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Nitrogen use efficiency of tef [Eragrostis tef (Zucc.) Trotter] as affected by nitrogen fertilizer under chickpea-tef rotation at Tahtay Koraro District, North Ethiopia

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Study was carried out to evaluate the supplementary nitrogen requirement of tef to enhance nitrogen use efficiency of tef grown under chickpea-tef rotation cropping. On-farm, experiment was conducted during the 2015 main cropping season at Tahtay Koraro District of the Tigray regional State, Ethiopia on tef after preceding chickpea. The experiment was set in a randomized complete block design with three replications. Seven treatments: Six N levels (0, 11.5, 23, 34.5, 46, and 69 kg N ha^{-1}) under the chickpea-tef rotation and the seventh one negative control (0 kg N ha^{-1}) under the continuous tef cropping were tested. Surface soil samples were collected before tef sowing and after harvesting. They were analyzed for selected soil properties. Clay sized particles dominate the soil of the experimental site and the textural class of the soil is clayey. There was a difference in the bulk density of the same soil between the chickpea-tef and tef-tef sequence. Nitrogen and organic carbon were higher in soil under chickpea-tef cropping sequence than in soil under continuous tef cropping. Application of different N rates under chickpea-tef rotation statistically significantly affected grain (GNU), straw (SNU) and total nitrogen uptake (TNU) (kg ha^{-1}). The highest total tef nitrogen uptake (59 kg N ha^{-1}) was obtained in response to application of 34.5 kg N ha^{-1}. The highest apparent nitrogen recovery (81%), agronomic efficiency (10.48 kg kg^{-1}) and physiological N use efficiency were obtained in response to the lower N rate (11.5 kg N ha^{-1}), 23 kg N ha^{-1} rate and 34.5 kg N ha^{-1} respectively. The highest grain protein content (7.78%) was recorded for grain harvested from plots fertilized with 23 kg N ha^{-1}. Hence, it could be concluded that, under chickpea-tef rotation cropping system some supplementary nitrogen is needed to fulfill the nitrogen requirement and nitrogen use efficiency of tef crop at the study area.

Key words: Chickpea, tef, nitrogen uptake, nitrogen use efficiency, protein content.

INTRODUCTION

Despite its staple importance in the overall national food security of the country (Kebebew et al., 2013), tef [*Eragrostic* tef (Zucc.) *trotter*] productivity is relatively low. Tef productivity and quality in Tigray is habituated by various factors of which environmental, genetics, management, capital, and input conditions are the most

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relevant. In most cases, high tef yield demands an increase in nitrogen application. Nitrogen fertilizer is one of the main inputs for cereals production; as it is often the most limiting nutrient for crop yield in many parts of the world (Giller, 2004).

Many-fold increase in the use of fertilizers nitrogen was detected with the increased agricultural food production worldwide over the past few decades. Therefore, the accommodation of the needs of the escalating world population by developing a highly productive agriculture, whilst at the same time preserving the quality of the environment (Hirel et al., 2007) is believed to be challenging for the next decades. Excessive addition of this nutrient can contribute to the combined effects of denitrification, volatilization and leaching then watercourse pollution (Semenov et al., 2007). Reduction of applied N fertilizer rate to an optimized level can reduce soil nitrate leaching (Power et al., 2000).

Development of a more sustainable agricultural production and cropping system is becoming very important nowadays to improve soil nitrogen; this includes legumes in the cereals cropping system; rotation, inter-cropping, which is the most effective tool for significant reduction of the uses of external mineral N-input and an increase of crops nitrogen uptake and use efficiency (Nevens et al., 2004); it maintains soil structure, increases soil organic matter, increases water use efficiency, reduces soil erosion and pest infestation (Halvorson et al., 2004 and Riedell et al., 2009). Nitrogen use efficiency (NUE) for cereal production including tef is approximately 33% (Raun and Johson, 1999) worldwide.

Research is required to increase crop NUE and profitability to develop sustainable farming systems in response to persistently increasing economic and environmental pressures. According to Sowers et al. (1994), the application of high nitrogen rates may result in poor nitrogen uptake and low NUE due to excessive nitrogen losses. A better insight of NUE of tef is needed to augment sustainability of legume-cereal base rotations. Lopez and Lopez (2001) showed that nitrogen efficiency indices are significantly affected by crop rotation and nitrogen fertilizer rate. Yamoah et al. (1998) concluded that nitrogen efficiency is greater in crop rotation than in monoculture systems.

Crop rotation; legume with cereals has been practiced for long to improve soil fertility and increase productivity of the succeeding non-leguminous crops in Tigray. Fababean, chickpea, and vetch are commonly used in the rotation system in most areas of the region. In the study area, farmers most time rotate chickpea with *tef*. The valuable influence of legume based rotation cropping system is well known in the study area.

