International Journal of Advanced Research in Biological Sciences
ISSN: 2348-8069
www.ijarbs.com
DOI: 10.22192/ijarbs Coden: IJARQG (USA) Volume 7, Issue 11 -2020

Research Article

DOI: http://dx.doi.org/10.22192/ijarbs.2020.07.11.008

Effect of planting density and time of white lupine relay intercropping on the productivity Teff (*Eragrostis tef* (Zucc.) Trotter) in Burie district, North Western Ethiopia

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Abstract

A field experiment was conducted during 2015/16 main rainy season in Burie District, North Western Ethiopia with an objective determining the influence of density and time of lupine rely intercropping on the productivity and production indices of teff. Factorial combinations of 3 relay intercropping time(after 4,6,and 8 weeks of teff sowing),2 inter-row spacing (40cm and 60cm) and 2 intra-row spacing of lupine (20cm and 30cm), totally 12 treatment combinations, and 2 sole cropping of teff and lupine were laid out in randomized complete block design at three replications. All collected data were subjected to ANOVA using SAS (9.2) software. The analysis showed that except number of effective tiller plant^{-1} and grain yield ha,$^{-1}$the phenological, vegetative growth and almost all yield and yield related parameters of teff were not significantly (P>0.05) affected by the main and interaction effects of time of relay intercropping and planting density of lupine. The highest number of effective tiller plant^{-1}(4.85) and grain yield of teff (2459.74kg/ha) were recorded from the delayed relay intercropping of lupine. The highest LER (1.62) and MAI (20402.42 birr/ha) values were obtained from relay intercropping of lupine after 4 weeks with narrower intra and inter row spacing (I2 and R2).

Keywords: intercropping, productivity, production, LER

1. Introduction

Teff [*Eragrostis tef* Zucc. Trotter] is an Ethiopian indigenous crop which taxonomically belongs to the grass family, *Poaceae*, and genus *Eragrostis* (Seyfu Ketema, 1997). It has been cultivated for thousands of years in high lands of Ethiopian (Viswanath, 2013). The above depicted nature of the crop drowns attention of growers outside of its origin and cultivated principally as forage for livestock feed in countries like Australia, South Africa, and United States (Baye Kaleb, 2014).

It grows at middle elevations between 1,800 and 2,200 meters above sea level and in regions that have adequate rainfall. From the total cereal production teff took the first 22.95% in area coverage and the second 16.76% in production (CSA 2015/16).

Recently there is an effort to increase the productivity of field crops using different cropping system such as intercropping. Furthermore, the world population is rising rapidly and it needs an option to feed; one possible approach to resolve this problem would be to maximize the utilization of limited agriculture land through multiple cropping so as to increase productivity per unit area of available land (Khan *et al.*, 2014). There for this research was initiated with the objectives of evaluating the potential, effects of lupine based relay intercropping on the productivity of teff.

2. Materials and Methods

2.1 Description of the Study Area

On farm experiment was conducted in 2015/16 main cropping season at Wangedam rural village in Burie District, North Western Ethiopia to study the potentials of lupine for relay intercropping in teff. The experimental site is found at 153 km far from Bahir Dar and 411km from Addis Ababa and located at $10^{O}44'$Nlatitude and $37^{O}06'$E longitude with an elevation of 2091 meters above sea level. Average minimum and maximum temperatures of the area are 12^{O}C and 28.4^{O}C, respectively. The average total annual rainfall of the site is about 945 mm.

The soil of the experimental site was well drained red-brown *nitosol*. To describe it with some selected physico-chemical characteristics, composite sample was collected before planting and sent to Soil Laboratory of Amhara Design and Supervision Works for further analyses. Composite soil sample was prepared from the mixture of samples collected on the top 20cm by using a sampling spoon along ''W'' shape of the experimental plot. The composite soil sample was analyzed for its texture, pH, organic matter (OC), total nitrogen content (TN), available phosphorous (Av.P) and cation exchange capacity (CEC) using their respective standard methods and procedures. The results are presented below in (Table 2.1).

