P-ISSN: 2305-6622; E-ISSN: 2306-3599

International Journal of

Agriculture and Biosciences

www.ijagbio.com; editor@ijagbio.com

Research Article

Supplementary Nitrogen Requirement of Teff [*Eragrostis teff* (Zucc.) Trotter] under Chickpea-Teff Rotation in Northwestern Tigray, Northern Ethiopia

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Article History: Received: November 22, 2018 Revised: January 12, 2019 Accepted: February 02, 2019

ABSTRACT

Small-scale farmers can't afford for commercial fertilizers, instead, they depend on rotating legume crops to provide nitrogen (N) for a subsequent cereal crops. Hence, on farm experiment was conducted to determine the supplementary nitrogen requirement of teff grown after chickpea at Tahtay koraro district. Six N levels (0, 11.5, 23, 34.5, 46, and 69 kg N ha^{-1}) were imposed on the plots under chickpea-teff rotation and one control treatment (0 kg N ha^{-1}) on plots under continuous teff cropping was also used to compare both rotations; laid in a randomized complete block design with three replications. Phosphorus, sulfur, and potassium fertilizers were also applied in basal for all plots at sowing. The soil samples collected from the 0-20 cm depth after chickpea and teff indicated that nitrogen status was medium and low, respectively. Teff grown after chickpea significantly responded to the different N rates and highest mean teff grain yield (13.06 q ha^{-1}) was obtained in response to application of 34.5 kg N ha^{-1}. However, the economic analysis showed that highest return (816%) was obtained in response to 23 kg N ha^{-1} rate. In conclusion, the contribution of chickpea to soil nitrogen was not enough to satisfy the succeeding teff N demand. However, more than half of the blanket recommended nitrogen fertilizer (64 kg N ha^{-1}) for teff can be reduced without any reduction in grain yield by practicing chickpea-teff rotation system. Hence, supplementation with 23 kg N ha^{-1} mineral fertilizer is necessary to fulfill the teff N requirement and attain optimum yield. Furthermore, legume-cereal rotation cropping reduces dependence on expensive chemical fertilizer inputs whereby protects the environment, human health and agricultural sustainability.

Key words: cereal-legume rotation, chickpea, fertilizer, grain yield, teff

INTRODUCTION

Teff, [*Eragrostis teff* (Zucc.) trotter] is an important cereal crop grown by over 5.6 million households, occupying more than three million hectares of land of cereals in the country (CSA, 2014) and it constitutes the major staple food grain for over 50 million Ethiopian people. This implies that teff is very important in the overall national food security of the country (Kebebew *et al.*, 2013) despite the relatively low productivity of the crop. Its overall national average grain yield is about 1500 kg ha^{-1} (CSA, 2014). The most important bottlenecks constraining the productivity of teff in Ethiopia are; the low yield potential of farmers' cultivars, lodging, and susceptibility to biotic (weeds and pests) and abiotic stresses (low moisture stress, waterlogging and low soil fertility conditions) (Fufa, 1998 and Kebebew *et al*., 2013).

Nitrogen (N) and phosphorus (P) were identified as being the most deficient nutrients in almost all Ethiopian soils four decades ago, and application of fertilizers containing N and P (urea and DAP) began in the late 1960s (Wassie and Tekalign, 2013) to improve the productivity of the soil. But, low soil nitrogen is often the major factor limiting crop production. Inorganic nitrogen fertilizer application, crop rotation and intercropping are some of the management practices.

Crop rotation is of great importance as it reduces insect, pest and disease incidence, ameliorate soil structure, improve organic matter levels, prevents proliferation of weeds and consequently increase yield of succeeding crops. Relying on leguminous crops in rotation and inter-cropping are also the most effective tools for significant reduction of the uses of external mineral N input and an increase of crops N use efficiency (Nevens *et al.*, 2004).

Cite This Article as: Tadele T, Wogi L, and A Kidanemariam, 2019. Supplementary nitrogen requirement of teff [*Eragrostis teff* (Zucc.) Trotter] under chickpea-teff rotation in northwestern Tigray, northern Ethiopia. Inter J Agri Biosci, 8(1): 25-31. www.ijagbio.com

Bereket *et al.*, (2011) reported that farmers in the mid-highlands and highlands of Ethiopia are well aware of the significance of crop rotation to replenish soil fertility and used this option. Smallholder farmers in Tigray and particularly in the study area have been introduced legume crops (mostly chickpea, fava bean, and field pea) in rotation with cereals since long time ago. In the study area, farmers most of the time rotate chickpea with teff.

