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Effect of lupine *(Lupinus* Spp.*)* intercropping and seed proportion on the yield and yield component of small cereals in North western Ethiopia

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Wheat, barley and finger millet as a major crop and lupine as a companion crop are food crops often traditionally grown in an intercropping in North Western Ethiopia. The experiment was conducted on intercropping of lupine (*Lupinus albus* L.) with wheat *(Triticum aestivum),* barely *(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/ h and 25, 50 and 75% of the sole lupine seed rate combined with each full cereal seed rate to determine the effect of lupine intercropping and seed proportion on the growth, yield and yield component; and lodging of wheat, barley and finger millet. The trial layout was a completely randomized block design with three replications. SAS software's were used to compute the analysis of variance. Increasing in lupine seed proportion in a mixture, delay in finger millet days to heading and maturity also significantly increased. The yield and yield component of most cereals were not significantly affected when they were intercropped with lupine in all seeding ratios except finger millet plant height, harvest index and wheat total biomass yield. Hence, growing cereals in association with lupine was not showed its yield reduction and the farmer's primary objective of maintaining a 'full' cereal yield was attained. Intercropping lupine with cereals gave physical support for cereals particularly in high lupine seed proportion. The combined yield advantage was greater than one in the cases of lupine-wheat followed by lupine-finger millet mixtures at all seeding ratios. Hence, two of the best combinations which were gave higher land use efficiency are the lupine-wheat mixture at the 75:100 seeding ratio (49.4%) followed by the lupine-finger millet mixtures at the 75:100 seeding ratio (29.4%).

Key words: Wheat, barley, finger millet, lupine, intercropping, seed proportion.

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. This farming practice

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is a popular crop production system used in subsistence tropical agriculture and is very common in the semi arid areas of Africa (Connolly et al*.,* 2001). It is also a cropping practice that possess the potential of providing valuable ecosystem services such as improved pest control (Mitchell et al*.*, 2002), increased resource use efficiency (Hauggaard-Nielsen et al*.,* 2001), lowered weed infestation levels (Liebman and Dyck ,1993) in crop livestock mixed farming system.

In many parts of Ethiopia, farmers traditionally harvest only 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 especially under conditions where average land holding is very small (Nigusei, 1994). In Ethiopia, 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. Thus, the most important intercrop mixtures used by farmers in Ethiopia can be grouped in to four broad categories: cereal-cereal; cereal-legume; tree-annual crop and legum-legum associations' (Yayeh et al*.*, 2014). Intercropping cereal with a legume, however, is relatively the most common in most parts of the country.

Cereals are the major food sources in Ethiopia and farmers regard the cereal as the major component of an intercrop (EIAR, 1992). 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 (Yayeh et al*.,* 2014).

Lupine *(Lupinus* Spp*.)* is one of the major highland food legumes grown in Ethiopia (Yayeh et al*.*, 2014). Its production is limited in North West Ethiopia and mainly used to prepare local drinks (Ali et al*.,* 2006). It is grown on an area of 25,526 ha with an annual average production and yield of 287, 17.3 t/ha and 1100 kg/ha (CSA, 2004), respectively. Out of this, 37% of the total land was cultivated by West Gojam. Farmers use intercropping different legumes with other crops as one of the strategies to overcome the shortage of arable land and attribute several crops for diversification of crop products, high productivity per unit area and for maintenance and improvement of soil fertility (Aleligne and Steven, 1987). Lune have been 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). They grow it as traditional additive system of intercropping in which lupine used as minor crop and cereals as major crop (Yayeh et al*.*, 2014).

The current trend in global agriculture is to search for highly productive, sustainable and environmentally friendly cropping systems (Crews and Peoples, 2004). One of the strategies to improve food security would be the inclusion of grain legumes either intercropped with cereal or in rotation with it. Farmers in West Gojam are seriously constrained by small farm size of 1.42 ha/household due to increase human population (CSA, 2007). Thus, intercropping lupine with cereals is cultivated to a greater extent than before because of its adaptability, stability and feasibility of production under low soil fertility status and biotic. It is also an annual legume, and non climbing growth habit and has high levels of protein (Jansen, 2006).

