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Research article

Potentials of legumes rotation on yield and nitrogen uptake of subsequent wheat crop in northern Ethiopia

Shimbahri Mesfin [a,b,*], Girmay Gebresamuel [a], Mitiku Haile [a], Amanuel Zenebe [a,b]

[a] Land Resource Management and Environmental Protection, Mekelle University, Mekelle, Ethiopia
[b] Institute of Climate and Society, Mekelle University, Mekelle, Ethiopia

A R T I C L E I N F O

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A B S T R A C T

Nitrogen has becoming the most limiting nutrient in the northern highlands of Ethiopia due to continuous cropping with application of limited external inputs. To improve soil nutrient availability, farmers have been using legumes in crop rotation. However, the roles of various legumes on subsequent wheat (*Triticum* aestivum) crop are unknown in northern Ethiopia. The objective of this study was to investigate impacts of legumes on yield and N uptake of subsequent wheat crop. Experiment was conducted at farmer's field with faba bean (*Vicia faba* L.), 'dekeko' field pea *(Pisum sativum* var. *abyssinicum*), field pea (*Pisum sativum*), lentil (*Lens culinaris*) and wheat (*Triticum* spp.) in the first season and all plots were rotated by wheat in the second season. Yield of subsequent wheat crop was recorded and N uptake was analyzed. The result revealed that grain yield and dry biomass yields of subsequent wheat crop were significantly ($p < 0.05$) higher in the legume-wheat rotations than in the wheat-wheat rotation. The wheat yield is increased by 2196, 1616, 1254 and 1065 kg ha^{-1} and the N uptake is increased by 71.4%, 51.0%, 49.2% and 29.8% in the faba bean-wheat, 'dekeko'-wheat, field pea-wheat and lentil-wheat rotation plots compared to the wheat continuous cropping, respectively. The findings indicated that legumes improved yield and N uptake of the subsequent wheat crop. Thus, soil fertility management policy need to consider legume crop rotations as nutrient management option to improve sustainable soil fertility and yield.

1. Introduction

Sustainable food production is one of the concerns in the global environmental dynamics such as climate change and natural resource degradation [1–4]. The increasing global food demand due to growing human population calls the importance of sustainable soil fertility management and crop production [5–8]. To feed the increasing human population, agricultural production need to be sustainably improved [9,10]. In the past, smallholder farmers in Ethiopia were using fallowing to maintain soil fertility; however, fallowing is abandoned due to less availability of cultivated lands. However, the limited availability of cultivated lands together with traditional agricultural system forced smallholder farmers to continuously cultivate their cropland without fallowing and exploit soil nutrient stocks [11]. This has caused soil fertility decline and low crop yields [12–15]. Instead, farmers traditionally integrate legumes as rotation in the cropping system to improve their soil fertility [16].

Soil fertility depletion due to nutrient exploitation has affected sustainable agricultural production in the smallholder farming

* Corresponding author. Land Resource Management and Environmental Protection, Mekelle University, Mekelle, Ethiopia.
E-mail address: shimbahri.mesfin@mu.edu.et (S. Mesfin).

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system. To minimize this problem, Ethiopian government has imported inorganic fertilizers and improved crop production; however, the inorganic fertilizers became expensive and unaffordable for resources poor farmers. Moreover, inorganic fertilizers are exposed to losses and long-term use of these inorganic fertilizers led to environmental [17]. Because of increasing costs of inorganic fertilizers and growing environmental concerns, there is an ever growing interest in the role of organic soil fertility management and ecological organic agriculture [16,18]. Biological nitrogen fixation (BNF) is one of the principal sources of organic N for increased yield of subsequent cereal production. Considering both environmental and economic perspectives, integrating legumes into cropping system improves soil N and reduces use of inorganic fertilizers [19]. Thus, the combined soil N and N obtained from BNF have the potential to soil N and subsequent crop yield improvements.

