DOI: 10.5965/223811712242023662

Revista de Ciências Agroveterinárias 22 (4): 2023
Universidade do Estado de Santa Catarina

Effect of Applying Mineral Nitrogen, Phosphorus, and Potassium Fertilizers on N, P, and K Uptake and Use Efficiency of Faba Bean (*Vicia faba* L.) on Acidic Soil in Wolaita Zone, Southern Ethiopia

Efeito da aplicação de fertilizantes minerais de nitrogênio, fósforo e potássio na absorção de N, P e K e na eficiência de uso do feijão Faba (Vicia faba L.) em solo ácido na zona de Wolaita, sul da Etiópia

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Submission: 18/05/2023 | Acceptance: 03/07/2023

ABSTRACT

Soil fertility problem is a major constraint to faba bean production in Wolaita Zone in Ethiopia. Hence, a field experiment was conducted in Kokate Marachare sub-district during 2019 and 2020 cropping seasons to determine the optimum N, P, and K fertilizers for enhanced uptake and use efficiency of faba bean. Three rates of N (0, 23, and 46 kg N $ha^{–1}$), P (0, 46, and 92 kg P_2O_5 $ha^{–1}$), and K fertilizer (0, 30, and 60 kg K_2O $ha^{–1}$) were tested using RCBD with three replications. Data on agronomic efficiency (AE), agro-physiological efficiency (APE), apparent recovery efficiency (ARE), and utilization efficiency of N, P, and K nutrients were analyzed. The results revealed N, P, and K uptake efficiency (UE) indices of faba bean were significantly influenced by the main effects of the rate of nitrogen, phosphorus, and potassium fertilizers. Thus, applying 23 kg N $ha^{–1}$, 46 kg P_2O_5 $ha^{–1}$, and 30 kg K_2O $ha^{–1}$ resulted higher N, P, and K AE, respectively (33.70 kg kg^{-1}, 13.43 kg kg^{-1}, and 27.32 kg kg^{-1}); PE (76.87 kg kg^{-1}, 104.51 kg kg^{-1}, and 118.83 kg kg^{-1}); APE (40.49 kg kg^{-1}, 104.51 kg kg^{-1}, and 68.07 kg kg^{-1}); ARE (84.48%, 2.00%, and 40.30%); and UE (63.47 kg kg^{-1}, 2.52 kg kg^{-1}, and 56.08 kg kg^{-1}). Therefore, 23 kg N $ha^{–1}$, 46 kg P_2O $_5ha^{–1}$, and 30 kg K_2O $ha^{–1}$ are recommended for the higher N, P, and K uptake and use efficiency of faba bean.

KEYWORDS: agronomic efficiency; agro-physiological efficiency; apparent recovery efficiency; physiologic efficiency; utilization efficiency.

RESUMO

O problema de fertilidade do solo é um grande constrangimento à produção de fava na zona de Wolaita, na Etiópia. Assim, foi realizada uma experiência de campo no subdistrito de Kokate Marachare durante as épocas agrícolas de 2019 e 2020 para determinar os fertilizantes N, P e K ideais para melhorar a absorção e eficiência de utilização da fava. Foram utilizadas três doses de N (0, 23 e 46 kg N $ha^{–1}$), P (0, 46 e 92 kg P2O5 $ha^{–1}$) e fertilizante K (0, 30 e 60 kg K2O $ha^{–1}$). testado usando RCBD com três repetições. Foram analisados dados de eficiência agronômica (AE), eficiência agrofisiológica (APE), eficiência de recuperação aparente (ARE) e eficiência de utilização dos nutrientes N, P e K. Os resultados revelaram que os índices de eficiência de absorção de N, P e K (UE) da fava foram significativamente influenciados pelos principais efeitos da dose de fertilizantes de nitrogênio, fósforo e potássio. Assim, a aplicação de 23 kg N $ha^{–1}$, 46 kg P2O5 $ha^{–1}$ e 30 kg K2O $ha^{–1}$ resultou em maiores AE de N, P e K, respectivamente (33,70 kg kg^{-1}, 13,43 kg kg-1 e 27,32 kgkg-1); PE (76,87 kg kg^{-1}, 104,51 kg kg^{-1} e 118,83 kg kg^{-1}); APE (40,49 kg kg^{-1}, 104,51 kg kg^{-1} e 68,07 kg kg^{-1}); ARE (84,48%, 2,00% e 40,30%); e UE (63,47 kg kg^{-1}, 2,52 kg kg^{-1} e 56,08 kg kg^{-1}). Portanto, 23 kg N $ha^{–1}$, 46 kg P2O $5ha^{–1}$ e 30 kg K2O $ha^{–1}$ são recomendados para maior absorção de N, P e K e eficiência de uso da fava.

PALAVRAS-CHAVE: eficiência agronômica; eficiência agrofisiológica; eficiência aparente de recuperação; eficiência fisiológica; eficiência de utilização.

INTRODUCTION

Faba bean (*Vicia faba* L.) has a significant dietary role both for humans and livestock in Ethiopia. It takes the largest share of area (492,271.60 hectares) and seed production (1,041,953.14 tons) of the pulses grown in the country (CSA 2019). The average national yield of the cop is about 2.1 t ha^{-1} (CSA 2019), which is very low compared to the average yield of 2.9 t ha^{-1} in major producing countries in the world (FAOSTAT 2019). Particularly in the Wolaita Zone farmers harvest an average yield of only about 1.2 t ha^{-1}, which is far less than the farmer-managed national average yield (2.1 t ha^{-1}) (CSA 2018).

