RESEARCH ARTICLE

Tef [Eragrostis Tef (Zucc.) Trotte] under Different Water Levels and N-P Fertilizer Rates in Tigray region, Northern Ethiopia

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ABSTRACT

On-field experiment on Tef performance was conducted in Tigray region of Northern Ethiopia with the objective of evaluating the effects of N-P rates and water levels on yield and yield components of tef. The experimental design was a factorial combination of three levels of water with three levels of N-P fertilizers replicated four times at Illala and Wukro research stations. The highest tef yield 2770 kg ha^{-1} was recorded at Illala site from 64 kg ha^{-1} N and 46 kg ha^{-1} P under full irrigation and that of Wukro was 1988 kg ha^{-1} under full irrigation with 32 kg N ha^{-1} and 23 kg P ha^{-1}. However, the lowest grain yield was obtained under rainfed with 64kg ha^{-1}N and 46 kg ha^{-1}P at Illala and at Wukro it was rain fed with N0P0 fertilizer. Increase in water level and N-P rates ($P<0.001$) increased the grain yield, biomass, days to maturity and harvest index. However, the interaction of water levels, N-P rates across locations did not show significant difference ($p=0.05$) for biomass, harvest index, days to heading, days to senescence, days to maturity, lodging%, plant height, panicle length and tiller number. Highest water use efficiency was obtained in full irrigation with 64kg ha^{-1}N and 46 kg ha^{-1}P at Illala with 0.643 kg m^{-3} and rainfed and deficit irrigation at Wukro with 0.374 kg m^{-3} whereas the lowest water use efficiency was obtained from treatments of rainfed and 64kg ha^{-1}N and 46 kg ha^{-1}P at Illala with 0.294 kg m^{-3} and deficit irrigation and N0P0 fertilizer at Wukro with 0.293 kg m^{-3}. The highest net benefit was obtained in deficit irrigation and 64kg ha^{-1}N and 46 kg ha^{-1}P at Illala with 35769 ETB ha^{-1} and full irrigation and N0P0 fertilizer at Wukro with 26253 ETB ha^{-1}.The lowest net benefit was also gained in deficit irrigation and 64kg ha^{-1}N and 46 kg ha^{-1}P at Illala and Wukro with 8335 birr ha^{-1} and 18231 ETB ha^{-1} respectively. It can be concluded that not only the amount but also the time of supplementary irrigation applied to mitigate water stress in combination with timely application of the recommended fertilizer dose has increased the yield of tef at the test sites. Both mineral fertilizer management and water management are found to be very important factors for areas with water scarcity and with degraded soils. Full irrigation with 64 kg ha^{-1} N and 46 kg ha^{-1} P could bring relatively better yield advantage to farmers around Enderta having soils of clay whereas it is full irrigation with 32 kg ha^{-1} N and 23 kg ha^{-1} P for farmers around Wukro with

commercial and no modifications or adaptations are made.

sandy clay loam soils. However, further research needs to know whether limited irrigation could bring higher yield in those sites.

Keywords: Tef, Irrigation, Nitrogen, Phosphorus, Water use efficiency

INTRODUCTION

Tef (Eragrostis tef (Zucc.) Trotter) is one of the oldest cultivated staple food crops for the majority of the Ethiopians. More than half of the area under cereal is for Tef production (Habtegebrial et al., 2007). Tef is adapted to a large variety of environmental conditions and widely grown from 1000 m up to 2500 m.a.s.l. and mean temperature range from 10°C to 27°C under various rainfall and soil conditions (Seyfu, 1997). Tef, is produced for local consumption and as cash crop. In the last decade, tef ranked first in area coverage and second in total production volume. In the whole country the area coverage for tef is 29% and its share in total production is 20%, while in Tigray region this is respectively 26% and 20% compared to other cereals (CSA, 2010).In Ethiopia, *tef* is mainly grown for its grain. The grain is used for making the special pancake like bread known as *injera*, the most popular food in the national diet. For Ethiopian farmers, tef is the most resilient cereal that grows in diverse agro-climatic conditions with a low risk of failure and fetches higher market prices than all the other cereals grown in the country. The preference of consumers for the best injera-making quality has led to this crop being in high demand. It stands first in its area coverage (CSA, 2011). According Tefera et al. (2003), the average tef grain yield of 1228 kg ha^{-1} is low compared to other cereals, which is attributed to nutrient limitations, drought and water logging (Tulema et al., 2005). Farmers using improved cultivars and management practices, however, can obtain yields up to 2500 kg ha^{-1} (Tefera and Belay, 2006) while the yield potential under optimal management and when lodging is prevented, is as high as 4500 kg ha^{-1} (Teklu and Tefera, 2005).For the last four decades, research activities on Tef have been carried out to generate new production technologies, mainly genetically improved varieties. Tef is a versatile and most suitable crop for multiple cropping systems such as double and relay cropping. Besides, compared to other cereals, tef has few insect pests and disease problems in the field (Seyfu, 1993). It is, therefore considered as a healthy, reliable and a low risk crop. Tef germinates quickly and it is adapted to environments ranging from drought stress to water logged soil conditions. There are 250 known species of Eragrostis, but only a few are of significant agricultural value (citation).

In arid and semi-arid environments the irregular and unpredictable character of the rainfall determines the agricultural production. Crop production including Tef production cannot guarantee the food security in Ethiopia. In semi-arid areas such as the northern highlands of Tigray the most limiting factors for low productivity and instability of crop production are water and soil fertility. Water is a limiting factor because the majority of the crop production sector relies on rainfall as a source of water. Rainfall in Tigray region is characterized as erratic, torrential, and highly variable in space and time, and poorly distributed over the growing season. Tef, which is predominantly sown at the end of July or early August in dry areas of Tigray, is strongly affected by this phenomenon of water stress. The rainfall often ends before the crop reaches flowering. Given these conditions, it is a challenge to secure food in the region. Hence, early secession of rainfall in the dryland areas of Tigray may cause low yield and biomass reduction (Tsegay, 2012). Low soil fertility is the second bottleneck for crop productivity in Tigray region. Intensification of staple food production using inputs, especially improved seed and fertilizers, is another intervention implemented in the country. However, despite the extension service and credit led strategies for fertilizers, only 37% of the farmers in the country use inorganic fertilizers. If fertilizers are applied, it is often at a lower rate than the recommended application rates 16 kg ha^{-1}, (Tsegay, 2012). Moreover, knowledge on nutrient uptake of tef and research on nutrient and water use efficiency is crucial for effective soil fertility management strategies. In addition, enhancing tef production using innovative and improved irrigation water management practices such as varying the level of water at different growth stage of tef production is crucial.

