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Influence of small cereal intercropping and additive series of seed proportion on the yield and yield component of lupine *(Lupinus Spp.)* in north western Ethiopia

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Abstract: Small cereals as a main crop and lupine as a minor crop are food crops often traditionally grown in association in North Western Ethiopia. The experiment was conducted on intercropping of lupine *(Lupinus albus L.)* with wheat *(Triticum aestivum)*, barley *(Hordeum vulgar)* and finger millet *(Eleusine coracana)* in 2009 at Adet Agricultural research station. The treatments were sole wheat at a seed rate of 175 kg/ ha, sole barley at a seed rate of 125 kg/ ha, sole finger millet at a seed rate of 30 kg/ ha, sole lupine at a seed rate of 90 kg/ ha, and an additive series of 25, 50 and 75 % of the sole lupine seed rate combined with the full cereal seed rate to determine the effect of small cereal intercropping in additive series on the yield and yield component of lupine. The experimental design was a completely randomized block with nine intercropping and four sole cropping systems in three replications. Lupine was planted in rows after establishment of main crops. SAS software's were used to compute the analysis of variance. Maximum lupine seed proportion was superior to the lowest when intercropped with wheat and finger millet. The lowest population density resulted in reduced agronomic attributes of lupine. Intercropping higher proportion of lupine with wheat and finger millet did help much in increasing grain yield and biomass yield of lupine without affecting cereal crop yield. However, nearly complete dominance of barley over lupine at all seeding ratios leads to absolute reduction in grain yield. The lupine-finger millet mixture at the 50:100 and 75:100 seeding ratio and lupine-wheat mixture at the 75:100 seeding ratio had a higher yield advantage of intercropping for exploiting the resources of the environment compared with the other intercropping systems.

Keywords: Intercropping, Wheat, Barely, Finger Millet, Lupine, Seeding Ratio

1. Introduction

Intercropping is the cropping system involving the growing of two or more crops in the same piece of land at the same time or relayed which could compute for growth resources for certain growth period. It provides valuable ecosystem services such as improved pest control (Mitchell et al., 2002), increased resource use efficiency (Hauggaard-Nielsen et al., 2001) in crop livestock mixed farming system. However, in many parts of Ethiopia, farmers traditionally harvest mainly once in a year on sole crop basis even in high rain fall areas. Moreover, in the past much research efforts have been directed towards improving technology for sole cropping. Such traditional farming did not insure the production of adequate food for a family (Nigusie, 1994). Different crops are grown traditionally in mixtures by small farmers to satisfy dietary needs, spread the period of peak demand for labor and minimize the risk associated with climate conditions (Tilahun eta al, 2012).

Intercropping cereal with a legume, however, is relatively the most common in most parts of the country. Indeed, the traditional objective has been to produce a full yield of cereal (as much as with a sole crop) while the associated legume yield is considered as additional yield (Tilahun eta al, 2012)

Lupine (Lupinus Spp.) is one of the major highland food legumes grown in Ethiopia. It is traditionally gown as intercrop with cereals and oil crops by low input farmers and is restricted to low-income classes, to times of drought (Jansen, 2006). Finger millet, wheat, and barley are the third, fourth and fifth stable cereal crops grown in west Gojam, respectively (CSA, 2007). Farmers grow it as traditional undefined additive system of intercropping in which lupine used as minor crop and cereals as major crop. They grow it for the strategies to overcome the shortage of arable land and attribute several crops for diversification of crop products and for maintenance and improvement of soil fertility (Allege and Steven, 1987).

Moreover, lupine normally has greater growth duration than cereals, so that when grown together at the same time, cereals utilize resources earlier than lupine. Another possible explanation for such intercrop yield advantage is that the tape root system of lupine could exploit water and nutrients from deeper soil layers than cereals (Jansen, 2006). Therefore, this cropping system may help improve productivity of low external input farming or scarce in natural resources, unreliable rain fall and poor soil fertility.

However, management of cereal intercropped with lupine to maximize their complementarity and to minimize competition between them follows simple natural principles, and its practice is limited only by the imagination of farmers. Therefore, the objective of this paper was to determine effect of small cereal intercropping in additive series on the yield and yield component of lupine (Lupinus Spp.)

