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Research Article

Evaluation of Nutrient Requirements of Sweet Lupine in Bread Wheat-Sweet Lupine under Additive Design Intercropping System in Northwest Ethiopia

Birhanu Bayeh,[1,2] **Getachew Alemayehu**,[1] **Tilahun Tadesse**,[3] and **Melkamu Alemayehu**[1]

[1]*College of Agriculture and Environmental Sciences, Bahir Dar University, P.O. Box 5501, Bahir Dar, Ethiopia*
[2]*College of Agriculture and Environmental Sciences, Debre Tabor University, P.O. Box 272, Debre Tabor, Ethiopia*
[3]*Ethiopian Institute of Agricultural Research, Fogera Rice Research and Training Center, P.O. Box 1937, Woreta, Ethiopia*

Correspondence should be addressed to Birhanu Bayeh; birhanub6@gmail.com

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The application of optimal fertilizer rates for component crops improves productivity, land use efficiency, and profitability in an intercropping system. Two field experiments during the 2019 and 2020 cropping seasons were conducted in Adet and Debre Tabor districts with the objective of evaluating the nutrient requirements of sweet lupine in bread wheat-sweet lupine under additive design intercropping systems. Sweet lupine grown in bread wheat-sweet lupine intercropping was fertilized with seven fertilizer levels (0%, 25%, 50%, 75%, 100%, 125%, and 150% of the blanket-recommended NP fertilizer rate of sole lupine) and laid out in a randomized complete block design with three replications. The findings revealed that the highest grain yield of sweet lupine in wheat-sweet lupine intercropping system at Adet was achieved at 125% NP (0.51 $t \cdot ha^{-1}$) and 150% NP (0.52 $t \cdot ha^{-1}$), followed by 100% NP (0.43 $t \cdot ha^{-1}$) and 50% NP (0.35 $t \cdot ha^{-1}$) fertilizer levels of sweet lupine. Similarly, the highest grain yield of sweet lupine in Debre Tabor was recorded by the application of 125% NP (2.07 $t\, ha^{-1}$) fertilizer level of sweet lupine followed by 150% NP (1.89 $t \cdot ha^{-1}$), 100% NP (1.71 $t \cdot ha^{-1}$), and 50% NP (1.70 $t \cdot ha^{-1}$) fertilizer levels. For every invested Ethiopian Birr in the treatments of 50% and 125% NP fertilizer levels of sweet lupine averaged additional profits of ETB 7.667 and ETB 4.537, respectively, can be obtained from sweet lupine that grew under bread wheat-sweet lupine intercropping system. Based on the averaged MRR across the different cost price ratio, application of 50% NP fertilizer level of sweet lupine can be recommended for profitable production of sweet lupine in bread wheat-sweet lupine under additive design intercropping system in Adet and Debre Tabor and areas with similar agroecology as it recorded the highest net return with acceptable marginal rate of return.

1. Introduction

Ethiopia's population is growing at an alarming rate, while the food supply is increasing at a much slower rate [1, 2]. In this regard, FAO [3] reported that farmland in the country becomes fragmented into small parcels that are less than one hectare per household at most and soil fertility of cropland has declined rapidly due to exploitative cultivation of cropland [4]. Quick corrective measures that help to sustainably increase agricultural productivity per unit of farmland are crucial. In this regard, diversification of crops through intercropping promotes land productivity and ensures the production of a given crop's sustainability. According to Panda [5], intercropping is the cultivation of two or more crop species in the same area, sharing resources for all or part of the growing season. The importance of intercropping increases as farm size decreases [6]. Intercropping supports sustainable and productive agriculture by addressing some of the major constraints associated with modern farming (monoculture) [7], such as yield stability [8], insect pests, and pathogen accumulation [9]. Moreover, intercropping provides insurance against crop failure and market fluctuations [10], soil degradation, and environmental deterioration [11], as well as lowering external inputs [12].

Cereal-legume intercropping is widely used in Ethiopia to ensure family food supply and income [13]. The benefits of cereal-legume intercropping systems in terms of yield may arise from complemented use of growth resources in either space or time [14, 15]. Among cereal-legume intercropping systems, additive design intercropping is the most popular traditional practice used by low-input farmers in northwest Ethiopia [16].