Despite of the above facts, the productivity of tef is lower than other cereals because of various production constraints. Limited knowledge on its agronomic and physiological responses to water and nutrients are among the major contributors for the low productivity of the crop. Even though attempts were made to examine the effect of water stress and nutrients at various developmental stages on the yield and yield components of the crop, very limited research was conducted to investigate the effect of water stress and inorganic fertilizers on its overall performances. Thus, studying the response of tef to N-P fertilizers and systematic application of irrigation water at a different tef growth stage is important.

MATERIAL AND METHODS

Experimental sites description

Location and Geology

Two experimental sites namely Wukro and Illala were selected for this study. Wukro is located at longitudes 39° 35'E and latitude13° 45'N with altitude 1978 m.a.s.l and the Illala is located at longitude 39° 30' E and latitude 13° 31' N at an altitude 1970 m.a.s.l. The two sites are agro-ecologically classified in the semi-arid region characterized by short rainy period (July to early September). According to Gebeyehu and Tibebu (2005), the geology of the Illala and Wukro(mytsiyuk) consists, limestone belonging to the Hintalo Formation of the Late Jurassic-Jurassic era.

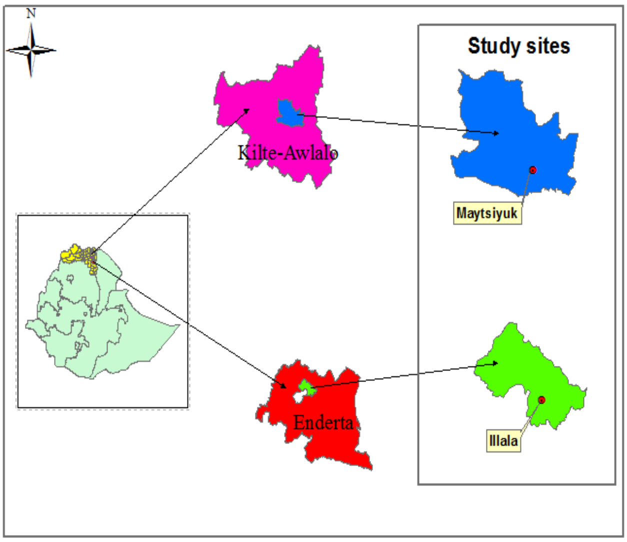

Figure 1: Map of the study area

Climate

Climate data for Ilalla site (1995–2012) that include daily rainfall maximum and minimum temperature was obtained from Mekelle Agricultural Research Center meteorological station whereas the climate data for Wukro site (1995–2012) that include daily rainfall maximum and minimum temperature was obtained from the National meteorology agency. Ilalla rainfall data for June to September (MARCMS, 1995-2012) is approximately 476.3 mm. It has a unimodal rainfall pattern and rainfall peaks in August. In addition the mean annual maximum temperature is 26.5 °C and monthly maximum temperature. Values range between 24.6 °C in August and 28.6 °C in May and June. The mean annual minimum temperature was 11.8 °C and monthly values range between 9 °C in December and 13.8 °C in April. The mean annual maximum temperature of Wukro reaches 28°C while the mean minimum temperature reaches 11.2°C. The June to November average Rainfall for Wukro is approximately 559.8 mm National metrological station, (NMA, 1995-2012). The highest rainfall was obtained in August at both locations. At both sites, the highest maximum temperature was observed during the month of May whereas lowest maximum temperature was observed during the month of November. At both locations, the highest minimum temperature was observed in July and August whereas the lowest minimum temperature was observed in December.

Soils

The predominant soil type comprises 21 % sand, 37 % silt and 42 % clay for Illala classified as clay based on the USDA soil textural class. The soil type (soil texture for Wukro site) is 71% sand, 7% silt, 22% clay classified as a sandy clay loam. Soil physical characteristics of the experimental sites were studied from the first (0-15 cm), second (15-30 cm), third (30-45cm) and fourth (45-60cm) layers. Accordingly soil water content at field capacity (FC), soil water content at permanent wilting point (PWP) were estimated from the respective layers using a pressure plate apparatus (Cassel and Nielsen, 1986) at -33 and -1500 kPa, respectively (Table 2).

Experimental design and procedures

The treatments had three levels of nitrogen (0, 32, 64 kg N ha-1), three levels of P (0, 23, and 46 kg P ha-1) which were combined to form one set of N-P treatments N0P0 (0,0 kg N-Pha-1); N1P1 (32, 23kg N-P ha^{-1}) and N2P2 (64, 46 kg ha^{-1}) and three watering levels; (M1) rainfed, (M2) Deficit Irrigation and (M3) full irrigation: which was preplanned based on crop water requirement considering crop, soil characteristics and weather conditions (Table 1). The treatments were laid out in a Factorial Randomized Complete Block Design (RCBD). Factorial combination of three levels of water (M1, M2 and M3) and three levels combinations of N-P at (0 kg N ha^{-1},0 kg P ha^{-1}; 32 kg N ha^{-1}, 23 kg P ha^{-1}and 64 kg N ha^{-1}, 46 kg P ha^{-1}) with four replications was used (Table 2). The N source was Urea whereas the P source was DAP (Di-ammonium phosphate. Urea was applied in split, half at planting and the remaining at the start of tillering while DAP was applied at planting only. The deficit irrigation was applied two times whereas the full irrigation was supplemented six times based on crop water requirement. Irrigation water was applied using watering can. The manual irrigation efficiency using watering can was taken as 90 % efficiency when using CROPWAT for irrigation scheduling and the crop water requirement was calculated accordingly. Soil water content at saturation (SAT), saturated hydraulic conductivity (K_{sat}) was estimated by SPAW (Saxton and Patrick, 2005). Bulk density was estimated according to procedures of (Blake and Hartge, 1986). Land was prepared and plowed by oxen. The gross experimental plot size was 3 m by 3 m (9 m^2) with a net area of 2m by 2m (4 m2) excluding the gangways; the gangways have a size of 1.5 m between replication and 1 m between plots. Thus the total area of each Illala and Wukro experimental site had 35 m x 16.5 m (577.5m^2) size. Sowing was carried out using commonly used farmers practice (by broadcasting). Quncho tef variety was used with seed rate of 25kg ha-1. The crop was kept to a weed free during its growing period.

M1N0P0=Rainfed with 0 kg N ha^{-1},0kg P ha^{-1}; M2N1P1= deficit irrigation (two times irrigation) with 32kgN ha^{-1},23kg P ha^{-1} and M3N2P2= full irrigation(six times irrigation with,64kg N ha-1,46 kg P ha^{-1}

Different crop parameters were taken from the net plot area. The experimental parameters considered in the present study were phonological data, growth, yield and yield related parameters. Days to emergence, days to heading, days to senescence, days to maturity were recorded, plant height (cm): height of 10 sample plants per plot were measured from the ground level to the top at physiological maturity of the crop, Panicle length (cm): Height of 10 sample plants per plot was measured from the start of the panicle to the top at physiological maturity of the crop, Tiller number: This was done from a randomly sampled 5 plants, Shoofly score (1-5 scale): Visual scoring by observing each plots, Lodging (%): was taken before senescence and at maturity by physical observation, Grain yield (kg ha^{-1}): Grain yield was obtained at maturity from the center 2m by 2m plot area, Dry aboveground biomass weight (kg ha^{-1}): Dry aboveground biomass weight was measured at maturity from center plot area of 2m by 2m, Harvest index: were calculated as the ratio of the grain yield to the dry aboveground biomass

Water use efficiency (ha^{-1} m^{-3}): the ratio of average yield (kg ha^{-1}) to total amount water applied (kg ha^{-1}m^3) (Steduto, 1996).