2. Materials and Methods

2.1. Description of the Study Area

The study was conducted in the 2009 rain fed cropping season at Adet Agricultural Research station (AARC), North Western Ethiopia. It is located between 11°17' N latitude and 37°43′ E longitude with an altitude of 2240 m.a.s.l (AARC, 2002). According to Gonder soil testing laboratory center (2009), the soil characteristics of experiment site were clay as shown Table 1.The study area receives a uni-modal rainfall which extends early June to late September with regard to its monthly distribution June, July and August are the three important months with high rain fall and more or less uniform spatial distribution (Aleligne and Steven, 1987). According to Adet Metrological station (2009), the total annual rainfall during the experimental growing season was 975.3 mm which is less than the 23 year average total annual rainfall (1253.4 mm) (Figure 1). The mean monthly minimum and maximum temperatures during the growing season were 11 ^{0}c and 27.2 ^{0}c which is greater than the 23 year average mean monthly minimum (9.1 ^{0}c) and maximum (25.7 ^{0}c) temperatures (Figure 2).

Table 1. *Physico-chemical properties of the soil.*

Chemical soil properties		Mechanical properties	
PH	6.06	Sand (%)	28.00
OC (%)	2.47	Clay (%)	46.72
Total N (%)	0.18	Silt (%)	25.28
Av.P (ppm)	1.98	Class	clay
CEC	37.97		

Notes: CEC: Cation exchange capacity measured in cmol (+)/kg soil (NHAc), Av.P: Available phosphors in ppm and OC: organic carbon

2.2. Field Experimental Design

Plots were laid out in randomized complete block design (RCBD) with three replications. Spacing between plots and replications were 0.5 and 1 m, respectively. There were nine intercropping and four sole cropping systems in additive series in the experiment (Table 2). The plot size was 12m^2 (2m*6m). Sole lupine was common to all lupine-cereal combinations for comparison purpose.

2.3. Sowing Method and Management Practices

The experiment was conducted in rain fed season. Pure stands of lupine, wheat, barley and finger millet as well as nine lupine-cereal mixtures in three seeding ratios in additive series (25 %, 50 % and 75 % of recommended lupine seed rate with full cereal seed rates) were planted. Sole cropping of lupine, wheat, barley and finger millet were planted at a recommended seeding rate of 90, 175, 125 and 30 kg/ha, respectively. In sole cropping, lupine was planted in an inter-row space of 30cm; and wheat, barley and finger millet were broadcasted. In the intercropping system, first lupine row was established in the inter-row spacing of 120, 66 and 35 cm for the 25 %, 50 % and 75 % seed proportion, respectively, and full cereal components were broadcasted. Lupine was planted after establishments of cereal crops. For all intercropping systems space between lupine plants were 5 cm.

All plots were received a basal application of Diammonium phosphate (DAP) at the rate of 100 kg/ha at planting. For cereal components, 100 kg/ha Urea was applied except the sole lupine treatment assuming the lupine was benefit from self-fixed nitrogen. One third basal and two third top-dressed application of UREA were applied during planting time and at tillering stage of sole and intercropped cereals, respectively.

2.4. Data Collected

Agronomic attributes of lupine includes plant height (cm), number of branches, and number of pods per plant, number of seeds per pod, grain and biomass yield (kg/ha), harvest index (%) and thousand Seed weight (gram). Moreover, to determine the competitive ability of the component crops partial land equivalent ratio was conducted using the formula developed by de Wit (1960). To find more realistic comparison of the yield advantage of intercropping over monocropping in terms of time taken by component crops in the intercropping systems Area time equivalent ratio (ATER) was calculated by formula developed by Heibsch (1980).

2.5. Data Analysis

Data were statistically subjected to analysis of variance (ANOVA) using JMP-5 (SAS, 2002). Combined analysis of variance was performed over the three lupine-cereal combinations to determine yield and yield component of lupine, partial land and Area time equivalent ratio (ATER). In all the comparisons, the level of significance was set at α

= 0.05. Mean comparison for the treatments were computed using each pair Tukey-HSD test for parameters found to be significantly different at a given level of significant

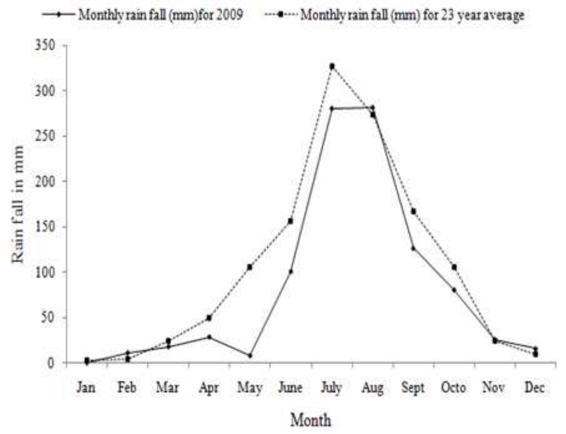

Figure 1. Mean monthly rainfall (mm) of the study area for 23 year average and 2009 cropping season.