Moreover, the tape root system of lupine could exploit water and nutrients from deeper soil layers than cereals (Jansen, 2006). Jansen (2006) and Gardner and Boundy (1983) also point out wheat intercropped with lupine has access to a larger pool of Phosphors, Manganese and Nitrogen than sole-cropped wheat. Production cereals in intercrop with lupine could also provide a rotational yield response to main season crops (Petch and Smith, 1985). However, management of cereals intercropped with lupine follows simple natural principles, and its practice is limited only by the imagination of farmers. They used less than 25% lupine seed rate with full cereal seed rate (Yayeh et al*.,* 2014). No published studies have been made in research areas to improve the productivity of this kind of cropping system. As a result, the yield of cereal crops vary considerably among farmers and in most cases the yield advantage is unknown. Therefore, the objective of this paper was to estimate the effect of lupine and seeding proportion on major cereal crops in lupine-cereal intercropping systems.

MATERIALS AND METHODS

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 and 27.2°C which is greater than the 23 year average mean monthly minimum (9.1°C) and maximum (25.7°C) temperatures (Figure 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 in additive series (25, 50 and 75% of recommended lupine seed rate with full cereal seed rates) and four sole cropping systems (pure stands of lupine, wheat, barley and finger millet). The plot size was 12 m^2 (2*6 m). Sole lupine was common to all lupine-cereal combinations

Table 1. Physico-chemical properties of the soil at Adet research station.

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		

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

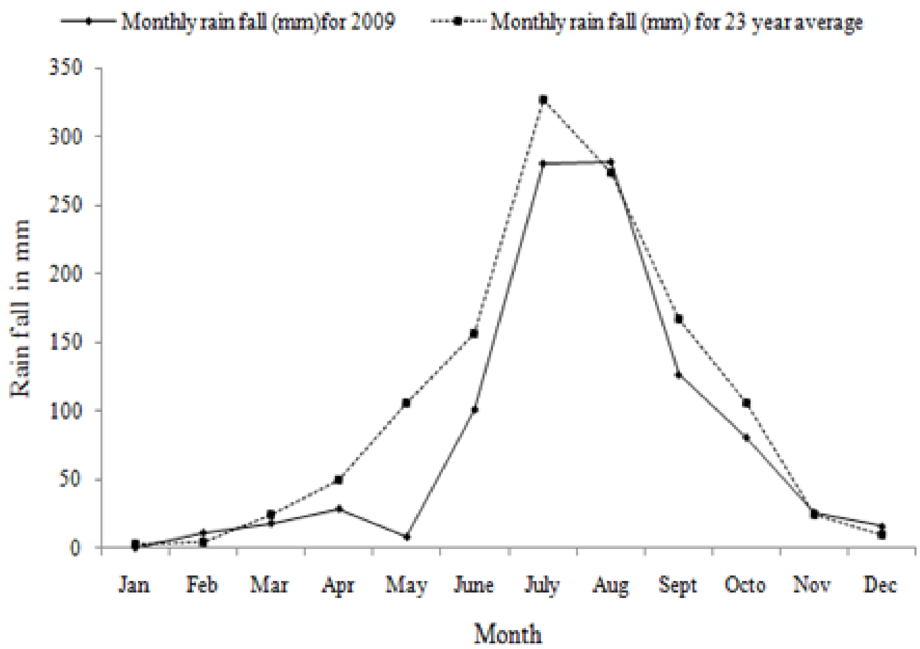

Figure 1. Mean monthly rainfall (mm) of the study area for 23 year average and 2009 cropping season.

for comparison purpose.

Sowing method and management practices

The experiment was conducted in rainfed season (2009). Additive series intercropping system was used which is cropping of the base crop/cereals at optimum level and the addition of a proportion of the minor crop/ lupine with the main crop being the one of primary importance because of economic or food production reasons in the area. 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 30 cm; 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.

Data collected

Agronomic attributes of cereals: Plant height in cm, spike length (cm) of barley and wheat and finger length (cm) of finger millet, seed per spike of barley and wheat, tiller per plant, finger per plant, stand cover per meter square, thousand seed weight, biomass and grain yield; and harvest index (%) and lodging index (%). Moreover, land use efficiency was also determined by land equivalent ratio (LER) which was calculated using the formula developed by Willey and Osiru (1972):