Table 2.1. Physical and chemical properties of the surface soils (0-20 cm) of the study site

pH (H_2O) 1:2.5	OC (%)	TN (%)	Av.P (ppm)	CEC ($cmol^{+}kg^{-1}$)	Texture			
					% clay	% silt	%sand	Texture class
4.88	1.33	0.11	18.8	28.9	60	24	16	Clay

2.2Planting Materials used for the Experiment

The research was conducted by using "Quncho" teff variety obtained from Ethiopian seed enterprise, Bahir Dar branch and local white lupine bought from the farmers.

2.3Experimental Treatments, Design and Procedures

Factorial combinations of three times of relay intercropping (4, 6 and 8 weeks after teff sowing), two inter-row spacing (40cm and 60cm) and two intra-row spacing (20cm and 30cm) of lupine in teff field as well as two sole cropping of teff and lupine for comparison purposes, totally 14 treatments, were laid out in randomized complete block design (RCBD) with three replications. A suitable plot of land $725m^2$ (62.5mx11.6m) was prepared according to farmers practice in the area (oxen-plough) four times. The experimental replications and plots were prepared as per the treatments and design just before planting. The gross sizes of experimental plots were 4mx3.2m ($12.8m^2$) but the net plot size was different for different treatments. Thus the net plot size was 3.4mx2.8m ($9.52m^2$) for teff and 3.4mx2.4m ($8.16m^2$) for sole, T1, T2. T5 and T6 lupine whereas for T3, T4, T7 and T8 of lupine was 3.4mx1.8m ($6.12m^2$). 1m and 0.5m spacing was used for replications and plots respectively.

In the mid of July, teff seed was drilled at the rate of 5kg/ha in rows at the spacing of 20cm. sole cropping, lupine was sown on the same date of teff sowing with inter- and intra-row spacing of 40cmx20cm, respectively. DAP and Urea fertilizers were applied at the rates of 100kg and 50kg per hectare, respectively, as used by the community. The whole DAP was applied at the time of sowing, while Urea was applied in split two times with equal proportion soon after the first and the second weeding after 20 and 42 days of teff sowing, respectively. The remaining agronomic practices were done timely as per their respective recommendations used for teff in the area.

Table2.2. Treatment combinations used for the study

Lupine plant density		Time of lupine relay intercropping after teff sowing	Treatment combinations
Intra row spacing	Inter row spacing		T4I2R2(T1) T4I3R2(T2) T4I2R3(T3) T4I3R3(T4) T6I2R2(T5) T6I3R2(T6) T6I2R3(T7) T6I3R3(T8) T8I2R2(T9) T8I3R2(T10) T8I2R3(T11) T8I3R3(T12) Sole teff (13) Sole lupine (14)
40cm(R2) 60cm(R3)	20(I2) 30(I3)	4weeks(T4) 6weeks(T6) 8weeks(T8)	

2.4 Data Collection

2.4.1 Vegetative growth of teff

Plant height; the average height of 10 randomly selected plants at physiological maturity in centimeter in the net plot area measured with linear meter from the ground level to the end of the longest panicle

Number of total and effective tillers per plant; after random tagging of the main plant, the average total and effective tiller of 10 plants was taken.

Panicle length; average length of the panicle of 10 randomly selected mother plants in the net plot area in centimeter measured with linear meter

2.4.2 Grain yield and related parameters of teff

Biomass yield (kg/ha); after harvesting teff in the net plot area of each treatment at 90% physiological maturity, it was sun dried properly and weighed and converted into hectare basis

1000 seeds weight (g); after harvesting, threshing and cleaning, 1000 seeds were taken randomly from each treatment plot and weighed with electrical sensitive balance

Grain yield (kg/ha); after harvesting, drying, threshing and cleaning of teff per the net plot area of the treatments, moisture content was physically assessed till it would be around 12%. After the estimation of the moisture content the teff grains weighed and converted into hectare basis.

Straw yield (kg/ha); after threshing of teff and separating grains, straw of each net plot area was weighed with and converted into hectare basis.