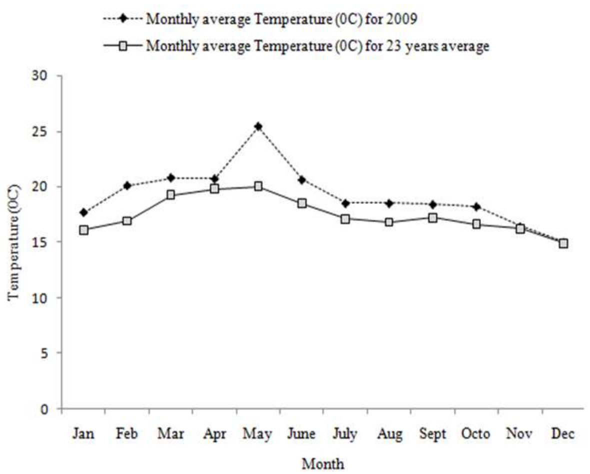

Figure 2. Mean maximum and minimum air temperature (Tc^0) of the study area for 23 year average and 2009 cropping season.

Table 2. Additive series of component crop production (Treatments)

Number	Crop species	Cereal Proportion (%)	Lupine (%)	Total population (%)
1	wheat	100	0	100
2	wheat	100	25	125
3	wheat	100	50	150
4	wheat	100	75	175
5	Barley	100	0	100
6	Barley	100	25	125
7	Barley	100	50	150
8	Barley	100	75	175
9	Barley	100	0	100
10	Finger millet	100	25	125
11	Finger millet	100	50	150
12	Finger millet	100	75	175
13	Lupine	0	100	100

3. Results and Discussion

3.1. Lupine Growth and Yield Components

3.1.1. Plant Height (cm)

Plant height appeared to be significantly (P<0.01) affected due to differences in seed ratio, associated crop types and cropping system. Though, sole lupine showed the highest plant height than the other seeding ratios, plant height increases from 25:100 (101.17 cm) to 75:100(106.89 cm) seeding ratios in lupine-cereal combinations. The study revealed that the overall highest mean plant height (cm) was recorded in sole lupine (133.88 cm) but statistically on par with lupine-finger millet association at 75:100 (133.63 cm) seeding ratios probably because of the presence of intra-specific competition particularly struggle for light in the former cropping system and presence of both intra-specific competition in the highest minor crop proportion and inter-specific competition between the component species in the latter cropping system (Table 3). The overall shortest plant height was recorded in lupine-barley intercropping systems at 75:100 seeding ratio (60.43 cm) but, it was not significantly differ from the other seeding ratios of the same combination. The reason might be due to the fact that barley causes nearly complete dominance of growth resources over lupine in all seeding ratios in the early stage of the minor crop. The other possible reason could be shading and lodging effect of barley over lupine. In lupine-finger millet (133.63 cm) and lupine-wheat (126.6 cm) combinations the highest plant height was recorded at the highest seeding ratios (Table 3). However, lupine-finger millet combination (128.97 cm) showed higher plant height than lupine-wheat (122.49) and lupine-barley (60.49 cm) combinations. Moreover, except lupine-barley combinations at all seeding ratios, as the companion crop proportion increases in each combination plant height had favoured to grow (Table 3). This agrees with the results obtained by Muoneke and Asiegbu (1997) in maize-okra mixture that high population densities induced higher plant height.

3.1.2. Branch Per plant

Results of the present study also showed that crop types, seed ratios and cropping systems were significant effect (P<0.01) on branch per plant, pod/plant and seed/pod (Table 3). Highest branch per plant was recorded in sole cropped (5.48) than intercropped seeding ratios (3-4.31). This result was in agreement with Rahman et al. (2008), who reported that branch per plant were maximum and minimum in sole and intercropped plants, respectively in mustard–lentil intercropping system. However, the experiment revealed that as seeding ratios increases branch per plant also increases (Table 3). With regarding lupine-cereal combination, lupine-finger millet (5.37) combination showed higher branch per plant as compared to other combinations (Table 3). Thus, the overall highest mean branch per plant was recorded in lupine-finger millet intercropping at 75:100 seeding ratio (5.67), but it was statistically on par with lupine pure stand (5.48), while the overall lowest mean branch per plant was recorded in lupine-barley intercropping at 75:100 (2.61) seeding ratio but statistically on par with the other seeding ratios of the same combination (Table 3). In lupine-wheat combination the highest branch per plant was recorded at the highest seeding ratio (75:100) (4.64). Except lupine-barley combinations, there was a general increase in branch per plant as the companion crop proportion increases in the case of lupine-wheat and lupine-finger millet combinations. This might be due to the fact that comparatively less tillering ability, slow and long growth period of wheat in general and finger millet in particular causes slow uptake of growth resources as compared to barley. However, this positive effect was more pronounced in lupine-finger millet combination (Table 3).

