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Performance Evaluation of Faba Bean and Field Pea Rotation Systems and Inorganic Fertilizer on Yield and Yield Component of Bread Wheat (*Triticum aestivum* L.) in the Highlands of Bale South Eastern Oromia

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Abstract

Grain legume production offers multiple environmental benefits and can enhance the sustainability of farming. This study investigated the impacts of introducing grain legumes faba beans (*Vicia faba* L.)] in cereal-dominated crop production systems typical for south eastern Ethiopia. Nitrogen has becoming the most limiting nutrient in the South Eastern 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 South Eastern Ethiopia. The objective of this study was to investigate impacts of legumes on yield of subsequent wheat crop. Experiment was conducted at farmer's field with faba bean (*Vicia faba* L.), ‘field pea (*Pisum sativum*) 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 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 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.

Keywords: Crop rotation, Grain yield, Legumes, Subsequent wheat crop.

Introduction

Bread wheat (*Triticum aestivum L.*) is one of the most important cereal crops of the world and is a staple food for about one third of the world’s population (Hussain, *et al., 2022*). It is one of the major cereal crops grown in the highlands of Ethiopia and the country is regarded as the largest wheat producer in Sub-Saharan Africa (Efrem, *et al.*, 2000).

Crop rotation is one of the oldest and most fundamental agronomical practices, and is thought to have great impact on increasing crop yield. It is primarily a management decision based on a desire to optimize financial, agricultural or environmental objectives through profit and yield maximizations as well as through minimized pesticide use (Harris, *et al.*, 2007). Rotations primarily help in weed control, improve soil fertility, and increase wheat grain yield when compared to mono-cropping (Yirga, *et al.*, 1992). A well planned rotation reduces weed pressure by eliminating the constant niche that mono cropping provides.

A leguminous crop usually precedes cereals for the aim of improving soil fertility. Therefore, the benefits of rotations could arise from increased nitrogen supply, soil organic matter, and improvement in soil structure, and decreased pests, disease or weed competition. The farming systems of southern Ethiopia, cereals predominate, often occupying over 80% of the total cropped land each season (Admasu, *et al.*, 2020). In the highland zones, bread wheat and barley are the most common cereals in production, while faba bean is common grain legume crop. Though the high proportion of wheat and barley in the highland cropping systems not satisfies the short term subsistence objectives of farmers, and also, may prove disadvantageous in the long term due to the absence of the inherent advantages of crop rotational systems. Hence, choice of appropriate precursor crop to wheat planting for rotation can affect wheat yield.

Materials and Methods

The experiment consisted of 10 (or ten) different treatments laid out in randomized complete block design (RCBD) with three replications. A field layout was prepared and the treatments were assigned randomly to each plot within a block. The experiment has been held in two phases. During the first phase the precursor treatments and crops were assigned to the experimental field and while the main crop (bread wheat) and treatments considered was conducted in this year. Each plot consisted of 10 (ten) rows 20cm apart in 4m length.

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Description of the Study Site

The study was conducted for two consecutive years from 2019 to 2023 main cropping seasons in the highland of Bale zone sinana and Agarfa District experimental field station. Agarfa district is found in the Bale Administrative Zone of Oromia Regional State, in Southeastern part of Ethiopia. It lies between 7˚8'N to 7˚28'N latitude and 39˚31'E to 40˚5'E longitude. Sinana site is located at $07^0$07'Nlatitude and $40^0$10'E longitude at an altitude of 2400 meters above sea level. This area is typical of the rain fed wheat growing regions of Ethiopia with average annual rainfall of 825 mm.

Treatments and Experimental Design

In the first year all plots were received wheat with recommended agronomic package to make the experimental units homogenous. In the second year crop grown potentially in the district were used as precursor crop which was field pea, faba bean and wheat. The precursor crops were arranged in randomized complete block design with three replications. The plot size for planting was 2.4m × 3.0m accommodating 12 rows spaced 20 cm apart. Eight central rows were used for data collection and measurement. The distance between the plots and blocks were kept at 0.5m and 1m apart, respectively.

Table 1: Description of the Treatments

No.	First Year (Precursors)	Second Year (Main Crop)
1.	Bread wheat only	Bread wheat only
2.	Bread Wheat + Recommended fertilizer	Bread wheat + Recommended N Fertilizer
3.	Faba Bean	Bread wheat + 25% from Recommended N Fertilizer
4.	Faba Bean	Bread wheat + 50% from Recommended N Fertilizer
5.	Faba Bean	Bread wheat + 75% from Recommended N Fertilizer
6.	Field pea	Bread wheat + 25% from Recommended N Fertilizer
7.	Field pea	Bread wheat + 50% from Recommended N Fertilizer
8.	Field pea	Bread wheat + 75% from Recommended N Fertilizer

Data Collected

In the first and second year only yield data was collected only yield data was collected in the first year from precursor crops. However, in the second year in the third year (last year) Agronomic data like plant height, tiller per plant, spike length, biomass, grain yield and thousand seed weight were recorded.