Mixed farming is the most common agricultural practice in the study area. Crops are integrated with animals to enhance agricultural production from their limited lands. Alaje is with cold sub-moist highland agro-ecology with dominant crops of wheat (*Triticum* spp.), barley (*Hordeum* spp.) and pulses such as faba bean (*Vicia faba* L.), field pea (*Pisum sativum* L.), 'dekeko' *(Pisum sativum* var. *abyssinicum L.*) and lentil (*Lens culinaris* L.). Farmers grow wheat for the second and third year of the sequence and rotate with barley for the fourth year of the sequence. This continuous cropping with cereals for the purpose of making their main food such as 'injera' and bread for three consecutive cropping seasons brought soil fertility decline, disease and weeds infestation and exposes farmers to extra addition of inorganic fertilizer application. To enhance soil fertility, farmers in the study area use inorganic fertilizers and animal manure based on the resources they have. But, some resource poor farmers do not use any inorganic fertilizers and manure because of high cost of fertilizer and they do not have livestock to produce and use manure as agricultural inputs.

In the highlands of Tigray region including the study area, diverse legumes have been grown in the cropping system [3] as a rotation but there is less information on their residual effects on subsequent wheat yield under rain-fed agriculture. Several studies conducted in Ethiopia and elsewhere in Africa have suggested that various legume crop rotations have different potentials to supply N to the soil [18,20]. However, as these studies were conducted in different areas, it is difficult to compare potential of various legumes to their subsequent wheat yield improvement. It is hypothesized that legumes have different potentials for BNF which affect yield of subsequent cereal crop. This also helps to identify which legume has highest potential to increase subsequent yield in the northern Ethiopia. The objective of this study was to evaluate impacts of legumes incorporation in the crop rotation system on yield and N uptake of subsequent wheat crop.

2. Methodology

2.1. Study area description

The study was conducted in Alaje district located at 39°25'52'' to 39°44'50'' E and 12°15'28'' to 12°59'21''N (Fig. 1a). The area is situated at an altitude of 2824 m a.s.l. The annual rainfall of the experimental areas during 2017 and 2018 cropping seasons were 417 and 479 mm, respectively with daily minimum and maximum temperature of 8^0_C and 26^0_C during 2017 cropping season and $8^0_C$and 27^0_C during 2018 cropping season, respectively. The geology of the study area is trap volcanic rocks from which dominant soil types such as Leptosols, Regosols, Cambisols and Vertisols are developed [21].

2.2. Experimental design and management

Soil samples were collected from 0 to 30 cm soil depth from each experimental plot. Soil was analyzed following different soil analysis standards. The experimental plots have an average soil pH value of 6.6 (6.0–8.0) and electrical conductivity (EC) of 0.3 (0.0–0.9) (ms/cm^3), soil organic carbon (g kg^{-1} soil) of 14.5 (9.4–24.0), soil total nitrogen (TN) (g kg^{-1} soil) of 1.2 (0.5–2.4), available

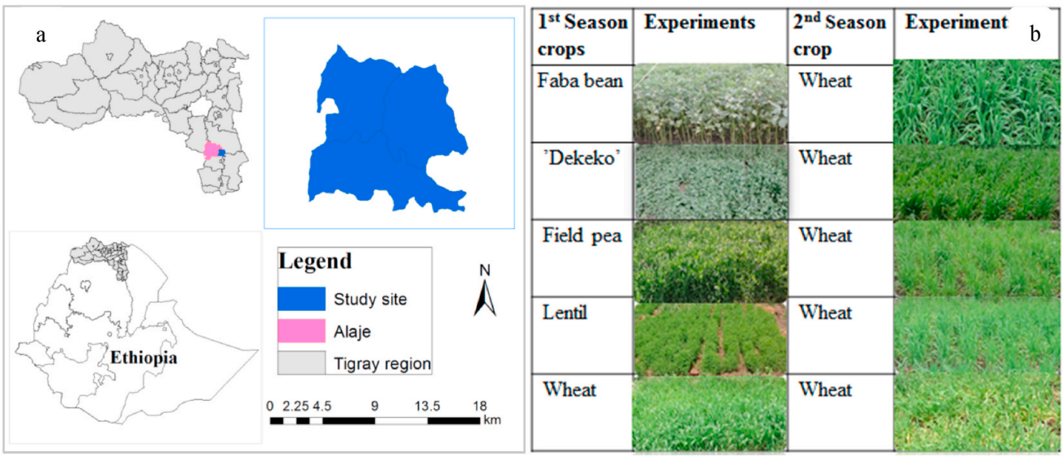

Fig. 1. (a) Location of the study area and (b) experimental layout of the crop rotations.