Figuring out the useful or competitive effects of intercropping on soil resources, particularly nutrient supplements of the component crops is a significant and unexplored research topic. Ghosh et al. [17] found that component crops in an intercropping system compete for soil resources more intensely than for light. For many years, blanket fertilizer recommendations for the component crop in crop mixes have been used [18, 19]. Many researchers believe that fertilizer recommendations are usually based on the fertilizer requirements of the crop chosen for intercropping, although no research evidence supports this. Furthermore, Ghosh et al. [20] demonstrated that fertilizer recommendations based on the aforementioned reasons may not meet the nutrient requirement of component crops in the intercropping system, because fertilizer requirements of the component crops can be different [21].

Most fertilizer research papers, according to Maman et al. [22], mostly concentrated on establishing the optimum fertilizer rates for sole crops. Moreover, fertilizer rates advised for solitary crops have been applied on component crops in an intercropping system. While competition between component crops for nutrient usage is more pronounced in the intercropping system, this may not meet the component crop's nutrient demand [20]. In cereal-legume intercropping, there is some published information on nutrient management and nutrient audit [12]. The optimal fertilizer need of sweet lupine in intercropping bread wheat-sweet lupine for improved productivity, land use efficiency, and profitability, which is different, has not yet been thoroughly researched. Thus, the objective of the present study was to assess the effects of applying NP fertilizer in sweet lupine on productivity, land use efficiency, and profitability in bread wheat-sweet lupine under an additive design intercropping system.

2. Materials and Methods

2.1. Experimental Sites. Field experiments were conducted in Adet and Debre Tabor districts, which are the key wheat and sweet lupine producing districts of northwest Ethiopia during the 2019 and 2020 cropping seasons. Adet district is located between 11°17′N latitude and 37°43′E longitude [23] where the experimental site is at an altitude of 2240 meters above sea level (m.a.s.l.). The other experimental site in the Debre Tabor district is located at 11°89°N and 38°9E latitude and longitude, respectively, with an elevation of about 2630 m.a.s.l. Weather data (rainfall and temperature) of the experimental years for experimental sites were collected from the northwestern Ethiopia meteorology station office in Bahir Dar, Ethiopia. The total rainfall at Adet during the 2019 and 2020 cropping seasons was 1592.1 and 1228.1 mm, respectively (Figure 1), while at Debre Tabor it was 1926.1 and 1739 mm, respectively (Figure 2). At Adet, the minimum and maximum temperatures were 5.4 and 30.2°C during 2019 and 6.8 and 30.7°C during 2020. At Debre Tabor, the minimum and maximum temperatures during the 2019 and 2020 cropping seasons were 7.5 and 25.3°C and 6.2 and 25.5°C, respectively.

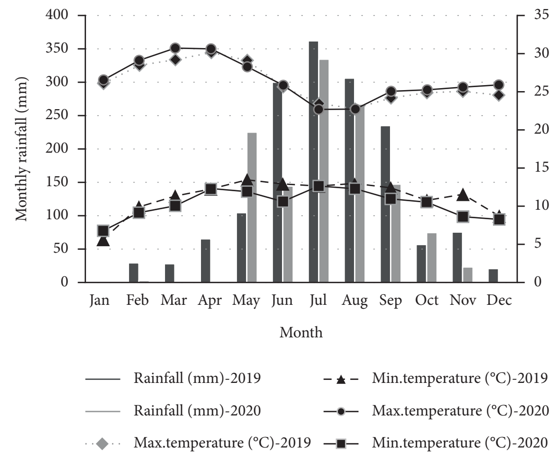

Figure 1: Average monthly rainfall and temperature distribution in Adet throughout the two-year experiment (2019–2020).

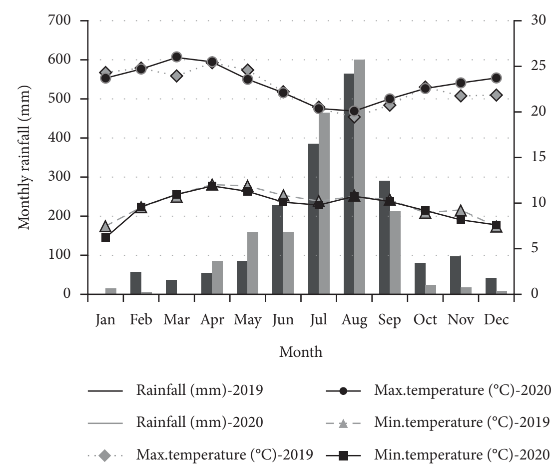

Figure 2: Average monthly rainfall and temperature distribution during the two experimental years (2019–2020) at Debre Tabor.

