Journal of Biology, Agriculture and Healthcare
ISSN 2224-3208 (Paper) ISSN 2225-093X (Online)
Vol.8, No.3, 2018

Effect of Rates and Time of Paclobutrazol Application on Growth, Lodging, Yield and Yield Components of Tef [*Eragrostis Tef* (Zucc.) Trotter] in Ada Woreda, East Shewa, Ethiopia

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Abstract

In Ethiopia, tef is a highly valuable crop to achieve national economic stability, and improved livelihood of many farmers. The objective of the present study was to assess the effects of rates and time of paclobutrazol (PBZ) application on growth, lodging, yield and yield components of tef. Twelve entire factorial combinations of four rates (0, 1, 2 and 3 kg ha^{-1}) and three growth stages (i.e. tillering, jointing and panicle emergence) of application of Paclobutrazol were evaluated in a field experiment on the research field of Debre Zeit Agricultural Research Center using randomized complete block design with three replication during the 2016 main season. Data were collected on plant height, number of tillers (fertile and total) per plant, panicle length, culm length, length of the upper three culm internodes, thousand seed weight, lodging index, grain yield, biological yield ,straw yield, harvest index (HI) and crude protein. The data were subjected to statistical analysis using SAS and mean differences were compared using Duncan's Multiple Range Test. The analysis of variance showed that time of application, PBZ rate, and their interaction had significant ($P \leq 0.01$) effect on all the characters except thousand seed weight. Spraying of PBZ 1kg ha^{-1}at jointing stage could suppress vegetative growth and increased number of fertile tillers and grain yield and minimized the risk of lodging. Therefore, spraying of PBZ 1kg ha^{-1}at jointing stage can be suggested as effective to maximize grain yield of tef.

Keywords: Paclobutrazol; yield; Lodging percentage

1. Introduction

Tef [*Eragrostis tef* (Zucc.) Trotter] is a C_4 self pollinated annual grass that belongs to the family *Poaceae* (Dejene and Lemlem, 2012). Tef is an indigenous unique cereal crop of Ethiopia, where it owes its center of both origin (the first domestication) and diversity (Vavilov, 1951).

In Ethiopia, tef is a very cherished crop and it is mainly grown for its grain that is used for making injera, which is a very popular staple food in the national diet of most Ethiopians (Asrat and Frew, 2001; Hailu *et al*., 2003).

In Ethiopia, tef is cultivated on an area of about 3 million hectares with tef and maize taking up about 24.02 % and 16.8% of the total grain crop area, respectively (CSA, 2015).This makes tef a frist crop among cereals in terms of area coverage. Although its large coverage and high importance, its productivity is very low which is nationally recorded about 1.64 t ha^{-1}(CSA, 2015). Among the factors that contributing to the stumpy yield of tef are low soil fertility status and sub optimal use of fertilizers, weeds, and inconsistent rainfall distribution and drought predominantly in the low altitudes areas, lack of high yielding cultivars, lodging (Ermias *et al*., 2007).

Lodging is the most serious problem particularly in areas that subjected to high rainfall and strong winds (Zerhun and Kebebew, 2012). Tremendous effort was carried out by the researchers to develop lodging-resistant tef cultivars, but currently no cultivar was develop with reasonable lodging resistance has been obtained (Zerhun and Kebebew, 2012). According to Seyfu (1983) natural lodging caused 17-23% of yield reduction of tef. Generally cereals that have higher stem height are more susceptible to lodging as compared to semi dwarf crops. (Emam, 2011). Consequently, control of plant growth such as plant or culm height, can be achieved by using plant growth regulators (PGRs). PGRs that inhibit biosynthesis of gibberellins (GA) are used in high input cereal management to shorten straw and thereby minimize lodging. They have been extensively used in many crops to reduce lodging through shortening of the stem and to maintain a steady improvement in grain yield (Pirasteh *et al*., 2014b;Rajala,2004).

Paclobutrazol is a broad spectrum gibberellin (GA) biosynthesis inhibitor that belongs to triazole plant growth regulator group (Orabi *et al*.,2010). The primary function of PBZ is inhibition of GA biosynthesis by interfering with the ent-kaurene oxidase, which catalyzes the sequential oxidations from ent-kaurene to ent-kaurenoic acid (Feletcher *et al*.,2000).One of the most important uses of plant growth retardants is lodging control and as such they are widely used in wheat, rice, rye and barley (Hajihashemi *et al*., 2007). Properly timed applications of PBZ have been reported to reduce lodging and increase yield in several agronomic crops including ryegrass rice and wheat (Bahramie *et al.,* 2014).

In Ethiopia, plant growth regulators as means of minimizing lodging problem have not been widely used. However few researchers was used Paclobutrazol to reduce lodging problem and promising results were observed (Tekalign ,2007). Similarly, Endale (2012) reported that PBZ is an effective plant growth regulator to control lodging and improve yield in tef. The response of plants to the growth regulators depends on species, cultivar, dose, method and time of application (Espindula *et al*., 2009). Lodging is a serious problem in major tef producing area of Oromia Region such as East Shewa and others part of major tef producing areas. To this effect it would be imperative to see the effect of PBZ on the lodging percentage and yield of tef variety .Therefore, this study was commenced with the objective of evaluating the effects of rates and time of PBZ application on growth, lodging, yield and yield components of tef.

2. MATERIALS AND METHODS

2.1. Description of the Study Area

The study was conducted at Debre Zeit Agricultural Research Center in Oromia Regional State during the main cropping season of 2016. The place is located of 8^0-44'N and 38^0-58'E at an altitude of 1900m above sea level. The area is differentiated by mono modal rainfall pattern. The annual rainfall recorded at the station was 660 mm and the annual minimum and maximum temperatures was 12°C and 27.4°C, respectively (Fig.1).The area was characterized by clay texture which is known as Vertisols (named locally "Koticha") and moderately acidic in reaction (pH 6.5) (DZARC, 2016).