phosphorus (mg kg^{-1} soil) of 15.7 (1.6–51.5), and exchangeable potassium (g kg^{-1} soil) of 0.63 (0.05–2.8).

Field experiment was conducted for two consecutive cropping seasons (2017 and 2018) and arranged in a randomized complete block design with three replications. In the first cropping season, the experiment consisted of four legumes and wheat: faba bean, field pea, dekeko and lentil, and wheat as control. The experiment was also replicated in six farmers' fields during both cropping seasons. In the first cropping season purpose of the study was to determine biological nitrogen fixation of each legume crop and their contribution to soil fertility taking wheat as a control plot. In the second cropping season field experiment was conducted to determine contribution of various legumes to subsequent wheat yield at smallholder farmers in northern highland of Ethiopia. All plots were rotated with wheat in the second cropping season (Fig. 1b). The experimental plots were prepared manually with plot size of 3 m by 3 m with 20 cm space between rows, 0.5 m between experimental plots and 1 m between blocks. Half meter width was left along all borders to protect and comfortably manage the plots. Wheat was sown mid-July and harvested early November. During the growing period, all plots received adequate with good distribution of rainfall, no heat stress was observed and weeds were controlled manually. Wheat color differences were observed among the different crop rotations at 30 days after planting (Fig. 1b).

2.3. *Data collection and analysis*

Five plants from each plot were selected randomly from middle rows to record all agronomic data such as plant height, number of tillers, spike length, number of seeds per spike and harvest index at plant maturity. A quadrant (1 m by 1 m) from middle part of each plot was harvested to determine grain and dry biomass yields. Crops were harvested manually and bundles of biomass yield were dried through exposing to direct sun light for 3 days to determine dry biomass while grain weight was estimated by weighing the total grains of the sampled quadrant after threshed and winnowed. Mass of 1000 grains of wheat was weighed for each plot.

To analyze N uptake, grain and straw samples were collected from all plots during harvesting. The samples were dried to a constant weight at 70^0C and passed through sieve. Total N contents of grain and straw were analyzed using Kjeldahl method [22]. The N nutrient uptake of wheat in each rotation was calculated through multiplying grain and straw yields (kg ha^{-1}) with their respective N concentration (g g^{-1}) whereas the N uptake were estimated by the sum of grain and straw N uptake. All collected data such as agronomic parameters, yield and N uptake of different crop rotations were subjected to analysis of variance using Gen-stat software. Data normal distribution and homogeneity tests were checked before variable tests. Analysis of variance (ANOVA) was used to detect differences using least significant difference test (LSD) at $p < 0.05$.

2.4. *Economic analysis*

Economic benefits of the full crop rotation (legumes and wheat) were estimated by subtracting costs from total gains [23]. The current average price of grain and straw yield of the different legumes and wheat during study time were valued at an average open market price of each crop. Adjusted grain and straw yield (AGY and ASY) (kg ha^{-1}) which were reduced by 10% to reflect the difference between the experimental yield and yield of farmers were used for gross field benefit (GFB) (ETB ha^{-1}) estimation by multiplying adjusted grain and straw yields with their respective current price. Farm management costs such as land preparation, planting, weeding and harvesting, threshing and seed cost were consider as total variable costs (TVC) in Ethiopian birr (ETB ha^{-1}). Net benefit (NB) in ETB ha^{-1} was calculated by subtracting TVC from gross benefits (GB) for each treatment.