$$LER = (Y_{AB}/Y_{AA}) + (Y_{BA}/Y_{BB})$$

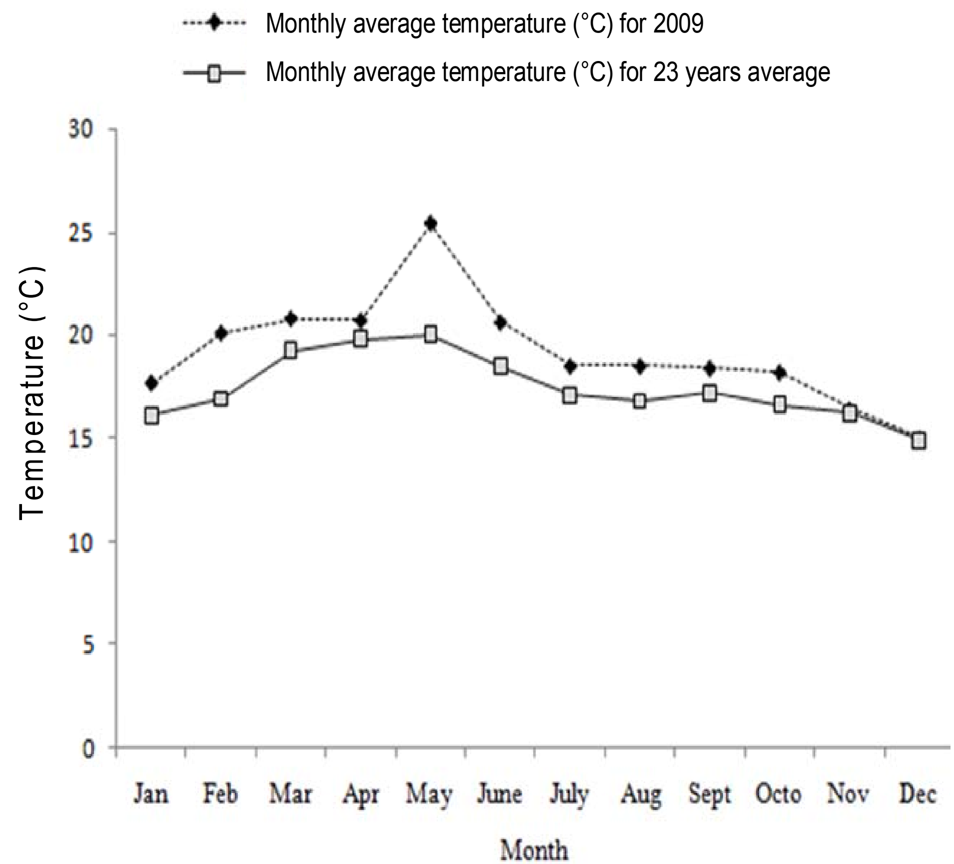

Figure 2. Mean maximum and minimum air temperature (T°C) of the study area for 23 year average and 2009 cropping season.

Y_{AB}= Yield of crop A when mixed with crop B
Y_{BA}= Yield of crop B when mixed with crop A
Y_{AA}= Yield from sole planted crop A
Y_{BB}= Yield from sole planted crop B

Lodging /index /percentage was proposed to be calculated using the formula developed by Caldicott and Nuttall (1979). Lodging scale was from 0 to 5 where, 0 mean no lodged plants and 5 mean plants completely lodged.

$$\text{Lodging Index} = \frac{\sum (\text{lodging score x their respective \% of area lodged})}{5}$$

Data analysis

Data were statistically subjected to analysis of variance (ANOVA) using JMP-5 (SAS, 2002). Separate Analysis of variance was performed over the three lupine-cereal combinations to determine yield and yield component of each cereal crops. However, combined analysis of variance was conducted over the three lupine-cereal combinations to determine land use efficiency using land equivalent ratio of each cropping system. In all the comparisons, the level of significance was set at $\alpha = 0.05$. Mean comparison for the treatments were computed using each pair Turkey-HSD test for parameters found to be significantly different at a given level of significant.

RESULTS AND DISCUSSION

Phenology

The influence of intercropped lupine crop proportion on cereal days to 50% heading and 50% maturity in lupine-cereal intercropping is presented in Table 2. The analysis of variance indicated that these treatments significantly influenced ($P<0.01$) only days to maturity of finger millet in the case of lupine-finger millet intercropping (Table 2). Days to maturity for sole finger millet were 158 as compared to 162 for 50:100 seeding ratio which took longer duration to maturity (Table 2). Result of this investigation also showed that increase in companion crop proportion in a mixture, delay in finger millet days to heading and maturity also significantly increased.