Farmers use nitrogen and phosphorus fertilizers for their cereal crops at a rate of 69 and 46 kg ha^{-1}, respectively which is a blanket recommendation. However, after leguminous crops, farmers decide on how much nitrogen fertilizer they have to apply for their subsequent cereal crops based on their experiences. They reduce nitrogen fertilizer to half and even to zero for their succeeding cereal crops. This is because there is a knowledge gap on the significant contribution of preceding legumes to soil nitrogen addition and its effect on nitrogen use efficiency for succeeding t*ef* crop. Hence, this study was carried out to evaluate the nitrogen use efficiency of tef as influenced by supplementary nitrogen fertilizer rates after chickpea.

MATERIALS AND METHODS

Field experiment was conducted during the 2015 cropping season on selected farmers' field at Tahtay Koraro District, northwestern Tigray, northern Ethiopia (1,957 m.a.s.l., 14°03' 48.9'' N and 38°23' 51.9'' E). The area was selected for its long term experience in chickpea-tef rotation cropping system. Soil type of the study area is mainly vertisol (TFEB, 1995) (Figure 1).

The district is categorized under the semi-arid tropical mid highlands (SA_3) belt of Ethiopia where most of the middle altitude crops such as tef *(Eragrostic tef*), fababean (*Vicia faba* L.), and chickpea (*Cicer arietinum* L.) are commonly grown. The area is characterized by uni-modal rainfall pattern and received annual rainfall of 769.71 mm during the experimentation in 2015 cropping season. The average maximum and minimum temperatures were 28.87 and 13.86°C, respectively (Figure 2).

The trial area was sown to tef without any fertilizers application in order to exhaust nutrients built up from previous cropping seasons during the 2013 cropping season. In the following year, 2014, chickpea cv. *Mariye* was sown at a seed rate of 150 kg ha^{-1}. During 2015 cropping season, tef cv. *Quncho* was sown at a seed rate of 10 kg ha^{-1}, with six levels of nitrogen (0, 11.5, 23, 34.5, 46, and 69 kg N ha^{-1}) applied to plots under chickpea-tef rotation and one negative control to plots under *tef-tef* cropping sequence. This negative control was used to see the contribution of chickpea to residual nitrogen. The experiment was arranged in a randomized complete block design (RCBD) replicated three times. Plot size was 4 by 3 m (12 m^2). The spacing between blocks plots and plant rows was 1 m, 0.5 m and 20 cm, respectively.

Most of the local farmers do not use fertilizer later for legumes for successive cereals, but some farmers use nitrogen fertilizer at a rate of 23 kg ha^{-1}. Thus, the nitrogen levels were formulated based on the level that the local farmers use. Nitrogen was applied in split at sowing and the remaining at tillering initiation period for the tef crop to supply nitrogen at different stages and to reduce nitrogen loss. Plots received phosphorus, potassium and sulfur fertilizers at rates 69 kg P_2O_5 ha^{-1}, 80 kg K_2O ha^{-1} and 30 kg S ha^{-1}as; triple super phosphate (TSP), potassium chloride (KCl) and calcium sulphate (gypsum), respectively in basal at planting. All plots were hand-weeded.

Representative soil samples were collected from 21 experimental plots before and after the experimentation in 2015 cropping season, using zigzag sampling method from 0 to 20 cm depth. Accordingly, seven composite samples were made from plots that received the same treatments. The collected composite soil samples were air dried, milled and sieved to pass through a 2 mm sieve except for soil organic carbon (OC) and total N analysis which passed through 0.5 mm sieve (Table 1). Organic matter (OM) was calculated by multiplying organic carbon figure by the conventional "Van Berminelen factor" of 1.724. Samples taken after the chickpea were used to see the contribution of precursor chickpea to soil physico-chemical properties. Later, crop maturity tef was hand harvested from a net plot size of (10.4 m^2), air dried and biomass was recorded and threshed.

