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Original Research

Response of Bread Wheat (*Tritcum aestivum* L.) to Nitrogen after Major Leguminous Crops Rotation in Tigray, Northern Ethiopia

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Abstract

Crop rotation is a common practice in the study area, but there is no enough information on the specific rate of nitrogen to be applied after legumes for wheat production. Hence, on farm field experiments were conducted to determine the amount of nitrogen fertilizer rates needed for bread wheat after chick pea, grass pea, fababean and field pea precursor crops. The field experiments were conducted during 2014 main cropping season at Hawzien after chick pea and grass pea and at Emba Alaje after fababean and field pea precursor crops. The experiment consists of six nitrogen rates (0, 11.5, 23, 34.5, 46 and 69 kg Nha^{-1}) laid in a RCBD with three replications. Phosphorus, sulfur and potassium fertilizers were also applied as basal for all plots at sowing. Surface soil samples were collected before planting and analyzed for selected soil properties. Soil analysis result of the experimental sites revealed that total nitrogen content (%) of the soil after chickpea-wheat (0.0695), grass pea-wheat (0.067), fababean-wheat (0.074) crop rotation were categorized under low range and after field pea-wheat (0.102) under medium range. Application of nitrogen had significantly increased grain and straw yield at Hawzien district after chick pea and grass pea precursor crops. At Emba-Alaje the highest grain yield was recorded on plots treated with 69 kg N ha^{-1} (6242 kg ha^{-1}). Grain and straw yields of wheat increased up to a rate of 46 kg N ha^{-1} after fababean at Emba-Alaje district. There is no significant difference in grain and straw yields of wheat due to application of nitrogen after field pea crop rotation. In Hawzien the highest agronomic efficiency after chick pea and grass pea was recorded from plots treated with 46 kg N ha^{-1} and 34.5 kg N ha^{-1}, respectively. In Emba Alaje the highest agronomic efficiency after faba bean and field pea was recorded from plots treated with 11.5 kg N ha^{-1} and 23 kg N ha^{-1} , respectively. At Hawzien, the partial budget analysis revealed that application of 46 kg N ha^{-1} for bread wheat after chick pea and grass pea was economical with 1545% and 796 % marginal rate of return, respectively. At Emba Alaje, the partial budget analysis revealed that application of 34.5 kg N ha^{-1} for bread wheat after fababean was economical with 895% marginal rate of return. It could be concluded that application rate of N for wheat after leguminous crops should consider initial soil N and precursor crop.

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INTRODUCTION

Wheat is one of the major cereal crops grown in Ethiopia. Wheat is ranked fourth of all cereals, based on area of production (more than 1.6 million hectare) and third based on total production (more than 3.9 million tons) (CSA, 2014). Although wheat is the most important cereal crop in Ethiopia, the national yield has remained low at 2.24 tha-1 (CSA, 2014).

Low soil fertility and slow progress in developing wheat cultivars with durable resistance to disease are considered the most important constraints limiting wheat production in Ethiopia (Demeke and Marcantonio, 2013). Soil fertility depletion is a key problem of cereal production in Ethiopia. Low soil nitrogen (N) is often the major factor limiting crop productivity. Application of inorganic nitrogen fertilizer, crop rotation and intercropping are some of the management practices.

Crop rotation is an integral part of the crop production system. A well planned cropping sequence will reduce insect, pest, disease, ameliorate soil structure, improve organic matter levels, prevents proliferation of weeds and consequently increase the crop yield. The general purposes of rotations are to improve or maintain soil fertility, reduce erosion, reduce the risk of weather damage, reduce reliance on agricultural chemicals and increase net profits (Bauman *et al.,* 2000). Arshad *et al.* (1998) reported that the benefits of crop rotation as compared to a mono cropping of wheat are increased grain and above ground dry matter yields. Crop rotation enhances soil nitrogen which plays a key role in achieving qualitatively and quantitatively high yields.