Intercropping of lupine with finger millet delays the days to maturity of finger millet as compared to sole finger millet perhaps due to competition for light in which the two crops were growing together for a long period of time. The second reason for delayed in maturity date of finger millet across increasing seeding ratio could also be attributed to as the minor crop proportion increases, the intra-specific competition between lupine stands hastens

Table 2. Effect of lupine-cereal intercrops on date of heading and maturity of cereals at Adet Agricultural research center, West Gojam in 2009.

Treatments and statistics	Mean	
	50 % DH	50 % DM
Lupine–wheat intercropping		
Sole wheat	62.00^a	128.33^a
25% Lupine+100% wheat	61.33^a	129.00^a
50% Lupine+100% wheat	61.67^a	128.33^a
75% Lupine+100% wheat	61.67^a	128.33^a
CV (%)	1.208	0.55
Lupine–Barely intercropping		
Sole barely	50.67^a	85.67^a
25% Lupine+100% barley	50.67^a	85.33^a
50% Lupine+100% barley	51.00^a	86.00^a
75% Lupine+100% barley	51.33^a	86.00^a
CV (%)	0.98	0.47
Lupine–Finger millet intercropping		
Sole finger millet	104.33^a	158.67^c
25% Lupine+100% f/millet	104.67^a	160.00^b
50% Lupine+100% f/millet	103.33^a	162.33^a
75% Lupine+100% f/millet	103.67^a	163.00^a
LSD (0.05)	-	0.23
CV (%)	2.60	0.25

Values (means) connected by different superscript letters are significantly (P<0.05) different within columns according to Tukey-HSD tests. DH: 50 % date of heading and DM: 50 % date of maturity. F/millet: finger millet.

efficient utilization of the growth resources thereby increases yield component parameters of lupine (Gabatshele et al., 2012).

The result also in parallel with the findings of Gabatshele et al. (2012), who found that Maize planted in Maize-cowpea intercropping, had longer flowering data as compared to maize planted in sole maize. Lupine growth causes high shading effect over the finger millet and then delayed maturity period. On the other hand, non significant differences (P>0.05) were observed to barley and wheat days to heading and days to maturity in intercropping in any change in companion crop proportion when compared to sole cropped (Table 2). This is probably because barley uses growth resources without lupine crop competition throughout all growth stages. Hence, barley has rapid and short growing period (85 days) as well as tillering ability and early germination (6 days). Barley dominates the minor crop (lupine) in all proportions in the system. Similarly, wheat had the second fast and short growing period (128 days) in lupine-wheat intercropping but much less than barley and used growth resources earlier than the minor crop (lupine) with a high competitive ability.

Growth and yield components

The plant height of finger millet was significantly affected by intercropped lupine proportion (P<0.05) in the case of lupine-finger millet intercropping system (Table 3). Maximum plant height was recorded at 75:100 seeding ratio (114.0 cm) due to struggle for light in such very dense stands while minimum plant height was observed in finger millet pure stand (102.7 cm) which did not differ statistically from 25:100 seeding ratio probably due to lower inter-specific competition for growth resources especially light between the component species (Table 3). However, finger length (cm), number of finger per plant and tiller per plant of finger millet were not significantly (P>0.05) affected by studied treatments (Table 3).Likewise, the plant height (cm), spike length (cm), seed per spike, tiller per plant, population per m^2 and 1000-seed weight (gram) of barley and wheat were not significantly affected by the same treatments (P>0.05) when each crop was intercropped with lupine in three seeding ratios (Table 3).

Intercropping lupine with barley and wheat in three seeding ratios did not show different response as compared to respective sole cropped (Table 3). This was probably because of early sowing of cereals which helps the crop to express its potential and makes favorable condition in utilization of growth resources in lupine-cereal intercropping. The result is in agreement with Gabatshele et al. (2012), who stated that maize growth and yield component were not significantly affected by maize-cowpea intercropping in different seeding ratios.

Table 3. Effect of lupine-cereal intercrops in additive series on growth and yield component of cereals at Adet Agricultural research center, West Gojam in 2009.