Before the start of the experiments, soil samples were collected diagonally at five spots from the depth of 0–20 cm and composited to evaluate the characteristics of the soil of the experimental sites. The composite soil samples were analyzed at Adet Agricultural Research Center Soil Laboratory. The soil samples were air-dried, crushed, and sieved through a 2 mm sieve and analyzed to determine soil texture, total nitrogen, pH, available phosphorous, organic carbon, and cation exchange capacity. Table 1 shows the findings of the soil analysis and the methodologies used.

2.2. Treatments and Design of Experiment. Sweet lupine intercropped with bread wheat was supplied with seven different NP fertilizer rates (0%, 25%, 50%, 75%, 100%,

Table 1: Soil properties of the study sites before the experiment[a].

Soil properties	Adet		Debre Tabor		Method of soil analysis
	Value	Rating	Value	Rating	
pH (H_2O) 1 : 2.5	5.08	Moderately acidic[b]	6.24	Slightly acidic[b]	pH meter (H_2O 1 : 2.5)
CEC (cmol(+) kg^{-1})	38.28	High[c]	42.73	Very high[c]	Ammonium acetate method [24]
OC (%)	1.21	Very low[c]	1.48	Very low[c]	Walkley and Black method [25]
TN (%)	0.17	Low[c]	0.16	Low[c]	Micro-Kjeldahl method [26]
Ava. P (ppm)	3.89	Low[c]	21.33	Low[c]	Bray method [27]
Soil texture					Hydrometer method [28]
Sand (%)	55	—	56	—	
Silt (%)	11	—	19	—	
Clay (%)	36	—	25	—	
Soil textural class	Sandy clay	Sandy clay[c]	Sandy clay loam	Sandy clay loam[c]	

OC: organic carbon; TN: total nitrogen; Ava. P: available phosphorous; CEC: cation exchange capacity. [a]Data were mean of 2 years (2019 and 2020). [b]Panda [5]. [c]Landon [29].

Table 2: Fertilizer percentages and rates applied for sweet lupine in bread wheat-lupine intercropping system.

Cropping system	Percentage of the recommended rate	Recommended fertilizer rate (kg/ha)		Fertilizer rate of the respective percentage (kg/ha)	
		N	P_2O_5	N	P_2O_5
BW + SL	0	18	46	0	0
	25	—	—	4.5	11.5
	50	—	—	9	23
	75	—	—	13.5	34.5
	100	—	—	18	46
	125	—	—	22.5	57.5
	150	—	—	27	69
Sole sweet lupine	100	18	46	18	46
Sole bread wheat	100	74	29	74	29

BW + SL: bread wheat and sweet lupine intercropping. N (nitrogen) and P_2O_5 (phosphorous) are applied to the component crops in the form of urea and DAP, respectively.

125%, and 150% of recommended NP fertilizer rate of sole sweet lupine). The treatments were laid out in a randomized complete block design with three replications. Sweet lupine was planted in a 2 : 1 row-planting pattern with intra- and interrow spacing of 10 cm and 40 cm, respectively (Table 2). The intercropping design was additive (2 : 1), while solitary cultures of the two crops were being used for estimating the partial land equivalent ratio. Sole bread wheat and sole sweet lupine sowing rates were indicated to be 150 kg/ha and 90 kg/ha, respectively. The gross and net areas of the experimental plots were 3.6 m × 2 m (7.2 m^2) and 3 m × 2 m (6 m^2), respectively, with a distance of 0.5 m and 1 m between adjacent plots and replications.