The yield of faba bean is low in Ethiopia due to climatic (WONDAFRASH et al. 2019), genetic (KIFLEMARIAM et al. 2019), edaphic (ENDALKACHEW et al. 2019), and biotic factors (diseases, pests, and weeds) (ALHAMMAD & SELEIMAN 2023, DEGIFE & KIYA 2016). Poor soil fertility is a serious problem constraining faba bean production in Ethiopia (GETACHEW 2018, GETAHUN & ABERE 2019). In most cases, soils with a pH value less than 5.5 are deficient in macronutrients like N, P, K, Ca, and Mg (FAGERIA et al*.* 2011). Thus, production of faba bean has been abandoned in some regions in the country due to its sensitivity to soil acidity (GENANEW et al. 2012). The inheritable sensitivity of the crop to acidic soils and less nutrient efficiency of the local faba bean cultivar is a major yield-limiting factor (TAMENE & TADESE 2019). Particularly, the productivity of the crop in Wolaita Zone is mainly reduced due to the lack of nutrient-efficient improved varieties that tolerate soil acidity and yield reasonably well (TADELE et al*.* 2016, FEKADU 2018).

In addition to the need of alleviating the problem of soil acidity in particular to increase the yield of faba bean, enhancing the productivity of the crop through increased nutrient use efficiency by both improving soil fertility and cultivating nutrient-efficient varieties of the crop is an important step. Some faba bean varieties remain productive and nutrient-efficient under low soil fertility when soil pH is as low as 4.5 (SINGH et al. 2012). Thus, the research findings from different countries indicated the advantages of determining the nutrient uptake and use efficiency of the faba bean for enhanced productivity. In this connection, the finding of SETLLING et al. (2018) indicated a significant improvement in seed, stover, and total N, P, and K uptake in response to applying at the rate of 700 mg P per pot compared to 00 mg P per pot. In addition, the authors reported 18.6 mg mg^{-1}, 162 mg mg^{-1}, and 30.6 mg mg^{-1} more N, P, and K utilization efficiency of faba bean, respectively, in response to the application of 700 mg P per pot compared to 100 mg P per pot. LONG et al*.* (2003) also indicated that 51%, 68%, and 46 % higher total N, P and, K uptake values of faba bean, respectively, in response to applying phosphorus at the rate of 33 kg P ha^{-1} than the control treatment. Furthermore, DAOU et al*.* (2012) indicated higher mean phosphorus uptake and 48% higher mean phosphorus use efficiency of eight Moroccan faba bean varieties in response to phosphorus applied at the rate of 40 P_2O_5 ha^{-1} than that applied at the rate of 0, 80, and 120 kg P_2O_5 ha^{-1}.

Research conducted in different parts of Ethiopia showed significant improvements in the total nutrient uptake and utilization of faba bean in response to applying inorganic fertilizers. For instance, BAYOU et al. (2020) showed faba bean inoculated with TAL_1035 rhizobium strains resulted in 305.6 kg N ha^{-1} nitrogen uptake and 68 kg P ha^{-1} phosphorus uptake, which were 57% and 77% higher than non-inoculated treatment, respectively. In contrast, NEBIYU et al. (2016) reported that phosphorus application had no significant effect on phosphorus use efficiency, while faba bean varieties showed significant variations in phosphorus use efficiency. Thus, the authors indicated that Moti variety demonstrated the highest agronomic phosphorus use efficiency that was 1.6-fold higher than the agronomic phosphorus use efficiency recorded for Gebelcho variety. This implies that nutrient uptake and use efficiencies of the faba bean depend on the optimal nutrient application. SHANKA et al. (2018) studied phosphorus use efficiency of common bean varieties in Wolaita area and found that Red-Wolaita, Dinkinesh, Tabour, Nasir, and Haramaya were P-efficient whereas other varieties were inefficient and recommended the use of the former varieties for use by smallholder farmers to enhance economic and sustainable production of the crop in the study area.

Overall, numerous studies revealed that the site-specific balanced N, P, and K fertilizer application is very important to improve soil fertility and increased faba bean productivity. However, managing the soil fertility by applying nutrients at adequate levels may be difficult for resource-poor farmers particularly when the varieties they cultivate have low nutrient use efficiencies. Thus, determining the nutrient use efficiency of the crop is required to minimize nutrient loss and improve productivity. However, not much research has been done to determine nitrogen, phosphorus, and potassium fertilizer uptake and use efficiencies of faba bean in Wolaita Zone in general and the study area in particular.

In addition, site-specific optimum N, P, and K fertilizer requirements for efficient utilization are required to improve faba bean seed yield productivity in the study area. It was hypothesized that the application of optimal N, P, and K fertilizers rate improves the uptake and use efficiencies of the nutrients by the crop. Therefore, this research was conducted to determine the uptake and use efficiencies of nitrogen, phosphorus, and potassium of faba bean in response to different rates of fertilizers containing the nutrients in Sodo Zuria district in Wolaita Zone.