3. Results

3.1. *Yield components of subsequent wheat crop*

The result revealed that agronomic parameters of subsequent wheat crop were significantly ($p < 0.05$) different among the different legume-wheat rotations (Table 1). Number of tillers per plant, number of seeds per spike and thousand seed weight of wheat in the faba bean-wheat rotation is significantly ($p < 0.05$) higher than all legume-wheat rotations and wheat-wheat production.

Plant height, number of tillers per plant, spike length, number of seeds per spike and thousand seed weight of wheat were significant ($p < 0.05$) different among the different legumes-wheat rotation plots (Table 1). The number of seeds per spike was also significantly different among all rotations. Highest wheat yield components were obtained in the faba bean-wheat rotation followed by 'dekeko'-wheat rotation whereas lowest wheat yield components were obtained in the continuous wheat cropping plot. Crop color

Table 1
Agronomic parameters of subsequent wheat crop grown after different legumes.

Cropping system	Plant height (cm)	Number of tiller	Spike length (cm)	No seeds/spike	1000 seeds weight (g)
Faba bean-wheat	93.7 a	5.5 a	7.0 a	50.9 a	52.0 a
Dekeko'-wheat	92.0 ab	3.9 b	6.8 a	39.0 b	50.0 b
Field pea-wheat	90.8 bc	3.9 b	6.5 b	38.2 b	48.4 bc
Lentil-wheat	90.5 bc	2.8 c	5.7 c	36.1 c	48.2 c
Wheat-wheat	78.8 c	2.7 d	4.8 d	33.1 d	44.4 d
L.s.d	2.8	0.2	0.3	2.0	1.8
Cv	10.8	19.2	17.4	17.6	12.9
F	<0.001	<0.001	<0.001	<0.001	<0.001

during growth period was one of the differences observed among the different legume crop rotations and continuous wheat cropping. Deep green, green, light green and yellowish colors of wheat leaves were observed in faba bean-wheat, 'dekeko'-wheat, field-wheat and lentil-wheat and wheat-wheat rotations, respectively (Fig. 1b).

3.2. Grain yield of subsequent wheat crop

The highest wheat grain yield (5285 kg ha^{-1}) was recorded in the faba bean-wheat rotation whereas the lowest wheat grain yield (3089 kg ha^{-1}) was recorded in the wheat-wheat rotation. The wheat grain yield advantages of the faba bean-wheat, 'dekeko'-wheat, field pea-wheat and lentil-wheat rotations were 2196, 1616, 1254 and 1065 kg ha^{-1} over the wheat-wheat rotation (3089 kg ha^{-1}), respectively (Table 2).

These were 71.1%, 52.3%, 40.6% and 34.5% higher than the wheat yield in the wheat-wheat rotation, respectively. The wheat grain yield obtained in the faba bean-wheat rotation was significantly ($p < 0.05$) higher than in all rotations and continuous wheat cropping (Table 2). However, there was no significant difference in wheat yield among 'dekeko'-wheat, field pea-wheat and lentil-wheat rotations (Table 2).

The biomass yield was significantly affected by the different legume crop rotations. The wheat biomass yield obtained in the faba bean-wheat rotation was significantly ($p < 0.05$) higher than field pea-wheat, lentil-wheat and wheat-wheat rotations (Table 2). Significant ($p < 0.05$) differences in biomass yields were also observed between 'dekeko'-wheat (4705 kg ha^{-1}) and wheat-wheat (3089 kg ha^{-1}) rotations; field pea-wheat and wheat-wheat rotations; lentil-wheat and wheat-wheat rotations. However, biomass yield of wheat was not-significantly different among 'dekeko'-wheat, field pea-wheat and lentil-wheat rotation plots as well as between faba bean-wheat and dekeko'-wheat rotations. The biomass yield advantage of various legume-wheat rotations over the continuous wheat cropping were 72.2%, 58.7%, 47.9% and 40.1% for faba bean-wheat, 'dekeko'-wheat, field pea-wheat and lentil-wheat rotations, respectively.