3.1.3. Pod per Plant

Among the cropping systems, the overall highest lupine pod/plant were remarkably observed in sole lupine cropping system (40.25) as compared to intercropped with cereals in all seeding ratios(28-31) (Table 3). But, it was statistically on par from lupine-finger millet at 75:100 (39.61) seeding ratio. Reduction in number of pods due to intercropping was also reported by Galal et al. (1979), who intercropped soybean in maize. The combined lowest pod/plant (16-16.9) and seed/pod (2.24-2.36) were obtained from all seeding ratios of lupine-barley intercropping system which were statistically on par with each other (Table 3). All seeding ratios in lupine-wheat combinations gave statistically different pod/plant in which the highest pod/plant was recorded at the highest seeding ratios (37.69). The same is true for lupine-finger millet combination (Table 3). However, each lupine-finger millet, lupine-wheat and lupine-barley combinations showed significantly different pod/plant in which the former combination (36.5) showed the highest pod/plant as compared to the others. As the companion seeding ratios increases on each combination, its pod/plant also increases (Table 3). However, this result was inconsistent with Mcgibbon and Waltkin (1980), who reported that high plant population (lupine) caused a reduction in lupine pod set and consequently in seed yield.

The overall highest pod/plant (40.25) and seed/pod (6) in sole lupine might be due to the absence of other species and presence of intra-specific competition between lupine crops which favoured efficient utilization of growth resources. This corroborate with the results of Ghosh (2004), who stated pod yield of groundnut were lower in groundnut-cereal (maize, sorghum, and pearl millet) intercropped than in monoculture. In general, the lowest agronomic attributes of lupine in lupine-barley combinations might be due to higher competitive advantage, shading and lodging effect of barley over lupine. This was consistent with Venkateswarlu (1984), who reported that a wrong choice of cereals and grain legumes causes a great risk of loss of yield and reduction in grain yield and quality. This illustrated by combining an early ripening crop like barley or pea, with a late ripening crop like wheat or faba bean was increase the risk considerably as the early crop can lose its grains while waiting for the late crop to ripen (Venkateswarlu, 1984).

3.1.4. Seed per Pod

The study indicated that the highest and the lowest seed/pod were recorded at sole lupine (6.08) and lupine-cereal combination at 25:100 seeding ratios (4.26) respectively. Intercropping lupine with finger mille (3.84) gave the highest seed per pod than with wheat and barley. The overall highest seed/pod was recorded in sole cropped (6.09) (Table 3). But, it was statistically on par from lupine-finger millet at all seeding ratios and lupine-wheat combinations at 75:100 seeding ratios (5.74). The overall lowest seed/pod was recorded in all lupine-barely combinations at all seeding ratios (Table 3). The latter cropping system was disagreement with Mandal et al (2010), who reported that number of seeds per pod for mungbean was more with rice-mungbean combination as compared to sole mungbean, though pod/plant increases in the reverse situation.

Generally, results of the present study showed that intercropping lupine with finger millet had less effect on growth and yield component of lupine as compared to wheat and barley. However, intercropping barley with lupine had adverse effect on those agronomic parameters as compared to wheat. This is mainly due to wheat in general barley in particular having fast growth and more extensive root system, particularly a larger mass of fine roots and nutrient utilize characteristics (Carr et al., 2004) (high competitive advantage) as compared to legumes. According to the results of the present study, except lupine-barley intercropping systems, as the companion crop seeding ratios increases on the constant full cereal seed rate, lupine growth and yield components also increases (Table 3). This situation probably due to intra-specific competition between lupine crops at higher proportion causes efficient utilization of growth resources and hence, hastens lupine growth and yield component parameters.

3.1.5. Thousand Seed Weight (Gram)

Thousand seed weight was significantly affected by the cropping ratios ($P<0.01$) and associated crop types ($P<0.05$) (Table 3). Sole lupine (336.67 gram) showed lower TSW than lupine-cereal combination at 25:100 seeding ratio (398.36 gram). In contrast to the other yield components, the highest TSW was recorded in lupine-barley combinations at 25:100 (407 gram) seeding ratio but statistically on par from the other seeding ratios in the same combination and lupine-wheat combination at all seeding ratios (Table 3). Lupine in lupine-barley followed by lupine-wheat combinations was slow and less vegetative growth showed higher mean seed weight. The highest TSW of lupine in lupine-barely could be due to large seed size in a very low plant population which could be attributed to large accumulation of assimilate due to long maturity period. Similarly, the highest TSW of lupine in lupine-wheat and lupine-barley combinations as compared to lupine-finger millet combinations might be attributed to early maturity of wheat and barley leaves the resources for long maturity of lupine to continue growth (Table 3).