MATERIAL AND METHODS

Description of the Experimental Site

The study was conducted for two consecutive years during the 2019 and 2020 main cropping seasons (June to November) on farmers' field at Kokate Marachere sub-district of Sodo Zuria district in Wolaita Zone, southern Ethiopia.

The study site was selected purposively based on its high faba bean production potential. The experimental site is located at 7°25'21" N latitude and 37°46'52" E longitude, and an altitude of 2156 meters above sea level (SHANKA et al. 2018). In the 2019 and 2020 cropping seasons, the mean monthly temperatures of the Sodo Zuria district ranged from 15 °C to 23.8 °C and from 14.5 °C to 25.8 °C, respectively with annual rainfall of 1,187 mm and 1376 mm, respectively (NMA 2020). The dominant soil type in the study area is Eutric Nitisols associated with Humic Nitisols (SHANKA et al. 2018).

Treatments and Experimental Design

The fertilizer treatments consisted of three rates each of nitrogen (0, 23, and 46 kg N ha^{-1}), phosphorus (0, 46, and 92 kg P_2O_5 ha^{-1}), and three rates of potassium (0, 30, 60 kg K_2O ha^{-1}). The middle rates of N and P fertilizers were fixed based on the recommendation given by the Ethiopian Institute of Agricultural Research (EIAR) for faba bean production (EIAR 2018). There is no K recommendation for faba bean production in Ethiopia, yet the rate was fixed following the the evidence reported by WASSIE & SHIFERAW (2011), HAGOS et al. (2017), and BEZABIH et al. (2018) in Ethiopia. Urea [$CO(NH_2)_2$] (46% N), triple superphosphate (TSP) [$Ca(H_2PO_4)_2$] (20% P), and KCl (62% K_2O) (muriate of potash) were used as a source of N, P, and K, respectively. The variety needs 120–130 days to reach maturity (BEKALU et al. 2022).

The experiment was laid out as a randomized complete block design in a factorial arrangement and replicated three times per treatment. The randomization used in the 2019 cropping season was used also in 2020 without any change of location to avoid bias. The plot size was 2.8 m x 2.1 m (5.8 m^2) with 0.5 m spacing between plots and 1m between blocks. The inter-row and intra-row spacings were 40 and 10 cm, respectively, and each row and plot consisted of 21 and 147 plants, respectively (EIAR 2018).

Soil Sampling and Analysis

Before planting, surface soil samples (0 – 30 cm depth) were collected in a zig-zag pattern from sixteen spots. Then soil samples were mixed to form a one-kilogram composite sample. The soil sample was analyzed at Hawassa soil laboratory for soil pH, CEC, soil organic carbon (OC), total N, available P, exchangeable cations, and soil particle size distibution. Soil pH (1: 2.5 soils to water ratio) was measured using a glass electrode pH meter as described by MYLAVARAPU (2009). CEC was determined from NH4OAc saturated samples, which measured through distillation using the micro Kjeldahl procedure. Soil OC was determined by the chromate acid oxidation method (WALKLEY & BLACK 1934). Total nitrogen was analyzed using the macro-Kjeldahl digestion method, followed by the ammonium distillation and titration method (BREMNER 1965). Soil available P was analyzed using the Olsen method (OLSEN et al. 1954). Exchangeable K was extracted by the ammonium acetate (1M NH OAc at pH 7) extraction method as described by ROWELL (1994) and determined by flame photometry. The particle size distribution was done following the Bouyoucos hydrometer method (BOUYOUCOS 1951) and the textural class was determined based on the soil textural triangle using the International Soil Science Society (ISSS) system (ROWELL 1994).

Tissue Sampling and Analysis

Plant samples were collected at crop maturity and representative samples of seed and non-seed aboveground plant parts were taken to determine stover and seed N, P, and K concentrations. The stover plant samples were rinsed with distilled water to remove soil dirt and oven-dried at 70 °C to a constant weight. The dry weight was measured using an electronic balance. The samples were ground and allowed to pass through a 0.5 mm sieve to prepare a 10 g sample for each respective treatment.

One gram of the ground stover sample of each treatment was subjected to digestion with H_2SO_4 (0.1 N) containing digestion mixture (10 parts potassium sulphate and one part copper sulphate). The nitrogen concentration in the plant tissue was determined by the Micro- Kjeldahl digestion method (BURESH et al. 1982). Likewise, seed N concentration was estimated from 1 g dry samples by the digestion method of

Micro- Kjeldahl's apparatus as described by BREMNER (1965). Phosphorus and potassium concentrations in the stover and seed were determined by the dry ashing method, whereby the plant material was calcinated in a muffle furnace at the temperature of 450 °C for four hours, dissolved in 20% HNO_3 solution. Total phosphorus in the filtrate was determined by vanadium phosphomolybdate (yellow color development) method by spectrophotometer at 460 nm wavelength. Potassium concentration in stover tissue was determined by using a flame photometer after diluting the ashed plant sample by 20% HNO_3 solution procedure as outlined by SAHLEMEDHIN & TAYE (2000). Nitrogen, P, and K use efficiency values for the respective faba bean treatments were calculated as described in FAGERIA & BALIGAR (2007).