3.3. Nitrogen uptake of subsequent wheat crop

The N contents of grain and straw of subsequent wheat crop were significantly ($p < 0.05$) different among all rotation plots (Table 3). The highest N nutrient concentration obtained in the wheat grain and straw in the faba bean-wheat rotation plots were 21.8 g N kg^{-1} and 10.9 g N kg^{-1}, respectively whereas the lowest N content were found in the wheat-wheat rotation plots (6.7 g N $kg^{-1}$and 2.4 g N kg^{-1}). Nutrient concentrations varied tremendously in both grain and straw of the different legume-wheat rotations and wheat continuous cropping. The wheat grain to straw N content ratios were 2:1, 1.1:1, 1.4:1, 1.7:1 and 2.5:1 in the faba bean-wheat, 'dekeko'-wheat, field pea-wheat, lentil-wheat and wheat-wheat rotations, respectively. The N uptake of the subsequent wheat crop showed that grain, residue and total N uptake of wheat were significantly ($p < 0.05$) different among all legume-wheat rotations except grain N uptake between lentil-wheat and wheat-wheat rotations, straw and total N uptake between 'dekeko'-wheat and field pea-wheat rotation plots.

The N uptake increase of faba bean-wheat, 'dekeko'-wheat, field pea-wheat, lentil-wheat over the wheat-wheat rotation were 137.6, 57.3, 53.2 and 23.4 kg N ha^{-1}, respectively. Wheat biomass grown after faba bean, 'dekeko', field pea and lentil accumulated 250.2%, 104.2%, 96.7 and 42.5% more N than under continuous wheat cropping. The N accumulation in the dry biomass varied from 192.6 kg N ha^{-1} in the faba bean-wheat rotation to 55.0 kg N ha^{-1} in wheat-wheat rotation plots. The relationship between grain yield and nutrient accumulation of the different legumes-wheat rotation plots revealed that higher N nutrient was observed in the faba bean-wheat rotation than the other legume wheat rotations and continuous wheat cropping. The highest N uptake of the subsequent wheat crop was recorded in the faba bean-wheat rotation (Table 3). At a given grain yields of subsequent wheat crop, higher and lower N nutrients were recorded in the faba bean-wheat and wheat-wheat rotation plots.

3.4. Economic analysis

The partial budget analyses results revealed that highest net benefit (121,117.90 ETBha^{-1}) was obtained in the full faba bean-wheat rotation plot (Table 4). However, lowest net benefit (94,444.6 ETB ha^{-1}) was obtained in the wheat-wheat rotation plot.

Table 2
Grain and biomass yields of subsequent wheat crop grown following different legume crops, northern Ethiopia.

Cropping system	Grain yield (kg ha^{-1})	Grain yield Increase (%)	Biomass yield (kg ha^{-1})	Biomass yield increment (%)	HI
Faba bean -wheat	5285 a	71.1	12588 a	72.2	0.43
Dekeko -wheat	4705 b	52.3	11598 ab	58.7	0.44
Field pea -wheat	4343 bc	40.6	10812 b	47.9	0.44
Lentil - wheat	4154 c	34.5	10244 b	40.1	0.42
Wheat-wheat	3089 cd	–	7310 c	–	0.42
L.s.d	547.9		1393.3		0.05
Cv	17.5		18.5		20.0
F	<0.001		<0.001		0.06

Table 3
N uptakes of subsequent wheat crop grown after different legumes, northern Ethiopia.

Cropping system	Grain N Content (%)	Straw N Content (%)	Grain N uptake (kg ha^{-1})	Residue N uptake (kg ha^{-1})	Total N uptake (kg ha^{-1})	Uptake Increase (kg ha^{-1})
Faba bean -wheat	2.18 a	1.09 a	115.3a	77.3 a	192.6 a	137.6
'Dekeko' -wheat	1.34 b	0.80 b	63.8 b	48.5 b	112.3 b	57.3
Field pea -wheat	1.19 c	0.87 c	52.5 bc	55.7 b	108.2 b	53.2
Lentil - wheat	1.00 d	0.60 d	42.2 cd	36.2 c	78.4 c	23.4
Wheat-wheat	0.67 e	0.24 e	37.0 d	18.0 d	55.0 d	–
L.s.d	0.09	0.07	14.29	10.90	15.15	
Cv	14.5	20.3	16.4	17.9	15.3	
F	<0.001	<0.001	<0.001	<0.001	<0.001	

Table 4
Economic analysis of wheat grown in different legume rotations.

