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Maize-lupine intercrop response to applied nitrogen and phosphorus in North-Western Ethiopia

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Maize (*Zea mays*) is a major staple crop in North-Western Ethiopia. Narrow leaf lupine (*Lupinus angustifolius*) grain is a commercial concentrates for livestock feed. Maize-lupine intercropping is a sustainable and emerging crop production approach for the resource poor smallholder farmers of North-Western Ethiopia; however, there is no recommended fertilizer rate for the intercrop. Therefore, field experiment was undertaken to determine maize-lupine intercrop yield response to applied N and P; to determine N use efficiency of maize; and to establish the basis for determining the most economical N and P rates with varying costs and commodity prices for the intercrop. The experiment was conducted at South Achefer and Mecha areas of North-Western Ethiopia in 2013 crop season. Four levels of each N (0, 64, 128 and 192 kg N ha^{-1}) and P (0, 20, 40 and 60 kg P ha^{-1}) were arranged in factorial combination. Sole crop maize and lupine were included as check treatments. The treatments were laid out in a randomized complete block design with three replications. The results indicated that maize growth parameters and yield components, maize grain yield, and total maize-lupine intercrop yield increased significantly with applied N, P, and N x P interactions. The highest total intercrop yields were obtained on 162/45 kg N/P ha^{-1} at South Achefer and 205/61 kg N/P ha^{-1} at Mecha with yield advantage of 4.14 and 7.05 t ha^{-1} over unfertilized, respectively. The economic optimum rates for maize-narrow leaf lupine intercrop were 130/39 kg N/P ha^{-1} at South Achefer and 177/53 kg N/P ha^{-1} at Mecha with cost price ratio of N cost kg^{-1}/maize grain price kg^{-1} equal to 6 and P cost kg^{-1}/maize grain price kg^{-1} equal to 11. The economic optimum rates decreased as cost price ratio increased, therefore, seasonal price information is vital to adjust the economic optimum rates. Maize N use efficiency declined as N rates increased in the maize-lupine intercrop.

Key words: Intercropping, lupine, maize, optimum rate, yield response.

INTRODUCTION

In Ethiopia, maize ranks second next to *tef* (*Eragrostis tef L*) in area coverage and first in quantity of grain produced (CSA, 2015). Mean maize yield, however, is very low (3.43 t ha^{-1}) (CSA, 2015) as compared to a global mean of 5.0 t ha^{-1} (CIMMYT and IITA, 2011). It is a priority staple food crop in many parts of the country. Narrow leaf lupine is of a recent introduction to Ethiopia and is commercial concentrate feeds for livestock in North-

Western Ethiopia (Likawent et al., 2012). The grain is an alternative to dry bean (*Phaseolus vulgaris*) and soya bean (*Glycine max*) for human consumption, and several modern cultivars have been developed for use as human food (Shahidul et al., 2011).

Maize-legume intercropping systems offer several advantages to small-scale maize farmers such as improved soil fertility, healthier diets, increased productivity, and reduced risk of total crop failure (CCRP, 2009). Seran and Brintha (2010) reported legume intercropping with maize as a way to grow a staple crop while benefiting from the additional crop. Higher productivity of the system as a whole in maize-common bean intercrop compared with maize sole crop has been reported for other parts of Ethiopia (Wortmann et al., 1996; Tamado and Eshetu, 2000).

Nitrogen (N) and phosphorus (P) are important constraints to maize production in Ethiopia (Kebede et al., 1993). Tilahun et al. (2007) recommended application of 128 kg N and 40 kg P ha^{-1} to maximize net returns to fertilizer use with sole crop maize in Dera area of North-Western Ethiopia. However, information is scarce on fertility response of maize-legume intercrop in North-Western Ethiopia. Narrow leaf lupine, hereafter referred to as lupine, is a relatively new crop with grain and forage potential in the region and more information is needed on intercropping it with maize. Optimum nutrient application rates and efficiency for maize-lupine intercrop is required to increase crop yields and profitability while minimizing environmental pollution. Therefore, this study was conducted to: 1) determine maize-lupine intercrop yield response to applied N and P; 2) determine N use efficiency of maize; and 3) establish the basis for determining the most economical N and P rates with varying costs and commodity prices for the intercrop.

MATERIALS AND METHODS

The experiment was conducted on Nitosols at Mecha (11.39° latitude and 37.11° longitude, 1982 meters above sea level) and South Achefer (11.34° latitude and 36.94° longitude, 2021 m above sea level) of North-Western Ethiopia in the 2013 crop growing season (June to October).

The soil analysis result at soil depth of 0 to 40 cm indicated that the sites had clay texture with low values of pH and available P (Table 1). According to Halm (1978), the available P was low (0-15 mg kg^{-1}, Bray) and according to the ratings by Tekalign (1991) the soils for both sites are strongly acid (4.5 to 5.2), organic carbon was moderate (15 to 30 g kg^{-1}), and total N content was high (1.2 to 2.5 g kg^{-1}) at both sites.