Crop information relevant to irrigation scheduling is presented in wukro and Illala (Appendix 1). Average length of growing period for tef was taken as 120 days. The estimated average maximum rooting depth from field measurement was 40 cm. The K_c factors for the mid and the late season were used from the FAO Irrigation and drainage paper 56 (Allen et al., 1998; Araya et al., 2010). Similarly, crop water depletion factor (p) for water stress (stomata closure) was taken from) (FAO irrigation and drainage paper 33 and 56).

Table 1: Treatment combinations (3 water levels and 3 N-P fertilizer rates)

	Plots by replications			
Treatments	I	II	III	IV
M1N0P0 (1)	9	12	24	32
M3N1P1 (2)	6	18	21	35
M2N2P2 (3)	3	16	23	28
M1N2P2 (4)	8	11	25	31
M3N0P0 (5)	7	14	20	29
M2N1P1 (6)	4	17	27	33
M1N1P1 (7)	1	15	26	36
M2N0P0 (8)	5	10	19	34
M3N2P2 (9)	2	13	22	30

The crop water requirement (ETc) over the growing season was determined from ETo and estimates of crop evaporation rates expressed as crop coefficients (Kc), based on well-established FAO procedures indicated (Doorenbos and Pruitt, 1977).

$$ETcrop = Kc \times ETo \quad \ldots\ldots\ldots\ldots\ldots\ldots 1$$

Where; ET crop is crop evapo-transpiration; Kc, crop cofficent and ETo, reference evapo-transpiration

Water Use Efficiency (WUE) refers to the amount or the value of product over volume or value of water depleted or diverted (Bessembinder et al., 2005). It can be expressed in general physical and economic terms. (Oweis and Hachum, 2006) defines physical use efficiency as the quantity of the efficiency divided by the amount of water depleted or diverted (kg m^{-3}). Economic water use efficiency is defined as value per unit of water or the Net Present Value (NPV) of the amount of the product divided by the NPV of the amount of water diverted or depleted (Seckler et al., 2003). We adopted water use efficiency as the efficacy of both grain yield and aboveground dry biomass of tef per unit amount of water applied under rainfed, and under various irrigation scenarios. (Molden and Rijsberman, 2001) give a simple argument to the above statement: by growing more yields with less water, more water will be available to irrigate arable land in water scarce semiarid region/area. Grain Water use Efficiency (GrainWUE) was calculated as

$$GrainWUE = \frac{Grain(kg/ha)}{W(m^3/ha)} \quad \ldots\ldots\ldots\ldots\ldots\ldots 2$$

Where; W = Water used for tef evapotranspiration m^3/ha; grain yield is yield obtained at harvest (kg/ha)

The reference evapotranspiration (ET_0) was calculated based on the FAO Penman-Monteith method (Allen et al., 1998) for Illala and Hargreaves method for Wukro due to limitation in the climatic data. The analysis was done using FAO-ET_0 calculator software.

A soil analysis of soil particle distribution was estimated by the hydrometer method (Gee and Bauder, 1986). Organic matter content was determined by Walkley and Black wet oxidation organic carbon method as described by (Jackson, 1967).Total Nitrogen was determined by using Micro Kjeldahl method (Jackson, 1967). Available P was also determined using spectrophotometer following the Olsen extraction method (Olsen and Dean, 1965).Similarly soil pH was measured from the composite soil sample in a suspension of a 1:2.5 soil to water ratio (Jackson, 1958).

Tef economic water productivity (EWP) was calculated as the gross income in ETB per gross water supplied in m^3. EWP was computed based on the size of irrigable area, maximum obtainable yield and the gross income gained from the sale of grain (main product) and straw (bi-product) considering the average seasonal local market price (ETB). The gross income is the product of the average price of tef per kg for the season and the average grain yield per given irrigable area plus the product of the price of tef straw per kg for the season and the average straw yield per given irrigable area.

$$EWP = \frac{GI}{GIWR} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3$$

Where, GI is gross income from the sale of grain and straw (ETB), GIWR is gross irrigation water requirement (m^3 ha^{-1}).

Partial budget analysis

Partial budget analysis of water levels and N-P rates was estimated considered the fertilizer cost, transport cost, application cost, water and watering cost. To assess the costs and benefits associated with different treatments the partial budget analysis technique (CIMMYT, 1988) will be applied on the yield results. The analysis was done using the prevailing market prices for inputs at planting and for outputs at the time of harvesting the crop. All costs and benefits was calculated on hectare basis in Ethiopian birr (Birr ha-1). Total variable cost (TVC) in this case is the cost of N and P which varies across treatments. Net benefit was calculated by subtracting total variable cost from the gross benefit. Marginal rate of return (MRR) was calculated as the ratio of differences between net benefits of successive treatments to the difference between total variable costs of successive treatments.

Statistical data analysis

To evaluate if separate as well as interaction effect of the treatments brought significant differences, all traits (characters) were subjected to analysis of variance (ANOVA) using GenStat (Payne et al., 2011).

Individual locations as well as combined ANOVA were conducted for all characters and treatment combinations. Prior to the execution of combined ANOVA, homogeneity of error variance was assessed using Bartlett's test as indicated by (Snedecor and Cochran, 1980). Based on the general ANOVA procedures of the GenStat (Payne et al., 2011), normality was tested using normal plot and histogram of residuals as well as a plot of residuals verses fit. Correlation analysis was performed to measure the strength of the linear relationship between grain yield and component traits derived from the average values of the treatment combinations (N-P-water level). Descriptive statistics (mean, range and standard error of the mean) were employed for all traits scored on average plot value basis. All difference between pairs of means was inspected using the Tukey's test, a procedure that is more efficient in pair wise comparison and also that makes use of the distribution range statistic (Steel and Torrie, 1980).

RESULTS AND DISCUSSIONS

Chemical and physical properties soil of the experimental sites

In this study, data were collected to evaluate the influence of water levels, N-P rates and locations on the yield and selected yield components of tef. Chemical and physical soil properties of the experimental sites are presented in (Table 2 and 3). The EC (ds/cm) was higher at Wukro (0.55) than at Illala (0.25). The Organic matter content was also higher at Illala (4.79 %) than at Wukro (2.78 %). The P-Olsen at Illala was 20.06 mg/kg^{-1} which was higher than Wukro with 4.82. The total N (%) of Illala was (0.24) which was higher than Wukro's result (0.102). CEC (mol kg^{-1}) of Illala was 42.4 mol kg^{-1} which is higher than Wukro's (17.8 mol kg^{-1}).