The lowest TSW was recorded in sole cropped (336.56 gram) followed by lupine-finger millet combination at 75:100 (365.33 gram) and 50:100 (379.67 gram) seeding ratios. This could be due to higher intra-specific competition causes reduction of assimilates for the former cropping system and the late maturity of finger millet that caused little difference in plant growth result in higher demand of resources at the same periods causes reduction of assimilates and might have resulted to poor seed filling of lupine. This result was corroborated with the findings of Bismillah and Khaliq (2004), who reported that sole cropped soybean showed lower thousand seed weight as compared to soybean-cotton, based intercropping systems. However, it was disagreement with the report obtained by Mandal et al. (2010), who noted that thousand seed weight for mungbean was higher in pure stand crops as compared to intercropped with rice. Further increase in seeding ratios in each lupine-cereal combinations TSW of local lupine decreases, though, all seeding ratios had statistically on par with each other in lupine-wheat and lupine-barley combinations (Table 3).

Table 3. *Mean Effect of crop proportion and crop types on growth and yield components of lupine in lupine-cereal intercropping system at AARC, North Western Ethiopia in 2009.*

Treatment and statistics	PH (cm)	B/P	PO/P	SE/PO	TSW(gram)
Seeding ratios (Lupine: Cereal)					
25:100	101.17 c	3.97c	28.45 c	4.26c	398.36a
50:100	104.46bc	4.35 b	30.17 b	4.51bc	395.33a
75:100	106.89 b	4.31 b	31.18 b	4.68b	387.11a
Sole lupine	133.88 a	5.48a	40.25a	6.08a	336.67b
Lupine-Cereal combination					
Lupine-barely	78.84 c	3.46c	22.36 c	3.26 c	389.17a
Lupine-finger millet	130.20 a	5.37a	38.67 a	5.84 a	368.25ab
Lupine-wheat	125.76 b	4.75b	36.49 b	5.55 b	380.67b
Cropping system					
Sole lupine	133.88a	5.48a	40.25a	6.08a	336.67b
25 % Lupine+100 % wheat	119.76bc	4.42c	32.25c	4.84b	401.67a
50 % Lupine+100 % wheat	121.13c	4.63bc	35.79bc	5.50ab	400.00a
75 % Lupine+100 % wheat	126.60abc	4.64bc	37.69ab	5.74a	391.33a
25 % Lupine+100 % barely	60.46d	2.83b	16.00d	2.25c	407.00a
50 % Lupine+100 % barely	60.59d	2.92b	16.97d	2.37c	406.33a
75 % Lupine+100 % barely	60.43d	2.61b	16.22d	2.35c	406.67a
25 % Lupine+100 % f/millet	121.63c	4.83b	37.08ab	5.68a	393.33a
50 % Lupine+100 % f/millet	131.66ab	5.50a	37.75ab	5.65a	379.67ab
75 % Lupine+100 % f/millet	133.63a	5.67a	39.61a	5.93a	363.33ab
LSD (0.05)	5.24	0.29	1.84	0.38	28.81
CV (%)	2.82	3.44	16.60	4.58	4.90

Notes: Values (means) connected by different superscript letters are significantly ($P<0.05$) different within columns according to Tukey- HSD tests. PH (cm): Plant height in cm; B/P: Branch per plant; PO/PL: Pod per plant; SE/PO: Seed per pod and TSW: Thousand seed weight in gram, respectively

3.2. Lupine Biomass, Grain Yield and Harvest Index

3.2.1. Grain Yield

The overall yield reduction of lupine yield below the optimum in all cropping systems was observed probably due to poor competitor of quick growing cereal crops, moisture deficiency during the reproductive period (Figure 1) and low phosphors availability (Table 1). Jansen (2006) reported that lupine is drought-tolerant due to their deep roots, but is sensitive to moisture during the reproductive period and P deficiency.

Nevertheless, the present study indicated that seeding ratios, crop types and cropping systems significantly affect grain yield of lupine ($P<0.01$). Though, different seeding ratios of lupine were planted, a substantial reduction in grain yield of associated lupine crop was observed as compared to lupine alone perhaps due to poor competitor of quick growing cereal crops. The reason also confirmed by Jansen, (2006), who stated lupine prefers disturbed sites and poor soils, where there is less competition from other species. It was performed better when grown as a sole crop (2852 kg/ha) than when grown in a mixture (Table 4). Yield reduction could be attributed to inter-specific competition for space, growth resources between the components species and genetical difference between cereals which, in turn made the reduction of plant population, number of branches/plant, pods/plant, seeds/pod, and other yield attributes that sufficiently reduced yields in all crop combinations. This corroborates the findings of Sheri et al. (2008), who reported a yield depression of intercropped lupine and faba bean when intercropped with higher seed rate of wheat. Similarly, Ofori and Stern (1987) reported a yield depression of cowpea as a result of intercropping with maize.