2.3. Experimental Materials and Planting Procedures. Taye cultivar of bread wheat, which is the most adaptable bread wheat variety, and Sanabor cultivar of sweet lupine were used as test crops. Bread wheat seeds were drilled in rows at a recommended interrow spacing of 20 cm, while sweet lupine seeds were planted every two rows of bread wheat at inter- and intrarow spacing of 40 cm × 10 cm, respectively, in an additive design (2 : 1) intercropping system. Sole bread wheat was sown in a row at the recommended interrow spacing of 20 cm. A sole sweet lupine was also planted in a row with a 40 cm interrow spacing and 10 cm intrarow spacing. At Adet and Debre Tabor, respectively, bread wheat in Adet experimental site was fertilized with 92 kg·ha^{-1} N and 46 kg·ha^{-1} P_2O_5 while in Debre Tabor it was supplied with 138 kg·ha^{-1} and 46 kg·ha^{-1} P_2O_5 as recommended. At wheat planting time, all the total amount of P_2O_5 and half of the N fertilizers were applied at the time of wheat planting while the remaining, half nitrogen was applied at the tillering stage. For sole sweet lupine 18 kg, ha^{-1} N, and 46 kg, ha^{-1} P_2O_5, were applied as recommended. Other agronomic practices were performed uniformly for all cropping systems as recommended.

2.4. Data Collection

2.4.1. Yield and Yield Attributes of Sweet Lupine in Bread Wheat-Sweet Lupine Intercropping. Branches number per plant, pod number per plant, total biomass yield, and grain yield of sweet lupine in bread wheat-sweet lupine intercropping were determined from 5 randomly sampled plants grown in the net plot area at physiological maturity. The total above-ground biomass of the component crops grown in the net plot area was measured after harvesting and sun-drying at an average air temperature of 25–27°C until the constant dry weight was attained (about two weeks). Correspondingly, the yield of the component crop was determined after the total biomass per plot was dried, threshed, cleaned, and then adjusted to a 12% moisture level.

2.4.2. Assessment of Component Crop Productiveness in Intercropping. Land equivalent ratio (LER) is a measure of the efficiency of land use in intercropping to sole cropping. It is the sum of the component crop yields. LER was calculated using the formula below as indicated by Mead & Willey [30]. Consider the following:

$$\text{LER} = (\text{PLERBW}) + (\text{PLERSL}) = \sum_{I=1}^{n}\left(\frac{Y_i}{Y_m}\right), \quad (1)$$

where Y_i and Y_m are yields of component crops in intercrop and sole cropping, respectively, and n is the number of crops involved. PLERBW: partial land equivalent ratio of bread wheat; PLERSL: partial land equivalent ratio of sweet lupine.

2.5. Data Analysis. Data analysis for the intercrop experiment was conducted using the GLM (General Linear Model) procedure of SAS version 9.2 (Statistical Analysis System (SAS) Institute, 2008) for each site and year. Finally, the data were combined over years and analyzed [31]. The least significant differences (LSD) were used to separate the means. In bread wheat-lupine intercropping systems, regression analysis was used to investigate the association between factors and NP fertilizer rates of lupine.

2.6. Partial Budget Analysis. The partial budget of the intercropping system was analyzed following the procedures described by CIMMYT [32] at three scenarios of cost price ratios. Cost price ratios were calculated by dividing the labor cost in man day^{-1} with grain prices of sweet lupine in kg^{-1}. The three scenarios considered were keeping sweet lupine grain price constant while labor cost in man day^{-1} increased from 75 to 100 and 125 Ethiopian Birr (ETB). Labor cost included costs for planting, harvesting, threshing, and cleaning of the component crops in each treatment. The average grain price of 20 ETB per kg of sweet lupine was used for the determination of cost price ratios at both locations, which was determined based on the average local market prices in the months from December to March. Gross return minus the total costs that vary gave the net return. According to Kiwia et al. [33], the acceptability of intercropping by farmers is best judged by the marginal rates of return (MRR), an approach to maximize profit. Kiwia et al. [33] also indicated as a rule of thumb that MRR less than 100% is considered low and unacceptable to farmers; a higher cut-off value (MRR greater than 1) has been recommended if the technology involves a significant change from current farmer practices.