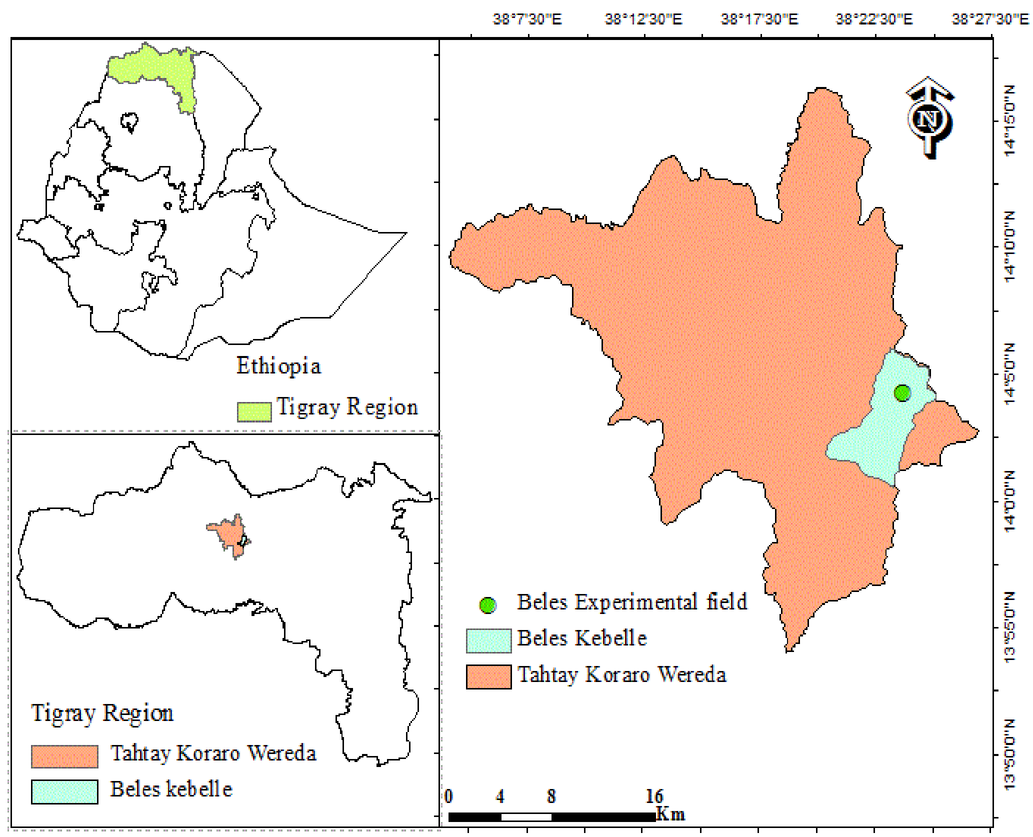

Figure 1. Location map of the study area.

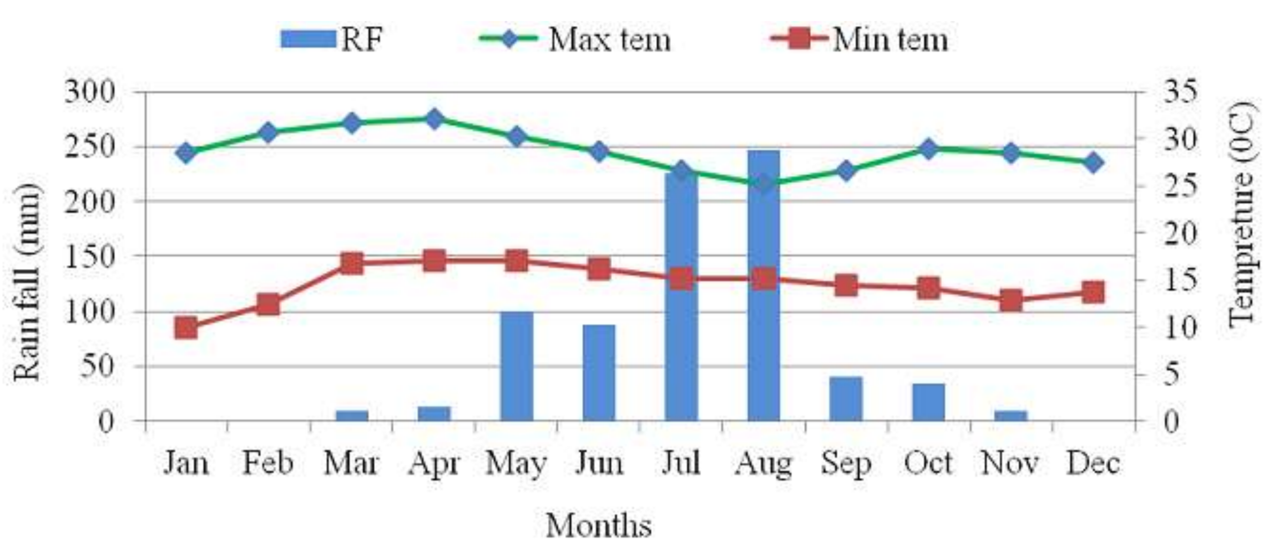

Figure 2. Monthly rain fall, maximum and minimum temperature of the study area for 2015 cropping season (Where; RF= Rain Fall, Max tem= Maximum temperature and Min tem= Minimum temperature).

Following threshing, grain and straw yields were calculated on a hectare basis at 12 and 20% moisture content, respectively. Plant samples were also collected randomly after maturity, from each experimental plot for nitrogen analysis. The plant samples were partitioned into grain and straw and washed with distilled water to clean the samples from contaminants like dust before grinding. The grain and straw samples (after washing) were separately oven dried at 70°C until it retained constant weight for 24 h. After drying, the

Table 1. Soil and plant parameters analyzed and their respective methods.