Data Collection and measurement

The different nitrogen, phosphorus, and potassium utilization efficiencies were calculated from established formulas (FAGERIA & BALIGAR 2005) as described below:

Agronomic Efficiency (AE) - is defined as the amount of seed production obtained per unit of nutrient applied, and is calculated as AE (kg kg^{-1}) = $\frac{Gf-Gu}{Na}$ where, Gf is the seed yield in the fertilized plot (kg); Gu is the seed yield in the unfertilized plot (kg), and Na is the quantity of nutrient applied (kg)

Physiological Efficiency *(PE)* - is defined as the biological yield obtained per unit of nutrient uptake and is calculated as PE (kg kg^{-1}) = $\frac{Yf-Yu}{Nf-nU}$ where, Yf is the biological yield (seed plus stover) of the fertilized pot (kg); Yu is the biological yield of the unfertilized plot (kg); Nf is the nutrient uptake (seed plus stover) of the fertilized plot; and Nu is the nutrient uptake (seed plus stover) of the unfertilized plot (kg).

Agro-physiological efficiency (APE) - is defined as the economic production (seed yield in case of annual crops) obtained per unit of nutrient uptake, and is calculated as APE (kg kg^{-1}) = $\frac{Gf-Uf}{Nf-Nu}$ where, Gf is the seed yield of fertilized plot (kg); Gu is the seed yield of the unfertilized plot (kg); Nf is the nutrient uptake (seed plus stover) of the fertilized plot (kg); Nu is the N uptake (seed plus stover) of unfertilized plot (kg).

Apparent recovery efficiency (ARE) **-** is defined as the quantity of nutrient uptake per unit of nutrient applied and is calculated as ARE (%) = ($\frac{Nf-Nu}{Na}$)$\times$100 where, Nf is the nutrient uptake (seed plus stover) of the fertilized plot (kg); Nu is the nutrient uptake (seed plus stover) of the unfertilized plot (kg); Na is the quantity of nutrient applied (kg) (FAGERIA & BALIGAR 2007).

Nutrient Utilization Efficiency (UE) **-** is the product of physiological efficiency and apparent recovery efficiency.

Data Analysis

All data were subjected to analysis of variance (GLM procedure) using SAS software program version 9.4 (SAS INSTITUTE 2013). Homogeneity of variances was evaluated using the F-test as described by GOMEZ & GOMEZ (1984). Since the F-test showed homogeneity of the variances of the two years for most of the nutrient uptake and use parameters. The treatment means were separated using the Least Significant Difference test at a 5% level of significance.

RESULTS AND DISCUSSION

Physical and Chemical Properties of the Experimental Soil

The results of the soil physical and chemical analysis are shown in Table 1. The texture of the soils of the experimental site is silty clay. This showed that the soil has limitations in soil pH and nutrient availability for crop production. According to MURPHY (1968), the soil of the experimental site is rated very strongly acidic. The value is far below the range suitable for most crops and optimum for the availability of nutrients i.e. 6.5 to 7.5 (FAO 2008). Faba bean grows best in soils with pH values ranging from 6.5 to 9.0 (JENSEN et al. 2010). Thus, the strong soil acidity could be one of the major factors responsible for reducing the seed yield of the crop, which is lower than the national average yield by about 100%. Hence, application of lime, which increases soil pH, is necessary for improving faba bean yield in the experimental area. This is because lime application increases soil pH in which Ca reacts with H^+ in the exchange site and neutralizes it, thereby increasing the pH of the soil (ANDERSON et al*.* 2013).

The CEC value of the soil is moderate according to the rating of HAZELTON & MURPHY (2007), which indicates its retention of adequate cations. The soil has moderate organic carbon and total N contents according to the rating of BERHANU DEBELE (1980). Thus, it indicates the ability of the soil to supply organic carbon and mineralizable nitrogen for the proliferation of soil biota, which is important for soil biochemical processes that increase mobility of nutrients such as P and others for plant uptake (MURAGE et al. 2000).

The available P content of the soil is low according to the rating of COTTENIE (1980). Thus, application of P fertilizer is required for improving faba bean yield in the study area (FAO 2008). The exchangeable K in the soil is low according to the rating of FAO (2006), which indicates the level is not sufficient for plant growth. Since critical values for K that begin to limit plant growth are around 0.2–0.5 cmol (+) kg ha^{-1} according to GOURLEY (1999), the content of exchangeable K is low and the soil requires external application of the nutrient. Thus, the external applications of N, P, and K fertilizers were in order.

Table 1. Soil physical and chemical properties of the study site in Sodo Zuria district, Southern Ethiopia in 2019 and 2020 cropping seasons.

Parameter	Year 2019	Year 2020	Rating	Reference
Sand (%)	15	19	-	-
Silt (%)	40	43	-	-
Clay (%)	45	38	-	-
Textural class	Silty clay	Silty clay		
pH (1: 2.5 H_2O**)**	4.9	5.6	Strong to moderately acidic	MURPHY 1968
CEC ($cmol_{(+)}$ kg^{-1})	23.1	24.6	Moderate	HAZELTON & MURPHY (2007)
OC (%)	2.7	2.9	Medium	BERHANU DEBELE (1980) as cited by TEKALIGN TADESE et al (1991)
Total N (%)	0.12	0.16	Moderate	BERHANU DEBELE (1980) as cited by
Available P(mg kg^{-1})	5.94	6.12	Low	COTTENIE (1980)
Exchangeable K ($cmo_{(+)}$kg $soil^{-1}$)	0.4	0.4	Low	FAO (2006)

CEC= Cation Exchange Capacity; OC= Organic Carbon; Total N = Total Nitrogen; Av.P= Available phosphorous.