3. Results and Discussion

3.1. Growth Responses of Sweet Lupine in Bread Wheat-Sweet Lupine Intercropping to NP Fertilizer Rates. Different NP fertilizer rates had a significant ($p < 0.01$) effect on the number of branches per plant, the number of pods per plant, total biomass yield, and grain yield (Table 3) in both experimental sites. At Adet experimental site, significantly the highest branches number per plant was obtained in BW–SL intercropping at 125% and 150% NP followed by 100% NP and 50% NP fertilizer levels (Table 3). The lowest branches number per plant of sweet lupine was recorded at zero fertilization. Similarly, the highest branches number per plant at Debre Tabor experimental site was obtained at 125% NP while the lowest branches number per plant was obtained at zero fertilization. The growth response of sweet lupine in the bread wheat-sweet lupine intercropping system increases as the NP fertilizer levels increase to the optimum level. This result agrees with the findings by Apoorva et al. [34] for wheat and chickpea. The marked difference in plant growth of the component crop was mainly due to the sufficient application of fertilizer.

The highest pod number per plant of sweet lupine at Adet was recorded from plants supplied with 150% NP and 125% NP fertilizer levels, followed by 100% NP and 50% NP (Table 3). Similarly, at Debre Tabor, the highest maximum pod number per plant of sweet lupine was at 125% NP and 150% NP. The lowest pod number per plant values were recorded from plants that were not supplied with fertilizers. Generally, the number of pods per plant recorded at Debre Tabor was higher than that at Adet (Table 3). Based on the results, the yield and yield attribute of sweet lupine in the intercrop increased as the number of fertilizers increased to the optimum level. This result is also consistent with Apoorva et al. [34] findings for wheat and chickpea. The significant difference in plant growth of the component crop was primarily attributable to adequate fertilizer treatment. The higher fertilizer levels could be due to adequate nutrition levels resulting in increased root growth and penetration, allowing the component crops to explore a larger volume of soil and gain better access to nutrients. Furthermore, improved growth response at these fertilizer levels could be attributed to increased availability of nutrients from the additional fertilizer and the intercropped legume's solubility action, resulting in much release of both native and applied nutrients [35]. On the other hand, growth responses of sweet lupine were lower in bread wheat-sweet lupine intercropping that received no fertilizer, most likely due to decreased yield attributes of the component crops induced by a lack of accessible N and P in the experimental field's soil solution.

3.2. Yield Responses of Sweet Lupine in Bread Wheat-Sweet Lupine Intercropping to NP Fertilizer Rates. At Adet, the maximum total biomass yield of sweet lupine was obtained by application of 125% NP (1.09 t·ha^{-1}) followed by 150% NP (0.93 t·ha^{-1}) while the lowest total biomass yield was recorded from plants grown without fertilizer. At Debre Tabor, the highest total biomass yield of sweet lupine was achieved at 150% (4.11 t·ha^{-1}) and 125% NP (4.11 t·ha^{-1}) fertilizer levels followed by 100% NP (3.71 t·ha^{-1}), 50% NP (3.52 t·ha^{-1}), and 75% NP (3.52 t·ha^{-1}) while the lowest total biomass yield was at zero and 25% NP fertilizer levels

Table 3: Yield and yield attributes of sweet lupine as influenced by NP fertilizer rates in Northwest Ethiopia[a].

Treatment	Adet				Debre Tabor			
NP fertilizer rate (%)	Branches number $plant^{-1}$	Pods number $plant^{-1}$	Total biomass yield ($t{\cdot}ha^{-1}$)	Grain yield ($t{\cdot}ha^{-1}$)	Branches number $plant^{-1}$	Pods number $plant^{-1}$	Total biomass yield ($t{\cdot}ha^{-1}$)	Grain yield ($t{\cdot}ha^{-1}$)
0.00	3.00^{c}	8.5^{c}	0.62^{d}	0.29^{c}	3.33^{d}	18.00^{c}	2.95^{c}	1.36^{c}
25.00	3.17^{bc}	9.5^{c}	0.64^{d}	0.34^{bc}	3.33^{d}	18.33^{c}	2.96^{c}	1.37^{c}
50.00	3.67^{bc}	13.0^{b}	0.79^{bcd}	0.35^{bc}	4.17^{bcd}	22.17^{b}	3.52^{b}	1.70^{b}
75.00	3.17^{bc}	9.5^{c}	0.66^{cd}	0.35^{bc}	3.5^{cd}	22.17^{b}	3.52^{b}	1.70^{b}
100.00	3.83^{b}	13.67^{ab}	0.87^{bc}	0.43^{ab}	4.33^{bcd}	23.83^{ab}	3.71^{ab}	1.71^{b}
125.00	5.17^{a}	15.33^{a}	1.09^{a}	0.51^{a}	5.33^{a}	26^{a}	4.11^{a}	2.07^{a}
150.00	4.83^{a}	15.67^{a}	0.93^{ab}	0.52^{a}	5^{ab}	25.17^{ab}	4.15^{a}	1.89^{ab}
LSD	0.68^{***}	2.09^{***}	0.22^{***}	0.1^{***}	0.93^{***}	3.6^{***}	0.55^{***}	0.28^{***}
CV (%)	15.1	14.58	22.85	19.97	18.99	13.74	13.14	14.16
SE±	0.32	1.12	0.06	0.04	0.3	1.18	0.18	0.1

