield in kg/ha (Uptake of nutrient by grain or straw = nutrient concentration in % multiplied by grain or straw yield in kg/ha). Moreover, apparent K recovery and K agronomic use efficiencies were calculated by following the Equations (1) and (2) respectively proposed by Fageria and Baligar (2003).

$$\text{Apparent K recovery (kg/kg)} = \left(\frac{U_n - U_o}{n} \right) \quad (1)$$

where; U_n stands for nutrient uptake at “n” rate of fertilizer and U_o stands for nutrient uptake at control (no fertilizer) and “n” stands for fertilizer applied.

$$\text{Agronomic K use efficiency (kg/kg)} = \left(\frac{G_n - G_o}{n} \right) \quad (2)$$

where G_n and G_o stand for grain yield of fertilized plots at “n” rates of fertilizer and grain yield of unfertilized plots, respectively, and “n” stands for nutrient applied.

2.3. Data analysis

Analysis of variance (ANOVA) was carried out using Statistical Analysis Software (SAS) version 9. Whenever treatment effects were significant, mean separations were made using the least significant difference (LSD) test at the 5% level of probability.

3. Results and discussions

3.1. Soil properties before planting

The physical and chemical properties of the soil in the experimental sites are indicated in Table 1. The textural class of the soil is clay and slightly alkaline in pH, high in the CEC (Landon, 1991) and exchangeable K (Jones, 2002), low in organic carbon and total nitrogen (Tadesse, Haque, & Aduayi, 1991) and low in available P (Olsen, 1954). The continuous cultivation without using organic source of fertilizer, and the continuous crop residue removal from the farmlands for fuel and animal grazing might be contributed to low levels of organic carbon and total nitrogen in the study sites. This result is in agreement with the research findings of Kebede and Yamoah (2009) who reported that organic carbon levels are usually low in Vertisol particularly when they are cultivated continuously.

3.2. Plant height and spike length

Results in Table 2 depicted that, the average plant height was increased with increasing K application levels. The tallest plant (71.1 cm) was measured on plots that received 90 kg/ha of K₂O even though it is statistically similar with the treatments that received 30 and 60 kg/ha of K₂O. However, the shortest plant height was measured from the control treatment. This result is in agreement with the findings of Tahir, Tanveer, Ali, Ashraf, and Wasaya (2008) and Abbas et al. (2013). Likewise, there was an increasing trend in spike length with increasing K application rates even though it was statistically similar except with the control treatment. These findings are in accordance with the research findings of Khan, Gurmani, Gurmani, and Zia (2007) who reported that spike length of wheat was not significantly affected by any of the K levels.

Table 1. Properties of soil surface layer of the experimental site at starting of the experiment

pH (H ₂ O)	%		Cmol (+)/kg		Texture (%)		
	Org. C	Total N	Exch. K	CEC	Sand	Silt	Clay
7.61	0.70	0.09	0.76	39.6	19	25	56

Table 2. Impact of K fertilization on wheat status

Fertilization kg K ₂ O/ha		Wheat properties					
		cm		kg/ha		Harvest index	g
		Plant height	Spike length	Biological yield	Grain yield		
a	Control	50.3 ^c	4.7 ^b	3,236.0 ^d	805.3 ^d	0.25 ^b	31.3
b	RBF	59.3 ^{bc}	6.2 ^a	4,944.8 ^c	1,193.0 ^c	0.25 ^b	32.8
c	b + 30	66.8 ^{ba}	6.9 ^a	5,420.5 ^{bc}	1,499.8 ^b	0.28 ^{ba}	31.8
d	b + 60	70.3 ^a	7.0 ^a	6,290.6 ^{ba}	1,887.8 ^a	0.30 ^a	33.4
e	b + 90	71.1 ^a	7.0 ^a	6,885.2 ^a	2,181.7 ^a	0.32 ^a	34.2
LSD 0.05		9.7	1.03	1,161.4	299.9	0.053	NS
CV		8.1	8.6	11.5	10.5	10.1	6.8

Notes: Means followed by the same letter along columns are not significantly different. RBF: recommended blended fertilizer (NPKSZn), LSD: least significant difference; CV: coefficient of variance, NS: non significant.