Agronomic Efficiency (AE)

The agronomic efficiency of the faba bean was significantly ($p \leq 0.01$) affected by the main effect of the rate of mineral nitrogen, phosphorus, and potassium fertilizers. However, the main effect of the year, the interaction effect of nitrogen, phosphorus, and potassium fertilizer rates with year did not significantly influence the AE of the faba bean.

The application of nitrogen, phosphorus, and potassium fertilizers at the rate of 23 kg N ha^{-1}, 46 kg P_2O_5 ha^{-1}, and 30 kg K_2O ha^{-1} increased the agronomic efficiency of N, P, and K of the faba bean, respectively. However, the increased application of nitrogen, phosphorus, and potassium fertilizers beyond the aforementioned level significantly reduced the agronomic efficiency of N, P, and K of the faba bean, respectively (Table 2). Thus, the higher AE of 33.70 kg kg^{-1}, 13.43 kg kg^{-1}, and 27.32 kg kg^{-1} of N, P, and K, respectively were recorded in response to 23 kg N ha^{-1}, 46 kg P_2O_5 ha^{-1}, and 30 kg K_2O ha^{-1}, respectively (Table 2).

These higher AE of N, P, and K were obtained at the aforementioned rate of nitrogen, phosphorus, and potassium fertilizers indicating an optimized rate for higher agronomic efficiency of the faba bean in the studied area. On other hand, the higher AE of nitrogen obtained in response to the application of 23 kg N ha^{-1} than 46 kg N ha^{-1} might be associated with the requirement of legumes with little nitrogen as starter fertilizer (MOHAMED & BABIKER 2012). Hence, higher doses of nitrogen might suppress the nodulation potential of the crops (BERRY et al*.* 2004).

Consequently, the seed production of the crop was negatively affected in nitrogen applied at the rate of 46 kg N ha^{-1} and resulted in a lower AE of nitrogen than that of nitrogen applied at the rate of 23 kg N ha^{-1}. Similarly, a decrease in AE of P and K of the faba bean in the increased rate of phosphorus and potassium fertilizers beyond the above mentioned rates might be related to the proportion for seed production decreased, which directly affect AE of the crop. Since, agronomic efficiency is about the amount of seed production obtained per unit of nutrient applied (FAGERIA & BALIGAR 2005).

In general, the AE of faba bean reported in sub-Saharan Africa ranges from 10 to 30 kg kg^{-1} (STELLING et al*.* 1996, JAIROS et al*.* 2020). SOFONYAS et al*.* (2018) also reported that the AE of faba bean ranged from 0.69 to 31.52 kg kg^{-1} in response to different N rates at Emba Alaje in northern Ethiopia. Overall, the values higher than 30 indicate efficiently managed systems (FAGERIA et al*.* 2008). Accordingly, AE of 33.7 kg kg^{-1} was obtained in response to nitrogen application at the rate of 23 kg N ha^{-1} is higher and indicates efficiency management systems.

Table 2. Main effect of mineral nitrogen, phosphorus, potassium fertilizer and year on agronomic efficiency of faba bean in Sodo Zuria district, Southern Ethiopia in 2019 and 2020 cropping seasons.

Fertilizer rate	Agronomic efficiency of nitrogen (kg kg^{-1})
Nitrogen (kg N ha^{-1})	
0	19.59b
23	33.70a
46	5.48c
LSD (5%)	7.07
CV (%)	10.36
Phosphorus (kg P_2O_5 ha^{-1})	Agronomic efficiency of phosphorus (kg kg^{-1})
0	9.86b
46	13.43a
92	6.28c
LSD (5%)	2.40
CV (%)	10.69
Potassium (kg K_2O ha^{-1})	Agronomic efficiency of potassium (kg kg^{-1})
0	20.76b
30	27.32a
60	14.20c
LSD (5%)	3.67
CV (%)	8.14

Means in columns followed by the same letter are not significantly different at P = 0.05 according to Fishers Protected LSD test; ns=non- significant.

Physiological Efficiency *(PE)*

The main effect of mineral nitrogen fertilizer application significantly influenced the PE of the faba bean. However, the main effect of year, phosphorus, and potassium, interaction among nitrogen, phosphorus, and potassium the three fertilizers interaction with year did not significantly influence the PE of the faba bean.

The significantly higher physiological efficiency of N of the faba bean was obtained at nitrogen fertilizer applied at the rate of 23 kg N ha^{-1} (Table 3). However, increasing the rate of nitrogen fertilizer beyond the abovementioned rate resulted in a significant reduction in PE of N of faba bean. Thus, application of 23 kg N ha^{-1} resulted in 95% more PE of N of faba bean than that applied at the rate of 46 kg N ha^{-1} (Table 3). These variations in physiological efficiency of N of faba bean might be linked with the increasing nitrogen fertilizer beyond the abovementioned rate may have resulted in a decreased proportion of biological yield production. Consequently, physiological efficiency is directly affected; because of biological yield obtained per unit of nutrient uptake is reduced (FAGERIA & BALIGAR 2005). On other hand, reduced PE of N of the crop in 46 kg N ha^{-1} than 23 kg N ha^{-1} might be linked with a higher rate of application resulted in relatively more lodging. Thus, the biological yield obtained in response to a unit of nutrient uptake decreased and leading to reduced PE of the crop (DERON et al. 2017). Furthermore, higher doses of nitrogen fertilizer might suppress the nodulating potential and reduce nutrient uptake attributed to the physiological efficiency of the crop (STELLING et al. 1996).