Treatments consisted of N (0, 64, 128 and 192 kg N ha^{-1}) and P (0, 20, 40 and 60 kg P ha^{-1}) arranged in factorial arrangement. Sole crop maize at spacing of 75 cm x 30 cm with recommended fertilizer rate of 128/40 N/P kg ha^{-1} and sole crop lupine at spacing of 40 cm x 10 cm with no fertilizer application were included as check treatments. The treatments were laid out in randomized complete block design with three replications. The fertilizer urea (46% N), DAP (18% N and 20% P) and triple super phosphate (TSP) (20% P) were used as sources of N and P. The fertilizers were applied as band application in the maize furrow. All P was applied at planting while one-third of the N was applied at planting and the remaining N was side-dress applied, and covered, at the 8- to 10-leaf stage of maize. The crop varieties used for the experiment were *BH-540* for maize and *Sanabor* for narrow leaf lupine. Both crops were planted in June at the same date in an additive series with 100% of maize plant population, and with lupine planted at 40% of sole crop stands. Maize was planted in paired rows spaced at 50 and 112.5 cm within and between paired rows, respectively. Paired rows of lupine were planted between the paired maize rows with 37.5 cm apart from adjacent maize row and within paired rows lupine (Figure 1). Intra row spacing was 30 and 10 cm for maize and lupine, respectively. Maize leaf area index (LAI) was recorded at silking stage (Dwyer and Stewart, 1986). Plant height, above ground dry biomass yield, ears $plant^{-1}$, kernels ear^{-1} were determined in middle 4 rows of 1.8m length which was the net plot for determination of grain yield of both crops.

Components of N use efficiencies of maize were calculated as described by Cassman et al. (2002).

$$PFP_N = Y_N / F_N \,;\, AE_N = (Y_N - Y_0)/F_N \,;\, RE_N = (U_N - U_0)/F_N$$

;and $$PE_N = (Y_N - Y_0)/(U_N - U_0)$$

Where, PFP_N = Partial factor productivity of applied N (kg grain per kg N applied); Y_N = crop yield (0% moisture) with applied N (kg ha^{-1}); F_N = amount of N applied (kg ha^{-1}); AE_N =Agronomic efficiency of applied N (kg grain increase per kg N applied); Y_0 = crop yield (0% moisture) in a control treatment with no fertilizer (kg ha^{-1}); RE_N = Crop recovery efficiency of applied N (kg increase in N uptake kg^{-1} N applied); U_N = total grain N uptake at maturity (kg ha^{-1}) in a plot that received N; U_0 = total grain N uptake at maturity (kg ha^{-1}) in a plot that received no N; and PE_N = Physiological efficiency of applied N (kg grain increase kg^{-1} increase in N uptake from fertilizer). A 500-g grain sample was taken to measure maize grain protein using Infratec 1241 Grain Analyser (Foss, Hilleroed, Denmark) and N concentration in the dry grain was calculated as protein content divided by 6.25.

Total intercrop yield (measured as equivalent yield of maize, EY_M) was calculated as $EY_M = Y_{ML} + (Y_{LM} x P_L / P_M)$ (Verma and Modgal, 1983), where Y_{ML} = intercrop maize grain yield ha^{-1}; Y_{LM} = intercrop lupine grain yield; P_M = price of maize grain kg^{-1}; P_L = price of lupine grain kg^{-1}. Grain moisture content was measured using a grain moisture tester (Dickey-John Multigrain) and final grain yield was adjusted to the moisture contents of 12.5% for maize and 10% for lupine.

Data were analyzed using the GLM procedure of the SAS 9.4 version (SAS Institute, 2013). Maize grain and total intercrop yield response to N, P, and N x P interaction were tested using single degree of freedom orthogonal contrasts to determine whether the response was linear or not. Mean separation for significant responses were compared using SAS LSMEANS test (probability of difference, PDIFF) at P < 0.05. Prediction of the optimal level of N and P for maximum and economic yield of the total intercrop was done using polynomial response equation (Dillon and Andreson, 1991). Economic return from the intercrop was performed at three scenarios of fertilizer cost to grain price ratios (CPR) for each N and

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Table 1. Soil properties of the Mecha and South Achefer experimental sites at the time of planting in the year 2013.

Soil properties	Mecha	South Achefer
Soil texture (%)		
Sand	13	8
Clay	65	65
Silt	22	27
Soil pH (H_2O) 1:2.5	4.6	4.8
Organic C (g kg^{-1})	24.4	20.3
Total N (g kg^{-1})	1.8	1.5
Available P (mg kg^{-1})	7.9	6.7