Harvesting index (HI in %); percentage of teff grain yield to biomass yield ratio of each treatment plot

2.5 Determination of Productivity Indices and Monetary Advantage Index

Land equivalent ratio was used as productivity index to compare the yield advantages of intercropping system over sole cropping**.** Besides, the monetary advantage index was also used to compare the intercropping monetary value with sole cropping.

2.5.1 Land equivalent ratio (LER)

LER is used as the criterion for mixed stand advantage as both lupine and cereal is desired species (Willey, 1972). In particular, LER indicates the efficiency of intercropping for using the resources of the environment compared with mono cropping. When the LER is greater than one, the intercropping favors the growth and yield of the species. It is an indicator of complementarity. The LER was calculated as (Willey, 1972).

LER= (*LER* Lupine + *LER* tef); *LER* Lupine= *YLI/YL* and *LER* tef *YTI/YT*

Where, *YL* and *Y*T are the yields of lupine and teff, respectively, as sole crops and *Y*LI and *Y*TI are the yields of lupine and teff, respectively, as intercrops.

2.5.2 Monetary advantage index (MAI)

The monetary advantage was determined by the existing local market prices of both crops. Due to the fluctuation of the market price, the value of combined intercrops in each cropping system was by prevailing market price of each component crop at the time of experiment (ETB/kg). The monetary advantage index (MAI) was calculated by the formula developed by Willey (1979):

$$MAI = \frac{(\text{Value of Combined Intercrops})\,(LER - 1)}{LER}$$

Where,

The value of combined inter crops= (**yield of teff** x **price of teff**) + (**yield of lupine** x **price of lupine**)

2.6 Data Analysis

All collected data were subjected to analysis of variance by SAS (version 9.2) and mean separation of significant treatments were carried out using the least significant difference (LSD) test.

3. Results and Discussion

3.1 Vegetative Growth of teff as influenced by time of rely intercropping and planting density of lupine

Plant height and panicle length

The plant height of teff recorded at physiological maturity was not significantly (p> 0.05) affected by the time and density of white lupine sown as a relay intercropping. This might be due the early sowing of teff used the growth resources. This is in corroborate with the work of Yayeh Bitew et al. (2014) who stated that intercropping lupine with barley and wheat in three seeding ratios did not show difference on the growth as compared to the respective sole crops.

The panicle length of at physiological maturity was not significantly affected (P > 0.05) by the main effects of density and time of relay cropping of white lupine (Tables 3.1). Though it was not significant the highest panicle length (4.67cm) was recorded from less lupine plant population and after late sowing of white lupine. The effect of relay intercropping of lupine on teff panicle length was not showing a continuous trend, the longest panicle length of teff (47.67cm) was recorded by relay cropping of lupine just after six weeks followed by relay cropping of lupine after 8weeks of teff sowing (47.37), but the shortest panicle length (46.78cm) was recorded by relay intercropping of lupine after four weeks of teff sowing (Tables 3.1). Similarly Gebatshel *et al*, (2012) stated that maize growth and yield components were not significantly affected by maize-cow pea intercropping by using different seeding ratios.

Total and effective number of tillers per plant

The analysis of variance showed that the total number of tiller per plant was not significantly (P > 0.05) affected by the main and interaction effects of lupine relay intercropping in teff (Tables 3.1). This is in agreement with Yayeh Bitew *et al.* (2014) who stated that intercropping of lupine with different ratio did not show a significant difference on plant height, spike length, tiller per plant and 100seed weight of wheat and barley.

The study on the other hand showed that the number of effective tillers per plant was significantly (P < 0.05) affected by the main effects of relay intercropping time of lupine. The highest effective tiller (4.85) was recorded from sowing of lupine after eight weeks of teff sowing whereas the lowest (4.51) was from the sowing of lupine after four weeks of teff sowing. This is in line with the work of Tamiru Hirpa (2013) who reported that early or simultaneous intercropping of legume crops reduced the number of harvestable cobs per unit area by about 18.45% compared to delay by eight weeks after sowing of maize.

