Vol. 16(12), pp. 1691-1699, December, 2020
DOI: 10.5897/AJAR2020.15181
Article Number: 8CFD16C65576
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

ACADEMIC JOURNALS
expand your knowledge

African Journal of Agricultural Research

Full Length Research Paper

Effect of ploughing and weeding frequencies on growth, yield and yield components of Teff [*Eragrostis tef* (Zucc.) Trotter] in Mirab Abaya Area, Southern Ethiopia

Zewditu Dawit[1], Berhanu Lemma Robe[2]* and Amare Girma[2]

[1]Gamo Zone Environment Protection, Forest and Climate Change Controlling Office, Arba Minch, Ethiopia.
[2]Department of Plant Science, College of Agricultural Sciences, Arba Minch University, Ethiopia.

Received 4 September, 2020; Accepted 16 November, 2020

Inappropriate ploughing and weed control practices are among the major limiting factors for teff productivity in Ethiopia. Hence, this study was conducted to evaluate the effect of ploughing and weeding frequencies on growth and yield of teff varieties in Mirab Abaya district of southern Ethiopia during short cropping season of 2019. The treatments as combinations of three levels of ploughing (ploughing six times, four times and once), three levels of weeding frequency (no weeding, weeding once at tillering, weeding twice at tillering and stem elongation stages of the crop) and two varieties of teff (local and improved variety Quncho) which were laid out in split-split-plot design using ploughing as a main plot factor, weeding as subplot and variety as sub-subplot treatment with three replications. Data on phenological, growth and yield, and yield related parameters were collected and analyzed using General Linear Model (GLM) procedures of SAS 9.0. Weeding twice at tillering and stem elongation stage increased yield by 20% over the un-weeding treatment. The highest grain yield (1193 kg/ha) was obtained when ploughing six times combined with weeding twice for improved teff variety (Quncho) followed by (1135 kg/ha) the combination of ploughing four times and weeding twice for the local variety. However, ploughing four times combined with weeding twice at tillering and stem elongation stage for improved teff (Quncho) variety was found to be economical practice with the highest net benefit (27,503.4 Ethiopian birr/ha) and marginal rate of return (5800%). This practice, therefore, may be recommended for higher yield and profitability of Quncho variety in the study area and other similar environments.

Key words: Teff, grain yield, biomass yield, economic analysis, harvest index, Quncho.

INTRODUCTION

Teff (*Eragrostis tef*) plays a major role in the livelihood of most smallholder farmers in Ethiopia. It is adapted to

*Corresponding author. E-mail: berhanu.lemma@amu.edu.et.

Table 1. Some selected physicochemical properties of the soil at the experimental site (0-20 cm).

Sand	Silt	Clay	Textural class
3.73	24.8	71.43	Clay loam
Parameters	Soil test value	Rating	Reference
pH (1:2.5 H_2O)	7.42	Moderately alkaline	Tekalign (1991)
TN %	0.2	Medium	Tekalign (1991)
OC %	1.99	Medium	Tekalign (1991)
AP (mg/kg)	11.01	High	Olsen et al. (1954)
OM (%)	3.48	Medium	Murphy (1968)
CEC (cmol (+)/kg soil)	16.5	Moderate	Landon (1991)
K (meq /100 g)	15.69	Very high	FAO (2006)

TN: Total nitrogen, OC: organic carbon, AP: available phosphorus, OM: organic matter, K: potassium, CEC: Cation exchange capacity.

diverse agro-ecological regions of Ethiopia and grows better under stress environments than do other cereals known world-wide (Hailu and Peat, 1996). The area covered by teff during the main season is about 1.91 million ha, which stands first in area coverage and accounts for 29% of the total cereal area in Ethiopia (CSA, 2010). However, its productivity is far lower than that of other major cereal crops growing in the country. Average national yield of teff in 2014/2015 production season ranged from 1281 to 1575 kg/ha (Sharma and Adera, 2016). Lower teff grain yield is mainly attributed due to inappropriate ploughing and weed control practices (Habtegebrial et al., 2007; Oicha et al., 2010). Other studies also indicated that weed is one of the key limiting factors for attaining higher teff yield (Mersie and Parker, 1983).

Tillage has been an important aspect of technological development in the evolution of agriculture, particularly in food production. Tillage systems are site specific and depend on crop, soil type and the climate (Rasmussen, 1999). Ploughing is one of the methods for soil tillage and weed control. Repeated ploughing makes the soil light and increase the available pore space for aeration in soil and root development. Due to this increase in available pore space, soil compaction is reduced and water holding capacity of soil increased (Bargali et al., 1993a, 2018, 2009) which enhanced the decomposition processes (Bargali et al., 1993b; Bargali, 1996), nutrient cycling (Bargali, 1995; Bargali et al., 1992; Bargali and Singh, 1997; Manral et al., 2020) and influences the crop productivity (Padalia et al., 2018). Some crops need very high tillage processes. Teff also needs high tillage frequencies as compared to other cereal crops in Ethiopia. It also requires firm, and level seedbed, free from clods and stumps. With respect to teff cultivation on vertisols, several ploughings are necessary, occasionally as much as 12 times, relative to nitosols (Deckers et al., 1998). According to Kenea et al. (2001) the tillage frequency for teff in Ethiopia ranges from three to twelve times. Though some research results indicated teff grain yield increased with increasing number of ploughings (IAR, 1998; Melese, 2007).