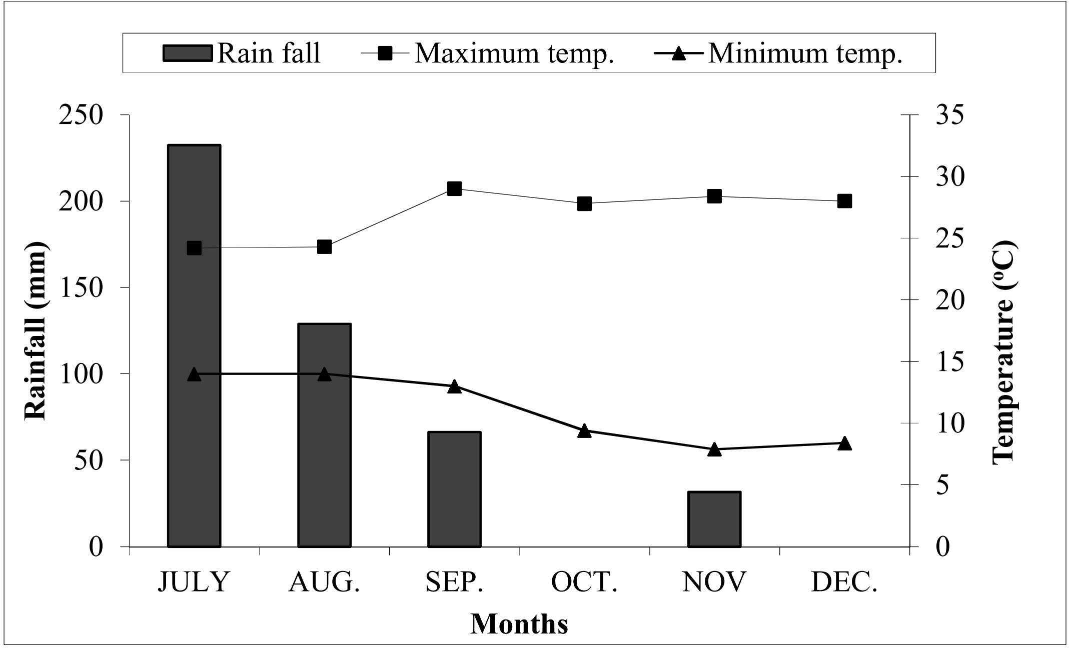

Fig. 1.Rain fall and temperature of the experimental area during 2016 period.
Source :DZARC (2016)

2.2. Planting Material

The tef variety named Dukem (DZ- 01 - 974) was used for the experiment. Dukem is a high yielding pale white-seeded variety. Due to its tallness, under favorable growing conditions it is found to be susceptible to lodging (MoARD, 2008).

2.3 .Treatments and Experimental Design

The treatments consisted of entire factorial combinations of four rates (0, 1, 2 and 3kg ha^{-1}) active ingredient of PBZ and three growth stages (*viz*. tillering, jointing and panicle emergence) of application. The treatments were laid out in a random complete block design with three replications. A plot size of 2m x1.4 m (2.8 m^2) with 20 cm row spacing and a total of 7 rows were used. The net harvestable area was 1.8m x 1m and adjacent plots and blocks were spaced 0.5m and 1 m apart, respectively. A given PBZ concentration was diluted in distilled water (250 L ha^{-1}) and the aqueous solution was applied uniformly to each plot as fine foliar spray using an atomizer.

2.4. Experimental Management

Seeds were drilled within each row at a rate of 1.2 g per plot (5 kg ha^{-1}). NPS (19%-N, 38%-P and 7% -S) fertilizer at rate of 100kg $ha^{-1}$was used as source of nitrogen, phosphorus and sulphur, and it was applied at a time of planting by band method. The remaining amount of nitrogen was supplied in the form of Urea at the rate of 90kg ha^{-1}, of which1/3 was applied at planting and 2/3 at tillering by broadcasting method. Land was prepared according to the local practice. It was ploughed five times before planting and the last plough was used for sowing tef plants. All other cultural practices were done as per recommendation. Harvesting was done at physiological maturity when the vegetative parts of the plants turned to light yellow or straw color. After good establishment, the main stems of ten randomly selected plants from each of the five central rows were tagged, and relevant data measurements were done on these selected plants.

2.5. Soil Sampling and Analysis

One representative composite sample was taken at a depth of 0-30 cm from five randomly selected spots diagonally across the experimental field using auger before planting and bulked. Working sample was obtained from the submitted sample and analyzed for selected physico-chemical properties mainly texture, bulk density, soil pH, cation exchangeable capacity (CEC), organic carbon, total N, and available P using standard laboratory procedures at Debre Zeit Agricultural Research Center soil laboratory.

2.6. Data Collection

Plant height was measured at physiological maturity from the ground level to the tip of the main shoot panicle from ten randomly selected plants in each plot. Panicle length was measured from the node where the first panicle branch emerges to the tip of the panicle and it was determine from an average of ten selected plants per plot. Length of the upper three culm internodes was measured from three uppermost internodes culm internodes of the main shoot culm and was recorded from average of ten randomly selected plants. Culm length was measured from the base of the main shoot culm to the base of the panicle and was recorded from average of ten randomly selected plants. Number of effective tillers was determined by counting the tillers from an area of 0.25 m x 0.25 m plants by throwing a quadrat into the middle portion of each plot. Grain yield was measured by harvesting the crop from the net middle plot area of 1m x 1.8m to avoid border effects. Biomass yield was measured at maturity, the whole plant parts, including leaves and stems, and seeds from the net plot area were harvested and after drying for three days, the total biomass was measured. Straw yield was determined by subtracting grain yield from total above ground biomass. Thousand kernel weights were counted after harvesting at random from each plot and their weights was measured with accurate balance at harvesting. Harvest index was calculated on a plot basis as the ratio of grain yield to the aboveground biomass yield and expressed as a percentage. Lodging index was assessed just before the time of harvest by visual observation based on the scales of 1-5 where 1 ($0-15^o$) indicates no lodging and 5 ($60-90^o$) indicates 100% lodging (Donald, 2004). Straw crude protein was determined on composite of 2g dried leaves and stem by using Kjeldhal method (Bremner, 1965).

2.7. Statistical Analyses

Data were subjected to analysis of variance (ANOVA) using General Linear Model (GLM) procedures of SAS 9.3 (SAS Institute, 2003).Whenever treatment effects were found significant, the differences among treatment means were compared using Duncan's Multiple Range Test (DMRT) at 5% level of significance and Linear Regression Analysis was done.

3. RESULTS AND DISCUSSION

3.1. Soil physiochemical properties

The experimental soil was silt loam texture composed of 14% clay, 32% sand and 54% silt. Its organic carbon content is 1.26%, which is low according to Roy *et al*. (2006) and medium OC in accordance with Sahlemedhin (2000). The CEC of the soil was 33.33 meq kg^{-1}, which could be considered as high (Landon, 1991). According to the rating of Olsen *et al.* (1954), P content (mg kg^{-1}) of < 3 is very low, 4 to 7 is low, 8 to 11 is medium, and > 11 is high. Thus, for the experimental site the available P content is low. The pH of the soil was 6.96, which is within the range of 4 to 8 suitable for tef production (FAO, 2000). The total N of the soil which is 0.17%, is medium in accordance with Havlin *et al*. (1999) who rated total N between 0.15 to 0.25% as medium (Table 1).