Table 3.1 Main effects of planting density and time of relay intercropping of lupine in teff on the vegetative growth of teff during 2015/16 in Burie District

Main factors	Plant height (cm)	Panicle length (cm)	Number of tillers plant^{-1}	
			Total	Effective
(a)Time of relay inter cropping				
After 4weeks of teff sowing (T4)	1.47	46.78	6.35	4.52b
After 6weeks of teff sowing (T6)	1.46	47.64	6.56	4.65ab
After 8weeks of teff sowing (T8)	1.45	47.37	6.63	4.85a
Sig. difference	**ns**	**ns**	**ns**	*****
SE±	**0.01**	**0.29**	**0.09**	**0.07**
CV (%)	**3.4**	**2.3**	**5.1**	**5.6**
(b) Intra-row spacing (I)				
20cm (I1)	1.47	47.07	6.50	4.66
30cm (I2)	1.45	47.46	6.53	4.69
Sig. difference	**ns**	**ns**	**ns**	**ns**
SE±	**0.01**	**0.24**	**0.07**	**0.06**
CV (%)	**3.4**	**2.3**	**5.1**	**5.6**
(c) Tef-lupine ratio(R)				
In every after 2 teff rows (R2)	1.46	47.20	6.48	4.66
In every after 3 teff rows (R3)	1.45	47.32	6.54	4.68
Sig. difference	**ns**	**ns**	**ns**	**ns**
SE±	**0.01**	**0.24**	**0.07**	**0.06**
CV (%)	**3.4**	**2.3**	**5.1**	**5.6**

* Significant at 5%; ns=non- significant at 5%; PH= Plant height; PL= Panicle length; TT= Total tiller number per plant ET=Effective tiller number per plant; CV= Coefficient of variation; SE= standard error; means followed with different letters are significantly different

3.2 Grain Yield and Related Traits of teff

Biomass yield

The biomass yield of teff was not significantly ($p>0.05$) affected by the main and interaction effects of planting density and the time of lupine relay intercropping (Table 3.2). This might be due to the domination of teff that lupine crop was not able to create an inter-specific competition to reduce the biomass yield of teff. This is in agreement with the work of Yayeh Bitew *et al*. (2014) who stated that intercropping of lupine with different ratio did not show a significant effect on the biomass yield of barley.

Thousand grain weight

The analysis of variance result showed that 1000 grain weight was not significantly ($p>0.05$) affected by the density and relay intercropping time of lupine in teff. Although it was not significantly affected, more 1000 grain weight (0.25g) was recorded from wider spacing of lupine relay intercropping and delayed relay intercropping of white lupine in teff (Table 3.2). This is in agreement with Tamiru Hirpa (2013) who stated that thousand grain weight of maize crop, was found to be unaffected by intercropping time of legume crops.

Grain Yield

The grain yield of teff was significantly ($p<0.05$) affected by the main effect of relay inter cropping time of white lupine. The highest grain yield was obtained from the lately relay inter cropping time of lupine (Table 3.2). This might be due to the inter-specific compaction from the early intercropped lupine plants. This was in agreement with Addo-Quaye (2011) who found that the time of introduction of soybean significantly affected maize grain yield and delayed soybean planting increased maize grain yield in maize/soybean cropping system. Similarly Langat *et al*. (2006) who indicated that intercropping significantly affected the yield of sorghum in sorghum/ groundnut intercropping.

Kinde Lamessa *et al*. (2015) also noted that, not only the yield of cowpea was depressed by sorghum but cowpea also depressed the yield of sorghum. Tamiru Hirpa (2014) also showed that total grain yield of the maize crop in his study showed a significant variation with respect to the staggered sowing of the haricot bean crop, whereby the highest being recorded when haricot bean was delayed simply for 3 weeks after maize.