Generally, farmers practice conventional tillage to control weeds, conserve moisture, and increase soil warming (Oicha et al., 2010). Other researchers (Mulumba and Lal, 2008; Rachman et al., 2003) noted that it is essential to select a tillage practice that sustains and favors successful growth of agricultural crops in a given environmental condition. An experiment conducted at DebreZeit Research Center in Ethiopia indicated that hand weeding once at early tillering or twice at early tillering and stem elongation stage depending on the degree of weed infestation of the crop was profitable (Seyfu, 1993). There is inadequate information on the effect of ploughing frequency and weed control practices on teff growth and yield in the low land areas of Gamo Zone. Therefore, the objective of this study was to evaluate the effects of tillage and weeding frequency on growth, yield and yield components of teff varieties.

MATERIALS AND METHODS

Description of the study area

The experiment was conducted at Fura kebele in Mirab Abaya woreda, Gamo Zone in Southern Ethiopia on a farmer’s field during 2019 short cropping season. The place is located in between 6°11′0″ - 6°13′0″N and 37°37′0″ - 37°45′0″E longitude and latitude, respectively and at an elevation of 1193 masl with the average annual rain fall of 610 mm and average minimum and maximum air temperatures of 19 and 34°C, respectively. The area is located at 30 km away from Arba Minch city in northern direction. Soil properties of the study site are described in Table 1.

Treatments, design and experimental procedures

The experiment consisted of three levels of tillage frequencies (one pass, four passes and six passes), three levels of weeding frequency (no weeding, one time weeding at tillering and two times weeding at tillering and stem elongation stages of the crop) and two varieties of teff (local and improved variety namely Quncho or DZ-Cr-387-RIL 355). Quncho was developed and released by Debrzeit Agricultural Research Centre in 2006, it is a high yielding variety (1.8-2.6 t/ha on-farm), early maturing (86-151 days), and white-

Table 2. Dominant weed species at tillering stage of teff on the clay-loam soil at experimental site.

Weed species	Family	Common name	Population/m^2
Cyperus rotundus L.	Cyperaceae	Purple nutsedge	109.2
Amaranthus retroflexus L.	Amaranthaceae	Redroot pigweed	60
Cynodon dactylon (L.) Pers.	Poaceae	Bermuda grass	58.4
Datura metel L.	Solanaceae	Thorn apple	42.2
Other minor weed species	-	-	168

Table 3. Weed density (plants/m^2) as affected by tillage frequency

Ploughing frequency	Weed population/m^2
One pass	9.0^a
Four passes	4.6^b
Six passes	4.3^b
LSD (0.05)	0.76
CV (%)	19

Mean values followed by the same letter are not significantly different at 5% probability level. LSD= List significant difference; CV= Coefficient of variation.

seeded cultivar adapted to a wide range of altitudes (MoA, 2010). The treatments were laid out in split-split plot design using tillage as a main plot factor, weeding as subplot factor and variety as sub-subplot factor with three replications. Those plots, which received six plowing frequencies, were plowed first at late January, 2020; second up to fifth plows were done within fifteen days interval and the sixth at sowing. The plots, which received four plowing frequencies, were plowed first, at the late February, 2020; second up to third plows were done within fifteen days interval and the fourth at sowing. The plots, which received one plowing, were plowed only at sowing.

After preparing the land as per treatments required, each main plot divided into three sub plots (1.2 m × 4 m) and finally each sub plots divided into two sub sub-plots (1.2 m × 2 m) with net plot size of 1.2 m × 2.0 m^2. A plot size of 1.2 m × 2 m (2.4 m^2) with 10 cm row spacing and a total of 10 rows were used. The net harvestable area was 1.0 m × 1.8 m and adjacent plots and blocks were spaced 0.5 and 1 m apart, respectively. All agronomic practices were conducted as per recommendations except the treatments.

Data collection

Data were collected on weed species composition and density as well on crop parameters including days to 50% panicle emergence, days to 90% physiological maturity, total tiller number/m^2, plant height (cm), number of effective tillers/plant, panicle length (cm), total dry biomass yield (kg/ha), grain yield (kg/ha), harvest index (%) and thousand seed weight (g).

Statistical analysis

Data were subjected to analysis of variance (ANOVA) using General Linear Model (GLM) procedures of SAS 9.0 (SAS, 2004). Differences among treatment means were compared using Least Significant Differences test at 5% level of probability.

Economic analysis

The economic analysis was done to determine the economic feasibility of the treatments following the procedure developed by CIMMYT (1988). Costs of tillage, weeding and teff seed were taken as variable costs during the experiment and prevailing market price of the crop was estimated at the time crop harvest as return. Seed yield was also adjusted down by 10%.