Table 2 Soil chemical and physical properties of Illala and Wukro experiment sites

Parameters	Soil depth at Illala (cm)				Soil depth Wukro (cm)			
	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60
Water content at saturation(SAT)%	263.5	278.3	283.8	282.2	290.9	281.9	260.3	295.6
PWP (vol%)at 1500Kpa	10.7	9.9	15.3	12.1	14.7	13.8	18.4	17.2
FC (Vol %) at 33Kpa	30.3	29.8	27.9	26.8	15.5	15.2	21.6	21.7
BD (g/cm3)	1.2	1.3	1.4	1.4	1.5	1.57	1.2	1.5
pH	7.7				7.7			
EC (ds/cm)	0.25				0.55			
OM (%)	4.8				2.8			
Total N (%)	0.24				0.1			
P-Olsen (mg/kg soil)	20				4.8			
Avail. K (mg/kg soil)	2410.8				1062.8			
CEC meq/100gm	42.4				17.8			
Saturate Hydraulic conductivity (cm^3/min)	56.7	55.4	40	24.7	12.5	36.9	49.8	64.5

Table 3 Some chemical and physical soil properties of the experimental sites

Soil parameters	**Ilalla**	**Wukro**
pH	7.75	7.73
EC (ds/cm)	0.25	0.55
Organic matter (%)	4.79	2.78
P-Olsen (mg kg^{-1})	20.06	4.82
Total N (%)	0.24	0.102
CEC (mol kg^{-1})	42.4	17.8
Sand (%)	21	71
Silt (%)	37	7
Clay (%)	42	22

Table 4 Mean square of yield related traits of tef across locations

Source of variation	PH	PL	TN	VG	SAG	DTH	DTS	DTM	LD (%)
Water levels	17.5ns	6.1ns	111.1ns	1.7ns	266.4ns	0.4ns	290.5**	476.7**	47598**
N-P rates	96.7ns	6.7ns	50.4	3.9**	620.0*	10.0ns	2.5ns	36.4**	1007.4ns
Location	314.6**	196.9**	2812.5**	0.0ns	3669.4**	206.7**	13.4*	32*	1790ns
Water_levels. N-P rates	41.4ns	18ns	20.4ns	1.1ns	247.5ns	3.9ns	4.1ns	0.4ns	234.4ns
Water_levels.Location	4.7ns	2.4ns	130.7ns	0.4ns	18.4ns	0.2ns	8.4ns	88.3**	1807.7ns
N-P rates. Location	173.7**	7.7ns	13.2ns	2.1*	112.7ns	9.4ns	16.4**	16.8*	700ns
Water_levels.N-P rates.Location	44.6ns	6.1ns	10.0ns	0.2ns	104.7ns	0.2ns	6.2ns	5.8ns	451.8ns
CV (%)	5.8	8.8	22.8	18.4	17.3	3	1.9	1.9	49.3
LSD(0.05)	4.529	1.521	3.306	0.6498	6.01	0.905	1.418	1.633	12.02
SE(±)	5.525	3.214	6.986	0.7928	12.70	1.913	1.730	1.993	20.74

*P<0.05, **P<0.01, NS=non-significant, Ph= Plant height (cm),Pl=Panicle length(cm),TN= Tiller number, VG= Vigor(%), SAG= Stand at germination (%), DTH= Days to heading, DTS= Days to senescence, DTM= Days to maturity, LD(%), Lodging (%), GYL= Grain yield, AGDB = Aboveground dry biomass, HI= Harvest index, WUE, Water use efficiency, NB= Net benefit.

Table 5: Mean square of grain yield and aboveground dry biomass, harvest index, water use efficiency and net benefit of tef across location

Source of variation	GYLD	AGDB	HI	WUE	NB
Water levels	4008984**	13337613**	0.0208195**	0.011179ns	7.051E+08**
N-P rates	203242ns	22604227**	0.02052**	0.020340*	1.830E+08**
Location	554361**	6110425*	0.000152ns	0.696128**	1.111E+08*
Water_levels.N-P rates	244972*	414058ns	0.0031841*	0.025179**	5.283E+07*
Water_levels. Location	706510**	1384488ns	0.0034898*	0.029700**	2.645E+08**
N-P rates. Location	75359ns	7165686**	0.0041949*	0.012304ns	1.631E+07ns
Water_levels.N-P rates.Location	373904**	795569ns	0.0024763ns	0.034144**	8.272E+07**
CV (%)	15.4	13.8	14.6	16.9	17.5
LSD	386.4	948.2	0.026	0.1015	5690.5
SEM(±)	272.2	1156.9	0.031	0.0715	4008.6

*P<0.05, **P<0.01,NS=non-significant, Ph= Plant height(cm),Pl=Panicle length(cm),TN= Tiller number, VG= Vigor(%), SAG= Stand at germination (%), DTH= Days to heading, DTS= Days to senescence, DTM= Days to maturity, LD(%), Lodging (%), GYL= Grain yield, AGDB = Aboveground dry biomass, HI= Harvest index, WUE, Water use efficiency, NB= Net benefit.

Table 6: Mean interaction effect of water levels, N-P rates on grain yield of tef at Illala and Wukro

Water levels	N0P0			N1P1			N2P2		
	Illala	Wukro	Mean	Illala	Wukro	Mean	Illala	Wukro	Mean
M1	1817cd	1357de	1587cd	1596cd	1608cd	1602cd	851e	1517de	1184d
M2	1547cde	1477de	1512cd	1806cd	1732cd	1769bc	1571cd	1620cd	1596cd
M3	2251abc	1966bcd	2108ab	2533ab	1988bcd	2261a	2770a	1898bcd	2334a
Mean	1871ab	1600b		1978a	1776ab		1731ab	1678ab	

CV (%) = 15.4, SE (±)=272.2,Water levels: P <0.001&LSD= 157,N-P rates =NS, Location: P=0.009&LSD= 128.8, Water levels and N-P rates: P=0.017& LSD= 273.2,Water levels and Location: P<0.001&LSD=223.1,N-P rates and Location: NS, Water levels,N-P rates and Location=0.002&LSD=386.4

CV%= coefficient of variation; ; SE (±) =standard error of mean; LSD=Least significant difference; M1= rainfed; M2= deficit irrigation; M3 = full irrigation; N0P0= 0 kg ha^{-1} N, and 0 kg ha^{-1} P; N1P1= 32 kg ha^{-1} N, 23 kg ha^{-1} P; N2P2= 64 kg ha^{-1} N, 46 kg ha^{-1} P