Straw yield

The straw yield of teff was not significantly ($p>0.05$) affected by the main and interaction effects of relay intercropping, intra row spacing and tef lupine ratio (Table 3.2). This was in agreement with Tamiru Hirpa (2013) who stated that the effect of intercropped legume crops sown as simultaneous, after four weeks and eight weeks after maize emergency was found to be non-significant on total maize Stover production.

Harvest index

Harvest index, the proportion of the mass of economic yield to total above ground biomass of teff crop, was found unaffected ($p>0.05$) by the component crop lupine (Table 3.2). Similarly, Carruthers *et al*. (2000) found no effect on maize harvesting index due to intercropping of soybean and lupine. Yayeh Bitew *et al*. (2014) also showed that the intercropped seed proportion of lupine-wheat and lupine-barley did not significantly affect the harvesting index of wheat and barley.

Table 3.2. Main effects of planting density and time of relay intercropping of lupine in teff on yield related parameters of teff in 2015/2016 in Burie District

Main factors	BY (kg/ha)	GY (kg/ha)	SY (kg/ha)	Hi (%)	TGW (g)
(a) Time of relay cropping(T)					
After 4weeks	8574.52	2380.54b	6193.98	0.27	0.23
After 6weeks	8630.28	2450.98ab	6179.30	0.28	0.25
After 8weeks	8645.84	2459.74a	6186.11	0.29	0.25
Sig. difference	**ns**	*****	**ns**	**ns**	**ns**
SE±	**29.63**	**20.25**	**37.18**	**0.002**	**0.004**
CV (%)	**1.2**	**3.1**	**2.1**	**3.3**	**7.6**
(b) Intar-row spacing					
20cm (I1)	8610.62	2427.08	6183.53	0.28	0.24
30cm (I2)	8623.14	2433.76	6189.39	0.28	0.25
Sig. difference	**ns**	**ns**	**ns**	**ns**	**ns**
SE±	**24.20**	**16.54**	**30.36**	**0.002**	**0.005**
CV (%)	**1.2**	**3.1**	**2.1**	**3.3**	**7.6**
(c)Tef lupin ratio(R)					
After 2 tef rows (R2)	8628.00	2421.80	6206.20	0.28	0.24
After 3 tef rows (R3)	8605.76	2439.04	6166.73	0.28	0.25
Sig. difference	**ns**	**ns**	**ns**	**ns**	**ns**
SE±	**24.20**	**16.54**	**30.36**	**0.002**	**0.005**
CV (%)	**1.2**	**3.1**	**2.1**	**3.3**	**7.6**

* Significant at 5%, ns= non-significant at 5%; BY= Biomass yield (kgha-^{1}); GY= Grain yield (kg ha-1); SY=Straw yield (kgha^{-1}); HI= Harvest index (%) and TGW= Thousand grain weight (g); CV=Coefficient of variation; SE= standard error; means followed with different letters are significantly different

3.3 Productivity of Intercropping

3.3.1 Land equivalent ratio

The LER was highly significantly ($p<0.01$) affected by the main effects of lupine teff ratio, intra row spacing, relay intercropping time of lupine in teff and by the interaction effects of relay intercropping time with inter row spacing and relay intercropping time with intra row spacing of lupine. The LER was also was significantly ($p<0.05$) affected by the interaction effects of inter row with intra row spacing and by the three way interaction effects of the three factors (Table 3.3).

The highest LER (1.62) was recorded from relay inter cropping of lupine at four weeks after teff sowing with 20 cm intra row spacing and 40 cm inter row spacing (Table 3.3). This showed that relay intercropping of lupine in teff after four weeks with narrower plant spacing provided 62% yield advantage than the sole cropping. The result showed that relay intercropping of lupine eight weeks after teff sowing is not economical from the point view of increasing the productivity. The total LER except after eight weeks of teff sowing was more than a unity showing that intercropping of lupine with teff was advantageous in all instances rather than sole planting of teff. This is in agreement with Ullah *et al*. (2007) who reported higher LER in intercropping than sole cropping of maize/soybean. Similarly Rashid *et al*. (2005) had reported that mung-bean associated with sorghum substantially increased income than sole cropping of sorghum.