Rotations	AGY (kg ha^{-1})		ASY (kg ha^{-1})		GYR (ETB ha^{-1})		SYR (ETB ha^{-1})		TR (ETB ha^{-1})	MTVC (ETBha^{-1})	NB (ETBha^{-1})
	1st CS	2nd CS	1st CS	2nd CS	1st CS	2nd CS	1st CS	2nd CS			
Faba bean-wheat	1562.0	4756.5	3693.6	6572.7	39050.0	79433.6	7387.2	19718.1	145588.9	24471	121117.9
'Dekeko'-wheat	1157.0	4234.5	2052.0	5496.3	50908.0	70716.2	4104.0	19588.5	145316.7	24796	120520.7
Field pea-wheat	1787.0	3908.7	4752.0	6529.5	44675.0	65275.3	9504.0	16488.9	135943.2	24471	111472.2
Lentil- wheat	1405	3738.6	4357.8	5481	39340.0	62434.6	8715.6	16443.0	126933.2	24996	102937.2
Wheat-wheat	2863	2780.1	3838.7	3798.9	47812.1	46427.7	11516.1	11396.7	117152.6	24708	92444.6

AGY: adjusted grain yield, ASY: adjusted straw yield, GYR: grain yield revenue, TR: total revenue, MTVC: marginal total variable cost, NB: net benefit CS: cropping season.

4. Discussion

The highest wheat agronomic parameters observed in the legume-wheat rotations compared to the continuous wheat-wheat cropping were attributed to availability and increased soil N concentration due to BNF. This is because legumes contribute to soil N and provide available soil N for subsequent wheat crop. These legumes-wheat rotations have positive effect on subsequent wheat yield components [19,24]. This is because legumes increased soil N through BNF or sparing effect since their demand for N is less than cereals [25]. Moreover, legumes modify interaction of physical, chemical and biological components of the soil system [24]. The higher yield component of subsequent wheat crop observed in the faba bean-wheat rotation can be due to better BNF of faba bean [16]. Several research findings also confirmed that soil N obtained from BNF significantly improved vegetative growth and biomass of wheat [26–28]. The legume residues and BNF have also increased grain yield of subsequent wheat crop. The faba bean-wheat, 'dekeko'-wheat, field pea-wheat and lentil-wheat rotations consistently increased grain yield of subsequent wheat crop over the wheat-wheat continuous cropping. However, poor plant growth parameters were observed in the continuous wheat-wheat cropping plots due to low supply of soil N.

This is because legumes improve soil N supply, stimulate soil biological activity and improve other soil properties [17]. Thus, biological nitrogen fixation is the distinguishing feature of legumes which encourage their inclusion in the cropping system. Several research findings also confirmed that there was an increased yield and N uptake of subsequent wheat crop grown after different legumes [25,29,30]. This is in line with research findings by Abera et al. (2015) who reported a yield increment of 35.8% in a legume cereal rotation compared to continuous cereal crops. Similarly, [31] found a yield increase of 77.8 kg ha^{-1} in the legume preceding plot. This is because legumes have the ability to fix atmospheric nitrogen and store N in the root systems which is ultimately released to cereal crops through decomposition. Thus, the cereal crop grown following legumes have reduced requirement of N fertilizer as external inputs [32].

Though all legumes-wheat rotations increased the grain yield of wheat, while faba bean-wheat rotation had highest yield increase compared to wheat-wheat rotation (Table 2). This showed that different legumes used as a preceding crop determined the quantity of soil N supply. This implies that introducing faba bean in the crop rotation reduces N fertilizer demand compared to the other legumes -wheat rotations and continuous wheat-wheat cropping [30]. This is because N uptake of the subsequent wheat in the faba-wheat rotation was higher than that of the other legume-wheat rotations and continuous wheat cropping. However, the lowest yield and N uptake obtained in the continuous wheat-wheat cropping plot attributed to limited soil N supply. [33] also suggested that yield difference is mainly due to inefficient soil N in the continuous cereal cropping. The higher wheat yield obtained following legume cropping is generally attributed to legumes release N due to direct transfer N from legume to wheat [17,34].