Although, there was a general reduction in the yield of lupine as a result of intercropping, highest grain yield among the combination was recorded in lupine-finger millet intercropping (1749 kg/ha) followed by lupine-wheat (1407 kg/ha) intercropping systems as compared to lupine-barley (757 kg/ha) combination (Table 4). Thus, combined mean highest grain yield was obtained from lupine-finger millet intercropping at 75:100 seeding ratio (1812 kg/ha), whilst the lowest grain yield was recorded in lupine-barley combinations at 25:100 seeding ratio (50 kg/ha). However, lupine-barley combinations at all seeding ratios were statistically on par with each other.

However, absolute lupine yield reduction was observed in lupine-barley intercropping at all seeding ratios (<100 kg/ha). In addition to the other reasons, it might be due to shading and lodging effect of barley. This result was in agreement with Jones and McCown (1983), who reported that Caribbean stylo (Stylosanthes hamata cv. Verano), produced little seed in an intercrop with maize due to its failure to flower in the shade of a full maize canopy. The former reason has also supported by Challa and Bakker (1998), who reported that growth and yield of crops are related to the amount of solar radiation received during the growing period. Higher loss in lupine yield due to barely intercropped were also in agreement with Knudsen et al. (2001), who reported that lupine-barely intercrops did not show intercropping advantage. To sum up, except lupine-barley intercropping, higher lupine yield was obtained when high proportion of lupine was intercropped with full finger millet (1812 kg/ha) and wheat (1558 kg/ha) seed rates as compared to low proportion of lupine was intercropped with full finger millet (1459 kg/ha) and wheat (785 kg/ha) (Table 4). These findings are also parallel to those of ATER (Table 5). The main characteristics defining the differences in yield of lupine were mainly effect of cereals and seed proportion. In descending order, barley, wheat and finger millet were taller and grew faster during the early growing period. Lupine was suppressed during initial stage but later except in lupine-barley combinations it grew taller and took over wheat and finger millet utilizing the remaining growth resources during the final part of the growing season. This difference in plant growth might have resulted in demand of resources at different periods allowing sharing of resources.

3.2.2. Biomass Yield

Lupine biomass yield was significantly affected ($P<0.01$) by seeding ratios, crop types and cropping systems (Table 4). Highest lupine seeding ratio intercropped with full cereal seed rate gave the highest biomass yield (Table 4). The combined mean highest biomass yield was recorded in sole cropping (12250 kg/ha) as compared to all lupine-cereal cropping systems. The combined lowest biomass yield was recorded in lupine-barley intercropping at 25:10 (333 kg/ha) but statistically on par from the other seeding ratio of the same combination (Table 4). This result was corroborated with Bismillah and Khaliq (2004), who reported that sole cropped soybean showed higher biological and seed yield as compared to soybean-cotton based intercropping systems. The highest biomass yield in lupine-wheat (6667 kg/ha), lupine-barley (1250 kg/ha) and lupine-finger millet (10667 kg/ha) was recorded at 75:100 seeding ratio as compared to the other respective seeding ratios. This means, the biomass yield increased in line with cropping ratios in each combinations (Table 4).

Comparatively, biomass production was very low in lupine-barley at all seeding ratios than lupine-finger millet and lupine-wheat combinations. Similarly, biomass production of lupine was lower in lupine-wheat than lupine-finger millet intercropping (Table 4). Biomass production of lupine was influenced by the duration of the growing season of the component crops, the rate of growth, cropping ratios and crop types of the component crops. Barley in particular wheat in general showed fast growth characteristics than finger millet, which reduces more the biomass of local lupine. The results revealed that in lupine-barley combinations the new intervention cropping ratios (50:100 and 75:100 seeding ratios) were not significantly different from the farmers' cropping ratios of ≤ 25:100 seeding ratios based on optimum seed rate. However, in lupine-wheat and lupine-finger millet combinations, the farmers' cropping ratios was significantly different from the new intervention cropping ratios (Table 4)

Thus, the highest seed rate of lupine used in the study in lupine-barley combinations did not help much to increase the grain and biomass yield of lupine but increase the grain and biomass yield of the same crop in lupine-wheat and lupine-finger millet combinations. The latter two intercropping systems disagree with Prasad and Brook (2005), who reported that biomass and grain yield of soybean were least at greater density and greatest at the lowest density, whilst biomass and grain yield of maize increased. In general, the above findings on grain yield and biomass yield suggest that difference in seeding ratios and crop types of the component crops could affect yield and yield attributes of lupine.