Treatments and statistics	Mean					
	HP(cm)	SP (F)L (cm)	SE/SP (F/PL)	TI/PL	ST/m^2	TSW (gram)
Lupine–wheat intercropping						
Sole wheat	153.22^a	7.73^a	17.00^a	16.33^a	317.11^a	21.25^a
25% Lupine+100% wheat	156.33^a	7.73^a	16.73^a	15.87^a	363.77^a	22.28^a
50% Lupine+100% wheat	151.00^a	7.93^a	17.13^a	15.13^a	339.11^a	22.51^a
75% Lupine+100% wheat	151.00^a	7.80^a	16.00^a	13.47^a	325.55^a	22.07^a
CV (%)	4.63	4.76	3.9	18.77	6.29	3.61
Lupine–barely intercropping						
Sole barely	113.00^a	9.13^a	21.27^a	17.40^a	1160.89^a	39.06^a
25% Lupine+100% barley	115.73^a	9.20^a	22.60^a	17.83^a	1220.89^a	38.82^a
50% Lupine+100% barley	114.53^a	9.07^a	20.60^a	18.07^a	1666.66^a	39.01^a
75% Lupine+100% barley	116.53^a	10.07^a	21.47^a	18.27^a	1450.63^a	39.00^a
CV (%)	2.44	6.75	8.21	2.99	29.62	0.92
Lupine–finger millet intercropping						
Sole f/millet	102.67^b	9.37^a	8.13^a	12.20^a	147.33^a	***
25% Lupine+100% F/millet	103.79^b	8.99^a	8.40^a	10.73^a	212.67^a	***
50% Lupine-+00% F/millet	111.47^{ab}	8.89^a	8.27^a	9.00^a	181.67^a	***
75% Lupine+100% F/millet	114.03^a	8.81^a	8.20^a	10.60^a	198.67^a	***
LSD (0.05)	7.10	-	-	-	-	-
CV (%)	3.29	3.76	7.13	26.04	16.85	-

Values (means) connected by different superscript letters are significantly (P<0.05) different within columns according to Tukey- HSD tests.HP: Plant height in cm; SP (F) L: Spike length (cm) of barley and wheat and finger length (cm) of finger millet; SE/SP: Seed per spike of barley and wheat; TI/PL: Tiller per plant; F/PL: Finger per plant; ST/m$^{2:}$ Stand cover per meter square and TSW: Thousand seed weight.***Difficult to measure.

Competitive ability of barley in particular and wheat in general for growth resources was higher than lupine in all seeding ratios which was also confirmed by Yayeh et al. (2014). This result was in agreement with the conclusion of Brandt et al. (1989), who found that no effect of intercropping clover cultivars on wheat yield components and phenological parameters.

Biomass, grain yield and harvest index

Biomass yield

Wheat biomass yield: The results showed that the biomass yield of wheat in lupine-wheat combinations significantly (P<0.05) influenced by intercropped seeding proportions (Table 4). Although, there was a general reduction in the biomass yield of wheat as a result of intercropping as compared to sole cropped wheat, lowest biomass yield was recorded in lupine-wheat intercropping at 75:100 seeding ratio (3666 kg/ha) (Table 4). This could be due to competition for light and nutrients. In the same experiment, the highest biomass yield was recorded in sole cropped wheat (7000 kg/ha) as compared to lupine-wheat combinations at all seeding ratios (Table 4) due to absence of inter-specific competition. Generally, at high crop proportion, lupine reduced the biomass yield of the wheat component. This result corroborates with Hauggaard-Nielsen et al. (2005), who found that wheat biomass yields falling with increased plant density in wheat-pea intercropping.

Barely biomass yield

The biomass yield of barely revealed a non significant effect of companion crop proportions (P>0.05) in the case of lupine-barely intercropping (Table 4). This could be explained due to nearly complete dominance of barely over lupine in all proportions at the early stage of lupine, and so no inter-specific competition of growth resources between component species that reduces the biomass yield of barely.

This is a common observation that one species grows faster than the other(s) in intercrops. A faster initial growth, that often leads progressively to dominance in terms of resource capture and thus to prospects of greater biomass growth and yield (Fukai and Trenbath, 1993).

Table 4. Effect of lupine-cereal intercrops on grain yield, biomass yield and harvest index of cereals at Adet Agricultural Research Center, West Gojam, in 2009.