Giller (2001) observed that legumes can fix substantial amounts of atmospheric N2, which allows them to be grown in N-impoverished soils without fertilizer or N inputs. Legume crops leave N-rich residues and improve soil properties that can boost the yield of subsequent crops. The indirect effects related to improved soil properties impacted positively corn and wheat yield and N nutrition (Adrian *et al.,* 2015).

Farmers in the mid-highlands and highlands of Ethiopia are well aware of the importance of crop rotation to replenish soil fertility and skill-fully used this option (Bereket *et al.,* 2011). Depending on agro-ecology, farmers in Hawzien grow legumes such as chick pea and grass pea and in Emba Alaje grow fababean and field pea as rotation crop with cereals to improve soil fertility, consequently to improve productivity of cereals. Farmers usually reduce the N requirement of next cereal crop after legume at both sites. However the N rate required after a specific legume crop for wheat is not well studied in Ethiopia specifically in northern Ethiopia. Therefore a study was conducted to evaluate the nitrogen requirement of wheat after chick pea, grass pea, fababean and field pea precursor leguminous crops in Tigray, Northern Ethiopia.

MATERIALS AND METHODS

On farm field experiments were conducted at districts of Hawzien and Emba Alaje in 2014. Two experiments were conducted at Hawzien district after precursor crops of grass pea and chick pea each in two sites. Two experiments were conducted at Emba-Alaje district after precursor crops of fababean and field pea each in one site. At Hawzien, Siluh *Tabia* the coordinate ranges from 39^0 27' 20" to 39^0 27' 30" latitude and 13^0 15' 16" to 13^0 59' 90" longitude. At Emba Alaje, Ayba Tabia the coordinate ranges from $39^0$29' 54" to 39^0 37' 25" latitude and 12^0 51' 50" to 12^0 54' 54" longitude (Figure 1).

The experiment consists of six nitrogen treatments: 0, 11.5, 23, 34.5, 46 and 69 kg Nha^{-1}. The design was Randomized Complete Block Design with three replications in a plot size of 3 m by 4 m. Each treatments were supplied with basal application of phosphorous, potassium and sulfur at rates of 69 kg P_2O_5 ha^{-1}, 80 kg K_2O ha^{-1} and 30 kg S ha^{-1}. Nitrogen, phosphorus, potassium and sulfur were applied in the form of urea, Triple Super Phosphate (TSP), potassium chloride and calcium sulfate, respectively. Phosphorus, potassium, sulfur and half of the nitrogen rates were applied at planting. The remaining half of the nitrogen rates were applied during tillering. The wheat varieties used in these experiments were *Kekeba* for the distrcit Hawzien and *Danda* for the district Emba-Alaje and was planted at a rate of 150 kg ha^{-1} in row planting.