Table 1.Soil physicochemical properties of the experimental site.

Soil Parameters	Value	Rating	Reference	Remark
Total N (%)	0.17	Medium	Havlin *et al*. (1999)	Sufficient
Available phosphors (mg kg $^{-1}$)	6.78	Low	Olsen *et al.* (1954)	Defficient
Organic carbon (%)	1.26	Low	Roy *et al.* (2006)	Deficient
Organic matter	2.17	Medium	Sahlemedhin (2000)	Sufficient
pH (H_20)	6.96	Slightly acidic	FAO (2000)	Suitable
Cation exchangeable capacity (meqkg^{-1})	33.33	High	Landon (1991)	Sufficient
Sand (%)	32%			
Silt (%)	54%			
Clay (%)	14%			
Texture class	Silt loam			

3.2 Effect on Growth Parameters

3.2.1 Plant height

According to this research finding the interaction effects between the rate of PBZ and its time of application reduced plant height in comparison with control and the difference between the two factors were found to be significant (Table 2).The highest plant height reduction was obtained from the plant that treated with the highest rate (3 kg a.i) of PBZ which reduced plant height by 51.52 % when applied at tillering stage, followed by the intermediate (2 kg a.i) at tillering stage and higher rates of PBZ sprayed at jointing stage which reduced plant height significantly by 50.17% and 46.94% respectively compared to the control. The late application of PBZ at panicle emergence stage reduced plant height with no significant difference between the intermediate (2kg) and highest rates (3kg) by 39.18% and 36.77% respectively compared to the control and as such these treatments reduced plant height less compared to those applications at tillering and jointing stages (Table 2). Irrespective of stages application PBZ rate influenced plant height significantly ($P <0.05$). Increasing rates from 0 to 1, from 1 to 2 and from 2 to3kg a.i PBZ reduced plant height progressively by 31.22%, 9.11% and 4% respectively. This indicates that with further increment in concentration of PBZ plant height diminished significantly. On other hand early application of PBZ effectively reduced plant height than mid and late stage of application (Table 2).

Reduction in plant height is considered as the most important morphological outcome of PBZ application. The expressive reduction in tef plant height might be attributed to inhibition of ent Kaurene oxidase which catalyze the sequential oxidation from ent-kaurene to kaurenoic acid in the early sequence of gibberellins biosynthesis. Sun (2004) reported PBZ resulted in preventing the formation of stem elongation promoters for this reason the plant had develop dwarf effect. Many similar results reported in several crops that PBZ application effectively reduced plant height in tef (Endale *et al*., 2012), wheat (Assuero *et al*., 2012) Soybean (Zhang *et al*., 2006), and camillina (Kumar *et al*., 2012) without decreasing flowering quality and improves resistance to environmental stress conditions. Similar to this finding Bahrami *et al*. (2014a) on barley reported that application of plant growth regulators at early stage had lower plant height than those late applied.

Table 2. Plant height of tef plants as affected by rate and stage of application of PBZ at Debre Zeit during the 2016 main season.

	Plant height (cm)			Means of rates of PBZ (Overall growth stages)
Rates (kg a.i ha^{-1})	Time of applications			
	Tillering	Jointing	Panicle emergence	
0	99.00^{a}	98.00^{a}	97.33^{a}	98.11^{a}
1	55.33^{ef}	64.67^{c}	80.67^{b}	66.89^{b}
2	49.33^{gh}	65.00^{c}	59.00^{de}	57.78^{c}
3	48.00^{h}	52.00^{fg}	61.33^{cd}	53.78^{d}
Means of growth stages (Over all rates)	62.91^{c}	68.42^{b}	76.08^{a}	
SEm±	2.24			
CV (%)	3.24			

SEM: Standard error of mean

Means within the same column and row followed by different superscript letters are significantly different as judged by DMRT at $P \leq 0.05$

3.2.2 Length of the Upper Three Culm internodes

The analysis of variance showed significant interaction effects of time and rate of PBZ application on length of the upper three culm internodes (Table 3). The length of the upper three culm internodes was significantly reduced by PBZ application compared to control. In the field observation the upper most three internodes were very short and compact particularly with the PBZ treatments at tillering stage. The highest reduction in the upper three culm internodes was obtained from plants that received 2, 3 and 1kg a.i ha^{-1} of PBZ when applied at tillering, jointing and panicle emergence stages that accounted 68%, 58.1% and 56% reduction in internodes length respectively compared to untreated plants. On the other hand increasing in the rate of PBZ treatment from 2 to 3kga.i ha^{-1} did not significantly influence the length of the upper three culm internodes with sprays both at tillering and jointing stage. Increasing rate of PBZ from 0 to 1 and 2 to 3kg a.i ha^{-1} significantly reduced the length of the upper three culm internodes by 41.48%, and 27.71% respectively when applied at panicle emergence (Table 3).

Table 3. Length of the upper three culm internodes of tef plants as affected by rate and stage of application of PBZ at Debre Zeit during the 2016 main season.

	Length of the upper three culm internodes (cm)			Means of rates of PBZ (Overall growth stages)
Rates (kg a.i ha^{-1})	Time of application			
	Tillering	Jointing	Panicle emergence	
0	13.33^{a}	14.33^{a}	13.67^{a}	13.78^{a}
1	10.00^{b}	7.00^{cde}	8.00^{cd}	8.33^{b}
2	5.00^{fg}	6.33^{def}	8.30^{bc}	6.56^{c}
3	4.33^{g}	6.00^{efg}	6.00^{efg}	5.44^{d}
Means of growth stages (Over all rates)	7.67^{b}	8.41^{b}	9.50^{a}	
SEm±	0.99			
CV (%)	5.29			

SEM: Standard error of mean

Means within the same column and row followed by different superscript letters are not significantly different as judged by DMRT at P≤0.05

The analysis of variance indicated that main effects of PBZ rate significantly ($P<0.01$) influenced the length of the upper three culm internodes. The highest reduction in the length of these internodes by 61%, 52% and 40% in a comparison to control were obtained from plant sprayed with 3, 2 and 1kg a.i ha^{-1} of PBZ respectively. Time application of PBZ significantly ($P<0.01$) affected the length of the upper three culm internodes. Applications of PBZ at tillering and jointing reduced the length of the upper three culm internodes effectively than applying at panicle emergence (Table 3).