[a]Data were combined over years (2019 and 2020). SE: standard error of the mean; *, **, and *** indicate significance at 0.05, 0.01, and 0.001 probability levels, respectively. Means in columns with the same letter are not significantly different.

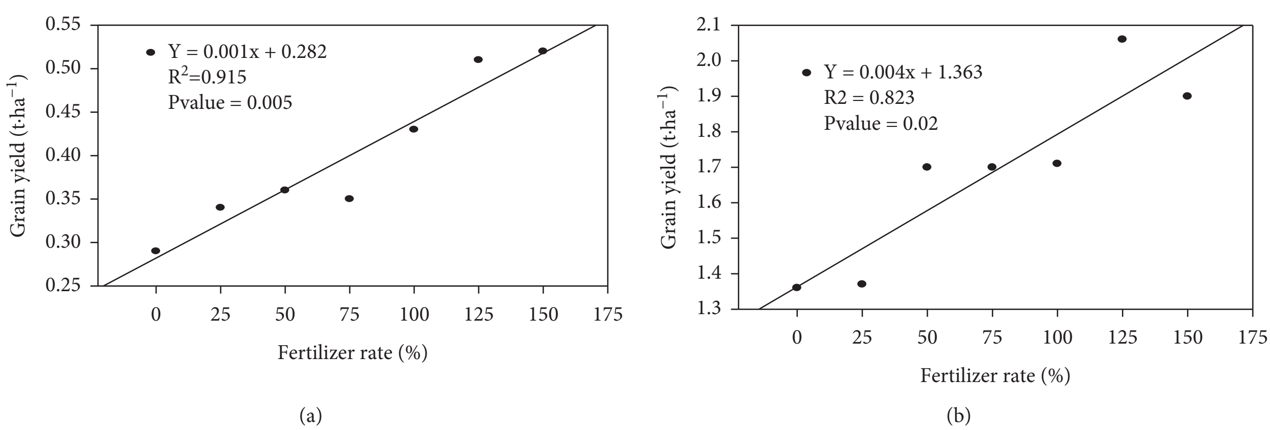

Figure 3: The relationship between grain yield of sweet lupine and fertilizer rate at (a) Adet and (b) Debre Tabor.

(Table 3). Because nutrients from mineral fertilizer were easily available, the higher NP fertilizer rates probably resulted in the highest total biomass. This may have occurred when a significant amount of fertilizer was applied to an intercrop, resulting in a decrease in interspecific competition. In line with this finding, Li et al. [36] found that increasing fertilizer application could reduce interspecific competition in an intercropping system. This result is also consistent with Azam et al. [37] findings. This result contradicts Ghosh et al. [20] findings for sorghum-soybean intercropping.

The highest grain yield of sweet lupine at Adet was recorded by application of 150% NP ($0.52\,t{\cdot}ha^{-1}$) fertilizer level, which was statistically similar with the yield recorded from 125% NP, followed by 100% ($0.43\,t{\cdot}ha^{-1}$), 75% ($0.35\,t{\cdot}ha^{-1}$), and 50% NP ($0.35\,t{\cdot}ha^{-1}$) as indicated in Table 3. Similarly, the application of 125% NP recorded the highest grain yield ($2.07\,t{\cdot}ha^{-1}$), followed by 150% ($1.89\,t{\cdot}ha^{-1}$) and 75% NP ($1.71\,t{\cdot}ha^{-1}$) at Debre Tabor. The lowest grain yields of sweet lupine on the other hand were recorded from plants, which were grown without fertilizers in both experimental sites. The relatively highest biomass and grain yields at 150% and 125% NP in both sites could be related to improvements in yield components for better carbohydrates partitioning from leaf to reproductive parts and efficient uptake of the applied nutrient. The linear relationship between fertilizer rate and crop yield observed in the present study also supports the idea mentioned above (Figures 3(a) and 3(b)). The grain yields of sweet lupine in Debre Tabor were relatively higher than those recorded in