3.3.2 Monetary advantage index

In the present study, monetary advantage index was highly significantly ($p<0.01$) affected by the main effects of lupine teff ratio, intra row spacing, relay intercropping time of lupine in teff and by the interaction effects of relay intercropping time with intra row spacing of lupine (Table 3.3) whereas The MAI value was significantly($p<0.05$) affected by the interaction effects of relay intercropping time with inter row spacing, inter row spacing with intra row spacing and by the three way interaction effects of the three factors (Table 3.3). This was in agreement with the findings of Wondimu Bekele (2013) work that higher monetary return from intercropping than sole maize.

Table 3.3. Three way interaction effects of intra row spacing, teff lupine ratio and relay intercropping time on the LER and MAI in Burie District in 2015/16

Treatments interaction			Grain yield		LER	Yield price		MAI (Birr/ha)
			Teff (kg/ha)	Lupine (kg/ha)		Teff (Birr/ha)	Lupine (Birr/ha)	
T4	R2	I2	2345.93	1674.84b	1.62a	39880.92	13566.20b	20402.421a
		I3	2380.95	1225.49c	1.45b	40476.20	9926.46c	15643.57b
	R3	I2	2412.63	925.92d	1.34bc	41014.82	7499.97d	12388.27bc
		I3	2382.63	762.52d	1.26c	40504.76	6176.43d	9770.88c
T6	R2	I2	2415.96	408.50e	1.14d	41071.43	3308.85e	5327.22cd
		I3	2450.98	285.95e	1.12d	41666.72	2316.19e	4032.75d
	R3	I2	2485.99	272.33e	1.10d	42261.94	2205.90e	4917.03d
		I3	2450.98	163.40e	1.05d	41666.72	1323.54e	2111.42d
	Sole crop		2483	2573.53 a	-	42211	20845.60a	-
Sig. difference			ns	*	*	ns	*	*
SE±			40.51	39.70	0.02	688.61	321.56	727.65
CV (%)			3.1	14.2	3.2	3.1	14.2	16.8

* Significant at 5%; ns=not significant at 5%; CV= Coefficient of variation; SE= standard error; T4and T6= time of relay intercropping after 4/6 weeks of teff sowing respectively, R2 and R3=teff lupine ratio in every after 2/3 teff rows respectively, I2 and I3= intra row spacing of lupine (20cm and 30cm) respectively; means not followed by the same letter are significantly different

The highest MAI (20402.42 Birr/ha) and the lowest (2111.42 Birr/ha) was obtained from the early sowing of lupine with narrow intra and inter row spacing and with delayed sowing of lupine with wider intra and inter row spacing respectively (Table 3.3). This could be due to the higher yield and LER obtained from the intercropping of these two crops. Similarly Knudsen (2001) also reported that when the LER were higher there is also significant economic benefit expressed with higher MAI. The higher LERs in intercropping than mono-cropping was also reported by Gani (2012) who obtained higher monetary returns from intercropping maize and soybean as compared to sole maize.

Conclusion and Recommendations

The present study revealed that there is a scope that farmers can increase the production and productivity per unit area of land. Additional yield could be produced by optimization with respect to spatial arrangements and relative planting time of intercrop components which can contribute complementarities of the crops in the mixture. The relay intercropping of lupine in teff gave additional income than the sole cropping of the two crops for which the LER and MAI showed a positive and hopeful result by the relay intercropping of lupine after 4 weeks with higher planting density of lupine in teff.

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Subject: Agriculture

Quick Response Code

DOI:10.22192/ijarbs.2020.07.11.008

How to cite this article:

Tesfaw Fetene, Getachew Alemayehu . (2020). Effect of planting density and time of white lupine relay intercropping on the productivity Teff (*Eragrostis tef* (Zucc.) Trotter) in Burie district, North Western Ethiopia. Int. J. Adv. Res. Biol. Sci. 7(11): 64-72.

DOI: http://dx.doi.org/10.22192/ijarbs.2020.07.11.008