Determination of length of internodes is crucial in relation to lodging index in which as length of internodes decrease, lodging index also decrease. The retardation of length of the upper three culm internodes might be associated with decreased level of gibberellins which control shoot growth, thus decrease level of gibberellins caused by PBZ application may be caused by blocking pathway for the production of gibberellins. This result is parallel with previous findings on tef (Endale *et al.*, 2012) and peanut (Zheng, 2008) in which foliar application of plant growth regulators shortened internodes distance. Similarly, Taiz (2006) reported that the inhibition of gibberellins production does not affect the activity of cell division, but the new cells do not elongate further.

3.2.3 Culm and panicle length

A significant interaction between time and rate of PBZ application was observed with respect to culm and panicle length reduction of plants by shortening of internodes (Table 4). The highest reduction of culm length of 64.34% were observed from plants treated with 3kg a.i ha^{-1} PBZ at tillering and jointing stages respectiveley followed by the highest rate of PBZ spray at panicle emergence stage which reduced culm length by 57% compared to the control. In general, increasing the rates of PBZ treatment caused a linear decline in culm length and the relationship between PBZ concentration and culm length were found linear. Culm length was described by the equation $Y= -9.667X + 42.83$ which means that for every unit increase in the concentration of PBZ (kg ha^{-1}), culm length decreased by 9.667 units (Fig.2).

The main effects of rate and time of PBZ application were found significant with respect to culm length. Plants treated with 2 and 3kg a.i of PBZ ha^{-1} reduced culm length with statistically comparable amounts of 57% and 63%, respectively, and the lowest culm length shortening was obtained with the lowest rate of 1 kg PBZ ha^{-1}spray, which reduced culm length by 43% in comparison to the control (47.67cm). On other hand, PBZ application significantly reduced culm length when applied at tillering (26.17cm) followed by spray at jointing (27.5cm) and panicle emergence (31.33cm) stages (Table 4).

Table 4. Culm length of tef plants as affected by rate and stage of application at Debre Zeit during the 2016 main season

	Culm length(cm)			Means of rates of PBZ (Overall growth stages)
Rates (kg a.i ha^{-1})	Time of application			
	Tillering	Jointing	Panicle emergence	
0	48.00^{a}	47.67^{a}	47.33^{a}	47.67^{a}
1	22.33^{cd}	24.33^{a}	35.67^{b}	27.44^{b}
2	18.33^{de}	21.00^{cde}	22.00^{cd}	20.44^{c}
3	16.00^{e}	17.00^{de}	20.33^{cde}	17.78^{c}
Means of growth stages (Over all rates)	26.17^{b}	27.5^{b}	31.33^{a}	
SEm±	2.97			
CV (%)	10.49			

SEM: Standard error of Mean

Means within the same column and row followed by the same superscript letters are not significantly different as judged by DMRT at $P \leq 0.05$

Stage and rate of PBZ application interacted significantly on panicle length (Table 5). The highest panicle reduction of 39% compared to untreated plant (51cm) occurred on plants treated with 2kg a.i of PBZ applied at tillering stage, and it was also observed that further increase in concentration of PBZ at this stage did not any further significantly influence panicle length. The second highest panicle length reduction was obtained from plants that received 3kg a.i PBZ at jointing stage (35cm) and panicle emergence (41cm). In contrast, panicle length to culm length ratio was 1.4, 1.8 and 2 with application of 1, 2 and 3kg a.i ha^{-1} of PBZ treatments, respectively. These ratios indicate that PBZ had a stronger effect on culm length than on panicle length (Table 4 and 5).

The main effects of both PBZ concentration and time of application were also significant on panicle length. Application of PBZ at the lowest rate of 1 kg ha^{-1} reduced panicle length by 22% in comparison to the control (50.44cm). Further increase in rates of PBZ from lower to intermediate and from the intermediate to the highest rates did not bring appreciable change with respect to panicle length reduction. Regarding the time of application, PBZ treatment reduced panicle length effectively when sprayed at tillering (36.75cm) stage and then followed by jointing (40.83cm) and panicle emergence (44.75 cm) stage (Table 5).

Table 5. Panicle length of tef plants as affected by rate and stage of application at Debre Zeit during the 2016 main season

Rates (kg a.i ha^{-1})	Panicle length (cm)			Means of rates of PBZ (Overall growth stages)
	Time of application			
	Tillering	Jointing	Panicle emergence	
0	51.00^{a}	50.33^{a}	50.00^{a}	50.44^{a}
1	33.00^{f}	40.00^{cd}	45.00^{b}	39.33^{b}
2	31.00^{f}	38.00^{ed}	43.00^{b}	37.33^{bc}
3	32.00^{f}	35.00^{ef}	41.00^{bcd}	36.00^{c}
Means of growth stages (Over all rates)	36.75c	40.83^{b}	44.75^{a}	
SEm±	2.15			
CV (%)	11.71			

SEM: Standard error of Mean

Means within the same column and row followed by the same superscript letters are not significantly different as judged by DMRT at $P \leq 0.05$

PBZ application greatly reduced culm and panicle length of tef plant particularly when it applied at early tillering stage. The retardation of culm and panicle length might be attributed from the reduction of gibberellins biosynthesis which resulted decrease internodes elongation. These findings were also consistent with finding of (Endale *et al*., 2012; Tekalign 2007) on tef and sunflower (Koutroubas *et al*., 2014). A given PBZ application astonishingly influences culm length than panicle length of tef plants, which indirectly entail higher demand of endogenous gibberellins, may exist for elongation culm than panicle. PBZ might have resulted in reduction in cell merstematic activity and cell elongation in the intercalary meristem (Kelbert *et al*., 2004). Many studies reported that culm length increment associated positively with lodging of plants. Minimizing culm length associated with improvement of yield will able to minimize the risk of lodging (Mansuroglu *et al*., 2009; Currey and Lopez, 2010).