The blanket fertilizers recommendation rate which is N and P at a rate of 69 and 46 kg ha^{-1}, respectively have been used for their cereal crops. However, following the preceding legumes, farmers reduce the N fertilizer by half and even to zero based on their long last experience. This is because; there is a dearth of information with respect to the significant contribution of previous legumes to the addition of soil N and its effect on yield of succeeding teff. Therefore, this study was initiated to determine the supplementary nitrogen requirement of teff grown after chickpea.

MATERIALS AND METHODS

Site description

Field experiment was conducted on selected vertisols (TFEB, 1995) of farmer's fields at Tahtay Koraro district, northwestern Tigray, northern Ethiopia (located at 14^0 03' 48.9'' N, 38^0 23' 51.9'' E and 1,957 meters above sea level elevation) (Figure 1 (a)). 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 teff (*Eragrostis tef*), fava bean (*Vicia faba* L.), and chickpea (*Cicer arietinum* L.) are commonly grown. Therefore, the area was selected mainly for its long-term experience in chickpea-teff rotation cropping system. The area like most part of the region is characterized by a uni-modal rainfall pattern and received an annual rainfall of 769.71 mm during the 2015 cropping season. The average maximum and minimum temperatures were 28.87 and 13.86 ^{0}C, respectively (Figure 1 (b)).

Experimental design and treatments

Treatments were set in a randomized complete block design (RCBD) replicated three times. Gross and net plot sizes were 3*4 m (12 m^2) and 4*2.6 (10.4 m^2), respectively. The spacing between blocks plots and plant rows were also 1 m, 0.5 m, and 0.20 m, respectively.

The trial was conducted on a permanent plot for three rotation cycles (2013-2015 cropping seasons) whereby teff was grown in the first year without any fertilizer in order to exhaust nutrients built up from previous cropping season. In the following year, 2014, the area was divided into two and sown to chickpea (cv. *Mariye*) and teff (cv. *Quncho*) at a seed rate of 150 and 10 kg ha^{-1}, respectively. During 2015, the teff rotation was imposed on the plots on which chickpea has been grown (chickpea-teff rotation) with six levels of nitrogen (0, 11.5, 23, 34.5, 46, and 69 kg N ha^{-1}) and on plots on which teff has been grown (teff-teff rotation) with 0 kg N ha^{-1} which is considered to be a negative control to compare crop rotation and continuous mono-cropping systems.

Most of the local farmers use no fertilizer after legumes for the successive cereals, but some farmers often use nitrogen fertilizer up to a rate of 23 kg ha^{-1}. Thus, the nitrogen levels were formulated based on the level that the local farmers use by going up and down. Nitrogen was applied in split at sowing and the remaining half at tiller initiation period for the teff crop to supply N at different stages and to reduce N loss. All plots received a basal dose of phosphorus, potassium and sulfur fertilizers at rates of 69 kg P_2O_5 ha^{-1}, 80 kg K_2O ha^{-1} and 30 kg S ha^{-1}. All plots were hand-weeded.

Collected agronomic data and analysis

Agronomic data such as days to emergence, heading, and physiological maturity; plant height, number of effective tillers per plant, spike length, biomass, and grain yield were recorded. Teff was hand harvested at maturity, dried and threshed. After threshing, grain and straw yields were weighed on a hectare basis at 12 and 20% moisture content, respectively. Harvest index was also calculated as a ratio of grain yield per plot to the total aboveground dry biomass. At crop maturity, net areas of each plot (10.2 m^2) were harvested and record the biomass yield.

All agronomic data were analyzed using the Gen stat 16^{th} ed. (2013) statistical package at a 95% confidence interval (Gomez and Gomez, 1984). Economic analysis was performed using a partial budget analysis to investigate the economic feasibility of the treatments which were tested in the experiment (CIMMYT, 1988). According to this manual, experimental yields are often higher than the yields that farmers could expect using the same treatments; hence in economic calculations, yields obtained from the experiment planted on representative farmers' fields were adjusted by 10% lower (CIMMYT, 1988).

Collected soil and plant samples and analysis

Representative soil samples were collected from the experimental area using zigzag sampling method from 0-20 cm depth during all rotation cycles. The three year soil samples are, i) one composite sample in the first year teff sole crop in 2013, ii) two samples from plots sown for teff and chickpea 2014 and iii) twenty-one samples from each experimental plot in 2015. Seven composite samples were made out of the twenty-one by merging samples from plots that were 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.