3.2.3. Harvest Index (HI)

The harvest index of lupine was significantly influenced ($P<0.01$) by seeding ratios, crop types and cropping system (Table 4). Sole cropping showed the highest harvest index (23.73 %) as compared to lupine-cereal combination at 50:100 seeding ratios. However, the latter seeding ratio did not significantly differ from the remaining seeding ratios (Table 4). Lupine-wheat combination gave the highest harvest index (20.18 %) were as lupine-barley combination gave the lowest harvest index (14.28 %).

The combined mean highest harvest index was recorded in sole cropped lupine (23.73 %) which was not statistically differed from lupine-wheat combinations at 75:100 seeding ratios (23.46 %) as compared to the other crop combinations in different seeding ratios (Table 4). This is mainly due to high grain yield and low biomass yield of lupine in the respective cropping system, since; HI is a derived parameter of economic yield (grain yield) and biomass yield. This result was corroborated with Bismillah and Khaliq (2004), who reported that sole cropped soybean showed higher HI as compared to soybean-cotton, based intercropping system.

The combined mean lowest harvest index was recorded in lupine-barley combination at 75:100 seeding ratios (5.82 %) followed by lupine-finger millet combination at 25:100 (11.76%) and lupine-barley combination at 50:100 (11.73%) seeding ratios. In intercropping, low harvest index could also be attributed to low plant population. The highest harvest index in lupine-wheat, lupine-barley and lupine-finger millet was recorded at 75:100 (23.46 %), 25:100 (15.8 %) and 50:100 (18.56 %) seeding ratios, respectively (Table 4). Except lupine-barley combinations, as the companion seeding ratio increased in each lupine-cereal intercropping, HI also increased.

In general, highest harvest index of lupine was obtained from the highest grain yield and the lowest biomass yield in sole cropped, lupine-wheat combination at the highest cropping ratios and in lupine-finger millet combinations at 50:100 seeding ratio, whilst lowest harvest index value was obtained from the lowest grain and lowest biomass yield in the highest cropping ratios in lupine-barley combinations (Table 4).

3.3. Partial Land Equivalent Ratio and Area Time Equivalent Ratio (ATER)

3.3.1. Partial Land Equivalent Ratio

The present experiment showed that except partial LER of wheat in lupine-wheat combinations, partial LER of barley and finger millet in lupine-barley and lupine-finger millet combinations and partial LER of lupine in all lupine-cereal combinations at all seeding ratios (<1.00) were lower than sole cropped of each crop species (1.00) (Table 5). Within the intercropping, the combined highest partial LER of lupine was recorded in lupine-finger millet combinations at 75:100 seeding ratio (0.63528), while the lowest was recorded in lupine-barley combination at 25:100 seeding ratios (<0.5) but statistically on par with the other seeding ratios of the same combinations (Table 5). A comparison of the data presented in Table 5 also show that partial LER of lupine increased as its proportion increased in all lupine-cereal combinations probably due to efficient utilization of nutrients created by intra-specific competition.

This more explained in which the partial LER of lupine was higher than 0.5 only in lupine-finger millet intercropping at 75:100 (0.635) and 50:100 (0.512) seeding ratios and in lupine-wheat intercropping at 75:100 (0.546) seeding ratios while, in most cases, partial LER of cereals at all seeding ratio was higher than 0.5 which indicates that there was an advantage for cereals and a disadvantage for lupine in these intercropping systems. Thus, the results ascertain that cereals were the major contributor to the mixture yield which also confirms farmers' justification of growing the lupine as an intercrop. This was in agreement with Chen et al. (2004), who reported that partial LER for cowpea was lower than 0.5 which indicated advantage for cotton in intercropping. While, partial LER for sorghum was more than 0.5, it indicated disadvantage for cotton in intercropping.

Table 4. *Mean effect of crop proportion and crop types on grain and biomass yield, and harvest index of lupine in lupine-cereal intercropping systems at AARC, North Western Ethiopia in 2009.*