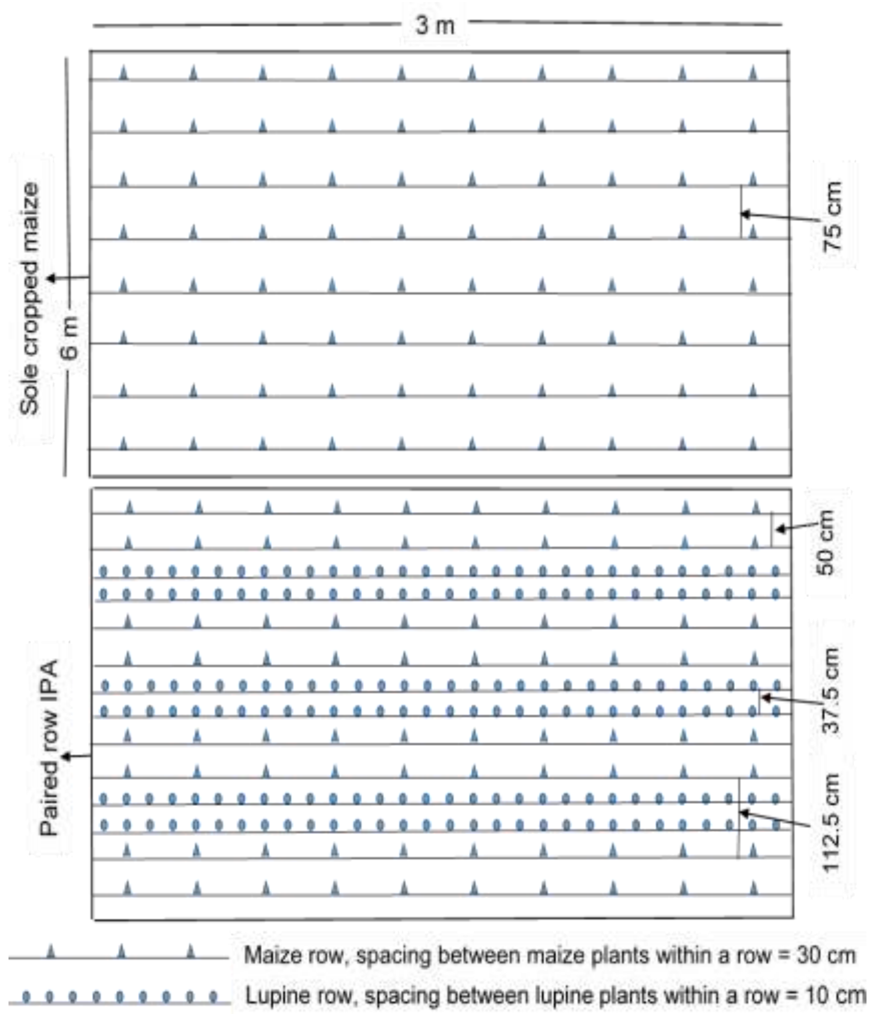

Figure 1. Experimental field layout for paired row intercrop planting arrangement (IPA) in comparison to sole crop maize.

P including ratios of 6, 9 and 13 for N cost kg^{-1} to maize grain price kg^{-1}; and 11, 18 and 25 for P cost kg^{-1} to maize grain price kg^{-1}. Cost of N, Birr 26.5 kg^{-1} (derived from cost of urea, Birr 12.2 kg^{-1}); cost of P, Birr 51 kg^{-1} (derived from cost of DAP, Birr 15 kg^{-1}) of the year 2013; and mean price of the maize grain (Birr 4.5 kg^{-1}) and lupine grain (Birr 3.0 kg^{-1}) from December to February of the year 2013/2014 were used as base for determination of current cost price ratio of 6 for N cost kg^{-1} to maize grain price kg^{-1} and 11 for P cost kg^{-1} to maize grain price kg^{-1}. The other CPR were determined based on the existing trend in increasing cost of production and it was assumed that cost of N increased to 42 and 58, cost of P to 82 and 112 while maize and lupine grain price kept constant.

RESULTS AND DISCUSSION

The intercrop system was 60% more productive at south Achefer and 100% more productive at Mecha relative to sole crop production as measured from land equivalent ratio (Table 2). Yield advantages of 27% at South Achefer and 61% at Mecha were obtained from intercropped maize relative to sole-cropped maize at 128/40 kg N/P ha^{-1} applied. Increased maize yield when intercropped with lupine relative to sole-cropped maize might be due to a positive effect of lupine to maize crop. Palmason et al. (1992) reported significant N transfer from narrow-leaf lupine to intercropped ryegrass (*Lolium multiflorum*).

Growth and yield components of maize such as LAI, plant height, biomass yield, ear $plant^{-1}$, kernel ear^{-1}, and TKW were significantly affected by N and P application at both sites. Interaction effect of N and P significantly affected plant height at South Achefer, and LAI, plant height, biomass yield and number of kernels ear^{-1} at Mecha. Maize LAI and plant height increased as N and P rates increased (Tables 3 and 4). The highest LAI and plant height were recorded on the application of 192/60 N/P kg ha^{-1} at both sites (Table 4). Increases in maize plant height and LAI in response to N and P was reported by Onasanya et al. (2009). The effect of N fertilization in enhancing LAI is well documented in maize because of higher photo assimilates that result in more dry matter accumulation (Uhart and Andrade, 1995).