After maturity, plant samples were randomly collected from each experimental plot for nitrogen analysis taking border effect into account. The plant samples were partitioned into grain and straw and washed with distilled water to clean the samples from contaminants such as dust before grinding. The grain and straw samples (after washing) were separately oven dried at 70 ^{0}C until it retained constant weight for 24 hours. After drying, the plant tissue samples were ground and passed through 0.5 mm sieve for soil N analysis.

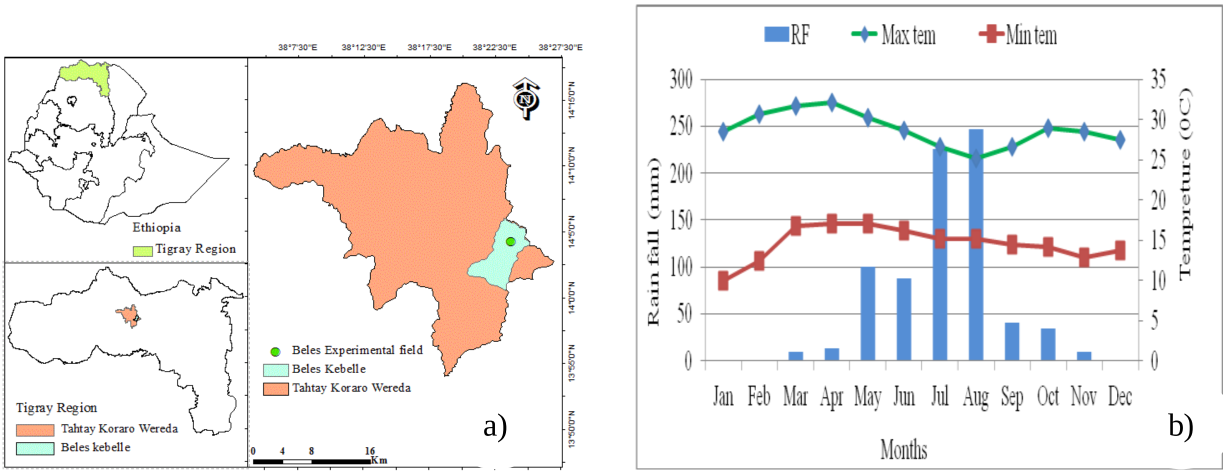

Fig. 1: Map of the study area (a) and monthly rainfall, maximum and minimum temperature for 2015 cropping season (b); Where; RF= rainfall, Max tem= maximum temperature and Min tem= minimum temperature

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

Parameter	Method of analysis	References
Particle size	Hydrometer method	Bouyoucos, 1962
pH (1:2.5)	pH meter	Rhoades, 1982
EC (1:2.5)	EC meter	Jakson, 1967
OC	Walkley and Black method	Walkley and Black, 1934
TN	Kjeldahl method	Bremner and Mulvaney, 1982
Avail. P	Olsen method	Olsen *et al*. 1954
Avail. K	Ammonium acetate method	FAO, 2008
CEC	Ammonium acetate method	FAO, 2008

Where; pH= power of hydrogen, EC = electrical conductivity, OC= organic carbon, TN= total nitrogen, Av.P= available phosphorus, Ex. K= exchangeable potassium, and CEC= cation exchange capacity.

RESULTS

Soil physicochemical properties

The physical and chemical properties of the experimental soil after chickpea and teff are indicated in Table 2. The textural class of the experimental soil is clayey which is due to the domination of clay sized particles. The bulk density of the experimental soil was also found to be lower after chickpea than teff (Table 2).