Treatments and statistics	Mean			
	GY	BY	HI	LI
Lupine–wheat intercropping				
Sole wheat	2030[a]	7000[a]	29.77[a]	18.13[a]
25 % Lupine+100 % wheat	2494[a]	4667[ab]	54.08[a]	17.45[a]
50 % Lupine+100 % wheat	2127[a]	5667[ab]	39.99[a]	13.67[a]
75 % Lupine+100 % wheat	1935[a]	3667[b]	52.79[a]	11.90[a]
LSD (0.05)	NS	19.98	NS	NS
CV (%)	9.85	23.32	19.49	35.6
Lupine–barely intercropping				
Sole barely	3805[a]	10667[a]	35.57[a]	22.00[a]
25 % Lupine+100 % barley	2845[a]	8417[a]	33.79[a]	21.43[a]
50 % Lupine+100 % barley	2912[a]	9400[a]	31.17[a]	11.13[a]
75 % Lupine+100 % barley	3301[a]	9267[a]	35.85[a]	16.70[a]
LSD (0.05)	NS	NS	NS	NS
CV (%)	16.30	11.48	10.73	39.5
Lupine–finger millet intercropping				
Sole finger millet	2936[a]	18667[a]	15.58[a]	20.32[a]
25 % Lupine+100 % f/millet	2323[a]	22000[a]	10.44[b]	16.00[ab]
50 % Lupine+100 % f/millet	2389[a]	22000[a]	10.97[ab]	15.87[ab]
75 % Lupine+100 % f/millet	1935[a]	23333[a]	8.50[b]	11.63[b]
LSD (0.05)	-	-	3.60	5.31
CV (%)	24.29	16.55	15.86	16.68

Values (means) connected by different superscript letters are significantly (P<0.05) different within columns according to Tukey-HSD tests. GY: Grain yield in kg/ha; BY: Biomass yield in kg/ha; LI: Lodging index in % and F/millet: finger millet.

In the present study, this is true particularly for lupine-barley intercropping systems. However, due to the same reason to the reduction of wheat biomass yield in lupine-wheat intercropping, there was a general decrease in barley biomass yield in lupine-barley intercrops from sole barley (10667 kg/ha) to 50:100 (9400 kg/ha) ,75:100 (9267 kg/ha) and 25:100 (8400 kg/ha) seeding ratios (Table 4).

Finger millet biomass yield

Biomass of finger millet was not significantly affected by intercropped seeding proportions (P>0.05) (Table 4). However, the highest biomass yield was recorded over the highest cropping proportion (75:100) (23333 kg/ha) as compared to sole finger millet (18666 kg/ha) (Table 4). This means, as the added proportion of the companion cop increase, finger millet biomass yield also increased (Table 4). This could be attributed to reduction of lodging due to intercropping across increasing cropping proportions. Lupines usually hold up lodging of finger millet when they were grown together and in turn protect reduction of finger millet yield. Increased in plant height of finger millet in line with seeding ratios might be also contributed to increase in biomass yield.

Grain yield

The intercropped lupine-cereal seeding proportions did not affect grain yield of cereals (P>0.05) (Table 4). The present results in agreement with Rudnicki and Galezewski (2007), who reported that lupine presence in lupine-oat intercropping in different seeding proportions, did not affect the grain yields of oat. This situation allows the cereal to be maintained at or near the optimum monocrop population and yield which is similar to the existing farmers' practices. It is similar to Natarajan and Willey (1980), who reported that 2 sorghum: 1 pigeon pea seeding ratios, sorghum growth was not affected by the presence of pigeon pea, and the farmers' primary objective of maintaining a 'full' sorghum yield was achieved if the density of the intercropped sorghum was equivalent to the sole crop optimum. Though, there were no significant difference between seeding ratios, grain yield reduction was pronounced in lupine-wheat (from 2400 to 1935 kg/ha) and lupine-finger millet (from 2300 to 1935 kg/ha) intercrops from a lower to a higher seeding ratios, while the reverse is true for barley (from 2800 to 3301 kg/ha) in lupine-barley intercropping (Table 4).

Sole cropped grain yield of barley (3805 kg/ha) and finger millet (2936 kg/ha) were higher than each intercropped with lupine perhaps due to the fact that absence of inter-specific competition in sole cropping, though, uneven rainfall distribution during the growing period and other factors (Figure 2) considerably reduced over all grain yields of cereal species. This was in agreement with the findings of Gardner and Boundy (1983), who noted that yield depression of cereal by lupine in intercropping. Similarly, Chetty (1983) reported that little depression of the yield of finger millet by fodder legumes, field beans, Dolichos lablab and Lucerne.