Parameter	Method of analysis	According to
Particle size	Hydrometer method	Bouyoucos (1962)
pH (1:2.5)	Potentiometric method	Rhoades (1982)
EC (1:2.5)	EC meter	Jakson (1967)
OC	Wet Oxidation method	Walkely and Black (1934)
TN	Kejeldah method	Bremner and Mulvaney (1982)
Avail. P	Olsen method	Olsen et al (1954)
CEC	Ammonium acetate method	FAO (2008)

plant tissue samples were ground and passed through 0.5 mm sieve for analysis of N concentration.

Grain and straw nitrogen contents (%), on a dry matter basis were determined by micro-Kjeldahl digestion procedure as described by Bremner and Mulvaney (1982). Total Nitrogen uptake (kg ha^{-1}) of teff was calculated by multiplying the nitrogen content of the straw and grain by their respective yields (Bowen and Zapata, 1991). Using the procedures described by Fageria and Baligar (2003), apparent N recovery (AR) in cereal biomass, agronomic efficiency (AE) of fertilizer N and physiological N use efficiency were calculated.

Total nitrogen uptake

N uptake of grain or straw (kg ha^{-1}) = Yield of grain or straw (kg ha^{-1}) x N concentration of grain or straw (%) x 10^{-2} (i)

Total N uptake = N uptake of grain + N uptake of straw (ii)

Apparent N recovery (kg kg^{-1})

Apparent N recovery = $(Un - U_0)/n$ ……………………..….. (iii)

Where; Un stand for nutrient uptake at 'n' rate of fertilizer, Uo stands for nutrient uptake at control (no fertilizer) and 'n' stand for amount of fertilizer applied.

Agronomic N use efficiency (kg kg^{-1})

Agronomic N use efficiency = $(Gn - G_0)/n$ ………..……….. (iv)

Where; Gn and Go stand for grain yield fertilized at 'n' rates of fertilizer and grain yield unfertilized, respectively, and 'n' stand for nutrient applied.

Physiological N use efficiency (kg kg^{-1})

Physiological N use efficiency = (Yn - Y0) / (Un - U0) …….. (v)

Where; Yn is the total biological yield (grain plus straw) of the fertilized plot, Yu is the total biological yield in the unfertilized plot, Un is the nutrient accumulation in a fertilized plot, and Uo is the nutrient accumulation in the unfertilized plot.

Grain protein

This was calculated as (AACC, 2000)
% grain protein = % N in grain × 5.7 ……………..…..……… (vi)

RESULTS AND DISCUSSION

Physical properties of the soil

Particle size distributions

Result indicated that particle size distribution is almost similar in both chickpea-tef and tef-tef cropping sequence. As shown in Table 2, clay size particles dominate from the soil particles in the experimental site; hence, the textural class of the soil is clayey.

Bulk density: Even though it is insignificant, the result showed a difference in bulk density among the two cropping sequences. The experimental soil was found to have bulk density of 1.33 and 1.34 g cm^{-3} for chickpea-tef and tef-tef sequence, respectively (Table 2). Since organic matter promotes aggregation and, thus, tends to reduce bulk density, this lower bulk density may be attributed to the effect of the precursor chickpea that contributes organic matter to the soil.

Chemical properties of soils

Soil reaction

The soil reaction (pH) level of the experimental site for both cropping sequences before planting tef and after harvest was almost constant (Table 3). According to Tekalign (1991), soil reaction rating, and soil of the study site is classified under moderately alkaline in reaction. Measurements of EC are used as indication of total quantities of soluble salts in soils. Also based on Marx et al. (1999) rating reported that, soil of the experimental site is categorized under low level of soluble salts and has no salinity problem.

Organic carbon

Results in Table 3 indicate that, organic carbon (OC) was higher in soil under chickpea-tef cropping sequence than in soil under continuous tef cropping. Hence, the preceding chickpea contributed to increased level of OC

Table 2. Physical properties of the soil of the experimental site (0-20 cm).

Cropping sequence	Particle sizes distribution			Textural class	Bulk density (g cm^{-3})
	Sand	Silt	Clay		
Chickpea-tef	16	30	54	Clay	1.33
Tef-Tef	18	29	53	Clay	1.34

Table 3. Selected soil chemical properties of the experimental site before and after tef planting.