The soil reaction (pH) of the experimental site after chickpea and teff was lied out with in the preferable range (4 to 8) for most crops and productive soils (FAO, 2000). The electrical conductivity was also low across the two cropping sequences (Marx *et al.*, 1999). According to the results available phosphorus (Olse, 1954), exchangeable potassium (FAO, 2006) and CEC (Hazelton and Murphy, 2007) were medium, medium and high range, respectively (Table 2). The higher CEC of the soil after chickpea and tef might be due to higher clay content of the soil which contributes to a higher exchange site. According to Tekalign (1991) rating organic carbon for both cropping sequences was classified as low while nitrogen was medium after chickpea and low after teff which might be? **Incomplete sentence?**

Teff response to N fertilizer following chickpea

Effects of nitrogen on phenological and growth traits of teff under chickpea-teff rotation

Days to 50% emergence, 50% heading and physiological maturity: Statistically nitrogen fertilizer rates insignificantly (P > 0.05) influence days to teff emergence under chickpea-teff cropping sequence. Nitrogen fertilizer significantly hastened days to heading emergence and physiological maturity of teff under higher N rates than the lower N rates (Table 3). Generally, the number of days to heading and physiological maturity recorded over all the treated plots was significantly lower than that of unfertilized plots.

Plant height and panicle length: The analysis of variance showed that plant height and panicle length were significantly influenced by N fertilizer rates under chickpea-teff rotation. These teff growth traits showed increased trend with an increase in the application of N fertilizer rates (fig 2). Mean teff plant height and panicle length from plots received 69 kg N ha^{-1} rates significantly exceeded plots received 0 kg N ha^{-1} (under Chickpea-teff and teff-teff cropping sequence) by 18.2%; 22.3% and 21.5%; 22.2%, respectively (Appendix table 1). The teff panicle length (filled seed spike per plant) was showed a reducing trend with further increase in nitrogen fertilizer rates beyond 34.5 kg ha^{-1} (Figure 2).

Effects of nitrogen rate on yield and yield components of teff under chickpea-teff rotation

The number of Effective Tillers: The number of effective tillers was significantly affected by N fertilizer rates under chickpea-teff rotation. It was significantly increased (ranging from 2-6) in response to the increasing rate of nitrogen fertilizer (Figure 3). The result indicated that the enhancement of effective tillers development of teff plants is higher on plots that received nitrogen at higher rates.

Table 2: Selected soil physicochemical properties of the experimental.

Cropping Sequence (yearly)	Physical properties				Chemical properties							
	Sand	Silt	clay	Tex. clas	Bd	pH_w (1:2.5)	EC (mmhos/cm)	OC (%)	N (%)	Av.P (ppm)	Ex.K cmol(+)/kg)	CEC cmol(+)/kg)
After chickpea (2014)	16	30	54	Clay	1.33	7.86	0.26	0.94	0.13	5.26	0.54	48.54
After teff (2014)	18	29	53		1.34	7.67	0.28	0.52	0.08	5.10	0.37	46

Where; Tex.clas= Textural Class, pH_w= power of hydrogen on water suspension, 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.

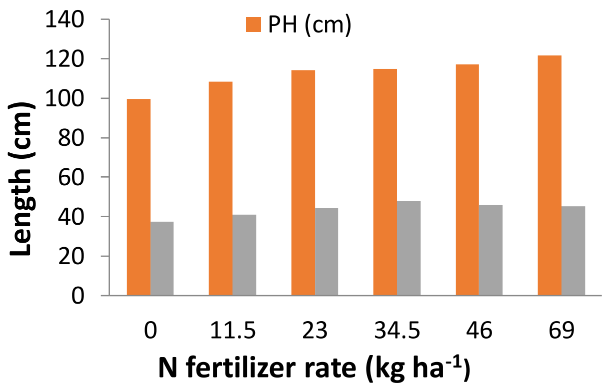

Fig. 2: Plant height and panicle length of teff as affected by nitrogen fertilizer after chickpea.

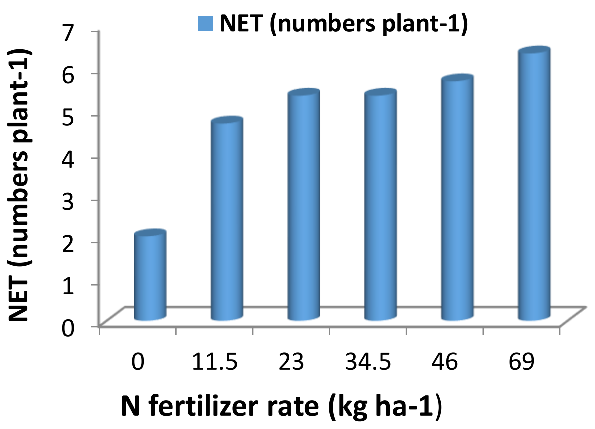

Fig. 3: Number of effective tillers as influenced by nitrogen fertilizer after precursor chickpea.