Biomass yield, TKW, number of kernels ear^{-1} and ears $plant^{-1}$ were also increased in response to N and P applied (Table 5). The increase in biomass yield and TKW with N applications was consistent with the findings of Kaleem et al. (2012) who reported significant increase in biomass yield and TKW with increasing N rates as high as 210 kg N ha^{-1}. The response of TKW to N and P rate is due to the fact that N and P deficiency decrease biomass production and partitioning, especially in reproductive organs, resulting in small kernel size (Uhart and Andrade, 1995). The increase in kernels ear^{-1} with N application was also consistent with those of Ali and Raouf (2012) who reported highest maize kernels ear^{-1} at the highest N rate of 225 kg N ha^{-1}. The highest biomass yield (17.07 t ha^{-1}) at Mecha was obtained at the highest fertilizer rates of 192/60 N/P kg ha^{-1} (Table 5).

Maize grain yield and the total intercrop yield, which was measured as equivalent yield of maize, were significantly affected by N and P application at both sites. Maize grain yield and equivalent yield of maize were significantly affected by N x P interaction at Mecha but not at South Achefer. Yield response functions were polynomial for the applied N and P rates at both sites with greater response at Mecha (Figure 2) though basal soil fertility status of the two sites was at the same range as indicated in Table 1. Therefore, the greater responses at Mecha compared to South Achefer suggests the need to repeat the study over seasons and sites to verify the results. Yields increased with nutrient rate to certain level. Averaged over P, total intercrop yield ranged from 3.68 to 6.07 t ha^{-1} at 0 and 162 kg N ha^{-1}, respectively at South Achefer (Figure 2a), and from 1.64 to 6.22 t ha^{-1} at 0 and 165 kg N ha^{-1}, respectively at Mecha (Figure 2b). Yield increased by 65 and 279% at South Achefer and Mecha, respectively, due to N application. Similarly, averaged over N, yield ranged from 4.10 to 5.83 t ha^{-1} at South Achefer (Figure 2c) and from 2.68 to 5.60 t ha^{-1} at Mecha (Figure 2d) at 0 and 45 kg P ha^{-1}, respectively. Yield increased by 42 and 109% at South Achefer and Mecha, respectively, due to P application.

The total intercrop yield (equivalent yield of maize) response functions for N and P applications were:

$$Yield_{Achefer} = 3.68 + 0.0296N - 9.155x10^{-5}N^2; \quad R^2 = 0.96$$

$$Yield_{Mecha} = 1.64 + 0.0553N - 1.672x10^{-4}N^2; \quad R^2 = 0.96$$

$$Yield_{Achefer} = 4.10 + 0.0765P - 8.438x10^{-4}P^2; \quad R^2 = 0.98$$

$$Yield_{Mecha} = 2.68 + 0.131P - 1.47x10^{-3}P^2; \quad R^2 = 0.99$$

The increased maize yield in both sites with N and P application has commonly occurred with maize (Ardell and Michael, 2014; Sun et al., 2014). The polynomial response for the highest N and P rates may suggest levels below the highest rates plus the residual nutrients in the soil is sufficient to sustain normal vegetative growth of maize. Depression in grain yield at higher levels of N and P might be also due to nutrient imbalances. Komljenovic et al. (2010) reported significant reduction of zinc status in the maize leaf at higher level of P application. Depression in grain yield of maize at higher N supply was reported (Sun et al., 2014).

The N x P interaction was very important to maize-lupine intercrop yield. Dramatically, yield increased at the lower rates of each nutrient in the presence of the other one (Figure 2) demonstrated the two nutrients are equally important and yield limiting for maize at these sites. Yield responses to N without P application (Figure 2a, b) and to P without N application (Figure 2c, d) were low. This result is in agreement with those of Alzubaidi et al. (1990) who reported significant grain yield response of maize for the interaction effect of N and P compared to application of N and P alone. Masaka (2006) further indicated that this was partly attributed to better plant growth by which N-fertilized plants have larger root systems for the capture of other nutrients. However, the N x P interaction

Table 2. Land equivalent ratio (LER) in maize-lupine intercrop at South Achefer and Mecha in North-Western Ethiopia.

Cropping system	South Achefer		Mecha	
	Grain yield (t ha^{-1})	LER	Grain yield (t ha^{-1})	LER
Intercropped				
Maize with 128/40 N/P kg ha^{-1}	6.75		7.24	
Lupine without N/P application	1.06		0.82	
Sole cropped		1.6		2.0
Maize with 128/40 N/P kg ha^{-1}	5.31		4.49	
Lupine without N/P application	3.30		2.08	

Table 3. Main effect of applied N and P on Leaf area index and yield components of maize under maize-lupine intercropping at South Achefer and Mecha in North-Western Ethiopia.