Data analysis

After verifying the homogeneity of error variances, analysis of variance was done using the procedure of SAS. Mean comparisons were done by Least Significant Difference (LSD) at the 5% level of significance.

Result and Discussion

Soil Analysis before Planting

Selected physico-chemical properties of the soil were determined for composite surface soil (0-20 cm) samples collected before sowing (Table 2). Accordingly, the texture of the soil of the experimental site is dominated by the clay fraction. The clay texture indicates the high degree of weathering that took place in geological times and the high nutrient and water holding capacity of the soil. Soil pH values for both locations varied from 7.7-6.7 for soils of the experimental sites (Table 2). PH status was categorized as neutral soil. Based on these results the pH value is optimum range for most crop production since most plant prefers the pH range 5.5 to 7.0. Soil Organic Matter values for both locations varied from 2.18 to 1.83 for soils of the experimental sites (Table 2). As the rating range established by (Tekalign Tadese. 1991) [6] Soil organic matter content categorized under moderate and low for Sinana and Agarfa, respectively. Soil total Nitrogen values for both locations varied from 0.16 – 0.15. As ratings suggested by (Landon, J. R., 1991) for soil total nitrogen soils of the experimental site were rated into low for Sinana and Agarfa. Available Phosphorous values for both locations varied from 6.8-11.7 (Table 2). According to the rating established by (Cottenie, A. 1980) [7] the studied soils have low phosphorus content for both locations Sinana and Agarfa. Cation exchange rating established by (Hazelton. 2007) [4] the soil of the study sites were high to moderate for sinana and Agarfa, respectively

Table 2: Selected Soil physio-chemical characterization of the experimental location

Location	pH (1:2.5H20)	Available P (mg kg-1)	Total N%	OM%	CEC (coml. kg-1)	Texture
Sinana	7.7	6.8	0.16	2.18	49.24	clay
Agarfa	6.7	11.7	0.15	1.83	37.38	clay

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 3). 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 3). 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 field pea-wheat rotation whereas lowest wheat yield components were obtained in the continuous wheat cropping plot. 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 (Yusuf, *et al*., 2009 and Rahman *et al*., 2014) [2, 1]. This is because legumes increased soil N through BNF or sparing effect since their demand for N is less than cereals (Uzoh, *et al*., 2019) [3].

Table 3: Agronomic parameters of subsequent wheat crop grown after legumes rotation.

Rotations	Fertilizer Rate Kg/ha	Plant Height (cm)	Number of Tiller Per Plant	Seed Per Spike	Spike Length (cm)
Wheat-Wheat	No fertilizer	98.67^{d}	3.16^{b}	38.13^{c}	9.42^{de}
Wheat-Wheat	100% RRF	104.94^{abc}	3.93^{ab}	45.85^{abc}	10.06^{bcd}
Faba bean-Wheat	No fertilizer	102.39^{dc}	3.65^{ab}	42.26^{bc}	9.33e
Faba bean-Wheat	25% RRF	103.06^{bdc}	3.92^{ab}	42.88^{bc}	10.11^{abcd}
Faba bean-Wheat	50% RRF	99.28^{d}	3.78^{ab}	47.98^{ab}	10.67^{ab}
Faba bean-Wheat	75% RRF	109.56^{a}	4.23^{a}	52.31^{a}	10.72^{a}
Field Pea-Wheat	No fertilizer	106.72^{abc}	3.45^{ab}	41.95^{bc}	9.56d^{e}
Field Pea-Wheat	25% RRF	108.28^{a}	3.76^{ab}	45.38^{abc}	10.36^{abc}
Field Pea-Wheat	50% RRF	102.72^{cd}	3.71^{ab}	47.40^{ab}	10.22^{abcd}
Field pea-Wheat	75% RRF	107.94^{b}	3.72^{ab}	47.56^{ab}	10.00^{dc}
	CV (%)	4.15	19.45	14.89	5.42
	LSD(0.05)	5.03	0.84	7.84	0.633

Note: *RRF= Recommended Rate of Nitrogen Fertilizers*

Grain Yield of Subsequent Wheat Crop

The highest wheat grain yield (4008.75 kg ha^{-1}) was recorded in the faba bean-wheat rotation with application of 75% of recommended inorganic fertilizers whereas the lowest wheat grain yield (2784.02 kg ha^{-1}) was recorded in the wheat-wheat rotation without fertilizer application. The wheat grain yield advantages of the faba bean-wheat, field pea-wheat and over the wheat-wheat rotation (2784.02 kg ha^{-1}), respectively (Table 4). 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 4). However, there was no significant difference in wheat yield among field pea-wheat and wheat-wheat rotations with different inorganic fertilizer application rates (Table 4). All legume wheat rotations have greater net economic benefits than the continuous wheat cropping (Table 5). 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.

Table 4: Grain and biomass yields of subsequent wheat crop grown following different legume crops, south eastern Ethiopia.