3.3. Biological yield (total above ground biomass) and grain yield

The K rates significantly ($p < 0.05$) affected biological and grain yields of wheat. The biological and grain yields of wheat increased consistent with the increased application of K rates and the highest biological and grain yields of wheat were obtained from the maximum K rates (90 kg/ha K_2O) though the initial exchangeable K level of the soil was high. This might be due to the high cationic exchange of the 2:1 clay in Vertisols. This result is in agreement with the research findings of Astatke, Mamo, Peden, and Diedhiou (2004), and Singh and Wanjari (2014) who conducted their experiment on Vertisols of Chefe Donsa (Ethiopia) and Vertisols of Akola (India) respectively; in both cases, the soils had higher exchangeable K as rated using the critical levels that are used in different countries. In addition, treatments which received 90 kg/ha K_2O increased grain yield by 45.42 and 82.82% over the treatments which received 30 and 0 kg/ha K_2O respectively.

3.4. Harvest index and 1,000 seed weight

The harvest index was significantly affected ($p < 0.05$) by the K rates. The highest harvest index (0.32) was recorded at a rate of 90 kg/ha K_2O . This result was in agreement with the research findings of Maurya et al. (2014). However, 1,000 seed weight did not respond significantly to the different treatment combinations, even though the highest result was recorded at the highest K rate (90 kg/ha K_2O). This finding is in agreement with the research findings of Khan et al. (2007) and Morshedi and Farahbakhsh (2010).

3.5. Nutrient uptakes, apparent recoveries and agronomic use efficiency

3.5.1. K uptake by wheat grain and straw

The results indicated that K uptakes by grain and straw were influenced by different K treatment combinations. K uptakes by grain and straw of wheat showed a linear increasing trend with increasing K rates though there were some inconsistencies. The highest K uptake by grain and straw were found at 90 kg/ha K_2O rates and the lowest grain and straw K uptake were obtained from the control treatment. This result is in agreement with the research findings of Ashok, Kumar, Chauhan, and Singh (2009), who reported that in Uttar Pradesh all the levels of K significantly proved superior to control with respect to K uptake by wheat grain and straw, and the maximum value of K uptake was recorded with highest K level among the treatments. A similar finding was also reported by Wani, Malik, Dar, Akhter, and Raina (2014) in Kashmir, India (Figure 2).

3.5.2. N uptake by wheat grain and straw

Results showed that K rates influenced nitrogen uptake of wheat by grain and straw. Nitrogen grain uptake increased linearly up to 90 kg/ha K_2O rate while, straw uptake depicted increasing trend up to 60 kg/ha K_2O . The lowest uptakes of N by grain and straw were found in the control. This is due to K affects nitrogen absorption and reduction, and rapid nitrogen (NO_3) uptake depends on adequate K in the soil solution (Crops, 1998). This result is consistent with the research findings of Ashok et al. (2009) (Figure 3).

Figure 2. Effect of potassium rates on K uptake by wheat grain and straw.

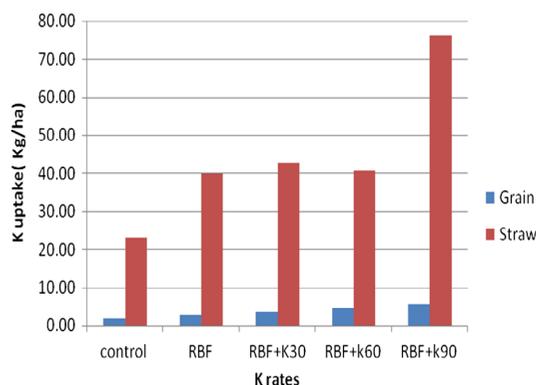
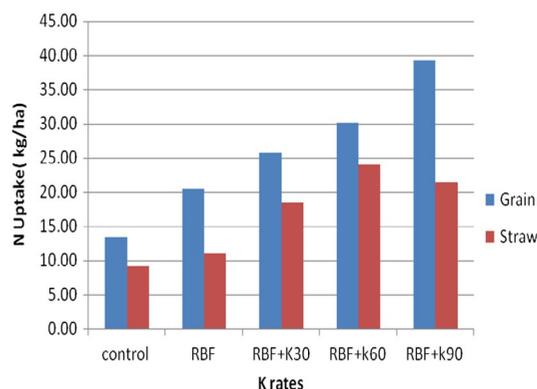


Figure 3. Effect of potassium rates on N uptake by wheat grain and straw.