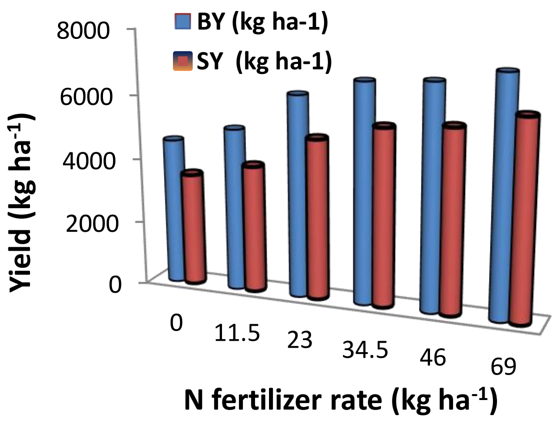

Fig. 4: Teff biomass and straw yields as affected by nitrogen after precursor chickpea

Table 3: Effect of nitrogen on teff emergency, heading and physiological maturity dates after precursor chickpea.

Treatment (kg N ha^{-1})		DE (days)	DH (days)	DPM (days)
Chickpea-teff sequence	0.00	6.67	59.33^{d}	112. 33^{d}
	11.5	6.33	54. 67^{b}	110. 00^{c}
	23.0	6.33	56. 33^{c}	109. 33^{c}
	34.5	6.33	54. 00^{b}	108. 00^{b}
	46.0	6.00	52. 67^{a}	106. 67^{a}
	69.0	6.00	51. 67^{a}	106. 33^{a}
Teff-teff sequence	0.00	6.33	59. 33^{d}	112. 33^{d}
Mean		6.29	55.43	109.29
LSD ($P \leq 0.05$)		ns	1.23	1.19
CV (%)		9.80	1.20	0.61

Where; DE= days to 50% emergence, DH= days to 50% heading, DPM= days to 90% physiological maturity, LSD= least significant difference, CV= coefficient of variance and ns= non-significant; means followed by the same letters are not significantly different.

Biomass and straw yield: The effect of fertilizer N on the biomass (BY) and straw yield (SY) of teff grown succeeding to chickpea was significant (Appendix table 1). Biomass and straw yields were increased with an increase in the rates of nitrogen fertilizer under chickpea-teff rotation (Figure 4). The highest biomass and straw yields were obtained in response to the application of 69 kg N ha^{-1} with 37.67; 41.56% and 42.6; 46.2% increase over plots received 0 kg N ha^{-1} under chickpea-teff rotation and continuous teff cropping, respectively. BY and SY production were relatively greater for plots under chickpea-teff cropping sequence than that of continuous teff mono-cropping.

Grain yield: Fertilizer N significantly affects teff grain (GY) which grown following to chickpea. GY showed an increasing trend as N fertilizer rates increased up to 34.5 kg N ha^{-1} rate. The highest grain yield obtained in response to the application of 34.5 kg N ha^{-1} with 20.14 and 24.96% increase over that of 0 kg N ha^{-1} under chickpea-teff rotation and continuous teff cropping, respectively (Table 4). Lowest grain yield was obtained from plots under continuous teff mono-cropping.

Harvest index: The effect of different rates of N fertilizer on teff harvest index in rotation with chickpea was statistically significant. The highest harvest index was scored on the control plots received 0 kg N ha^{-1} similar for both cropping sequences (chickpea-teff and teff-teff rotation) (Table 4). The harvest index was also low on plots treated with higher N rates.

Table 4: Grain yield and harvest index of teff as influenced by N rate after precursor chickpea, 2015 main cropping season

Treatment (N kg ha^{-1})		Grain yield			HI
		GY (kg ha^{-1})	IOC of (chickpea-teff) (%)	IONC (teff-teff sequence) (%)	
Chickpea-teff Sequence	0.00	1043^{cd}	0	6.04	0.23^{a}
	11.5	1098^{c}	5	10.75	0.22^{ab}
	23.0	1284^{a}	18.77	23.68	0.21^{bc}
	34.5	1306^{a}	20.14	24.96	0.19^{cd}
	46.0	1266^{ab}	17.61	22.59	0.18^{de}
	69.0	1196^{b}	12.79	18.06	0.16^{e}
Teff-teff sequence 0.00		980^{d}	-6.43	0	0.23^{a}
Mean		117			0.20
LSD (P≤0.05)		87			0.02
CV (%)		4.2			6.10

Where; GY= grain yield, IOC= increase over control, IONC= increase over negative control, LSD= least significant difference, CV= coefficient of variance and HI= harvest index; Variable means followed by the same letters are not significantly different (P ≤ 0.05) according to LSD tests.