Cropping sequence	Time of sampling	pH	EC (mmhos cm^{-1})	OC (%)	TN (%)	Av. P (mg kg^{-1})	Ex. K (ppm)	CEC (cmol(+) kg^{-1})
Chickpea-tef	Before	7.86	0.26	0.94	0.12	5.26	0.54	48.54
	After	7.73	0.23	0.67	0.08	6.39	0.59	50.2
Tef-Tef	Before	7.67	0.28	0.52	0.10	5.10	0.37	46
	After	7.61	0.24	0.60	0.06	5.62	0.66	47.8

Where; pH= power of Hydrogen, EC = Electrical Conductivity, OC= Organic Carbon, OM= Organic Matter, TN= Total Nitrogen, Av.P= Available Phosphorus, Ex.K= Exchangeable Potassium and CEC= Cation Exchange Capacity.

in the soil as compared to the tef-tef mono cropping. After harvesting tef, percent organic carbon in soil under chickpea-tef cropping sequence decreased by 28%, while it increased by 15% under tef-tef cropping sequence compared to that before tef sowing. This shows organic carbon depletion from soil under chickpea-tef cropping sequence.

This depletion could be due to higher soil nitrogen content (Table 3) under chickpea-tef cropping sequence that could be used by microorganisms to multiply their cells and subsequently increase organic matter decomposition.

Total nitrogen

Soil TN content is higher for chickpea-tef cropping sequence than continuous tef cropping before sowing and after harvesting (Table 3). This higher nitrogen concentration in the chickpea-tef rotation might be due to the contribution of previous chickpea to soil N accumulation.

In line with this, chickpea has a role to play in the maintenance of the soil N fertility in the cereal-based cropping systems of the Ethiopian highlands, either directly through the net effect of fixed or more likely through the sparing of soil nitrate (Holford and Crocker, 1997). The soil TN content before tef sowing was higher than that of after harvest for both cropping sequences.

Available phosphorus (Olsen P)

Available phosphorus content of soil was higher for soil under chickpea-tef cropping sequence relative to tef mono cropping system. Therefore, chickpea-tef cropping sequence has potential of improving available soil phosphorus.

Cation exchange capacity (CEC)

Data in Table 3 indicate that, CEC of the soil was very high as per the rating established by Landon (1991). This high CEC might be due to, higher clay content of the soil which contributes to higher CEC. CEC of soil under both cropping sequences was higher after harvesting than before tef sowing.

Residual nitrogen in the soil

Nitrogen accumulated in soil before tef sowing and after tef harvesting was assessed as the average result of plots that received the same treatments. Before sowing tef, higher residual nitrogen was recorded for the chickpea-tef rotation as compared to that of tef-tef sequence. This might be because of, part of the N fixed by the precursor chickpea remains in the soil as root residues or litter fall (Table 4).

Yaacob and Blair (1980) noted that, N content of soil is increased by including legumes in the cropping systems. Hence, legume cultivation increases soil organic N content which conserves N for use by subsequently planted cereal crops. However, after harvesting tef, results revealed depletion of N rather than its accumulation as residual N in the soil. More N was depleted from plots treated with 0 and 69 kg N ha^{-1} under

Table 4. Amounts of nitrogen in soil before and after tef harvesting.

Treatment (kg N ha^{-1})	Soil N before sowing		Soil N after harvesting		Depleted N (kg ha^{-1})
	SN (%)	T + SN (kg ha^{-1})	(%)	(kg ha^{-1})	
0	0.12	3192	0.06	1596	1596
11.5	0.11	2938	0.10	2660	278
23	0.11	2949	0.09	2394	555
34.5	0.10	2695	0.06	1596	1099
46	0.09	2440	0.07	1862	578
69	0.13	3527	0.07	1862	1665
Under continuous tef cropping					
0	0.10	2680	0.06	1596	1084

Where; SN= Soil Nitrogen, T= treatment.

Table 5. Nitrogen uptake of tef as affected by nitrogen fertilizer and previous chickpea.

Nitrogen rates (N kg ha^{-1})		GNU	SNU	TNU
			(kg ha^{-1})	
	0.00	12.72	15.01	27.73
	11.50	13.68	23.89	37.57
	23.00	17.53	31.85	49.38
	34.50	15.41	36.57	51.98
Chickpea-tef sequence	46.00	16.31	40.02	56.33
	69.00	16.24	39.00	55.24
Tef-tef sequence	0.00	11.76	25.69	37.45

Where; GNU= Grain Nitrogen Uptake, SNU= Straw Nitrogen Uptake and TNU= Total Nitrogen Uptake.

chickpea tef cropping sequence followed by plots treated with 0 and 34.5 kg N ha^{-1} under tef-tef and chickpea-tef cropping sequences, respectively.

More depletions of N from plots not treated were expected as plant that used the available N in the soil.

Conversely, more depletion of N from plots treated with higher rates of N could be due to higher biomass production than grain yield (Appendix Table 1). Only higher grain yield was obtained from plots treated with 34.5 kg N ha^{-1}. Therefore, at higher rates more N was used for plant biomass production than grain yield in this study.