However, the reverse is true for wheat in lupine-wheat intercropping. Maximum wheat grain yield in lupine-wheat combinations at 25:100 seeding ratios (2494 kg/ha) than sole cropped wheat (203 kg/ha) could be due to lower septoria infestation and differences with respect to resource use in both time (e.g. crops of differing growth phenologies), space (e.g. crops of different rooting depth) and physiology (e.g. legume and non-legume crops differing in source of N) could gave rise to more efficient resource capture and/or use in intercrops than corresponding sole crops.

In terms of competition, this means that crops grown in mixture do not compete for exactly the same ecological niche and that competition between crop species is therefore weaker than between plants of the same species (Yayeh et al*.,* 2014). This was similarly reported by the competitive production principle in which if the two species cannot occupy the same niche, which is to say they cannot compete with one another intensely (Vandermeer, 1989).

This is in agreement with Sarunaite et al*.* (2009), who reported that the wheat intercropped with lupine, bean and pea produced significantly higher grain yield than wheat in sole crop. Similarly, Chen et al. (2004) reported that increased cereal seed yield in legume-cereal mixture may be attributed to nitrogen fixing ability of legumes and extensive root system of cereals. This result inconsistent with Gardner and Boundy (1983), who reported that high lupine seed proportion, causes reduction in wheat yields in lupine-wheat intercropping**.**

Harvest index

Low crop harvest index is the major cause of less crop yield (Murray et al*.,* 2010). Analysis of variance indicated that harvest index of finger millet was significantly (P<0.05) influenced by intercropped seeding proportions in lupine-finger millet intercropping systems (Table 4). The highest harvest index was recorded in sole cropped finger millet (15.58%) followed by 50:100 seeding ratio (10.97%) while the lowest harvest index was recorded in 75:100 (8.50%) and 25:100 (10.4380%) seeding ratios (Table 4). In general, lowest harvest index was recorded in intercropping system than sole cropping system probably due to higher competition from the intercropped lupine.

Reduction in plant height lowered the dry weight of the vegetative parts and thereby lowered the straw yield which resulted in an increased harvest index. Harvest index was positively correlated with grain yield but negatively correlated with vegetative growth (Murray et al*.,* 2010; Yayeh et al*.,* 2014). However, intercropped seed proportion in lupine-wheat and lupine-barley intercropping did not significantly (P>0.05) affect harvest index of wheat and barley as compared to the respective sole cropped (Table 4).

Lodging

Generally, two types of lodging were occurring in cereals during this experiment. These are: wheat and barley root lodging in the case of lupine-barley and lupine-wheat combinations early in the season and finger millet stem breakage in the case of lupine-finger millet later in the season as the stalk becomes more brittle due to maturation (Table 4). Lodging in barely was often a result of the combined effects of a tall standing and large head crop, diseased plant (net blotch and scald) and wind. Lodging in wheat was often a result of the combined effects of diseased plant (Septoria Infestation) and wind. Likewise, lodging in finger millet was caused by the weight of the higher internodes of the stems plus leaves and heads and wind.

Wheat and barley lodging did not affected significantly by lupine-wheat and lupine-barley intercropping in three seeding ratios (P>0.05) (Table 4). This is might be due to lupine at the early stage in all lupine-barely intercropping was near to completely dominated by barely, and so barely did not physically supported by lupine. Though, statistically not significant, lodging was more pronounced under barley and wheat sole cropping as compared to intercropping (Table 4). Highest lodging percentage was recorded in sole barley (22%) and sole wheat (18.13%) as compared to all lupine-barely and lupine-wheat intercropping system. Moreover, as seeding ratios increases in the combination, barley and wheat lodging was reduced (Table 4).

This corroborate with Beyenesh (2009), who reported that barley was sensitive to lodging under sole cropping than mixtures. Nonetheless, finger millet lodging was significantly (P<0.05) affected due to intercropping in different seeding ratios in the case of lupine-finger millet intercropping (Table 4). The present study indicated that lodging was highly reduced in all lupine-finger millet combinations as compared to sole cropped finger millet (20.32%). Moreover, lupine-finger millet combination at 75:100 seeding ratio (11.63%) highly reduced lodging as compared to 25:100 (16.00%) and 50:100 seeding ratios (15.87%) which were statistically on par with each other

Table 5. Land use efficiency of lupine-cereal intercrops at three seeding ratios at Adet Agricultural Research Center, West Gojam in 2009.