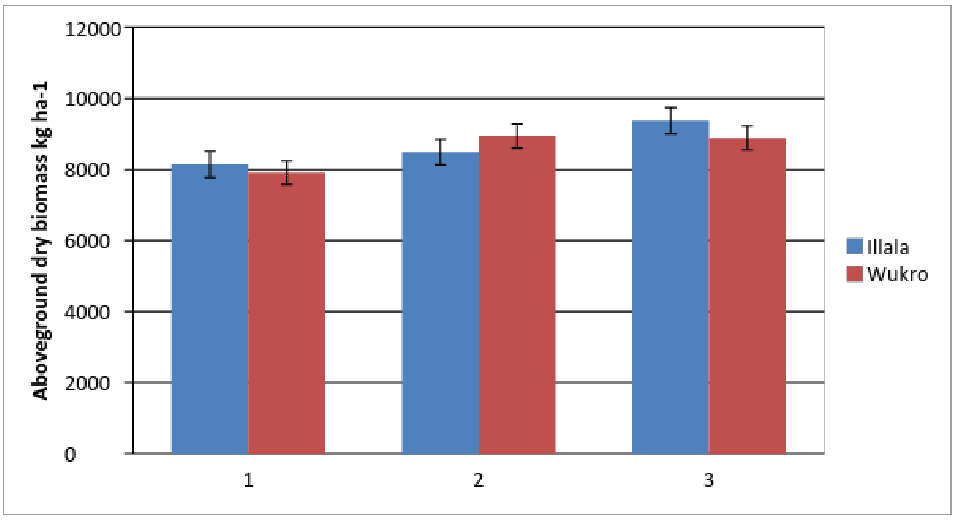

Figure 2. Response of aboveground dry biomass (kg ha^{-1}) to N-P rates across locations
N0P0= 0 kg N ha^{-1}, 0 kg P ha^{-1}; N1P1= 32 kg N ha^{-1}, 23 kg P ha^{-1}; N2P2=64 kg N ha^{-1}, 46 kg P ha

5.2 **N-P and water effect on Grain yield and selected yield related traits of tef across locations**

Table 4 and Table 5 shows mean square of yield and yield components of tef during the cropping season in 2012

Grain yield

The main effect of water levels significantly increased tef grain yield (Table 6), over the control for treatments that received deficit irrigation and full irrigation, respectively. However, there was no significant effect due to the N-P rates. Tef grain yield differ significantly due to location. Higher grain yield was obtained at Illala site compared to Wukro. There was significant interaction effect of water levels and N-P rates (Table 6). Higher grain yield of tef was obtained from treatment M3N2P2 while the lowest tef grain yield was obtained from treatment M1N0P0. Highest tef grain yield was obtained at Illala location with water level (M3) whereas the lowest tef grain yield was obtained at both locations from rainfed treatments (M1). There was no significant interaction effect of N-P rates with location on tef grain yield. There was significant interaction effect of location, N-P rates and water level. Lowest grain yield were obtained from M1N2P2 and M1N0P0 treatments at Illala and Wukro respectively, whereas the highest grain yield were obtained from M3N2P2 and M3N1P1 treatments from Illala and Wukro sites, respectively. The M3 water level with different N-P rates gave higher grain yield when compared to M2 and M1 water levels. Here from the result one could observe that the most limiting factor was water when compared to increasing N-P rates.

Above ground dry biomass

Full irrigation (M3) significantly increased tef aboveground dry biomass (Fig.2) over the control at fertilizer levels of N1P1 and N2P2.

Harvest index

ANOVA (Table 7) indicated that harvest index was significantly affected by water levels and locations at Illala and Wukro. The mean comparison for water level indicated that the highest harvest index was obtained from full irrigation at Illala and Wukro. The lowest harvest index was obtained from M1 (control) at both locations. Moreover; single effect of water levels and N-P fertilizer rates were statistically significant but the interaction of water levels and N-P fertilizer rates were not significant.

Table 7: Effect of water levels on harvest index at Illala and Wukro sites

Water Level	Illala	Wukro	Mean
M1	0.18c	0.19bc	0.185
M2	0.21bc	0.21bc	0.21
M3	0.26a	0.23ab	0.245
Mean	0.22	0.21	

CV%= coefficient of variation; SE (±) =standard error of mean; Lsd=Least significant difference;M1=Rain fed; M2= Deficit irrigation; M3= Full irrigation;

The highest harvest index was obtained from control at both locations whereas the lowest harvest index was also obtained from N2P2 at Illala and Wukro (Table 7).

Table 8 Effect of N-P rate on harvest index at Illala and Wukro sites

N-P rates	Illala	Wukro	Mean
N0P0	0.24ab	0.25a	0.245
N1P1	0.23ab	0.20bc	0.215
N2P2	0.18c	0.19c	0.185
Mean	0.22	0.21	

N0P0= 0 kg N ha^{-1}, 0 kg P ha^{-1}; N1P1= 32 kg N ha^{-1}, 23 kg P ha^{-1}; N2P2=64 kg N ha^{-1}, 46 kg P ha^{-1}

Lodging percentage

The ANOVA (Table 9) result indicates that lodging% was attributed to water levels at Illala and Wukro. On the other hand, the main effect of N-P rates and the interaction of water levels and N-P rates on lodging were not significant. The mean comparison for lodging % indicated that the water levels with rainfed M1, had the lowest lodging% at Illala and Wukro. The highest lodging % was found under full irrigation at Illala and wukro.

Table 9 Effect of water levels on lodging (%) of tef at Illala and Wukro

Water analysis	**Illala**	**Wukro**	**Mean**
M1	0.4c	4.2c	2.3
M2	6.7c	58.6b	43.8
M3	93.0a	89.6a	91.3
Mean	40.8	50.8	

M1= Rainfed, M2= Deficit irrigation, M3= Full irrigation

Crop water use efficiency

Interaction effect of water levels and N-P rates on crop water use efficiency is presented in Table 9. The main effect of water levels and N-P rates were not significant whereas supplemental irrigation significantly increased the WUE of tef at Illala (Table 9). The WUE values obtained ranged from 0.585 kg m^{-3} (in full irrigation) to 0.491 kg m^{-3} (Rainfed) at Ilala, and 0.347 kg m^{-3} (Rainfed) to 0.309 kg m^{-3} (full irrigation) at Wukro. The implication of high WUE with the full irrigation indicated that, the applied water might be efficiently used at Illala. At Wukro rainfed (the control) treatment has higher WUE than deficit and full irrigations and this shows that the irrigation water applied was not efficiently used by the crop. On the contrary the applications of N-P did not increase water use efficiency.