Table 4: The partial land equivalent ratio of sweet lupine at Adet and Debre Tabor experimental sites.

Fertilizer levels	Adet PLERSL	Debre Tabor
0% NP of sweet lupine	0.18	0.52
25% NP of sweet lupine	0.21	0.52
50% NP of sweet lupine	0.23	0.66
75% NP of sweet lupine	0.22	0.65
100% NP of sweet lupine	0.28	0.66
125% NP of sweet lupine	0.31	0.79
150% NP of sweet lupine	0.32	0.73
SSL	1	1
SE±	0.09	0.05

Data were combined over years (2019 and 2020). SSL: sole sweet lupine.

Table 5: Net return and marginal rate of return of sweet lupine in wheat-sweet lupine additive design intercropping system.

Different NP fertilizer levels	CPR1		CPR2		CPR3		
	NR (ETB ha^{-1})	MRR (%)	NR (ETB ha^{-1})	MRR (%)	NR (ETB ha^{-1})	MRR (%)	MRR*
0% NP of sweet lupine	14850		14850		14850		
25% NP of sweet lupine	15040	54	15015	44	14990	35	44.3
50% NP of sweet lupine	17930	826	17880	764	17830	710	766.7
75% NP of sweet lupine	17475^D		17425^D		17375^D		
100% NP of sweet lupine	17935	0.8	17860^D		17785^D		
125% NP of sweet lupine	20825	825	20725	276	20625	260	453.7
150% NP of sweet lupine	19830^D		19730^D		19630^D		

^{D}Treatments 4, 5, and 7 are dominated. Data were combined over years (2018 and 2019) and sites (Adet and Debre Tabor). CPR: cost price ratio; ETB: Ethiopian Birr; NR: net return; MRR: marginal rate of return. *Mean marginal rate of return over the three labor cost to legume price ratios.

Adet at all treatments. However, the highest grain production at 125% NP fertilizer level was 19% and 21% higher than the respective control treatment at Adet and Debre Tabor experimental sites, respectively. In most cases, biomass and grain yield increase in line with fertilizer mount to the optimum level. The results agree with the works by Li et al. [36].

3.3. Partial Land Equivalent Ratios. A useful expression in assessing crop productivity in solitary cropping systems is mass yield (mass per unit area). Direct comparison is difficult in intercropping systems, however, because the products are different for the different plant species growing on the same area of land [38]. The PLERSL in the present study ranged from 0.18 to 0.32 in Adet and 0.52 to 0.79 in the Debre Tabor experimental locations (Table 4). When the PLER for component crops cultivated in intercropping systems is smaller than unity, according to Beyenesh et al. [39], both component crops are compatible for intercropping under varied cropping intensities. The highest PLERSL at Adet experimental site was recorded from the application of 125% (0.31) and 150% NP (0.32) fertilizer levels while the lowest (0.18) was recorded from 0% NP fertilizer level (Table 4). While in Debre Tabor, 125% NP (0.79) had the greatest PLERSL, followed by 150% NP (0.73) and 100% NP (0.66) and 50% NP (0.66) fertilizer levels in bread wheat-sweet lupine intercropping system; the lowest PLERSL was recorded by zero fertilization. As the amount of fertilizer climbed to the optimum level, all of the intercrops in the current study had higher PLERSL. The results of the present are consistent with the results of Holland and Brummer [40] who reported better resource-use efficiency of intercrops linked to better growth conditions. Crop mixes have been shown to maximize resource usage efficiency under both marginal and better growth circumstances [41, 42].