Parameter	South Achefer					Mecha	
N rate (kg ha^{-1})	**LAI**	**BiomassYield (t ha^{-1})**	**TKW (g)**	**Ear $plant^{-1}$**	**Kernels ear^{-1}**	**TKW (g)**	**Ears $plant^{-1}$**
0	$1.60^{c†}$	6.06^{c}	301^{b}	0.8^{b}	228^{c}	351^{b}	0.8^{b}
64	3.07^{b}	10.87^{b}	334^{a}	0.9^{a}	328^{b}	389^{a}	0.9^{b}
128	3.61^{a}	13.49^{a}	343^{a}	1.0^{a}	377^{a}	397^{a}	1.1^{a}
192	3.83^{a}	13.23^{a}	319^{ab}	1.0^{a}	386^{a}	349^{b}	1.1^{a}
PDIFF	***	***	*	***	***	*	***
P rate (kg ha^{-1})							
0	2.50^{b}	9.21^{b}	295^{c}	0.9^{b}	293^{b}	332^{c}	0.8^{b}
20	3.20^{a}	11.03^{a}	322^{b}	1.0^{a}	340^{a}	354^{bc}	1.0^{a}
40	3.17^{a}	11.80^{a}	349^{a}	0.9^{b}	331^{a}	410^{a}	1.1^{a}
60	3.24^{a}	11.63^{a}	331^{ab}	1.0^{a}	356^{a}	389^{ab}	1.1^{a}
PDIFF	***	***	**	*	**	***	***
CV (%)	11.39	13.82	9.43	12.05	12.96	11.95	14.50

† Numbers followed by different letters on main effect of N and P on the same column indicated significant difference of each other (PDIFF) at P < 0.05. *, ** and *** significant difference at probability level of 0.05, 0.01 and 0.001, respectively.

Table 4. Interaction effect of applied N and P on maize growth parameters under maize-lupine intercropping at South Achefer and Mecha in North-Western Ethiopia.

P rate (kg ha^{-1})	South Achefer				Mecha							
	N rate (kg ha^{-1})				N rate (kg ha^{-1})				N rate (kg ha^{-1})			
	0	64	128	192	0	64	128	192	0	64	128	192
	Plant height (cm)				Plant height (cm)				Leaf area index			
0	$133^{i†}$	161^{g}	176^{ef}	173^{f}	103^{fg}	129^{de}	142^{d}	123^{def}	1.00^{h}	1.89^{efg}	1.83^{fg}	1.63^{gh}
20	142^{hi}	176^{ef}	200^{ab}	187^{cde}	94^{g}	164^{c}	190^{ab}	172^{bc}	0.95^{h}	2.77^{cd}	3.76^{b}	3.75^{b}
40	147^{h}	184^{de}	197^{abc}	194^{bcd}	116^{ef}	175^{bc}	197^{a}	195^{a}	1.39^{gh}	2.53^{def}	3.95^{ab}	4.12^{ab}
60	140^{hi}	177^{ef}	191^{bcd}	207^{a}	123^{def}	173^{bc}	184^{ab}	199^{a}	1.32^{gh}	2.65^{cde}	3.43^{bc}	4.65^{a}
PDIFF	*				**				**			
CV (%)	3.71				7.87				18.66			

† Numbers followed by different letters indicated significant difference of each other (PDIFF) at P < 0.05. * and ** significant difference at probability level of 0.05 and 0.01, respectively.

is likely to be much less important in cases where N is much more limiting than P deficiency (Dobermann et al., 2011; Kaizzi et al., 2012).

From response of N, P, and the N x P, polynomial response function for the intercrop yields were generated for each of the site.

Table 5. Interaction effect of applied N and P on maize biomass yield and number of kernels ear^{-1} under maize-lupine intercropping at Mecha in North-Western Ethiopia.

P rate (kg ha^{-1})	N rate (kg ha^{-1})				N rate (kg ha^{-1})			
	0	64	128	192	0	64	128	192
	Biomass yield (t ha^{-1})				Kernels ear^{-1}			
0	2.16^{f†}	6.12^{cdef}	7.68^{cde}	5.06^{def}	102^{ef}	219^{cd}	214^{cd}	181^{def}
20	2.57^{f}	8.98^{cd}	13.45^{ab}	13.84^{a}	96^{f}	261^{cd}	462^{a}	414^{a}
40	4.95^{def}	9.67^{bc}	13.52^{ab}	16.98^{a}	181^{def}	195^{cde}	400^{a}	419^{a}
60	3.70^{ef}	8.68^{cd}	13.88^{a}	17.07^{a}	112^{ef}	286^{bc}	372^{ab}	452^{a}
PDIFF			*				**	
CV (%)			26.82				21.57	

† Numbers followed by different letters indicated significant difference of each other (PDIFF) at P < 0.05. * and ** significant difference at probability level of 0.05 and 0.01, respectively.