Therefore, the increased wheat yields that ranges from 1065 kg ha^{-1} in the lentil-wheat crop rotation to 2196 kg ha^{-1}in the faba bean-wheat crop rotation and N uptake of wheat which ranges from 23.4 kg N ha^{-1} in the lentil-wheat crop rotation to 137.6 kg N ha^{-1} in the faba bean-wheat crop rotation were an evidence for the importance of legumes to improve soil fertility management through fixing atmospheric N. There is considerable evidence that inclusion of legumes in cropping system results in improving soil N for subsequent crops. This clearly showed that BNF is one of the most important sources of soil N [20]. Other studies have also indicated that concentrations of available soil N in the legume plots is increased by 42–92 kg N ha^{-1} compared to the continuous wheat-wheat cropping plots [35]. As faba bean has significantly improved soil N and yield of subsequent wheat crop than the other legumes, it is a promising legume for farmers during crop rotation. This agrees with many researchers who suggested that faba bean was the most favorable and break crops for wheat production in most wheat growing areas [11]. The higher soil N in the faba bean plots (37 kg N ha^{-1}) and higher N uptakes (192.6 kg N ha^{-1}) of wheat in the faba bean plots showed that higher amount of N was fixed in the faba bean plots than in other legume plots (Table 3). This is in line with Lupwayi et al. (2014) who observed that increased N uptake of grain and straw yields of wheat grown after legume than N uptakes of wheat grown after barley. The increased N uptake of wheat grown after different legumes over the continuous wheat cropping in this study showed that inclusion of legumes reduced N fertilizer by 137.6, 57.3, 53.2, and 23.4 kg ha^{-1} following the faba bean, 'dekeko' field pea and lentil productions, respectively (Table 3). This helps resources poor farmers to reduce cost of inorganic fertilizer demand and enhance sustainability of agro-ecology. This is similar with the results reported by [36] who stated that legumes saved 150–200 kg N ha^{-1} of required N fertilizer for subsequent cereal crop.

All legume wheat rotations have greater net economic benefits than the continuous wheat cropping (Table 4). This is because all legume crop rotations brought higher subsequent wheat yields than the continuous wheat-wheat cropping. Since subsequent wheat yield in all legume-wheat rotations have greater net benefit than wheat-wheat rotation, legume-wheat rotations have an economic profitability with the highest in faba bean-wheat rotation than the other legumes-wheat rotations and continuous wheat-wheat cropping in the study area.

5. Conclusion

The legume-wheat crop rotation field experiment conducted in Alaje, northern Ethiopia showed that faba bean-wheat, 'dekeko'-wheat, wheat-field pea and lentil-wheat rotations have increased yield and yield components and nutrient uptake of subsequent wheat crop compared to the wheat-wheat rotations. This study clearly showed that legume crop rotations have an important role for yield-economic profitability of subsequent wheat cropping systems which needs to be taken into account for policies and researches for agricultural soil fertility managements. The legume crop rotations not only provided economic returns to the farmers but also contributed to sustainable soil fertility management. Hence, introduction of legumes such as faba bean, 'dekeko' field pea and lentil in wheat cropping is a viable strategy for the reduction of inorganic N fertilizer for the resource poor farmers in the study area.

Therefore, due to both economic and environmental advantages, the research and agricultural extension systems have to promote incorporation of legumes, especially faba bean, as rotational crop. For this, there is a need to enhance the capacity of frontline extension agents and farmers via farm demonstration and popularization of the extension methods.

Author contribution statement

Shimbahri Mesfin: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Girmay Gebresamuel, Mitiku Haile1, Amanuel Zenebe: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data.

Data availability statement

No data was used for the research described in the article.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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