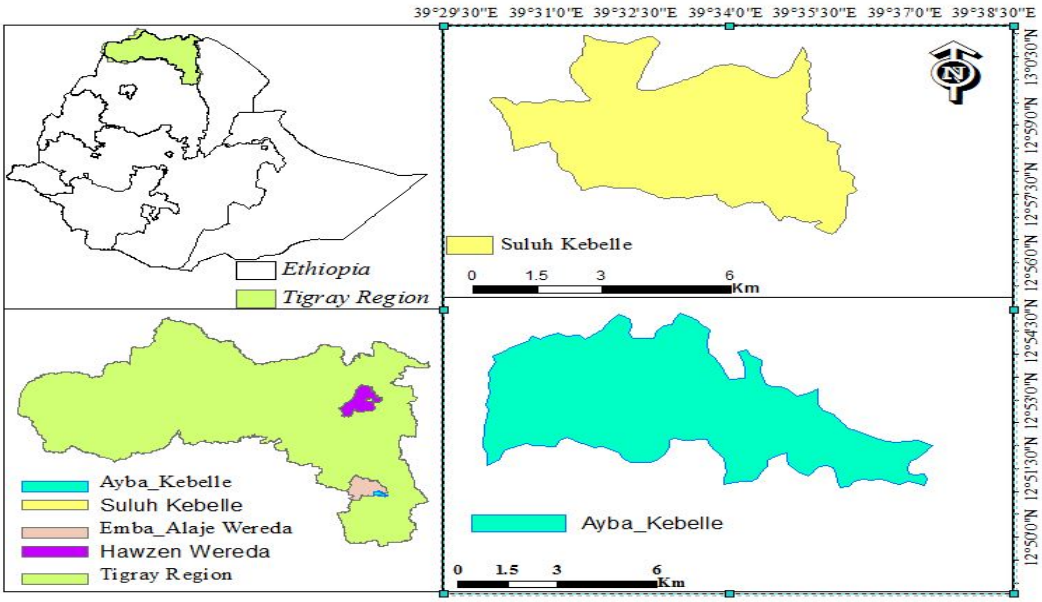

Figure 1: Map of the study sites

Soil Analysis

The initial experimental soils (0-20 cm) were analyzed for texture, organic carbon, total nitrogen, CEC, available P, pH. The methods used for samples physicochemical analysis were pH (Jackson, 1967), organic carbon [modified Walkley and Black method (Jackson, 1967)], texture [hydrometer method procedure of Bouyoucos (Day, 1965), available phosphorous (Olsen *et al*., 1954), total nitrogen by Kjeldehal method (Bermner and Mulvaney, 1982) and CEC by Neutral ammonium acetate method (Black, 1965).

Data Collection

Plant height, head length, straw yield and grain yield of wheat for all experimental sites were collected following the standard procedure. Above ground biomass from whole plots were sun-air dried before weighing. The spikes were threshed and cleaned and grain yield was weighed. The straw yield was calculated by subtracting grain yield from the above ground biomass.

Agronomic Efficiency of Nitrogen

$$\text{Agronomic N use efficiency (kg kg}^{-1}) = \left(\frac{\text{Gf} - \text{GU}}{\text{Na}}\right)$$

Where;
Gf is the grain yield in the fertilized plot (kg)
Gu is the grain yield in the unfertilized plot (kg)
Na is the quantity of N applied (kg)

Data Analysis

Generated data were subjected to analysis of variance. All analysis was performed with SAS statistical software package (SAS, 2002). Marginal rate of return (MRR) was calculated as the change in net revenue (NR) divided by the change in total variable cost (TVC) of the successive net revenue and total variable cost levels (CIMMYT, 1988). Daily labor costs were calculated by assuming 60 ETB per person and revenue was calculated by considering the prevailing market price which is 11 ETB per kg of grain. The cost of urea was 1125.57 ETB per 100 kg according to Enderta Union.

RESULTS AND DISCUSSION

Soil Properties before Planting

The chemical and physical property of the soils of the experimental sites after the precursor legume crops is indicated in Table 1. Textural class of Hawzien sites was sandy loam and clay for Emba Alaje. According to FAO (2000) the preferable pH ranges for most crops and productive soils are from 4 to 8. Thus, the soil pH of the experimental sites were within the range for productive soils. According to Tekalign (1991) rating of soil pH, the pH of soils of Hawzien was moderately acidic and slightly acidic to neutral in Emba Alaje. The organic carbon content of soils of the experimental sites was very low for Hawzien sites and low in Emba Alaje District (Tekalign, 1991). According to Birhanu (1980) total nitrogen content at both sites were low. Available phosphorous (Olsen P) for fababean- wheat and chickpea- wheat crop rotation was medium and for grass pea -wheat and field pea -wheat crop rotation was high (Olsen, 1954). According to Landon (1991) rating, CEC was medium to high in Hawzien and very high in Emba Alaje.