Nitrogen uptake of tef

Grain, straw and total N uptake of tef

Tef responded considerably to the precursor chickpea during two year of experiment at the study area. Fertilizer nitrogen application for tef after chickpea positively affected grain (GNU), straw (SNU) and total nitrogen uptake (TNU) (kg ha^{-1}). The result shows that total nitrogen uptake improved with increasing rate of nitrogen and tend to decline at higher rates beyond 46 kg N ha^{-1} (Table 5) in rotation with chickpea. Highest total nitrogen uptake (56.33 kg N ha^{-1}) was recorded for 46 kg N ha^{-1} rate.

In line with this study, Selamyihun et al. (1999) reported that total N uptake increased significantly, concomitant with grain and straw yields, up to the application 30 kg N ha^{-1} rate: TNU values were 43.9, 62.2 and 66.6 kg N ha^{-1} for 0, 30 and 60 kg fertilizer N ha^{-1}, respectively. The total nitrogen uptake has a positive association with that of economic yield. Therefore, the treatment that gave maximum economic yield (23 kg N ha^{-1}) statistically the same with plots received 34.5 kg N $^{ha-1}$ was also highest in total nitrogen uptake. (23 kg N ha^{-1}) was also highest in economic yield statistically the same with plots received 34.5 kg N ha^{-1}.

Nitrogen use efficiency indices

Apparent nitrogen recovery (ANR)

The different rates of nitrogen applied under chickpea-tef rotation cropping influenced by apparent nitrogen recovery of tef. According to the result obtain, ANR was highest (90%) at the lower N rate applied (11.5 kg N ha^{-1})

Table 6. Apparent nitrogen recovery, agronomic and physiologic nitrogen use efficiency of tef.

Treatments (kg N ha^{-1})		ANR (%)	ANUE (kg kg^{-1})	PNUE (kg kg^{-1})
	0.00	0	0	0
	11.50	90	4.78	47.94
	23.00	75	10.48	98.02
	34.50	75	7.62	85.83
Chickpea-tef sequence	46.00	62	4.85	82.92
	69.00	41	2.22	97.68
Tef-tef sequence	0.00	0	0	0.00

Where; ANR= Apparent Nitrogen Recovery, ANUE= Agronomic Nitrogen Use Efficiency and PNUE= Physiological Nitrogen Use Efficiency.

and lowest (41%) at the higher (69 kg N ha^{-1}) N rate applied. This indicates that, as the application of fertilizer nitrogen increases the chance of tef plants to extract the entire applied N to its biomass decreases (Table 6).

In line with this study, Abraha (2013) and Haile et al. (2012) also reported that N uptake efficiency was higher at lower rates of N application but drastically decreased with further increase in the rate of the nutrient for tef and wheat, respectively. This might be due to combination of leaching, fixation and volatilization at higher N rates other than plant uptake.

According to Dobermann (2005), apparent N recovery efficiency of tef at the plot supplemented with higher N (69 kg N ha^{-1}) fell within the common range (30 to 50%) values, whereas the rest of the plots showed the experiment was under well managed system (> 50%). Selamyihun et al. (1999) also reported that; mean apparent recovery (ANR) of fertilizer N in above-ground biomass of tef was 61.1 and 14.5% across two seasons for 0 to 30 and 30 to 60 kg N ha^{-1} intervals, respectively for tef.

Agronomic (ANUE) and physiological nitrogen use efficiency (PNUE)

Both ANUE and PNUE of tef were significantly affected by the different nitrogen rates applied under chickpea-tef rotational cropping. Teff ANUE exhibited decreasing mean values with increasing levels of nitrogen (from 10.48 to 2.22 kg grain per kg applied N) which means under lower N rates, dry matter partitioned to the grain per unit of total plant N was higher compared with the higher N rates (Table 6). This indicated that at low level of nitrogen the primary factor limiting crop growth and final yield is nitrogen and at higher N supply incremental yield gains become smaller because yield determining factors other than N become more limiting as the maximum yield potential is approached (Dobermann, 2005). According to this author, the higher agronomic efficiency (10.48 kg kg^{-1}) of N applied to tef at this particular study falls within the common range (10 to 30 kg kg^{-1}). The N requirement of tef after precursor chickpea targeting on an economic yield was 23 kg ha^{-1} as compared with the other rates.

Physiological N use efficiency of tef under different N application rate ranged from 47 to 98 kg kg^{-1} N. Highest PNUE of nitrogen was obtained from plots supplemented with 23 kg N ha^{-1} (Table 6). Except for plots that were treated with 11.5 kg N ha^{-1}, physiological N efficiency was whether beyond the common range (> 60 kg kg^{-1}) which might contribute to the fact that the experiment was under well managed system or the soil had low nitrogen supply or else there was higher N loss through leaching, volatilization, and so on (Dobermann, 2005).

Grain protein content

Grain protein content of tef was affected by the N rates applied at the study area. The highest and lowest grain protein contents were recorded for grain harvested from plots fertilized with 23 kg N ha^{-1} (7.78%) in the form of urea and 0 kg N ha^{-1} (on both rotation systems) (6.95%), respectively (Figure 3). In general grain protein content showed nearly increasing trend with nitrogen rates at the study area.