Overall, the result suggests that for the maximized physiological efficiency of N of faba bean in the studied area, the application of 23 kg N ha^{-1} is the optimum rate. This result is in close agreement with the study by AMANULLAH et al. (2012) who reported that PE decreased with the increased rate of nitrogen from 15 to 48 kg N ha^{-1}.

Studies in different parts of the world indicated that the physiological efficiency (PE) of faba bean ranges from 30 to 60 kg kg^{-1} (AMANULLAH et al. 2012, JAIROS et al. 2020). My result is consistent with this finding of DOBERMANN (2005), who reported the PE for cereals grown in the tropics from field studies to range from 30 to 60 kg kg^{-1}. The values higher than 60 indicate efficiently managed systems. Thus, physiological efficiency of N higher than 60 in fertilizer applied rate of 23 kg N ha^{-1}. This indicates that the soil of the experimental site was low in nitrogen.

Table 3. Main effect of mineral nitrogen, phosphorus, potassium fertilizer and year on physiologic efficiency of faba bean in Sodo Zuria district, Southern Ethiopia in 2019 and 2020 cropping seasons.

Fertilizer rate	Physiological efficiency of nitrogen (kg kg^{-1})
Nitrogen (kg N ha^{-1})	
0	58.14b
23	76.87a
46	39.41c
LSD (5%)	25.69
CV (%)	18.03
Phosphorus (kg P_2O_5 ha^{-1})	Physiological efficiencyin of phosphorus (kg kg^{-1})
0	120
46	104.51a
92	135.46a
LSD (5%)	ns
CV (%)	16.53
Potassium (kg K_2O ha^{-1})	Physiological efficiency potassium (kg kg^{-1})
0	129a
30	118.83a
60	139.30a
LSD (5%)	ns
CV (%)	18.55

Means in columns followed by the same letter are not significantly different at P = 0.05 according to Fishers Protected LSD test; ns=non- significant.

Agro-physiological efficiency *(APE)*

The agro-physiological efficiency (APE) of faba bean was significantly ($P \leq 0.01$) affected by the main effect of mineral nitrogen and potassium fertilizers application. However, the main effect of year and phosphorus, interaction among the three fertilizers, and the three fertilizers interaction with year did not significantly influence the APE of the faba bean.

The significantly higher agro-physiological efficiency (APE) of N, P, and K of the faba bean were obtained at 23 kg N ha^{-1}, and 30 kg K_2O ha^{-1}, respectively (Table 4). However, increasing the rate of nitrogen and potassium fertilizers beyond the above mentioned rates resulted in a significant reduction in APE of N and K of faba bean. Thus, the application of 23 kg N ha^{-1} and 30 kg K_2O ha^{-1} resulted 128 and 23 % more APE of N and K of faba bean than that applied at the rate of 46 kg N ha^{-1} and 60 kg K_2O ha^{-1}, respectively (Table 4). These variations in physiological efficiency of N and K might be linked with the increasing nitrogen and potassium fertilizers beyond the above mentioned rates resulted in a decreased proportion of seed yield production. Consequently, agro-physiological efficiency is directly affected, because of seed yield obtained per unit of nutrient uptake is reduced (FAGERIA & BALIGAR 2005). Particularly, reduced APE of N of the crop in nitrogen applied at the rate of 46 kg N ha^{-1} than 23 kg N ha^{-1} might be linked with a higher rate of application resulted in relatively more lodging. Thus, seed yield obtained in response to a unit of nutrient uptake decreased and leading to reduced APE of the crop (DERON et al. 2017). Overall, the results suggest that for the maximized agro-physiological efficiency of N and K of faba bean, the optimum rate of nitrogen and potassium is required. This result is in close agreement with the study by AMANULLAH et al. (2012) who reported that PE decreased with the increased rate of nitrogen from 15 to 48 kg N ha^{-1}.

Studies in different parts of the world indicated that the agro-physiological efficiency (APE) of faba bean ranges from 30 to 60 kg kg^{-1} (AMANULLAH et al. 2012, JAIROS et al. 2020). Consistent with this finding, DOBERMANN (2005) reported the APE for cereals grown in the tropics from field studies to range from 30 to 60 kg kg^{-1}. The values higher than 60 indicate efficiently managed systems. Thus, agro-physiological efficiency of K higher than 60 in potassium fertilizer applied rate of 30 K_2O ha^{-1}. Thus, the findings of this study are quite higher than previous studies. This indicates that the soil of the experimental site was low in potassium nutrient, and there was good management at the experimental site.

Table 4. Main effect of mineral nitrogen, phosphorus, potassium fertilizer and year on agro-physiological efficiency of faba bean (kg kg^{-1}) in Sodo Zuria district, Southern Ethiopia in 2019 and 2020 cropping seasons.