Table 1: Surface (0-20 cm) soil properties of experimental sites after leguminous precursor crops

	Hawzien		Emba-Alaje	
Parameters	**Chick Pea**	**Grass Pea**	**Fababean**	**Field Pea**
pH_{water} (1:2.5)	5.82	5.92	6.74	6.6
Organic carbon (%)	0.2465	0.27	0.88	1.47
Total N (%)	0.0695	0.067	0.074	0.102
P-Olsen (mg kg^{-1})	9.37	10.46	5.86	11.12
CEC (meq/100 gm soil)	15.4	31.10	50.2	53.6
Clay (%)	17	34.00	42	56
Silt (%)	12	13.00	35	23
Sand (%)	71	53.00	23	21
Textural Class	Sandy Loam	Sandy Loam	Clay	Clay

Yield Components: Plant Height and Head Length

Application of nitrogen fertilizer after different legume crops significantly influenced plant height and head length (Table 2 and 3). Effects of nitrogen rate after legume on plant height was not statistically significant after fababean and field pea at Emba Alaje. Plant height was increased with the increase in the application rates of N for wheat after chick pea and grass pea in Hawzien district. The tallest plants were obtained from the plots received nitrogen rate of 69 kg N ha^{-1} after chick pea and grass pea in Hawzien. Head length was not influenced by different nitrogen rates after fababean at Emba Alaje, but was significant after grass pea, field pea and chickpea. Abreha (2013) and Bereket (2014) reported that plant height and head length of wheat increased with N application rate.

Table 2: Effect of nitrogen on wheat plant height after chickpea, grass pea, fababean and field pea precursor leguminous crops at Hawzien and Emba-Alaje districts

	Plant Height (cm)			
	Hawzien		Emba-Alaje	
Treatments (kg N ha^{-1})	**Chick Pea**	**Grass Pea**	**Fababean**	**Field Pea**
0	75.5b	70.4b	86.3	96.4
11.5	76.8b	73ab	89.2	94.9
23	78.8ab	73.2ab	87.9	95.1
34.5	77.8ab	75ab	90.2	98.5
46	82.2a	78.6a	91.5	95.3
69	82.7a	78.9a	90.6	99
LSD	**5.17**	**6.1**	**7.6NS**	**8.6 NS**
CV (%)	**5.5**	**6.96**	**7.2**	**7.6**

Table 3: Effect of nitrogen on wheat head length after chickpea, grass pea, fababean and field pea precursor leguminous crops at Hawzien and Emba-Alaje districts

	Head length (cm)			
	Hawzien		Emba-Alaje	
Treatments (kg N ha^{-1})	Chick pea	Grass pea	Fababean	Field pea
0	6.41c	5.83b	7.2	7.2ab
11.5	6.46bc	6.03ab	9	7.3ab
23	6.86a	6.05ab	6.7	7.3ab
34.5	6.85ab	6.12ab	7.2	7.46ab
46	6.76abc	6.18ab	7.5	7.1b
69	6.63abc	6.46a	7.7	7.8a
LSD	**0.39**	**0.58**	**NS**	**0.64**
CV (%)	**5.05**	**8.1**	**26.4**	**7.4**

Yields

There is a significant difference in grain and straw yields of wheat due to application of nitrogen after chick pea and grass pea crops rotation (Table 4 and 5). Grain and straw yields of wheat increase with an increase in nitrogen application. Indicating that there is need for application of nitrogen after chick pea and grass pea in the sandy soils of Hawzien. There is a significant difference in grain and straw yields of wheat due to application of nitrogen after fababean crop rotation (Table 4 and 5). Grain and straw yields of wheat increase with an increase of nitrogen application up to a rate of 46 kg N ha^{-1} though it was not significant with the application rate of 34.5 kg N ha^{-1}. Indicating that there is a need for application of nitrogen up to 34.5 kg N ha^{-1} after fababean leguminous crop rotation. There is no significant difference in grain and straw yields of wheat due to application of nitrogen after field pea crop rotation (Table 4 and 5). The grain and straw yields of wheat after field pea crop rotation was highest than others, this may be due to the better initial soil nitrogen. Crop sequence with preceding crop such as grass pea, chick pea and fababean had little additional benefit of residual fertility from the proceeding leguminous crop, which when utilized in addition to the applied inorganic nitrogen and resulted exuberant crop growth, which ultimately resulted in increased biological yield. Maadi *et al*. (2012) stated that the preceding leguminous crop increases the grain yields of wheat significantly. Nehra *et al*. (2001) reported that nitrogen is a nutrient which enhances vegetative growth of the crop and have positive relationship with biological yield.