3.4. Profitability of Sweet Lupine in Bread Wheat-Sweet Lupine Intercropping Systems. It is crucial to assess the impact of fertilizer rates of sweet lupine in bread wheat-sweet lupine intercropping on smallholder farm earnings in disadvantaged areas undergoing ecological degradation [43]. According to a partial budget analysis (Table 4), the highest net return (NR) and marginal rate of return (MRR) of sweet lupine were obtained from 50% NP and 125% NP fertilizer levels of sweet lupine in bread wheat-sweet lupine intercropping systems, respectively, across the three labor cost to legume price ratios. Under the additively designed intercropping system, investing one Ethiopian Birr (ETB) in 50% NP of sweet lupine on average (the three labor costs) recovered with additional profit of 7.667 ETB, while 125% NP of sweet lupine in bread wheat-sweet lupine 4.537 ETB of extra profit. As a result, the maximum MRR was obtained from 50% NP of sweet lupine, which could be attributable to the sweet lupine's better productivity combined with lower labor expenses. This NP fertilizer rate, in general, provides for increased land utilization and economic benefits. The MRR in the treatments 125% NP and 50% NP in bread wheat-sweet lupine intercropping was greater than 100% throughout all the three labor cost to price ratios, which is acceptable as indicated by CIMMYT [32]. The MRR of sweet lupine in bread wheat-sweet lupine intercropping is generally reduced as the labor cost to sweet lupine price ratio increased in the present study. As indicated in Table 5, when the labor cost to price ratio of sweet lupine increased from CPR1 to CPR2, the MRR of the treatment 50% NP was reduced by 18.5 in bread wheat-sweet lupine intercropping systems. Based on the present study, the 50% NP and 125% fertilizer levels of sweet lupine in bread wheat-sweet lupine intercropping systems are economical while the use of the other rates is not economical (cost-effective) in the research areas. As can be seen, 50 percent NP is cost-effective; the amount of fertilizer used was decreased by half when compared to the suggested sole crop treatment. When compared to typical nonintercropped crop stands, nutrient utilization efficiency can be improved and fertilizer requirements of the main crops can be reduced [20, 21]. This finding also revealed that using fertilizers wisely in cereal-legume could produce profitable total yields per unit of land area. Intercropping corn and soybeans yielded similar outcomes [44].

4. Conclusion

Different NP fertilizer rates had a significant effect on yield attribute and yield of sweet lupine in bread wheat-sweet lupine at a 2 : 1 row ratio at Adet and Debre Tabor. At the Adet site, the highest grain yields of sweet lupine were achieved at 125% NP (0.51 $t\cdot ha^{-1}$) and 150% NP (0.52 $t\cdot ha^{-1}$) fertilizer levels of sweet lupine, followed by 100% NP (0.43 $t\cdot ha^{-1}$) and 50% NP (0.35 $t\cdot ha^{-1}$) fertilizer levels of sweet lupine in bread wheat-sweet lupine additive design intercropping system. Similarly, the highest grain yield at Debre Tabor was achieved by 125% NP (2.07 $t{\cdot}ha^{-1}$) fertilizer level of sweet lupine followed by 150% NP (1.89 $t{\cdot}ha^{-1}$), 100% NP (1.71 $t{\cdot}ha^{-1}$), and 50% NP (1.70 $t{\cdot}ha^{-1}$) fertilizer levels of sweet lupine in bread wheat-sweet lupine intercropping system. The partial land equivalent ratio of sweet lupine in the bread wheat-sweet lupine intercropping system ranged from 0.18 to 0.32 and 0.52 to 0.79 at Adet and Debre Tabor, respectively. Investing one Ethiopian Birr on 50% NP fertilizer of sweet lupine under average cost price ratio in bread wheat-lupine intercropping can help to earn an additional profit of 7.667 ETB. On the other hand, investing one Ethiopian Birr on 125% NP fertilizer of sweet lupine under averaged cost price ratio in bread wheat-lupine intercropping can help to earn an additional profit of 4.537 ETB. As it recorded the highest MMR, application of 50% NP fertilizer level can be recommended for the production of sweet lupine in bread wheat-sweet lupine under additive design intercropping system in Adet and Debre Tabor areas and areas with similar agroecology.

Data Availability

On reasonable request, the corresponding author, Birhanu Bayeh, will provide the data that support the findings of this study.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

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