Fertilizer rate	Agro-physiological efficiency of nitrogen
Nitrogen (kg N ha^{-1})	
0	28.75b
23	40.49a
46	17.00c
LSD (5%)	9.15
CV (%)	16.48
Phosphorus (kg $P_2O_5ha^{-1}$)	Agro-physiological efficiency of phosphorus
0	119.98a
46	104.51a
92	135.46a
LSD (5%)	ns
CV (%)	17.26
Potassium (kg K_2O ha^{-1})	Agro-physiological efficiency of potassium
	61.80a
30	68.07a
60	55.53b
LSD (5%)	7.68
CV (%)	13.92

Means in columns followed by the same letter are not significantly different at P = 0.05 according to Fishers Protected LSD test; ns=non- significant.

Apparent Recovery Efficiency *(ARE)*

The apparent recovery efficiency of faba bean significantly varied in response to the main effect of year, nitrogen, phosphorus, and potassium fertilizers application. However, interaction among nitrogen, phosphorus, and potassium fertilizers, and the three fertilizers interaction with year did not significantly influence the ARE of the faba bean.

The apparent recovery efficiency of faba bean significantly ($P<0.01$) responded to nitrogen, phosphorus, and potassium fertilizers. Thus, higher ARE of N, P, and K obtained in 23 kg N ha^{-1}, 46 kg P_2O_5 ha^{-1}, and 30 kg K_2O ha^{-1}, respectively. Conversely, increasing the rate of nitrogen, phosphorus, and potassium fertilizers beyond the aforementioned rate significantly reduced the ARE of N, P, and K of the faba bean (Table 5). The results suggested that increased application of nitrogen, phosphorus, and potassium fertilizers over the medium level reduces the quantity of N, P, and K uptake per unit of nutrient applied (ARE). These could link with efficient uptake and utilization of each applied nutrient unit (FAGERIA et al. 2008).

The highest apparent recovery efficiency of 84.48% was obtained with application of 23 kg N ha^{-1} and the lowest with application of 46 kg N ha^{-1}. The magnitude of increase in ARE value over the 46 kg N ha^{-1} was 180%. Thus, higher apparent crop nitrogen recovery efficiency of 84% is obtained in this study. The highest recovery in the study site might be due to the low initial soil N of the soil which increases uptake efficiency and at the same time the best management practices adopted during experimentation might have improved nitrogen recovery. The highest apparent recovery obtained in this study is comparable with those obtained 87.04% by BEYENESH et al. (2017) at Enderta in northern Ethiopia, 53.1% by AMSAL & TANNER (2001) in the non-*Vertisol* of central Ethiopia and 86.23% by GENENE (2003) at Kulumsa, southern Ethiopia.

Regarding the rate of phosphorous application, low P recovery efficiency were obtained at both 46 and 92 kg P_2O_5 ha^{-1} (Table 5). This could be related to high P fixing on strongly acidic soil due to their high Al and Fe oxide concentrations. In this situation, the result agrees with those of ÁLVAREZ-SOLÍS et al. (2007) and ABREHA et al. (2012) who reported low available P on strongly acidic soils. Furthermore, low P recovery efficiency could also be ascribed to massive nutrient depletion of applied nutrient through surface soil erosion (TESHOME et al. 2013). Apart from this, organic matter is also one of the pools of P in the soil. Its mineralization can contribute to available P (ÁLVAREZ-SOLÍS et al. 2007). While low soil OM may therefore imply low available phosphorous and low P recovery efficiency; even if in external fertilizer applied condition.

The year of planting significantly ($P\leq0.05$) influence the ARE of N and K, while it did not influenced the ARE of P. Thus, nitrogen and potassium fertilizers applied in the 2019 cropping season attributed to higher N and K ARE of the faba bean that were 65.6% and 36.5%, respectively while, the lower N and K ARE of the faba bean in the 2020 cropping season were 49.0% and 29.5%, respectively (Table 5). The result might associate with relatively increased rainfall in 2020 than in 2019, which reduces the amount of applied nitrogen and potassium fertilizers through leaching. Consequently, the quantity of nutrient uptake per unit of nutrient applied reduced, in which ARE is directly affected (FAGERIA et al. 2008).

The common ARE values ranging from 50 to 80% indicate a well-managed system (DOBERMANN 2005). Furthermore, FAGERIA et al. (2008) also reported nitrogen apparent recovery efficiency in lowland rice genotypes ranged from 23 to 83%. On other hand, SETLLING et al. (2018) reported 54 to 92% potassium apparent recovery efficiency of the faba bean. Thus, the values higher than 30 indicate efficiently managed systems (FAGERIA et al. 2008). Accordingly, AE of 50% was obtained in response to nitrogen application at the rate of 23 kg N ha^{-1} and nitrogen applied in the 2019-cropping season. This indicates that the highest recovery in the study site might be due to the low initial soil nitrogen, which increases uptake efficiency due to external applications. In addition, the best management practices adopted during experimentation might have improved the N recovery of the faba bean.

Table 5. Main effect of mineral nitrogen, phosphorus, potassium fertilizer and year on apparent recovery efficiency of faba bean in Sodo Zuria district, Southern Ethiopia in 2019 and 2020 cropping seasons.