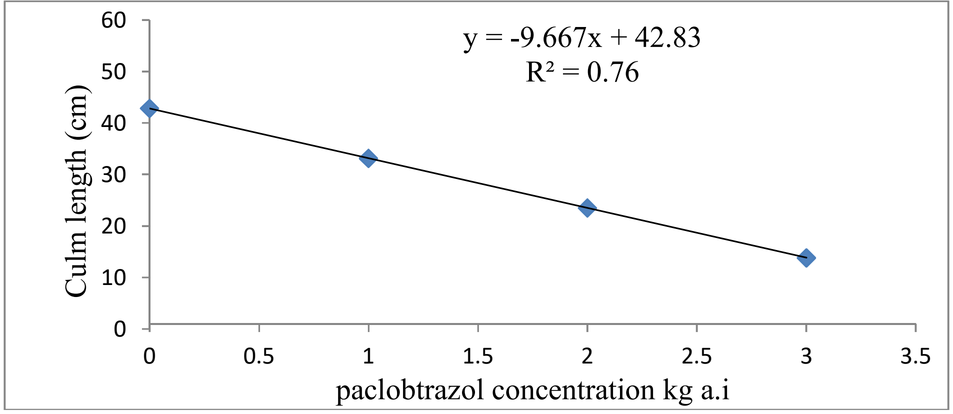

Fig. 2. Relationship of PBZ concentration and culm length.

2.3 Effect on Yield and Yield components

3.3.1 Number of tillers

A significant interaction between time and rate of PBZ application was observed on number of fertile (Table 6) and total tillers (Table 7). The highest number of fertile tillers (16.33) was obtained from the lower rate of PBZ spray at jointing stage while the lowest number of fertile tillers (8.67) occurred from the no spray and late time of PBZ application at growth stage of tillering and panicle emergence respectively (Table 6). Likewise the highest number of total tillers was obtained (19.00) from the lower rate of PBZ spray at jointing stage and the lowest total tillers (11.00) was at late time of PBZ application (Table 7).

The main effects of PBZ rate were significant on the number of fertile tillers (Table 6). Tef plants treated with PBZ at jointing, tillering and panicle emergence stages gave 14.08, 11.75, 9.00 fertile number of tillers respectively (Table 6).

Table 6. Means of fertile tiller of tef plants as affected by rate and stage of application at Debre Zeit during the 2016 main season

Rates (kg a.i ha^{-1})	No. of fertile tillers			Means of rates of PBZ (Overall growth stages)
	Time of application			
	Tillering	Jointing	Panicle emergence	
0	8.67^{c}	9.30^{b}	9.00^{c}	9.00^{c}
1	14.30^{b}	15.67^{ab}	9.00^{c}	13.00^{a}
2	$14.67^{a b}$	$15.00^{a b}$	8.67^{c}	12.78^{a}
3	9.33^{c}	16.33^{a}	9.33^{c}	11.67^{b}
Means of growth stages (Over all rates)	11.75^{b}	14.08^{a}	9.00^{c}	
SEm±	1.01			
CV (%)	8.69			

SEM: Standard error of Mean

Means within the same column and row followed by the same superscript letters are not significantly different as judged by DMRT at P≤0.05

It was observed that PBZ rate increased number of total tiller. Similar to the rates, time of application affected total number of tillers significantly and the highest amount of total tillers (17.17) was obtained when PBZ was applied at jointing stage followed by spray at tillering (14.75) and panicle emergence stages (11.58) (Table 7).

Application of PBZ with lower doze strongly promoted higher fertile and total tiller number without affecting the number of unfertile tillers compared to those untreated plants. Similar result reported in promoting of higher tiller number on tef (Endale *et al.*, 2012), barley (Bahram *et al*., 2014a) and sun flower (Ribeiro *et al.*, 2011). This might be attributed due (i) PBZ application favors height reduction at tillering stage and photoassimilation there by reducing the energy required for rapid growth. The reserved carbohydrate directly involved to produce more tiller production and enhance fertile tillers and (ii) the other possible reason for the notable augmentation in fertile tillers number might be attributed to the high levels of cytokinins accompanied by low level of Indole acetic acid (IAA) which led to limitation of apical dominance and there by prevent excessive vegetative growth. Also Mekki and Orabi (2007) reported that PBZ application may prevent excessive vegetative growth and improve translocation of photosynthates from source to sink. Similar to this finding Bahrami *et al.* (2014a) found that height reduction led to higher tiller survival and enhanced fertile tillers, which resulted in greater yield in barley.

Table 7. Total tillers of tef plants as affected by rate and stage of application at Debre Zeit during the 2016 main season

Rates (Kg a.i ha^{-1})	No. of total tillers			Means of rates of PBZ (Overall growth stages)
	Time of application			
	Tillering	Jointing	Panicle emergence	
0	12.33^{c}	12.30^{b}	11.67^{c}	12.10^{b}
1	16.67^{b}	19.00^{ab}	11.00^{c}	15.56^{a}
2	17.33^{ab}	17.67^{ab}	11.33^{c}	15.44^{a}
3	12.67^{c}	17.67^{ab}	12.33^{c}	14.89^{a}
Means of growth stages (Over all rates)	14.75^{b}	17.17^{a}	11.58^{c}	
SEm±	1.36			
CV (%)	9.43			

SEM: Standard error of Mean

Means within the same column and row followed by same letters are not significantly different as judged by

DMRT at $P \leq 0.05$

3.3.2 Thousand seed weight

The analysis of variance showed that the main effect as well as the interaction effects of rate and time of PBZ application was not significant ($P > 0.05$) on thousand seed weight.

From this result thousand seed weight of tef was not affected by PBZ application time and rates as well as by their interaction effect. Rajala (2003) opined that grain weight remain unaffected or slightly reduced by plant growth regulators. According to Khaje *et al*. (2008) thousand seed weight mainly depends on carbohydrate reserved at initiation of grain filling and plant genotype. Cultivar affects on increased weight of thousand grains, maximum weight of each grain is among the properties dependant on plant genotype. In his study, it was indicated that plant growth regulators didn't show significant difference in respect of weight of thousand grains of barley. From the result of this study it can be concluded that the weight of thousand seed weight of tef is affected by genotype of plant and not by utilized input that was used. In general mean thousand weights of cereals in almost stable yield components of cereals and in lower rate affected by environmental factors (Pirasteh *et al*., 2016). In teff, PBZ application increased thousand seed weight of by enhancing starch synthesis (Tekalign, 2007).

3.3.3 Biomass yield

The biomass yield was significantly influenced by the interaction effect of rate and time of PBZ application (Table 8). Biomass yield generally decreased significantly and progressively with increase in the rate of PBZ treatments especially when applied at tillering and jointing stages. The highest biomass yield (13,090kg ha^{-1}) was obtained from the plants that are not treated with PBZ followed by plants sprayed with 0kg a.i ha^{-1} of PBZ at jointing stage (13050kg ha^{-1}). Whereas the lowest biomass yield was obtained from plants treated with 3kg a.i ha^{-1} of PBZ at tillering stage which reduced biomass yield by 26% over the control. Following this application of the higher rate of PBZ at jointing stage reduced biomass by 18% in comparison to the control. Generally, further increase in rate of PBZ application reduced biomass yield at all growth stage at panicle emergence stage (Table 8).