Table 9 Interaction effect of water levels and N-P rates on grain-WUE ha^{-1} m^{-3} of tef at Illala and Wukro

Water levels	N0P0 Illala	N0P0 Wukro	N0P0 Mean	N1P1 Illala	N1P1 Wukro	N1P1 Mean	N2P2 Illala	N2P2 Wukro	N2P2 Mean
M1	0.627a	0.315e	0.471a	0.551ab	0.374bcde	0.462a	0.294e	0.353cde	0.323b
M2	0.461abcde	0.293e	0.377ab	0.538abc	0.344de	0.441a	0.468abcde	0.321e	0.395ab
M3	0.523abcd	0.305e	0.414ab	0.588a	0.327e	0.458a	0.643a	0.294e	0.469a
Mean	0.537ab	0.304c		0.559a	0.348c		0.468b	0.323c	

M1=Rain fed, N0P0=0kg N ha^{-1} and 0 kg P ha^{-1}, M2= Deficit irrigation, N1P1=32 kg N ha^{-1}, and 23 kg P ha^{-1}; N2P2= 64 kg N ha^{-1} and 46 kg P ha^{-1}; M3=Full irrigation.

Table 10: Partial budget analysis on Net benefit (ETB ha^{-1}) of Water levels and N-P rates on Grain yield and Straw at Illala and Wukro

Water levels	N0P0 L1	N0P0 L2	N0P0 Mean	N1P1 L1	N1P1 L2	N1P1 Mean	N2P2 L1	N2P2 L2	N2P2 Mean
M1	26980abcd	20618cde	23566	23162bcde	31489abcd	27326	10267e	21039cde	15653
M2	22713bcde	24425bcde	23569	23215bcde	32350abcd	27783	17936de	19696cde	18816
M3	34399abc	27629abcd	31014	34915abc	37616ab	33633	41208a	27625abcd	34417
Mean	28031	24068		27097	32063		23137	22787	

CV(%)=22.5;SE(±)=5977.6;Waterlevels,p<0.001&Lsd=3464.2;N-Prates=p<0.001 &LSD=3464.2;Location,p=NS&LSD=2828.5;Water level and N-P rates, p=0.071&LSD=6000.2;water level and location, p=0.006&LSD=4899.2;N-P rate and location, p=0.012 &Lsd=4899.2; water level, N-P rate and locations, p=NS&LSD=8485.6

CV%= coefficient of variation; SE (±) =standard error of mean; LSD=Least significant difference; M1=Rain fed, M2= Deficit irrigation, M3= Full irrigation; N0P0= 0kg N ha^{-1} and 0 kg P ha-1; N1P1= 32 kg N ha^{-1} and 23 kg P ha^{-1}; N2P2= 64 kg N ha^{-1} and 46 kg P ha^{-1}; L1=Illala; L2=Wukro.

Table 11 Total marginal return ETB ha^{-1} of Water levels and N-P rates on Grain and Straw yield at Illala and Wukro

Locations	Treatments	Net benefit ETB ha^{-1}	Total variable cost ETB ha^{-1}	Net Income ETB ha^{-1}	Total marginal return (%)
Illala	M1N0P0	26980	0	26980	---
	M3N1P1	34915	3210	31705	147.20
	M2N2P2	17936	7364	10572	D
	M1N2P2	10267	4300	5967	150.29
	M3N0P0	34399	1049	33350	D
	M2N1P1	23215	5218	17997	D
	M1N1P1	23162	2155	21007	D
	M2N0P0	22713	3064	19649	D
	M3N2P2	41208	5369	35839	702.39
Wukro	M1N0P0	20618	0	20618	---
	M3N1P1	37616	4604	33012	269.20
	M2N2P2	19696	5280	14416	D
	M1N2P2	21039	4302	16737	D
	M3N0P0	27629	2945	24684	D
	M2N1P1	32350	3128	29222	2479.78
	M1N1P1	31489	2151	29338	D
	M2N0P0	24425	977	23448	501.70
	M3N2P2	27625	7247	20378	D

D= dominated, M1N0P0= Rainfed and zero N-P;M3N1P1= Full irrigation and 32 kg N ha^{-1} and 23 kg P ha^{-1}; M2N2P2= Deficit irrigation and 64 kg N ha^{-1} and 46 kg P ha^{-1};M1N2P2= Rainfed and 64 kg N ha^{-1} and 46 kg P ha^{-1}; M3N0P0= Full irrigation and Rainfed; M2N1P1= Deficit irrigation and 32 kg N ha^{-1} and 23 kg P ha^{-1}; M1N1P1 = Rainfed and 32 kg N ha^{-1} and 23 kg P ha^{-1}; M2N0P0 = Deficit irrigation and zero N-P; M3N2P2= Full irrigation and 64 kg N ha^{-1} and 46 kg P ha^{-1}.

Net benefit analysis

The partial budget analysis of net benefit for water levels and N-P rates is presented in Table10. M3N2P2 and M3N1P1 significantly increased tef net marginal rate of return at Wukro. This considered the evaluation of water levels, N-P rates and their cost to the profitability of each level of water and N-P fertilizer rates from their respective produce. The main effect of water levels and N-P rates significantly increased tef net benefit (birr ha^{-1}) over the control. Tef grain yield differ significantly by location. The highest and lowest net benefit was obtained at Illala site. There was a significant interaction effect of water levels and N-P rates (Table 10). Highest marginal rate of return of tef was obtained from treatment M3N2P2 whereas the lowest tef net benefit was obtained from treatment M1N2P2 at Illala. Similarly at Wukro, the highest net benefit was obtained from M3N1P1 whereas the lowest tef was obtained from M1N2P2. There was a significant interaction between water levels and location. There was no significant interaction effect of N-P rates of location on tef net benefit. There was not significant interaction effect of location, N-P rates and water level. The net benefit indicated profitability in all the water level and N-P rates of fertilizer compared to the control.

The net income was obtained from M3N2P2 at Illala and M3N1P1 at Wukro. Total marginal rate of return indicated in (Table 11) the highest was obtained from M3N2P2 at Illala and M2N1P1 at Wukro. The lowest was also obtained from in the dominated treatments at both locations.

DISCUSSION

The estimates of the correlation coefficients among measured parameters of water levels M1= rain fed; M2=deficit irrigation; M3= full irrigation and N-P rates N0P0=0kg N ha^{-1},0 kg P ha^{-1} ; N1P1=32 kg N ha^{-1} and 23 kg P ha^{-1} ; N2 P2=64 kg N ha^{-1} and 46 kg P ha^{-1} in the two locations at Wukro and Illala . According to FAO, (1983); Landon, (1991) and Sertsu (1999), total N less than 0.2 is categorized as low. The initial soil analysis results of N (0.241 %) and P value obtained (20.06 ppm) (Table 3) indicates that N was below the required range whereas P was found to be optimal for Illala. Moreover; the initial soil analysis of wukro results of N (0.102%) and P value obtained (4.82 ppm) (Table 3) showed that the nutrients were found to be low in the experimental area.