Table 4: Effect of nitrogen on wheat grain yield after chickpea, grass pea, fababean and field pea precursor leguminous crops at Hawzien and Emba-Alaje districts

	Grain yield (kg ha^{-1})			
	Hawzien		Emba-Alaje	
Treatments (kg N ha^{-1})	Chick Pea	Grass Pea	Fababean	Field Pea
0	2433b	1825d	3633d	5569
11.5	2442b	2579cd	4108dc	6069
23	2833b	2475c	3983dc	6792
34.5	2875b	3096bc	4783ab	6750
46	3433a	3400ab	4892a	6236
69	3500a	3750a	4292bc	6056
LSD	**457.8**	**566.3**	**581.3**	**NS**
CV (%)	**13.2**	**16.7**	**7.6**	**18.8**

Table 5: Effect of nitrogen on wheat straw yield after chickpea, grass pea, fababean and field pea precursor leguminous crops at Hawzien and Emba-Alaje districts

	Straw yield (kgha-1)			
	Hawzien		Emba-Alaje	
Treatments (kg N ha^{-1})	Chick Pea	Grass Pea	Fababean	Field Pea
0	4117d	3275d	4208	6542
11.5	4350cd	3883cd	5042	6861
23	5125b	4325b c	4817	7847
34.5	4742bc	4821bc	5725	8264
46	5825a	5475ab	5942	7097
69	6242a	6108a	5383	6764
LSD	**624.7**	**979**	**883**	**NS**
CV (%)	**10.4**	**17.7**	**9.4**	**19.3**

Agronomic Nitrogen Efficiency of Wheat after Major Leguminous Crops

Agronomic efficiency is the amount of additional yield obtained for each additional kg of nutrient applied (Mengel and Kirkby, 2001). Agronomic efficiency showed inconsistent trend by applying different N rates after major leguminous crops. Relatively agronomic efficiency decreases with N rates (Table 6). In Hawzien the highest agronomic efficiency after chick pea and grass pea was recorded from plots treated with 46 kg N ha^{-1} and 34.5 kg N ha^{-1} ,respectively. In Emba Alaje the highest agronomic efficiency after faba bean and field pea was obtained from plots treated with 11.5 kg N ha^{-1} and 23 kg N ha^{-1} , respectively. According to Dobermann (2005) if obtained agronomic efficiency results are above 30, it could be concluded that the farm was under well managed system and reverse is true, if the results obtained are below the common values which is 10 to 30. The result from Hawzien and Emba Alaje were nearly in line with Abebe (2012) and Dargie *et al.* (2016) reported that, AE of wheat decreases with N rates. Craswell and Godwin (1984) asserted that high agronomic efficiency could be obtained if the yield increment per unit N applied is high because of reduced losses and increased N uptake.

Table 6: Agronomic Nitrogen efficiency of Wheat after major leguminous crops

	Hawzien		Emba Alaje	
Treatments (kg N ha^{-1})	AE of wheat after chick pea (kg /kg)	AE of wheat after Grass pea (kg /kg)	AE of wheat After Fababean (kg /kg)	AE of wheat after Field pea (kg /kg)
0	-	-	-	-
11.5	0.78	65.56	41.30	43.47
23	17.39	28.260	15.21	53.17
34.5	12.81	36.84	33.33	34.23
46	21.73	34.23	27.36	14.5
69	15.46	27.89	9.55	7.05

Partial Budget Analysis of Nitrogen Rates after Major leguminous Crops

The results of marginal rate of return (MRR) of the Hawzien and Emba Alaje districts are presented in Tables 7, 8 and 9. At Hawzien, the partial budget analysis revealed that application of 46 kg N ha^{-1} for bread wheat after chick pea and grass pea was economical with 1545% and 796 % marginal rate of return, respectively. This implies that for each birr invested in the production of wheat, the farmers could earn birr 15.45 after chickpea and birr 7.96 after grass pea after recovering their cost of production.