The main effects of PBZ rate were significant on biomass yield. The highest biomass reduction was recorded from plants receiving 3kg a.i of PBZ ha^{-1} which reduced biomass yield by 15%, followed with 2kg and 1kg a.i of PBZ ha^{-1} which reduced biomass yield by 17% and 11% in comparison to the control (Table 8). The analysis of variance also showed that main effects of time application of PBZ significantly reduced biomass yield. The highest biomass yield (12,160kg ha^{-1}) was recorded from plants that receive PBZ at panicle emergence; the next highest biomass yield (11,660kg ha^{-1}) was recorded from jointing stage of application of PBZ while the lowest (11570kg) was obtained from the earliest stage of application of PBZ (Table 8).

PBZ application decrease total biomass yield of tef particularly when applied at tillering and jointing stage. Similar results have been reported on potato biomass yield reduction due to application of PBZ (Tekalign and Hammes, 2005). This might be attributed due to the collective effect of having shorter plants with reduced culm length and plant height. Contradicting results have been reported by Mohammadi *et al.* (2011) on canola (*Brassica napus* L.) and Hagazi and Elshraiy (2007) on bean found that foliar applications of PBZ increased biomass yield. Some of the reasons which cause inconsistency between this experiment and the result given by the other researchers might be the concentration of growth moderators, application method, application time, application number, the formula of used substance, and type of plant growth regulators (Pirahmadi *et al*., 2016).

Table 8. Biomass of tef plants as affected by rate and stage of application of PBZ at Debre Zeit during the 2016 main season.

Rates (Kg a.i ha^{-1})	Biomass yield (kg ha^{-1}) Time of application: Tillering	Jointing	Panicle emergence	Means of rates of PBZ (Overall growth stages)
0	13090^{a}	13050^{a}	12830^{a}	12990^{a}
1	10760^{d}	11730^{b}	12110^{b}	11530^{b}
2	9930^{e}	11170^{c}	11880^{b}	10990^{c}
3	9730^{e}	10700^{d}	11810^{b}	10740^{d}
Means of growth stages (Over all rates)	11570	11660^{b}	12160^{a}	
SEm±	0.22			
CV (%)	1.97			

SEM: Standard error of Mean

Means within the same column and row followed by the same superscript letters are not significantly different as judged by DMRT at $P \leq 0.05$

3.3.4. Grain Yield

The analysis of variance showed that grain yield of tef was significantly influenced by the interaction of rate and time of PBZ application (Table 9). The highest grain yield (3,800kg ha^{-1}) was obtained from the plants treated with rate of 1kg a.i of PBZ ha^{-1}at jointing stage which increased grain yield by 20.8% (Table 9). This was followed by plants treated with 2 kg a.i of PBZ ha^{-1}at jointing stage (3,470kg ha^{-1}). But further increase in rate of PBZ spray at jointing stage, there was no appreciable change with respect to yield (Table 9). At panicle emergence stage application, PBZ concentration did not cause any significant increment in the grain yield, rather the grain yield was found to decrease with increased rate of PBZ spray.

Table 9. Grain yield of tef plants as affected by rate and stage of application of PBZ at Debre Zeit during 2016 main season.

	Grain yield (kg ha^{-1})			Means of rates of PBZ
Rates (Kg a.i ha^{-1})	Time of application			(Overall growth stages)
	Tillering	Jointing	Panicle emergence	
0	3110^{cde}	3010^{e}	2980^{e}	3030^{d}
1	3420^{b}	3800^{a}	3140^{cde}	3460^{a}
2	3180^{cd}	3470^{b}	3070^{ed}	3240^{b}
3	3120^{cde}	3250^{c}	3050^{ed}	3140^{c}
Means of growth stages (Over all rates)	3210^{b}	3380^{a}	3060^{c}	
SEm±	0.08			
CV (%)	2.76			

SEM: Standard error of Mean

Means within the same column and row followed by the same superscript letters are not significantly different as judged by DMRT at P≤0.05

In general further increase in rate of PBZ spray reduced yield and applying lower rate resulted in higher yield than intermediate and highest rates (Table 9). Likewise, the main effects of both rates and time of application influenced yield significantly. The lower rate of PBZ at 1kg a.i ha^{-1} gave highest yield (3,460kg ha^{-1}) followed by the intermediate (3,240kg ha^{-1}) and highest rate (3,140kg ha^{-1}). This implies that further increase in the doze of PBZ was found to decrease yields. On the other hand, time of application significantly affected yields, among the three different stages of application PBZ spray at jointing stage (3,380kg ha^{-1}) give the highest grain yield than that at tillering (3,210kg ha^{-1}) and panicle emergence (3,060kg ha^{-1}) stages (Table 9).

The positive effect of PBZ application on grain yield improvement of tef relies on a number of yield attributing traits including number of fertile tillers, fertile florets and better plant canopy has been showing in number of studies evaluating the production potential of cereals. The increment in grain yield of tef, due to PBZ treatments might be (i) through the initiation of more fertile tiller per plant resulting in more grain yield production. Similar studies indicated that PBZ increased grain yield of winter wheat (Shekoofa and Emam, 2008) by increasing fertile tiller and higher grain number. In field experiments, application of growth regulators at mid-tillering stage increased grain yield of spring barley 10 %to 17% and increased grain yield of winter barley 12 to 18 %. The reason for this increase in grain yield was the increase of spike number per unit area (Heidari and Kavousi, 2013), (ii) the other possible reason for increment of grain yield might be due to altered phenology (days to maturity) that might have enhanced photosynthesis for longer time which in turn contributed to better plant productivity in tef (iii) decreased plant height can cause increase plants resistance against factor like lodging and plants reducing which itself cause the decrease of yield (Mohaghegh *et al*., 2007). Contradicting result has been reported by El-Khallal *et al.* (2009) who found foliar application of PBZ under favorable moisture conditions decrease maize grain yield due to an increase in the concentration of abscisic acid hormone. The mentioned hormone (Abscisic acid) reduces grain yield through reducing the number of endosperm cells, followed by decreasing grain size and also motivating for embryonic loss, and decreasing grain number.