Table 5: Partial budget analysis of N fertilizer for chickpea-teff cropping sequence

Treatments	fertilizer cost [Birr]	Transport and Application cost [Birr]	Total variable cost (TVC) [Birr]	Adj. yield (10% less) (kg ha^{-1})	Total Revenue (TR) [Grain yield*18]	Net Revenue [TR-TVC]	MRR (ratio)	MRR (%)
0.00	0.00	0	0.00	938.39	16891.09	16891.02	0.00	0.00
11.50	299.37	30	329.37	987.80	17780.31	17451.03	1.70	170
23.00	598.74	60	658.74	1155.44	20797.88	20139.18	8.16	816
34.50	898.11	90	988.11	1175.49	21158.82	20170.71	0.096	9.60
46.00	1197.48	120	1317.50	1139.18	20505.31	19187.74	D	D
69.00	1496.85	150	1646.90	1076.61	19378.93	17732.08	D	D

Where; ha= hectare and MRR= Marginal Rate of Return; X^D = this indicates dominance analysis.

Appendix Table 1: The mean of teff growth and [yield] as influenced by N fertilizer rates after precursor chickpea.

Rotation	N rates (kg ha^{-1})	Plant Height (cm)	Head Length (cm)	Net Effective Tillers (numbers plant^{-1})	Teff Biomass Yield (kg ha^{-1})	Teff Straw Yield (kg ha^{-1})
Chickpea-tef sequence	0.00	99.67^{cd}	37.53^{c}	2.00^{c}	4544^{cd}	3501de
	11.5	108.33^{bc}	41.00^{bc}	4.67^{b}	5041^{c}	3943d
	23.0	114.13^{ab}	44.27^{ab}	5.33^{ab}	6234^{b}	4950c
	34.5	114.93^{ab}	47.80^{a}	5.33^{ab}	6767^{ab}	5461bc
	46.0	117.27^{ab}	46.00^{ab}	5.67^{ab}	6894^{a}	5629bc
	69.0	121.80^{a}	45.27^{ab}	6.33^{a}	7290^{a}	6094a
Tef-tef sequence	0.00	94.67^{d}	37.20^{c}	2.00^{c}	4260^{d}	3280^{e}
Mean		110.11	42.72	4.48	5860	4690
$LSD_{(P\leq0.05)}$		11.69	5.99	1.33	638	613
CV (%)		6.00	7.90	16.7	6.12	7.35

Where; LSD= least significant difference and CV= coefficient of variance; Variable means followed by the same letters are not significantly different (P ≤ 0.05).

Partial budget analysis

According to the findings of this study the maximum grain yield was recorded form plots that were supplemented with 34.5 kg N ha^{-1} (Table 4). However, the undertaken economic analysis indicated that under the chickpea-teff rotational cropping system, the net revenue obtained in response to the application of 23 kg ha^{-1} nitrogen fertilizer for teff is economically beneficial after the precursor chickpea (Table 5). This indicated that no further earnings can be obtained by applying N fertilizer beyond that specific rate.

DISCUSSION

Soil texture is an indication of the degree of weathering, nutrient, and water holding capacity of the soil. Therefore, because of its higher clay content soils of the study site might have high nutrient and water holding capacity. The lower bulk density after chickpea might be attributed to the contribution of the precursor chickpea to soil organic matter which promotes aggregation thereby improves bulk density.

The observed higher residual nitrogen accumulation after chickpea might be due to the fact that chickpea has a role to play on soil N improvement either directly through the net effect of fixed nitrogen or more likely through the sparing of soil nitrate (Holford and Crocker, 1997). Yaacob and Blair (1980) noted that N content of soil increased by including legumes in the cropping systems.

The non-significant effect of N fertilizer rates on days to 50% emergence might be due to the reason that the residual N which has been already in the soil was enough as a starter for teff emergence. In contrast to this, Abraha (2013) reported that increasing rate of nitrogen significantly prolonged days until teff emergence. Early teff maturity on plots received higher N fertilizer rates might be due to the late drought; because the moisture was not enough for the highly vegetated plant biomass thereby forced the teff to mature early.