Fertilizer rate	Apparent recovery efficiency of nitrogen (%)
Nitrogen (kg N ha^{-1})	
0	57.34b
23	84.48a
46	30.20c
LSD (5%)	12.19
Year	
2019	65.64a
2020	49.04b
LSD (5%)	12.19
CV (%)	9.02
Phosphorus (kg $P_2O_5ha^{-1}$)	Apparent recovery efficiency of phosphorus (%)
0	1.62ab
46	2.00a
92	1.23b
LSD (5%)	0.62
Year	
2019	1.63a
2020	1.61a
LSD (5%)	ns
CV (%)	9.64
Potassium (kg K_2O ha^{-1})	Apparent recovery efficiency of potassium (%)
0	32.96b
30	40.30a
60	25.61c
LSD (5%)	3.85
Year	
2019	36.47a
2020	29.45b
LSD (5%)	3.85
CV (%)	9.83

Means in columns followed by the same letter are not significantly different at P = 0.05 according to Fishers Protected LSD test; ns=non- significant.

Nutrient Utilization Efficiency *(NUE)*

The N, P, and K utilization efficiency of the faba bean were significantly ($P \leq 0.01$) responded to the main effect of mineral nitrogen, phosphorus, and potassium fertilizers. The main and interaction effect of year, the interactions of applied nitrogen, phosphorus, and potassium fertilizers did not significantly influence the variable.

The application of 23 kg N ha^{-1}, 46 kg P_2O_5 ha^{-1}, and 30 kg K_2O ha^{-1} higher N, P, and K utilization efficiency of the faba bean. However, the increased application of nitrogen, phosphorus, and potassium fertilizers beyond the aforementioned level significantly reduced the N, P, and K utilization efficiency of the faba bean. Thus, 23 kg N ha^{-1}, 46 kg P_2O_5 ha^{-1}, and 30 kg K_2O ha^{-1} were attributed to 392%, 102%, and 25% more N, P, and, K utilization efficiency than that applied at the rate of 46 kg N ha^{-1}, 92 kg P_2O_5 ha^{-1}, and 60 kg K_2O ha^{-1}, respectively (Table 6.).

This result notified that application of 23 kg N ha^{-1}, 46 kg P_2O_5 ha^{-1}, and 30 kg K_2O ha^{-1} were the optimal level for maximized biological yield and quantity of nutrient uptake. Consequently, N, P, and K utilization efficiency of faba bean improved because nutrient utilization of a crop is the product of biological yield and quantity of nutrient uptake (FAGERIA & BALIGAR 2005). Furthermore, the above result signifies that a crop N, P, and K utilization response do not depend on the amount of application, but it depends on the optimal level of nitrogen, phosphorus, and potassium fertilizers application. Generally, for higher uptake and translocation of the applied nitrogen, phosphorus, and potassium fertilizers into the seed, applying at the rate of 23 kg N ha^{-1}, 46 kg P_2O_5 ha^{-1}, and 30 kg K_2O ha^{-1} are vital for the studied area.

Table 6. Main effect of mineral nitrogen, phosphorus, potassium fertilizer and year on nutrient use efficiency of faba bean in Sodo Zuria district, Southern Ethiopia in 2019 and 2020 cropping seasons.

Fertilizer rate Nitrogen (kg N ha^{-1})	Nitrogen utilization efficiency of faba bean (kg kg^{-1})
0	38.18b
23	63.47a
46	12.89c
LSD (5%)	12.20
CV (%)	7.33
Phosphorus (kg P_2O_5ha^{-1})	Phosphorus utilization efficiency of faba bean (kg kg^{-1})
0	1.89ab
46	2.52a
92	1.25b
LSD (5%)	0.68
CV (%)	11.09
Potassium (kg K_2O ha^{-1})	Potassium utilization efficiency of faba bean (kg kg^{-1})
0	43.34b
30	56.08a
60	30.59c
LSD (5%)	10.41
CV (%)	10.54

Means in columns followed by the same letter are not significantly different at P = 0.05 according to Fishers Protected LSD test; ns=non- significant.

CONCLUSION

The results of this study have demonstrated that N, P, and K uptake and use efficiencies were significantly influenced by the rate of mineral nitrogen, phosphorus, and potassium fertilizers application. The highest total N, P, and K uptake values were obtained from nitrogen fertilizer applied at the rate of 23 kg N ha^{-1}. The higher agronomic efficiency, physiologic efficiency, agro-physiological efficiency, apparent recovery efficiency, N, P, and K utilization efficiency of faba bean were recorded at 23 kg N ha^{-1}, 46 kg P_2O_5ha^{-1}, and 30 kg K_2O ha^{-1}, respectively. However, increasing beyond the aforementioned rate significantly reduced all N, P, and K use efficiency indices in both growing seasons. Overall, 23 kg N ha^{-1}, 46 kg P_2O_5ha^{-1}, and 30 kg K_2O ha^{-1} are optimum for enhanced N, P, and K uptake and use efficiency of faba bean in the study area. Thus, future research should focus on the integrated effect of mineral nitrogen, phosphorus, and potassium fertilizers with organic fertilizer to improve the uptake and use efficiencies of the nutrients by the crop in the study area.

ACKNOWLEDGEMENTS

We would like to thank Woliaita Sodo University (WSU) and the Ministry of Science of Education (MoE) of Ethiopia for the scholarship and financial support.

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