3.3.5 Straw yield

Straw yield was significantly affected by both main effects as well as the interaction effects of rate and time of PBZ application (Table 10). It was observed that application of PBZ reduced straw yield. The highest straw yield (10,040kg ha^{-1}) was obtained from untreated plants followed by early application untreated (9980kg ha^{-1}) and the lowest straw yield (6,610kg ha^{-1}) was obtained from plants that treated with 3kg a.i of PBZ ha^{-1} at tillering stage. In general it was observed that further increase in concentration of PBZ reduced straw yield at tillering stage and no appreciable change occurred with applications at jointing and panicle emergence stages (Table 10).

It was observed that increase the rate from 0 to 1kg and 1 to 2kg a.i of PBZ reduced straw yield by 19 % and 4%. But further increase in concentration did not significantly reduced straw yield. Regarding, the time of application PBZ treatment was decreased straw yield more when sprayed at tillering (7,670kg ha^{-1}) followed by application at jointing (8,280kg ha^{-1}) and panicle emergence stages (9,100kg ha^{-1}) (Table 10).

Table 10. Straw yield of tef plants as affected by rate and stage of application of PBZ at Debre Zeit during the 2016 main season.

Rates (Kg a.i ha^{-1})	Straw yield (kg ha^{-})			Means of rates of PBZ (Overall growth stages)
	Time of application			
	Tillering	Jointing	Panicle emergence	
0	9980^{a}	10040^{a}	9850^{a}	9960^{a}
1	7340^{d}	7930c	8970 ^{b}	8070^{b}
2	6750^{e}	7700^{cd}	8810 ^{b}	7750^{c}
3	6610^{e}	7450^{d}	8760^{b}	7600^{c}
Means of growth stages (Over all rates)	7670^{c}	8280 ^{b}	9100^{a}	
SEm±	0.21			
CV (%)	2.54			

SEM: Standard error of Mean

Means within the same column and row followed by the same superscript letters are not significantly different as judged by DMRT at P≤0.05

The reduction in straw yield due to the application of PBZ might be attributed from shorter plant height and from better assimilate portioning, which favor the grain development since PBZ inhibit vegetative growth. Similar result reported by Espindula *et al*. (2009) who said that PBZ can alter the growth and developmental processes, leading to reduce vegetative growth (plant height and straw) ,increased yield, improved grain quality or facilitated harvesting.

3.3.6 Harvest index

Harvest index was significantly affected by the interaction of rate and time of PBZ application (Table 11). The highest harvest index (32.07%) was obtained from plants treated with the highest rate of 3kg a.i ha^{-1} PBZ application at tillering stage. The lowest harvest index (23.07%) was obtained from jointing stage. The analysis of variance also indicated that the main effects of both time and rate of PBZ application were significant on harvest index (Table 11). Harvest index was improved by concentration of PBZ application and the highest harvest index (30.01%) was obtained from plants treated with 1kg a.i of PBZ ha^{-1} which increased harvest index by 22% in comparison to the control (Table 11). But with increased rates of PBZ application harvest index was not significantly affected. Overall rates of PBZ application harvest index values of statistically comparable and highest for applications at tillering (29.51%) and jointing stage (28.99%) and lowest (25.17%) for sprays at panicle emergence (Table 11).

Harvest index of tef plants was found increased due to PBZ application .This might be attributed to better partitioning coefficient in which plant growth regulators are known to promote distribution of photoassimilate and changed the pattern of assimilate distribution towards reproductive part especially to upper parts of the plant thus increasing their sink capacity which leading higher yield, improved harvest index. Similar to this result PBZ application altered the distribution of dry matter in favor the grain and increased grain yield and harvesting index (Hussain *et al*., 2009).

Table 11. Harvest index of tef plants as affected by rate and stage of application of PBZ at Debre Zeit during the 2016 main season.

Rates (Kg ha^{-1}a.i)	Harvest index (%)			Means of rates of PBZ (Overall growth stages)
	Time of application			
	Tillering	Jointing	Panicle emergence	
0	23.76^{d}	23.07^{d}	23.23^{d}	23.33^{b}
1	31.79^{ab}	32.03^{a}	25.93^{c}	30.01^{a}
2	32.03^{a}	31.07$^{a\ b}$	25.85^{c}	29.49^{a}
3	32.07^{a}	30.38 ^{b}	25.83^{c}	29.24^{a}
Means of growth stages (Over all rates)	29.51^{a}	28.99^{a}	25.17^{b}	
SEM±	0.57			
CV (%)	2.09			

SEM: Standard error of Mean

Means within the same column and row followed by the same superscript letters are not significantly different as judged by DMRT at P≤0.05

3.4 Straw crude protein content

The analysis of variance showed significant interaction between rate and time of PBZ application with respect to straw crude protein content (Table 12). The highest straw crude protein content (9.21%) was obtained from plants that treated with 1 kg ha^{-1}a.i. PBZ at jointing stage followed by the intermediate rate of 2 kg a.i. ha^{-1}(9.13%) applied at the same stage. The main effects of PBZ rate significantly influenced straw crude protein content of the tef plants. Applying a.i of PBZ from 0 to 1kg ha^{-1} increased crude protein content of tef straw by 31% and further increase from 1 to 2kg PBZ increased it only by 6% while further increased in PBZ rates from 2kg a.i. ha^{-1} didn't influence straw crude protein content. On the other hand, time of application also affected straw crude protein content such that averaged overall rates the highest mean value of 8.16% occurred with application at jointing followed by significantly diminishing order with sprays at tillering (7.21%) and at panicle emergence (6.34%) (Table 12).

The increased value of straw crude protein content of tef plant due to PBZ application might be attributed from PBZ which help to releases their amino acid from their storage and there by increases protein. Sawan (2008) reported that the primary effect of plant growth regulators is affecting GA, sterols and ABA biosynthesis and they indirectly affects starch percentage; as result protein increased. There are similar reports which indicate that PBZ increases the amount of proteins in wheat (Nouriyani, 2012) and brassica (Razavizadeh and Amu, 2013). Also Campell (2008) observed that PBZ enhance level of cytokinin which in turn prevents protein degradation and promotion of protein synthesis which have resulted an increase protein content of the plant.

Table 12. Straw crude protein content of tef plants as affected by rate and stage of application of PBZ at Debre Zeit during the 2016 main season.