Plant height and head length are the main attributes contributing to teff grain and biomass yields. According to this study, plants on plots treated with higher rates of nitrogen were taller compared to plots treated with lower rates of nitrogen. Plant height obtained from all treated plots was significantly higher than unfertilized plots, which might be attributed to the fact that fertilizer N directly affects the vegetative growth of teff crop (Legesse, 2004).

The decreasing content or length of the spike with increasing fertilizer N rates might be because of the precursor chickpea which contributed residual N to the soil, and some of the mineralized N from this residual N in addition to that of applied N might have played a part on developing higher plant stature rather than grain filling. On the other hand, the limited amount and uneven distribution of rainfall throughout the cropping season might also be the reason for this because during the grain filling period rainfall was already off.

Enhancement of effective tillers of teff received higher N rates might be attributed to the role of nitrogen in the vegetative growth of plants. Supporting the results of this study, Botella *et al*., (1993) reported that stimulation of tillering with the high application of nitrogen was due to its positive effect on cytokinin synthesis. The increasing trend in biomass and straw yields with an increase in the N rates due to a better vegetative growth of teff, which ultimately produced more teff biomass (Abraha, 2013). In general, the biomass yield obtained from the fertilized plots exceeded that of obtained from the unfertilized plots.

The observed negative response of teff grain yield to higher N fertilizer rates beyond a certain level might be attributed to early lodging associated with luxuriant crop growth which causes a reduction in the proportion of the number of filled spikelet per panicle (Reinke *et al.,* 1994).

The lowest teff harvest index under higher nitrogen rates could be due to the lower biomass partitioning to grain production per unit of total plant N as N fertilizer rates increased. This indicated that at a low level of nitrogen the primary factor limiting crop growth and final yield is nitrogen whereas 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).

Application of nitrogen fertilizer for teff grown after chickpea at a rate of beyond 23 kg ha^{-1} has no further earnings which might be because legume-cereal rotation helps farmers to reduce inputs by creating a more balanced nutrient cycle at the field level which brings about a lower costs and increased profit margins. For example, inclusion of legumes in the rotation can lessen the need for additional synthetic nitrogen fertilizer (Selamyihun *et al*., 1999), minimizing costs, reducing water pollution from runoff and in some cases providing farmers with an extra income stream (Khan *et al*., 2007; Al-Kaisi, 2010; Don Reicosky, 2010).

Conclusions

It is obvious that nowadays soil health is becoming remarkably important for the evolution of a more sustainable agriculture. The inclusion of leguminous crops in a rotational cropping system is a principal focus. The major source of benefit in incorporating leguminous species in a crop rotation system is the amount of fertilizer N that can be replaced by fixed atmospheric nitrogen. The current study revealed that the blanket fertilizer recommendation (64 kg N ha^{-1}) for teff can be reduced by more than half without any reduction in grain yield by practicing chickpea-teff rotation system.

The highest mean grain yield of teff was obtained in response to the application of 34.5 kg N ha^{-1} rate with 263 and 326 kg ha^{-1} increments over the 0 kg N ha^{-1} rate for both cropping sequences. Teff biomass and straw yields also significantly enhanced with an increasing rate of N fertilizer from 0 to 69 kg ha^{-1} when rotated with chickpea. Generally, yield obtained from teff-teff cropping sequence was low as compared to the chickpea-teff rotation.

Even though highest grain yield was obtained in response to 34.5 kg N ha^{-1} rate applied, the highest marginal rate of return which means more economical benefit was found from plots received 23 kg N ha^{-1} rate. This indicated that no further earnings could be obtained beyond the application of that specific N rate. Therefore, based on the results and the above summary, it could be recommended that,

- ✓ Under the chickpea-teff rotation cropping system supplementary nitrogen fertilizer is needed fulfill the nitrogen requirement of teff at the study area.
- ✓ After chickpea, farmers shall supplement nitrogen fertilizer at a rate of 23 kg ha^{-1} for teff.
- ✓ This legume-cereal rotation cropping is important to reduce the prevailing dependence on expensive chemical fertilizer inputs that are potentially unsafe for the environment, human health and for the soil to sustainably produce yield.

Acknowledgments

The institutional support of Haramaya University, Tigray Agricultural Research Institute, and Shire Soil Research Center for jointly made this study possible are highly cherished. It is also a great pleasure to thank all individuals for their keen and much needed professional support, consistent guidance, and encouragement throughout the study period which stimulated us to implement the research and produce this paper.

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