3.5.3. Apparent recovery and agronomic use efficiency of K

Potassium application rates had influenced apparent potassium recovery and agronomic use efficiency. Both results had shown decreasing trend with increasing K rates though it was not consistent in apparent recovery. The highest apparent K recovery and agronomic use efficiencies were obtained at the lowest K rate (30 kg/ha K₂O). These results are consistent with the findings of Tariq, Saeed, Nisar, Mian, and Afzal (2011) who reported that wheat apparent recovery and agronomic use efficiency have decreased as the level of K increases (Table 3).

3.6. Partial budget analysis of potassium rates

The results of the study indicated that potassium fertilization gave promoting benefit over the control. Partial budget analysis was done based on the view of CIMMYT Economics Program (1988) recommendations, which stated that application of fertilizer with the marginal rate of return above the minimum level (100%) is economical.

The highest marginal rate of return was obtained at 90 kg/ha K₂O. This result had shown that further earnings from wheat yield could be obtained beyond this application rate. However, from the analysis of variance, wheat grain yield at 90 kg/ha K₂O was not statistically different from 60 kg/ha

Table 3. Effect of K rates on apparent recovery and agronomic use efficiency

Level of K (kg/ha)	ARK (kg/kg)	AUEK (kg/kg)
30	0.71	23.15
60	0.34	18.04
90	0.63	15.29

Notes: ARK = apparent recovery of potassium; AUEK = agronomic use efficiency of potassium.

Table 4. Partial budget analysis of wheat produced by K fertilizer rates at Vertisols

FR (kg K ₂ O/ha)	FC (Birr)	FA & TC [Birr]	TVC (Birr)	GY (kg/ha)	TR (GY*9.6)	NR (TR-TVC)	MRR (ratio)	MRR (%)
0	0	0	0	1,193	11,452.8	11,452.8		
							4.61	461
30	490	35	525	1,499.8	14,398.1	13,873.1		
							6.09	609
60	980	70	1,050	1,887.8	18,122.9	17,072.9		
							4.37	437
90	1,470	105	1,575	2,181.7	20,944.3	19,369.3		

Notes: FR: fertilizer rate; FC: fertilizer cost; FA & TC: fertilizer application & transport cost; TVC: total variable cost; GY: grain yield; TR: total revenue; NR: net revenue; MRR: marginal rate of return

K₂O application and growers prefer 60 kg/ha K₂O since the total variable cost of 90 kg/ha K₂O is higher. Thus, 60 kg/ha K₂O is economically profitable. This finding is in agreement with research findings of Khan et al. (2007), who reported that application of K at a rate of 60 kg/ha K₂O increased wheat grain yield and it is economical (Table 4).

4. Conclusions

The study was aimed at optimum rates of potassium fertilization on top of the blended fertilizers for wheat yield in Vertisols of northern Ethiopia. The results indicated that nutrient uptake, recovery, agronomic use efficiencies, yield and yield components of wheat significantly responded to the additional K rates. Thus, the level of potassium in the blended formula did not meet the growth and yield requirement of wheat on Vertisols of the study sites. In line with this, the highest biological and grain yields of wheat were obtained at the highest level of K (90 kg/ha K₂O) irrespective of their initial soil K content. Moreover, 60 kg/ha K₂O is economically feasible rates of K for Vertisols of Enderta soils. Similarly, the highest K and N uptakes by grain were found at a level of 90 kg/ha K₂O. However, the highest apparent K recovery and agronomic use efficiencies were found at the lowest K level (30 kg/ha K₂O). Hence, potassium fertilization is important and it should be applied independently rather than incorporating it as blended.

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Competing Interests

The authors declare no competing interest

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