Rates (Kg a.i ha^{-1})	Straw crude protein content (%)			Means of rates of PBZ (Overall growth stages)
	Time of application			
	Tillering	Jointing	Panicle emergence	
0	5.22^{f}	5.19^{f}	5.18^{f}	5.19^{c}
1	7.35^{c}	9.21^{a}	6.16^{e}	7.57^{b}
2	8.12^{b}	9.13^{a}	7.02^{d}	8.09^{a}
3	8.14^{b}	9.12^{a}	7.00^{d}	8.09^{a}
Means of growth stages (Over all rates)	7.21^{b}	8.16^{a}	6.34^{c}	
SEm±	0.06			
CV (%)	2.27			

SEM: Standard error of Mean

Means within the same column and row followed by the same superscript letters are not significantly different as judged by DMRT at P≤0.05

3.5 Effects on lodging index

A significant interaction between time and rate of PBZ application was observed with respect to lodging index (Fig.3). Remarkable reduction (36.7%) in lodging due to PBZ application with sprays rate of 2kg a.i ha^{-1} at tillering and jointing in comparison to the control, while late application of 3kg a.i of PBZ ha^{-1}reduced lodging by 20% (Fig.3). It was also observed that further increase in the concentration of PBZ leads to linear reduction in lodging index (Fig. 4). In addition, intermediate and higher rate of PBZ application did not significantly influence lodging when sprayed at tillering and jointing stages, while late application of PBZ significantly affect lodging in all rates.

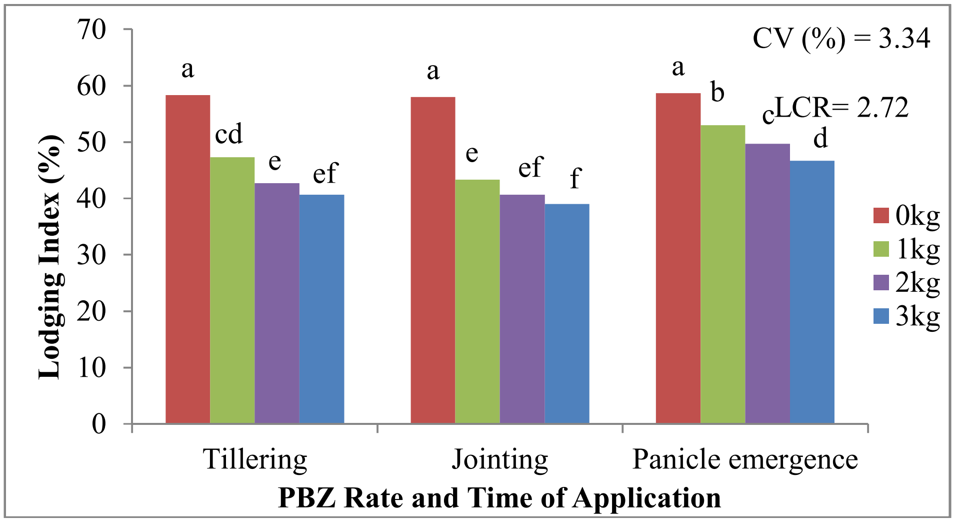

Fig 3. Lodging index as affected by PBZ rate and time of application.

The main effects of both rate and time of application were also significant in affecting lodging index. The highest lodging reduction was observed from plants that treated with 3kg a.i of PBZ which reduced lodging by 27.8%, followed 2kg a.i of PBZ which reduced lodging by 24%.The lower rate of PBZ application at 1 kg a.i ha^{-1} PBZ contributed 18% reduction in lodging index in comparison to the control. Regarding stage of application PBZ treatment reduced lodging effectively when applied at the jointing stage (45%) compared to the other two stages. Next to jointing application of PBZ at earlier at tillering stage (47%) reduced lodging of tef plants more than late application (52%).

The relationship between PBZ concentration and lodging index are linear. Lodging index was described by the equation Y= -5.22X + 56 which means that for every unit increase in the concentration of PBZ (kg), lodging index decreased by 5.22 unit (Fig.4).

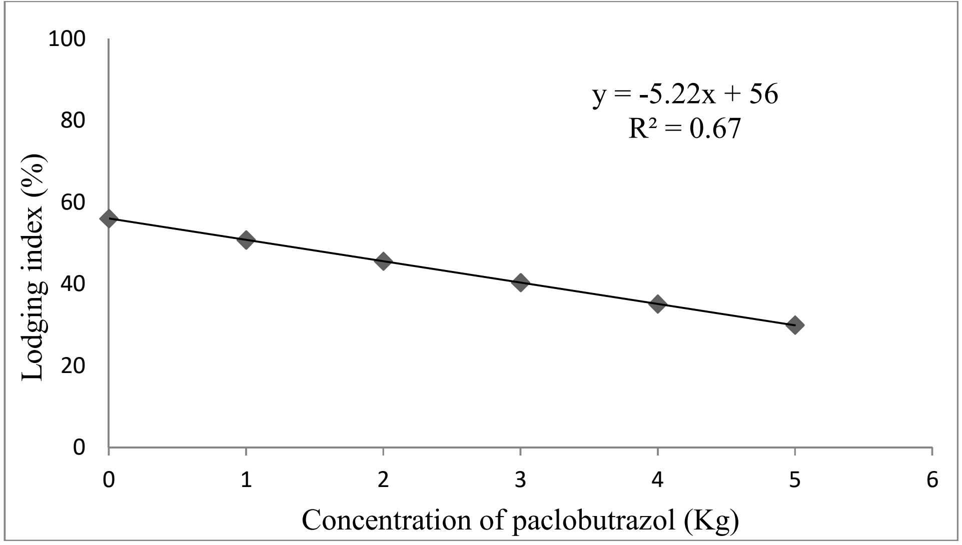

Fig .4. Relationship of PBZ concentration and lodging index

Lodging incidence during grain filling time considerably reduces grain filling capacity of crop and PBZ application reduces the lodging intensity (Rajala, 2003). The reduction of lodging due to PBZ application might be associated with reduction of excessive vegetative growth and plant height. This idea strengthen by Espindula *et al.* (2009) who reported that using short stature cultivars or plant growth regulators have more strength to resist lodging than tall stems.. Similar reports on different crop depicted that foliage application of PBZ at early stage reduced lodging and improved grain yield in tef (Tekalign, 2007), wheat (Toyota *et al.*,2010) and pea (Elkoca and Kantar, 2006).

4. Conclusions

In conclusion plants treated with of PBZ 1kg a.i ha^{-1}at jointing stage resulted in more number of fertile tillers, high grain yield and minimized lodging risk, coupled with the best economic benefit or profitability. Therefore, this treatment combination can be suggested for use by tef farmers in the study area. However, further validation and demonstrations across multiple environments would be necessary in order to make conclusive recommendation.

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