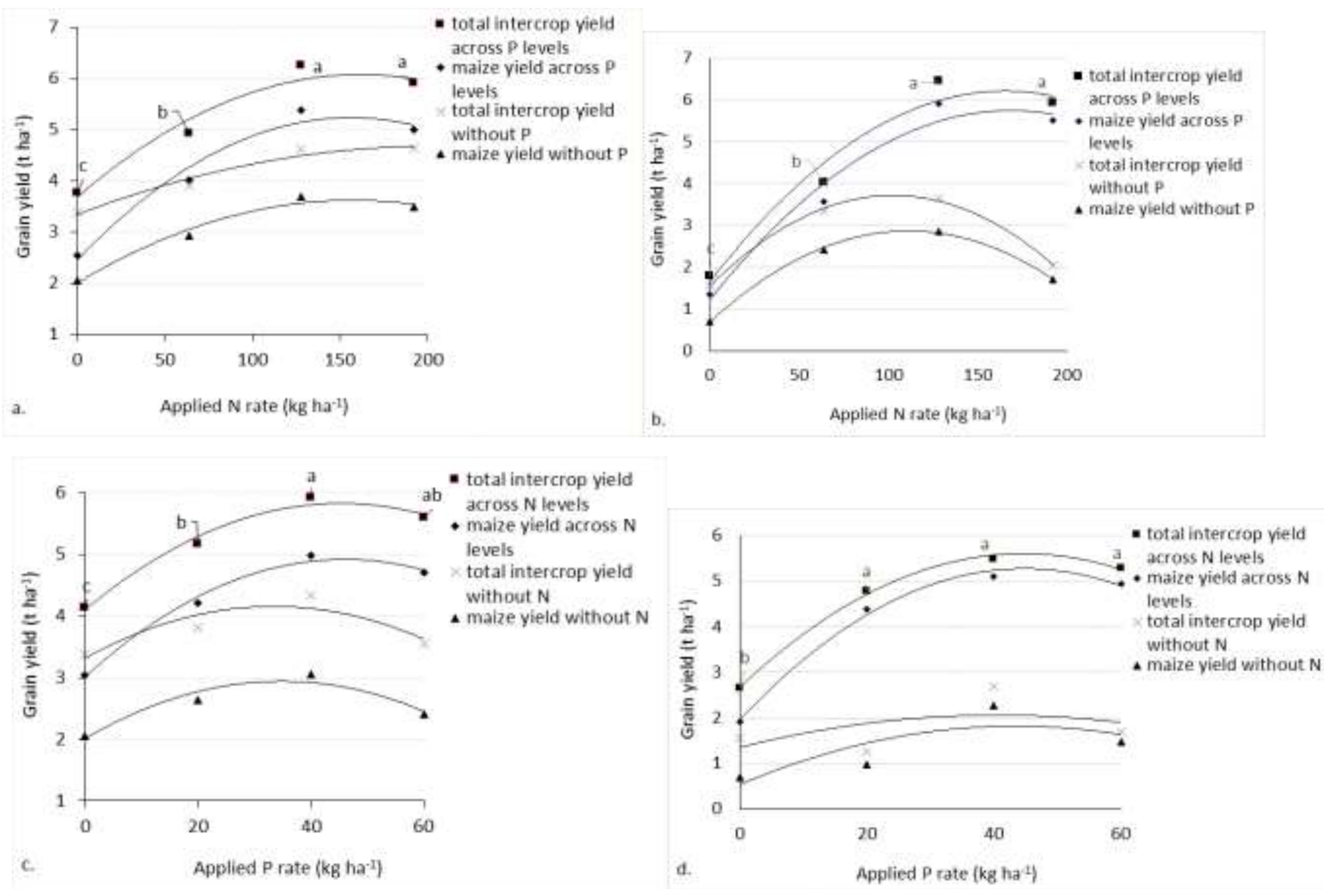

Figure 2. Yield response to applied N and P under maize-lupine intercropping at South Achefer and Mecha in North-Western Ethiopia. **a**) Response to N at South Achefer; b, Response to N Mecha; c, response to P at South Achefer; d) response to P at Mecha (d). Different letters in curve lines indicate significant difference in total intercrop yield (equivalent yield of maize) for N and P levels at P < 0.05.

$$Yield_{Achefer} = 2.56 + 0.0297N + 0.0768P - 9.171x10^{-5} N^2 - 8.484x10^{-4} P^2 \quad R^2 = 0.87$$ (Equation 1)

$$Yield_{Mecha} = 1.01 + 0.0424N + 0.0897P - 1.674x10^{-4} N^2 - 1.47x10^{-3} P^2 + 4.32x10^{-4} NP \quad R^2 = 0.91$$ (Equation 2)