Thus results are in line with Halvorson et al. (2004) and Bereket et al. (2014) who reported that grain protein content of cereals increased with nitrogen rates. Grain protein content under chickpea-tef rotation was greater than that of tef-tef rotation at the study area. This may be due to the effect of legumes on residual N.

Conclusion

Crop rotation especially, legume with cereals has been practiced for long to improve soil fertility for the succeeding non-leguminous crops in Tigray. In the study area, farmers most of the time rotate chickpea with tef in order to improve fertility of their soil, nutrient use efficiency of their crops and increase tef productivity. Although the beneficial effects of rotating leguminous crops with

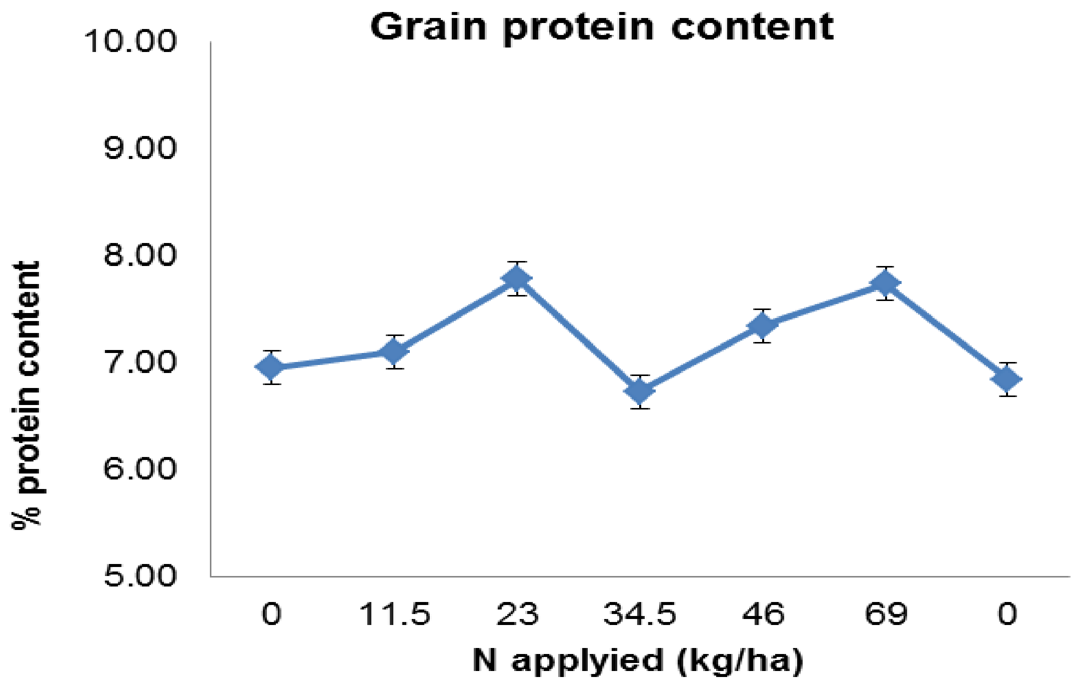

Figure 3. Grain protein content as affected by the different N rates at the study area.

cereals were well known in the study area, there was an information gap on contribution of preceding legumes on the significant nitrogen addition to the soil and its effect on nitrogen use efficiency for succeeding cereal crops (tef). Accordingly, study was carried out to determine the nitrogen use efficiency of teff as influenced by supplementary nitrogen fertilizer rates after chickpea.

Application of different N rates in the chickpea-teff rotation significantly affected crop nitrogen uptake and use efficiency indices. The highest total nitrogen uptake was recorded from the 46 kg N ha^{-1} rate. Apparent nitrogen recovery, agronomic and physiological nitrogen use efficiencies were also significantly influenced by different nitrogen levels applied. Apparent nitrogen recovery of N applied to tef was decreased with increased rates of nitrogen in the chickpea-tef rotation. Maximum agronomic efficiency (10.48 kg kg^{-1}) of N applied to tef was obtained from the 23 kg N ha^{-1} rate and decreased beyond this rate; indicating reducing biological response to increased N rates exceeding 23 kg ha^{-1}. Highest physiological efficiency of nitrogen was also obtained from plots supplemented with 34.5 kg N ha^{-1}.

Therefore, it could be concluded that, under chickpea-teff rotation cropping system some amount of supplementary nitrogen input is needed to fulfill the nitrogen requirement and nitrogen use efficiency of tef crop at the study area. Legume-cereal rotational cropping system is important to reduce the input of inorganic nitrogen fertilizers, improve crops nitrogen use efficiency, reduce environmental pollution and for the soil to sustainably produce yield.

CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

REFERENCES

Abraha A (2013). Effects of rates and time of nitrogen fertilizer application on yield and yield components of tef [*Eragrostis* tef (zucc.) trotter] in habro district, eastern Ethiopia. M.Sc.Thesis.

Bowen GD, Zapata F (1991). Efficiency in uptake and use of nitrogen by plants. In: IAEA (ed.) Stable isotopes in plant nutrition, soil fertility and environmental studies. IAEA, Vienna pp. 349-362.

Bremner JM, Mulvaney CS (1982). Nitrogen - Total. In A.L. Page, R.H. Miller and D.R.Keeney (eds.). Methods of soil analysis. Part 2-Chemical and microbiological properties. Agronomy 9(2):595-624.

Dobermann A (2005). International fertilizer association. Nitrogen use efficiency – state of the art. International Workshop on Enhanced-Efficiency Fertilizers. Frankfurt, Germany pp. 28-30.

Fageria NK, Baligar VC (2003). Methodology for Evaluation of Lowland Rice Genotypes for Nitrogen Use Efficiency. Journal of Plant Nutrition 26(6):1315-1333

Giller KE (2004). Emerging technologies to increase the efficiency of use of fertilizer nitrogen. In: A.R. Mosier, J. K. Syers and J.R. Freney (eds), Agriculture and the nitrogen Cycle. Scope 65. Island Press Washington DC pp. 35-51.

Haile D, Nigussie D, Ayana A (2012). Nitrogen use efficiency of bread wheat: Effects of nitrogen rate and time of application. Journal of Soil Science and Plant Nutrition 12(3):389-410.

Halvorson AD, Nielsen DC, Reule CA (2004). Nitrogen fertilization and rotation effects on no-till dry land wheat production. Agronomy Journal 96:1196-1201.

Hirel B, Le Gouis J, Ney B, Gallais A (2007). The challenge of improving nitrogen use efficiency in crop plants: toward a more central role for genetic variability and quantitative genetics within integrated approaches. Jornal of Experimental Botany 58(9):2369-2387.

Kebebew A, Solomon C, Gizaw M (2013). Conventional and Molecular Teff Breeding. pp. 33-37. In:Zerhun Tadele (eds.), Achievements and

Prospects of Teff Improvement; Proceeding of the Second International Workshop, November 7-9, 2011, Debre Zeit, Ethiopia. Ethiopian Institute of Agricultural Research Institute, Addis Ababa, Ethiopia; Institute of Plant Sciences, University of Bern, Switzerland. Printed at stampfli AG, 3001 Bern, Switzerland. ISBN: 978-3-033-03818-9.

Lopez-Bellido RJ, Lopez-Bellido L (2001). Efficiency of nitrogen in wheat under Mediterranean condition: effect of tillage, crop rotation and N fertilization. Field Crop Research 71(1):31-64.

Nevens F, Bommele LM, Reheul D, Verbruggen I, De Cauwer B (2004). Reducing fertiliser N use by application of ley-arable rotations. Grassland Science 9:532-534.

Power JF, Wiese R, Flowerday D (2000). Managing nitrogen for water quality: Lesson from management systems evaluation area. Journal Environmental Quality 29:335-366.

Raun WR, Johnson GV (1999). Improving nitrogen use efficiency for cereal production. Agronomy Journal 91:357-363.

Selamyihun Kidanu, Tanner DG, Tekalign Mamo (1999). Effect of Nitrogen Fertiliser Applied to Tef on the Yield and N Response of Succeeding Tef and Durum Wheatona Highland Vertisol. African Crop Science Journal 7:35-46.

Semenov MA, Jamieson PD, Martre P (2007). Deconvoluting nitrogen use efficiency in wheat: A simulation study. European Journal of Agronomy 26:283-294.

Tigray Finance and Economic bureau (TFEB) (1995). Major soil types of Tigray regional state. Physical planning development, GIS center.

Yamoah CF, Varvel GE, Waltman WJ, Francis CA (1998). Long-term nitrogen use and nitrogen removalindexincontinuous crops and rotations. Field Crop Research 57:15-27.

Appendix Table 1. Grain yield of tef as influenced by N rate after precursor chickpea, 2015 main cropping season.

Cropping sequences	Treatment (N kg ha^{-1})	GY (kg ha^{-1})
Chickpea-tef Sequence	0.00	1043^{cd}
	11.5	1098^{c}
	23.0	1284^{a}
	34.5	1306^{a}
	46.0	1266^{ab}
	69.0	1196^{b}
Tef-tef sequence	0.00	980^{d}
Mean		117
LSD (P≤0.05)		87
CV (%)		4.2

Where; GY= Grain Yield, LSD= Least significant difference and CV= Coefficient of Variance; Variable means followed by the same letters are not significantly different (P ≤ 0.05) according to LSD Tests.