According to Landon (1991) organic matter (OM) below 4 % is rated as low, thus the organic matter at Illala site (4.79 %) was found to be higher than the lower threshold limit while at Wukro (2.78%) the OM was lower than the lower threshold limit. Soil Cation Exchange Capacity (CEC) is an important parameter of soil; because it gives an indication of the type of clay mineral present in the soil and its capacity to retain nutrients against leaching (Landon, 1991). According to Landon (1991), soil with CEC values of 25-40 cmol kg^{-1} rate as high and the experimental site (42.4 cmol kg^{-1}) presented in (Table 3) is in the very high range for Illala and 17.8 $cmolkg^{-1}$ rated as high for wukro respectively. Furthermore, the soil is categorized as having low EC with a high to moderately alkaline in pH.

Tef grain yield was higher at Illala site than Wukro except M1N2P2 (Table 6). The possible reason could be due to higher initial soil fertility level at Illala site (such as Organic matter, Phosphorus, total N, available K). Though the total rainfall during the experimental season was higher at Wukro than Illala (Fig. 2) tef grain yield was higher at Illala than Wukro (Table 6). The possible reason might be due to higher soil fertility at Illala than Wukro (Table 2 & Table 3). In this regard the P (20.06 ppm), Organic matter (4.79 %) and CEC (42.4 cmol kg^{-1}) at Illala site was much higher than Wukro. Even though total N% at both locations is low, total N% (0.24) at Illala was also greater than Wukro's (0.102).

The main effect of water levels significantly increased tef grain yield (Table 6), over the control by 11% and 53% for treatments that received deficit irrigation and full irrigation, respectively. The highest grain yield was obtained in treatment M3N2P2 at Illala and in M3N1P1 at Wukro. Grain yield increased by 52% and 46.5% at Illala and Wukro respectively from the control. Full irrigation has given higher grain yield at both locations as compared to deficit irrigation and rainfed. This might be due to the early cessation of rain and thus the tef crop needs several irrigation to reach physiological maturity. This is in agreement with (Araya et al., 2010). From the result the most limiting factor was water when compared to N-P rates. The result obtained is in agreement with the results of (Araya et al., 2010) and (Tsegay, 2012), they found out that uptake of both nutrients was enhanced as the nutrients rate was increased in the presence of supplemental irrigation. This suggests that sufficient moisture in the late growing season enhances translocation of the nutrients from the soil to the crop and the grain. The uptake of both nutrients increased as both components increased. Raes and Woundimagegnehu (2007) found out that higher yield was obtained when tef crop was irrigated during flowering and grain filling stage. Yenesew et al.,(2011) reported that maximum yield of tef was obtained under optimum irrigation. High water stress (75 % deficit) throughout the growth period resulted in the minimum yield. Kirda and Kanber (1999) stated that the most sensitive period for the crop is the one that correspond to flowering stage. When a severe moisture stress prevails, the crop tends to deplete the soil water stored in the root zone and starts to wilt before the completion of additional root development. Deficit irrigation experiments on vegetables and cereals, showed lower yield during the full stress (75% deficit) throughout the growing season; however, stressing the crops during initial and late season stage of the growing season did not affect the crop yield significantly (Bazza and Tayaa, 1999). Similar result in this experiment showed that increasing application of water increased uptake of N-P by the crop but when the water was decreased (stressed condition) the application of N-P negatively affected the grain yield. As stated by Shock et al. (2005), tef yield increased from 1087 kg ha^{-1} to 2718 kg ha^{-1} as water was increased from 22.9cm^3 to 49.2cm^3, respectively. When combining harvests, Tef yield and total N uptake increased with increasing irrigation to 219.6 cm^3 of water. When irrigating beyond 219.6 cm^3, yield declined and total N experienced a significant decline from 198 to 148 kg ha^{-1}. This reduction in total N uptake at the highest irrigation rate may have been due to N leaching beyond the root zone, in addition to the effect of decreased yield.

The main effect of water levels significantly increased the tef aboveground dry biomass (Fig.2) over the control by 15.8 % at full irrigation while with deficit irrigation aboveground dry biomass was lower than the control. The main effect of N-P rates significantly increased tef aboveground dry biomass (Fig.2) over the control by 19.7% at N1P1 and 25% at N2P2. Higher aboveground dry biomass was recorded at N2P2 at Illala when compared with the control. At Wukro aboveground dry biomass of N1P1 had also increased by 39% from the control. This result is in agreement with the result from (Tsegay, 2012) which reported the uptake of both nutrients enhanced aboveground dry biomass growth with the application of supplemental irrigation. Higher uptake of both nutrients was observed with the application of supplemental irrigation directly correspond with the aboveground dry biomass. Increase for the supplemental irrigation increases the uptake of both nutrients. Yenesew et al.(2011) reported that as the moisture stress intensity increased, aboveground dry biomass production decreased. These finding is similar to what was reported by (Bouman and Toung, 2001).which attributed lower leaf production and dry matter due to water stress. Since dry matter accumulation is the balance between photosynthesis and respiration, any process that promotes photosynthesis and decreases respiration will usually increase dry matter production. Hence, as an increase in amount of water application favors photosynthesis rate and decreases respiration rate, it results in high dry matter production (Bouman and Toung, 2001). Similarly Soltani et al.(2000) stated that soil moisture stress during vegetative and reproductive stages results in the reduction of above ground dry biomass.

Mean comparison for water level indicated the highest harvest index was obtained with application of full irrigation and zero fertilizer. This might be due to higher aboveground dry biomass. Interaction effect of water level M3 and locations had increased harvest index by 44% at Illala and 21% at Wukro as compared to control. Interaction effect of N-P rates and locations the highest harvest index was obtained with N0P0 at Wukro and Illala. On the other hand, the lowest harvest index was obtained from N2P2 at Illala and wukro. The high WUE with full irrigation at Illala indicates that, the applied water was efficiently used whereas full irrigation did not result in high WUE at Wukro. This indicating the water applied might have not been used efficiently due to pervious nature of the soil. Full irrigation had increased WUE by 19% from the control at Illala while it reduced by 11% from the control at wukro (Table7). Similarly; Araya et al., (2010) reported that tef grain water use efficiency increased under a nearly optimal water condition than under water stress condition as Illala. On-farm research studies in semi-arid location in Kenya (Barron et al., 1999) and in Burkina Faso (Fox and Rockström, 2000) also reported significant contribution of supplemental irrigation especially when combined with soil fertility management to improve water use efficiency of rainfed maize and sorghum respectively. The possible benefit of supplemental irrigation on the yield and WUE in water limited environmental conditions was also confirmed by (Turner, 2004) and (Oweis and Hachum, 2006).