Treatment and statistics	Grain yield (kg/ha)	Biomass yield (kg/ha)	Harvest -index (%)
Seeding ratios (Lupine: Cereal)			
25:100	459d	3432c	14.92b
50:100	768c	4444c	15.53b
75:100	1146b	6194b	15.41b
Sole lupine	2852a	12250a	23.76a
Lupine-Cereal combination			
Lupine-barley	757c	3597c	14.28b
Lupine-finger millet	1749a	9562a	17.76ab
Lupine-wheat	1413b	6581b	20.18a
Cropping system			
Sole lupine	2852a	12250a	23.76a
25 % Lupine+100 % wheat	456e	3667ef	13.90abc
50 % Lupine+100 % wheat	785de	4861de	16.31abc
75 % Lupine+100 % wheat	1558ef	6667cd	23.46a
25 % Lupine+100 % barley	50f	333f	15.80abc
50 % Lupine+100 % barley	59f	556f	11.73bc
75 % Lupine+100 % barley	69f	1250f	5.82c
25 % Lupine+100 % f/millet	872d	7417cd	11.76bc
50 % Lupine+100 % f/millet	1459c	7916bc	18.56ab
75 % Lupine+100 % f/millet	1812b	10667ab	16.96ab
LSD (0.05)	198	1723	6.29
CV (%)	10.82	16.21	26.00

Notes: Values (means) connected by different superscript letters are significantly (P<0.05) different within columns according to Tukey- HSD tests. F/millet: finger millet

Table 1. *Partial land equivalent ratios and Area time equivalent ratios of grain yield in lupine-cereal intercrops at three seeding ratios (additive series) at AARC, North Western Ethiopia in 2009.*

Treatments and statistics	Partial LER		ATER
	Lupine	Cereal	
Sole lupine	1.000a	-	1.000ab
Sole wheat	-	0.990ab	0.990b
Sole barley	-	1.000ab	1.000ab
Sole finger millet	-	1.000ab	1.000ab
25 % Lupine+100 % wheat	0.160e	1.174a	1.049ab
50 % Lupine+100 % wheat	0.275e	1.038ab	1.075ab
75 % Lupine+100 % wheat	0.546c	0.944ab	1.313a
25 % Lupine+100 % barley	0.017f	0.748b	0.391c
50 % Lupine+100 % barley	0.021f	0.765ab	0.402c
75 % Lupine+100 % barley	0.024f	0.868ab	0.455c
25 % Lupine+100 % f/millet	0.306d	0.791ab	1.111ab
50 % Lupine+100 % f/millet	0.512c	0.813ab	1.378a
75 % Lupine+100 % f/millet	0.635b	0.659b	1.372a
LSD (0.05)	0.05	0.24	0.23
CV (%)	6.16	15.75	12.79

Notes: Values (means) connected by different superscript letters are significantly (P<0.05) different within columns according to Tukey- HSD tests. F/millet: finger millet

3.3.2. Area Time Equivalent Ratio (ATER)

ATER values showed an advantage of 37.87 % and 37.19 % in lupine-finger millet combination at 50:100 and 75:100 seeding ratios, respectively and 31.34 % in lupine-wheat at 75:100 seeding ratio followed by 11% in lupine-finger millet combination at 25:100 seeding ratios than the other mixtures and all sole cropped (Table 5). This could be due to the reason that intercropping systems can actually give more efficient total resource exploitation and greater overall production than sole crops (compatible intercrops) (Reddy et al., 1994), optimum mixture ratios and staggered planting arrangements particularly planting dates. Similarly, compared with corresponding sole crops, yield advantages have been recorded in many non-legume-legume intercropping systems, including groundnut-cereal fodders (Ghosh, 2004), barley-pea (Chen et al., 2004), and faba bean-barley (Trydemanknudsen et al., 2004), bean-wheat (Hauggaard-Nielsen et al., 2001).

Whereas, all lupine-barley intercropping showed values less than 1.00 and pure stands thus indicated the disadvantage. Lupine-barley intercropping resulted in 55-61 % disadvantage with maximum disadvantage at 25:100 seeding ratio (61 %) with similar response to the other seeding ratios. This was in agreement with Banik et al. (2000), who reported that intercropping reduced the yield of mustard-pea, mustard-lentil, and mustard-gram mixtures over sole-cropping. In other words the present experiment showed that the higher seeding ratio gave the highest yield advantage which was differ from what farmers currently used (≤25 % lupine seed rate with full cereal seed rate).

4. Conclusion

The present study demonstrated that lupine agronomic attributes were less affected when intercropped with finger millet than wheat and barley. Intercropping higher proportion of lupine with wheat and finger millet did help much in increasing grain yield and biomass yield of lupine without affecting main crop yield. However, nearly complete dominance of barley over lupine at all seeding ratios leads to absolute reduction in grain yield and ATER as compared to sole cropped. The lupine-finger millet mixture at the 50:100 and 75:100 seeding ratio and lupine-wheat mixture at the 75:100 seeding ratio had a higher yield advantage of intercropping for exploiting the resources of the environment compared with the other intercropping systems. This also indicated that the area planted to monocultures would need 37.78 %, 37.19 %, and 31.3 % more lands, respectively than the area planted to intercropping for the two crops to produce the same combined grain yield.

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