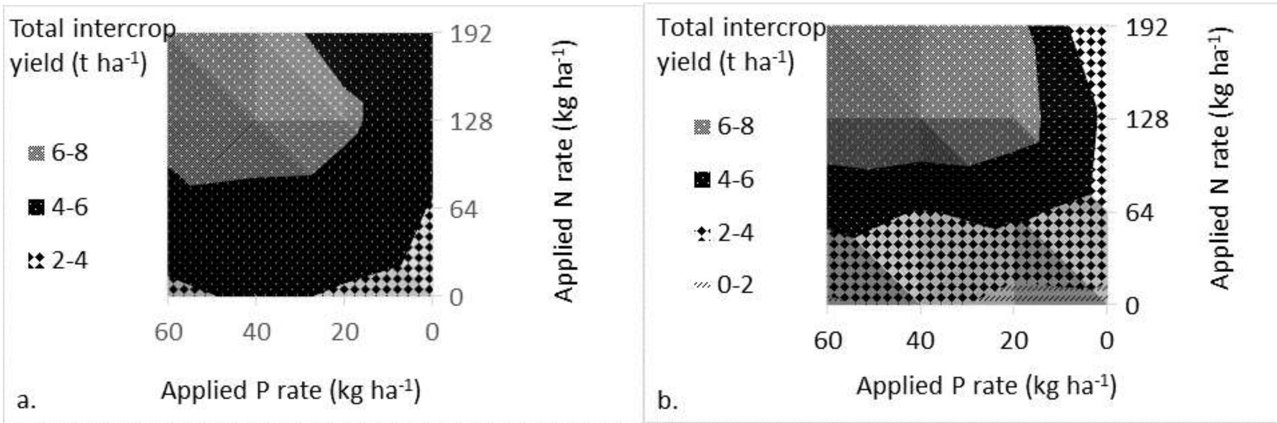

Figure 3. Response surface of N and P interaction effect on maize-lupine total intercrop yield (as measured by equivalent yield of maize) at South Achefer (a) and Mecha (b) in North-Western Ethiopia.

Agronomic optimum N rate (AONR) and P rate (AOPR) at South Achefer were calculated from the following equations which were generated from Equation 1.

$0.0297-1.83x10^{-4}N=0$ and $0.0768-1.7x10^{-3}P=0$

Similarly, AONR and AOPR at Mecha were calculated from the following two simultaneous equations which were generated from Equation 2.

$0.0424-3.348x10^{-4}N+4.32x10^{-4}P=0$ and
$0.0897+4.32x10^{-4}N-0.00294P=0$

The agronomic optimum rates for total intercrop yield were 162/45 kg N/P ha^{-1} at South Achefer and 205/61 kg N/P ha^{-1} at Mecha. Yield ranged from 2.56 at 0/0 N/P to 6.70 t ha^{-1} at 162/45 kg N/P ha^{-1} at South Achefer (Figure 3a), and from 1.01 at 0/0 N/P to 8.06 t ha^{-1} at 205/61 kg N/P ha^{-1} at Mecha (Figure 3b). Yield increased by 4.14 and 7.05 t ha^{-1} at South Achefer and Mecha, respectively relative to the unfertilized.

The cost price ratio affects the economic optimum N rate (EONR) and P rate (EOPR). The economic optimum rates decreased as cost price ratio increased. EONR and EOPR at South Achefer were calculated from equations which were generated from Equation 1 at cost price ratio of N cost kg^{-1} / maize grain price kg^{-1} equals to 6, and P cost kg^{-1} / maize grain price kg^{-1} equals to 11.

$106.97-0.82539N=0$ and $294.465-7.63596P=0$

Similarly, EONR and EOPR at Mecha were calculated from simultaneous equations which were generated from Equation 2.

$164.12-1.50651N+1.943775P=0$ and

$352.83+1.943775N-13.23P=0$

The economic optimum rates were 130/39, 110/35 and 91/31 kg N/P ha^{-1} at South Achefer and 177/53, 160/48 and 143/43 kg N/P ha^{-1} at Mecha at cost price ratios N cost kg^{-1}/maize grain price kg^{-1} and P cost kg^{-1}/maize grain price kg^{-1} of 6 and 11, 9 and 18, 13 and 25, respectively (Figure 4).

Accordingly, the maximum economic net return that can be estimated from maize-lupine intercrop on the above economic optimum rates are 24123, 21110 and 18512 Birr ha^{-1} at South Achefer, and 28338, 24121 and 20314 Birr ha^{-1} at Mecha, respectively. Net return decreased by 23 and 28% at South Achefer and Mecha, respectively, as cost price ratio of N/maize grain and P/maize grain increased from 6 and 11 to 13 and 25. Fertilizer costs and grain prices can fluctuate across years, therefore, profitability of fertilizer use is highly variable. Variations in the profitability of fertilizer use due to variable cost price ratios require that farmers adjust the EONR and EOPR based on current information.

Components of N use efficiencies declined as N rates increased. The decline was significant for most efficiencies except PE_N at South Achefer, and RE_N and AE_N at Mecha (Table 6). At South Achefer, the decline was from 53 to 22, 22 to 12, and 0.32 to 0.19 kg kg^{-1} for PFP_N, AE_N, and RE_N, respectively, as N rates increased from 64 to 192 kg ha^{-1} whereas at Mecha, the decline was from 47 to 24 and from 97 to 69 kg kg^{-1} for PFP_N and PE_N, respectively as N rates increased from 64 to 192 kg ha^{-1}. These declines in N use efficiency might be due to more loss of N in the higher N rate than lower N rate. Decreases in N use efficiencies of maize as N rates increased was due to substantial N losses to the environment and low N use efficiency (Kaizzi et al., 2012 and Wortmann et al., 2011). Ardell and Michael (2014) reported significant decrease in PFP and AE as N rate increased. Sun et al. (2014) and Xueli et al. (2014) also

Table 6. Nitrogen use efficiencies of maize under maize-lupine intercropping as affected by N rates at South Achefer and Mecha in North-Western Ethiopia.