Rotations	Fertilizer Rate Kg/ha	Biomass Yield (Kg/ha)	Seed yield (Kg/ha)	Thousand Kernel Weight(gm)
Wheat-Wheat	No fertilizer	6399.5^{f}	2784.02^{d}	41.80^{abc}
Wheat-Wheat	100% RRF	7272.5abc	3418.22^{abcd}	40.67^{bc}
Faba bean-Wheat	No fertilizer	6459.6^{def}	2997.89^{bcd}	40.23^{bc}
Faba bean-Wheat	25% RRF	7071.3bc	3150.14^{abcd}	40.93^{bc}
Faba bean-Wheat	50% RRF	6865.3cdef	3612.49^{a}	39.33^{c}
Faba bean-Wheat	75% RRF	7719.2^{a}	4008.75^{a}	41.25^{abc}
Field Pea-Wheat	No fertilizer	6430.8^{ef}	2847.77^{cd}	42.54^{ab}
Field Pea-Wheat	25% RRF	6917.8cde	3250.59^{abcd}	41.91^{abc}
Field Pea-Wheat	50% RRF	6956.4bcd	3579.38^{abc}	42.32^{ab}
Field pea-Wheat	75% RRF	7453.8^{ab}	3754.63^{ab}	43.88^{a}
	CV (%)	6.37	18.05	5.56
	LSD(0.05)	514.75	711.01	2.68

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 and wheat-wheat rotations (Table 4). Significant ($p < 0.05$) differences in biomass yields were also observed between 'Field pea'-wheat (7453.8 kg ha^{-1}) and wheat-wheat (6399.5 kg ha^{-1}) rotations. However, biomass yield of wheat was not-significantly different among 'faba bean'-wheat and field pea-wheat rotations.

Partial Budget Analysis

The maximum net benefit (197278.5ETB ha^{-1}) with an acceptable MRR(7062.49) was obtained from the faba bean-wheat rotation with application of 75% of recommended nitrogen fertilizer with recommended NPS followed bean-wheat rotation with application of 50% of recommended nitrogen fertilizer. From field pea –wheat rotation with application of 50% recommended nitrogen fertilizer provide maximum net benefit(176200.752ETB ha^{-1}) while the least net benefit(140314.608 ETB ha-1) was obtained from continues wheat-wheat rotation and unfertilized treatment (Table 5 Therefore, faba bean-wheat rotation with application of 75% of recommended nitrogen fertilizer with recommended NPS followed field pea –wheat rotation with application of 50% recommended nitrogen fertilizer for the production of bread wheat was more economically profitable application rates and can be recommended for farmers of the study area and other areas with similar agro-ecological conditions.

Table 5: Partial budget analysis for bread wheat production under different subsequent wheat crop grown following different legume crops, south eastern Ethiopia.

Rotations	Fertilizer Rate kg/ha	Adjusted Yield kg/ha	NPS Cost	UREA Cost	Total Cost	Total Return	Net Benefit	MRR (%)
Wheat-Wheat	No fertilizer	2505.618	0	0	0	140314.6	140314.608	-
Faba bean-Wheat	No fertilizer	2698.101	0	0	0	151093.7	151093.656	-
Faba bean-Wheat	25% RRF	2715.126	2850	562.5	3413	152047.1	148634.556	D
Faba bean-Wheat	50% RRF	3320.241	2850	1350	4200	185933.96	181733.96	565.7
Faba bean-Wheat	75% RRF	3607.875	2850	1913	4763	202041	197278.5	7062.49
Wheat-Wheat	100% RRF	3076.398	2850	2700	5550	172278.3	166728.288	D
Field Pea-Wheat	No fertilizer	2562.993	0	0	0	143527.6	143527.608	-
Field Pea-Wheat	25% RRF	2625.531	2850	562.5	3413	147029.7	143617.236	D
Field Pea-Wheat	50% RRF	3221.442	2850	1350	4200	180400.8	176200.752	4137.6
Field pea-Wheat	75% RRF	3379.167	2850	1913	4763	189233.4	184470.852	1470.26

Conclusion

Crop rotation with legume crop species. Rotation with dicotyledonous crop species, particularly the faba bean and field pea grain legume crop, increased wheat grain yield in succeeding crops. This experiment revealed that the first wheat following a faba bean precursor crop in rotation resulted in superior grain yields. Field pea precursor also resulted in important grain yield increments in a succeeding wheat crop. The low yields obtained from the continuous cereal rotations at both locations indicate the need to encourage the adoption of appropriate crop rotations by peasant in Ethiopia. In particular, the proportion of legumes should be increased in the currently cereal-dominated cropping systems. Crop rotation provided effects on wheat response to applied N nutrients: rotation with faba bean and field pea minimized wheat response to fertilizer N; crop rotation. The use of the N2 fixing leguminous crop faba bean and field pea in rotation with wheat in the present experiment clearly demonstrated the importance of legume-cereal rotation systems in sustaining wheat production and reducing the consumption of costly imported inorganic N fertilizer. Therefore, faba bean-wheat rotation with application of 75% of recommended N fertilizer with recommended NPS followed field pea –wheat rotation with application of 50% recommended nitrogen fertilizer for the production of bread wheat was more economically profitable application rates and can be recommended for farmers of the study area and other areas with similar agro-ecological conditions.

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