At Emba Alaje, the partial budget analysis revealed that application of 34.5 kg N ha^{-1} for bread wheat after fababean was economical with 895% marginal rate of return. This implies that for each birr invested in the production of wheat, the farmers could earn birr 8.95 after fababean after recovering their cost of production.

According to the manual for economic analysis of CIMMYT (1988) the recommendation is not necessarily based on the treatment with the highest marginal rate of return compared to that of neither next lowest cost, the treatment with the highest net benefit, and nor the treatment with the highest yield. The identification of a recommendation is based on a change from one treatment to another if the marginal rate of return of that change is greater than the minimum rate of return (100%). According to the marginal rate of return 46 kg Nha-1 and 34.5 kg N ha^{-1} was found economically profitable compared to other treatments at Hawzien and Emba Alaje, respectively.

Table 7: Partial budget analysis of wheat after Chick pea

Fertilizer rate (kg N ha^{-1})	Fertilizer cost (Birr)	Fertilizer application and transport cost (Birr)	Total variable cost (TVC)[Birr]	Grain yield (kgha-1	Total Revenue (TR) [Grain yield*11 Birr]	Net Revenue [TR-TVC]	Marginal Rate of Return (ratio)	Marginal Rate of Return (%)
0	0	0	0	2442	26862	26862	0	0
11.5	313	60	373	2433	26763	26390	D	D
23	626	12	746	2833	31163	30417	4.765	476.5
34.5	939	180	1119	2875	31625	30506	D	D
46	1252	240	1492	3433	37763	36271	15.45	1545
69	1878	300	2178	3500	38500	36322	D	D

Table 8: Partial budget analysis of wheat after Grass pea

Fertilizer rate (kg N ha^{-1})	Fertilizer cost (Birr)	Fertilizer application & transport cost (Birr)	Total variable cost (TVC) [Birr]	Grain yield (kgha-1)	Total Revenue (TR) [Grain yield*11 Birr]	Net Revenue [TR-TVC]	Marginal Rate of Return (ratio)	Marginal Rate of Return (%)
0	0	0	0	1825	20075	20075	0	0
11.5	313	60	373	2579	28369	27996	21.23	2123
23	626	12	746	2475	27225	26479	D	D
34.5	939	180	1119	3096	34056	32937	6.62	662
46	1252	240	1492	3400	37400	35908	7.96	796
69	1878	300	2178	3750	41250	39072	4.61	461

Table 9: Partial budget analysis of wheat after Faba bean

Fertilizer rate (kg N ha^{-1})	Fertilizer cost (Birr)	Fertilizer application & transport cost (Birr)	Total variable cost (TVC)[Birr]	Grain yield (kgha-^{1})	Total Revenue (TR) [Grain yield* 11 Birr]	Net Revenue [TR-TVC]	Marginal Rate of Return (ratio)	Marginal Rate of Return (%)
0	0	0	0	3633	39963	39963	0	0
11.5	313	60	373	4108	45188	44815	13.00	1300
23	626	12	746	3983	43813	43067	D	D
34.5	939	180	1119	4783	52613	51494	8.95	895
46	1252	240	1492	4892	53812	52320	2.21	221
69	1878	300	2178	4292	47212	45034	D	D

D= Dominated Treatment

CONCLUSIONS

Grain and straw yields of wheat increased significantly with application of nitrogen after chick pea, grass pea and fababean precursor crops. Although the precursor crops were leguminous with nitrogen fixing ability nature, there was significant increase in grain and straw yields of wheat up to 46 kg N ha^{-1}. Both biological and partial budget analysis revealed that the optimum nitrogen rate after chickpea and grass pea was 46 kg N ha^{-1} and after fababean 34.5 kg N ha^{-1}. There was no significant effect of nitrogen application for wheat after field pea indicating the precursor crop (field pea) had contributed for fixation of nitrogen in the soil.

Conflict of Interest

Conflict of interest none declared.

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