Cropping system	Seed proportion (%)	Land use efficiency (%)
Sole lupine	100	0
Sole wheat	100	0
Sole barely	100	0
Sole finger millet	100	0
Lupine: wheat	25:100	33.4
Lupine: wheat	50: 100	31.3
Lupine: wheat	75: 100	48.9
Lupine: barley	25: 100	-24.0
Lupine: barley	50: 100	-21.0
Lupine: barley	75: 100	-11.0
Lupine: f/millet	25: 100	9.7
Lupine: f/millet	50: 100	23.4
Lupine: f /millet	75:100	29.4

Values (means) connected by different superscript letters are significantly (P<0.05) different within columns according to Tukey-HSD tests. LER: Land equivalent ratio.

(Table 4). In other words, finger millet was physically supported by lupine particularly in high lupine seed proportion. This result was in agreement with Putnam (1993), who reported that in lupine-pea combination the lupine prevent lodging of pea, and the pea provides an earlier canopy closure for weed control in the lupine. Barley culms (stem) were regaining their upright position and gave optimum yield due to lodging before flowering and prevailing favorable weather conditions. Similarly, finger millet lodging did not much affect the yield probably due to lodging occurs after the plant had matured and finger millet was physically supported by lupine but it might reduce the amount of harvestable grain.

Land use efficiency

In assessments of crop productivity of sole cropping systems, a useful expression is mass yield (mass per unit area). However, in intercropping systems, direct comparison is difficult because products are different for the different plant species growing on one piece of land (Beets, 1982). In this case, crop productivity should be evaluated using a common unit. A widely used method to know land use efficiency in terms of hectare of land saved due to intercropping or in terms of percentage of yield advantage or disadvantage is the land equivalent ratio (LER) (Beets, 1982). Total land equivalent ratio (LER) was significantly higher than 1.00, which shows an advantage from intercropping over pure stands in lupine-wheat and lupine-finger millet combinations in terms of the use of environmental resources for plant growth.

The combined land use efficiency was greatest in the cases of lupine-wheat mixture at the 75:100 seeding ratio (48.9%), followed by the same combination at the 25:100 seeding ratio (33.4%) and at 50:100 seeding ratio (31.3%) (Table 5). This indicates that 0.489 ha, 0.334 ha and 0.313 ha more area would be required by a sole cropping system to equal the yield of intercropping system.

The second crop combination which gave higher land use efficiency was lupine-finger millet at 75:100 seed ratio (29.4%) followed by the same combination at 50:100 (23.4%) and 25:100 (9.7%) seeding ratios which causes, 29.4, 23.4 and 9.7% higher yield than sole cropping (Table 5). These findings were in agreement with Caballero et al. (1995), who reported a mixed stand advantage at lower oat seeding proportions in common vetch-oat combination. Similarly, compared with corresponding sole crops, yield advantages have been recorded in pearl millet-cluster bean (Yadav and Yadav, 2001). On the other hand, total LERs below 1.00 were found in all lupine-barley combinations, which gave a disadvantage of these mixtures over pure stands (Table 5). This result was in agreement with Ghosh (2004), who reported that common vetch–barley and common vetch-triticale mixtures shows a disadvantage over pure stands. This could be due to competitive ability of barely was higher than lupine.

SUMMARY AND CONCLUSIONS

The present study demonstrated that, except days to maturity of finger millet, intercropping of lupine with wheat, barley and finger millet at three different seeding ratios had no effect on phenological attributes of cereal species. The agronomic attributes of most cereals were not significantly affected when they were intercropped with lupine in all seeding ratios except finger millet plant height, harvest index and wheat total biomass yield. Cereal growth was not affected by the intercropped lupine, and the farmers' primary objective of maintaining a ‘full’ cereal yield was attained.

The maximum lupine seed proportion was superior to the lowest when intercropped with wheat and finger millet. Intercropping higher proportion of lupine with wheat and finger millet did help much in increasing total grain yield and biomass yield without affecting main crop yield. Intercropping lupine with cereals gave physical support for cereals particularly in high lupine seed proportion. The combined yield advantage was greater than one in the cases of lupine-wheat followed by lupine-finger millet mixtures at all seeding ratios. Hence, two of the best combinations which were differed from what farmers currently use and gave higher land use efficiency were the lupine-wheat mixture at the 75:100 seeding ratio (49.4%) followed by the lupine-finger millet mixtures at the 75:100 seeding ratio (29.4%). These mixtures seem promising in the development of sustainable crop production with a limited use of external inputs.

Conflict of Interests

The authors have not declared any conflict of interests.

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