N rate (Kg ha^{-1})	South Achefer			Mecha	
	PFP_N‡	AE_N	RE_N	PFP_N	PE_N
			kg kg^{-1}		
64	53^{a†}	22^{a}	0.32^{a}	47^{a}	97^{a}
128	36^{b}	21^{a}	0.31^{a}	38^{a}	79^{ab}
192	22^{c}	12^{b}	0.19^{b}	24^{b}	69^{b}
PDIFF	***	**	**	**	*
CV (%)	13.89	33.38	31.29	35.64	27.25

† Numbers followed by different letters on the same column indicated significant difference of each other (PDIFF) at $P < 0.05$. ‡ PFP_N,Partial factor productivity of applied N (Kg grain per kg N applied); AE_N, Agronomic efficiency of applied N (kg grain increase per kg N applied); RE_N, Recovery efficiency of applied N (kg increase in N uptake per kg N applied); PE_N, Physiological efficiency of applied N (kg grain increase per kg N uptake increase from applied N); and *, ** and *** significant difference at probability level of 0.05, 0.01 and 0.001, respectively.

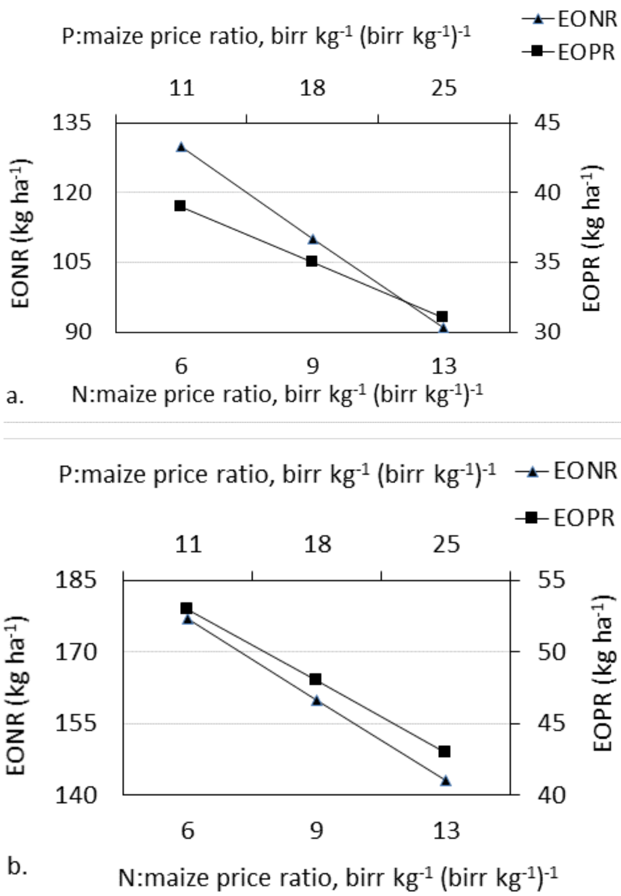

Figure 4. The effect of cost/price ratio on economic optimum N rate and P rate on maize-lupine total intercrop yield at South Achefer (a) and Mecha (b) in North-Western Ethiopia.

reported low N use efficiency at higher N application with increased residual soil nitrate and increased risk of N leaching.

Conclusions

Maize-lupine intercrop responded to N and P application in North-Western Ethiopia with yield increase of 4.14 t ha^{-1} at South Achefer and 7.05 t ha^{-1} at Mecha over unfertilized. Economic optimum rates decreased from 130/39 to 91/31 N/P kg ha^{-1} at South Achefer and from 177/53 to 143/43 kg N/P ha^{-1} at Mecha as cost price ratios of N cost kg^{-1}/maize grain price kg^{-1} increased from 6 to 13 and P cost kg^{-1}/maize grain price kg^{-1} increased from 11 to 25. Therefore, seasonal price information is vital to adjust the economic optimum rates. Nitrogen use efficiencies of maize decreased as high as 58% in maize-lupine intercropping when N applied increased from 64 to 192 kg N ha^{-1}. Further studies need to be conducted over seasons and locations to verify the results.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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ABBREVIATIONS:

AEN, agronomic efficiency of applied Nitrogen; **AONR,**

agronomic optimum Nitrogen Rate, **AOPR,** agronomic optimum phosphorus rate; **CPR,** cost price ratio; **EONR,** economic optimum nitrogen rate; **EOPR,** economic optimum phosphorus rate; **EYM,** equivalent Yield of Maize; **LAI,** leaf area index; **PEN,** physiological efficiency of applied nitrogen; **PFPN,** partial factor productivity of applied Nitrogen; **REN,** recovery efficiency of applied Nitrogen; **TKW,** thousand kernel weight.

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