The relationships between WUE and grain yield is shown for tef on (Table 9). Linear relationship was found between yield and seasonal irrigation at Illala while nonlinear relationship was found at wukro. Some studies have shown linear relationships as that of Illala between yield and irrigation water applied (Payero et al., 2006) and (Farre and Faci, 2006). In the contrary, other studies like that of wukro found non-linear relationship between yield and seasonal irrigation (Tolk and Howell, 2003). The relationship between yield and irrigation is affected by factors such as climate, soil properties and irrigation practices (Farre and Faci, 2006). These factors should be considered when proposing deficit irrigation strategies. The trend of WUE in this experiment is in agreement with the findings of (Yuan et al. 2004) who reported the linear WUE trend for both biomass and total fresh berry yield. The authors concluded that the lower the amount of irrigation water received, the higher the water use efficiency obtained for the drier plant biomass and berry yields. Mao et al.(2003) reported that highest WUE of cucumber yield was obtained in treatment groups with minimal irrigation levels. Similarly, Sezen et al. (2005) reported that higher WUE was obtained with lowest irrigation level in field grown beans similar to that of our location two although lower irrigation level resulted in lower yield.

As far as correlation is concerned Water use efficiency, Harvest index, Days to maturity, Lodging % and aboveground dry biomass had a strong correlation with grain yield. This indicated that the parameters had a positive impact on the increase of grain yield. However plant height, panicle length, days to heading, days to senescence and tiller number had a negatively and non -significantly correlated with grain yield. This also indicates that these parameters had a negative implication on grain yield. That means this parameters had decreased the yield of tef grain yield in the experimental sites.

The partial budget analysis for the water and N-P fertilizer rates is presented in (Table 10). This considered the evaluation of water levels and N-P fertilizer and its associated cost to the profitability of each levels of water and rates N-P fertilizer from its respective produce. The net return (NR) from the water level and N-P fertilizer rates application treatment was from which obtained a highest net income of 35839, 33350 and 31705 ETB ha^{-1} and the highest the marginal rate of return (MRR) obtained was 702.39 %, 150.29 % and 147.20 % at Illala comparing to control. Similarly a highest net income of 33012, 29338 and 29222 ETB ha^{-1} and marginal return of 2479.38 %, 501.70 % and 269.20 % was also obtained at Wukro site comparing to control. The lowest net income was obtained 5967 ETB ha^{-1} at Illala and 14416 at Wukro compared to control. The lowest marginal return was also obtained from the dominated treatment at both locations. The highest marginal rate of return in which M3N2P2 had increased over the control at full irrigation at Illala and at M2N1P1 (Table 11). This show that the regional fertilizer recommendation must be accompanied by full irrigation package otherwise increasing fertilizer under rainfall condition (without supplementary irrigation) will have negative consequences. Therefore; this research refutes the blanket recommendation of fertilizer in the region.

CONCLUSION AND RECOMMENDATIONS

Tef (tef [Eragrostis tef (Zucc.)Trotte]) is one of the major cereal crops produced in Tigray. However, information on the response of the crop to different fertilizer N-P rates and water levels has not been adequately understood. Therefore this study was conducted to investigate the performance of tef productivity through water and N-P fertilizer applications on yield and yield components of tef. A factorial experiment using three levels of water and three rates of N-P fertilizer at (0 kg N ha^{-1}, 0kg P ha^{-1}; 32 kg N ha^{-1}, 23 kg P ha^{-1}; 64, 46 P kg ha^{-1}) with four replications was conducted at two locations namely of Illala and Wukro.

The results indicates that the main effect of water level had significant influence on grain yield, harvest index, aboveground dry biomass, days to maturity, lodging%, days to senescence, water use efficiency and Net benefit. Main effect of N-P rate was also significant on aboveground dry biomass; Days to maturity, harvest index, and vigor (1-5 scale). Interaction effect of N-P rates across locations were significant for aboveground dry biomass, harvest index, days to senescence, days to maturity, plant height and vigor (1-5 scale). However, the interaction of water level with N-P rates were not significant for aboveground dry biomass, days to heading, days to maturity, days to senescence, panicle length, plant height, tiller number, vigor(1-5 scale) and lodging %. Maximum aboveground dry biomass and grain yield were obtained by applying full irrigation throughout the growing season at Illala and Wukro. Full irrigation with N2P2 fertilizer combination resulted statistically higher average grain yield and aboveground dry biomass.

From the field experiments it is concluded that the amount of supplementary irrigation and timing of the supplemental in conjunction with the timely application of the recommended fertilizer dose increases yield of tef. Use of mineral fertilizers and proper water management are very important factors especially in areas with water scarcity and in fertile soils. When the soils are poor in fertility, the crop responds very well to additional supply of fertilizers especially when complimented with supplementary irrigation. In the absence of supplementary irrigation, the optimal N-P rate will be N1P1 (32 kg N ha^{-1} and 23 kg P ha^{-1}). The increased rate of N-P combinations from 0 kg N ha^{-1},0 kg P ha^{-1} to 32 kg N ha^{-1},23 kg P ha^{-1} and from 32 kg N ha^{-1},23 kg P ha^{-1} to 64 kg N ha^{-1},46 kg P ha^{-1} increase the grain and biomass yield with proportional increase in water level. The main reason why fertilizer rates have to be increased to certain limits in conjunction with water is mainly due to its role in nutrient assimilation and translocation in plants. In this research, higher net income was obtained from M3N2P2 at Illala and M3N1P1 at Wukro. Highest marginal return was also obtained from M3N2P2 at Illala and M2N1P1 at Wukro compared to their respective control treatments. The lowest net income was from M1N2P2 at Illala and M2N2P2 at Wukro. The lowest marginal rate of return was also obtained from all dominated (D) at both locations compared to control. Further trial could be necessary to verify the reliability of the result regarding the effect of N-P rate and water level combinations on tef yield and selected yield components.

Considering the cost of the mineral fertilizers and the risk associated with water stress, optimizing fertilizer application depending on the availability of water is the main recommendation from this research. Application of nutrients (N and P) in high dose may result in low net benefit due to high cost of fertilizers. This suggests avoiding such application not only to optimize tef yield but also to reduce cost and the possible environmental impact that could be caused by over fertilization.

1 Full water and 100% N-P could be applicable for farmers with clay soils around Enderta While for farmers around Wukro with soils sandy clay loam that could be full water and 50% N- P fertilize.
2 Further research is recommended to set or establish a volume of water below which production starts decreasing or kept high but constant.
3 Further research is needed to optimize the N-P rates and interaction with water at which net return is high.
4 From this research the optimal fertilizer application rate under rainfed condition is 32 kg ha^{-1} N and 23 kg ha^{-1} P (50 kg ha^{-1} Urea and 50 kg ha^{-1} DAP). The recommended fertilizer rate under rainfed condition by Bureau of Agriculture in this region is higher by half compared to this finding, which means this finding disproves the regional recommendation rate. Hence further research is recommended to establish optimal fertilizer rate under different soils and climate in the region.

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