RESULTS AND DISCUSSION

Weed species composition

Weed species recorded during the study period were grasses and broad-leaved species of herbs. The dominant weeds were grasses in the experimental site (Table 2).

Effect of tillage frequency on weed density

Weed density was significantly (P< 0.05) influenced only by the main effect of tillage frequency (Table 3). Weed density was significantly reduced with increase in the number of tillage passes. 52 and 50% reduction in weed density was observed due to six and four tillage passes, respectively, compared to the value obtained single pass plow. Accordingly, maximum value of weed density (9 plants/m^2) was recorded due to one pass tillage. This result is in agreement with report of ICARDA (1984) which shows that repeated tillage compared to no-till reduced weed infestation by 50%.

Table 4. Days to 50% panicle emergence as affected by tillage and variety.

Treatment	Days to 50% panicle emergence
Ploughing frequency	
One pass	36.0[b]
Four passes	36.9[a]
Six passes	37.0[a]
P-value	**
CV (%)	2.4
Variety	
Local	36.8[a]
Improved (Quncho)	36.4[b]
P-value	*
CV (%)	2.6

Mean values followed by the same letter with in a column for a given treatment level are not significantly different at 5% probability level. ** and * denote significant differences at $P < 0.01$ and $P < 0.05$ probability levels, respectively.

Days to 50% panicle emergence

This parameter was significantly influenced only by the main effects of ploughing frequency and variety (Table 4). Statistically similar and longer durations of days to 50% panicle emergence were recorded due to fourth plowing and six times compared with single pass plowing. The increment in duration of panicle emergence with increase in plowing frequency might be associated with easy and efficient utilization of soil nutrients and moisture from fine seedbed which favored prolonged time for vegetative growth with delayed heading of the crop. Regarding varietal effect, local variety took statistically longer duration to (36.8 days) 50% panicle emergence compared with improved variety (Quncho). This variation might be due to genetic difference between the two varieties as reported by Seyfu (1993).

Days to maturity and growth parameters

Days to maturity, total number of tillers/m^2, number of effective tillers/plant and plant height were significantly affected by the interaction effects of plowing frequency, weeding frequency and variety (Table 5).

Days to 90% physiological maturity

The maximum number of days to maturity (69.67 days) was observed for treatment combination of ploughing six times with two times hand weeding at tillering and stem elongation stage for the local variety, while the lowest value (65 days) was recorded for ploughing once combined with un-weeded control for the improved variety. The prolonged period for maturity with increased ploughing frequency and weed free environment or minimized weed population might be due to prolonged period of vegetative growth at the expense of reproductive development as a result of probably improved nutrient and moisture supply to the plants. Varietal difference in maturity period could be attributed to differences in the genetic makeup. This result was in agreement with the findings of Haftamu et al. (2009) who reported that teff requires 90 to 130 days for growth depending on variety and altitude. In contrast, Evert et al. (2008) reported that little weed competition due to suitable agronomic management practice results in fast growth and earlier maturity of crops.

Total tiller number

The highest total tiller number (182.67) was recorded for the combination of six plows with two times hand weeding for the improved teff variety, followed by the same treatment combination for the local teff type (177.67) (Table 5), while one plow with un-weeded control resulted in lower values for both local (95.67) and improved (122.30) varieties. This might be due to more availability of soil nutrients and other environmental inputs for the crop due to repeated tillage and in the absence of weed competition. The result was in line with the findings of Aleligne (1988) who reported that fine seedbed preparation is to get weed free environment and good crop germination. Similarly, Tenaw (2010) has reported that repeated tillage created conducive environment for better plant establishment, growth and production because of reduced weed competition and possibly better root growth.

Plant height

Maximum plant height (114.3 cm) was recorded for

Table 5. Interaction effect of treatments on days to maturity, tillering and plant height.

Ploughing frequency	Weeding frequency	Variety	Days to maturity	Total tiller number/m^2	Plant height (cm)	Number of effective tillers/plant
	No weeding	Local	67.0^{defg}	95.60^{h}	114.3^{a}	2.6^{d}
One pass	Weeding once	Local	68.6^{abcd}	139.6^{def}	89.3^{f}	5.3^{abc}
	Weeding twice	Local	68.6^{abcd}	135.6^{ef}	92.0ef	6.0^{abc}
	No weeding	Local	67.0^{defg}	139.3^{def}	100.6^{bcdef}	4.6^{bcd}
Four passes	Weeding once	Local	67.6^{bcde}	148.3^{cde}	96.3^{cdef}	6.0^{abc}
	Weeding twice	Local	68.6^{abcd}	160.0^{bc}	112.0^{ab}	7.0^{a}
	No weeding	Local	69.0^{abc}	145.6^{def}	106.3^{abc}	4.3^{cd}
Six passes	Weeding once	Local	69.3^{ab}	177.6^{a}	107.0^{abc}	5.6^{abc}
	Weeding twice	Local	69.6^{a}	177.6^{a}	102.3^{abcdef}	6.0^{abc}
	No weeding	Quncho	65.3^{g}	122.3^{g}	112.3^{ab}	3.0^{d}
One pass	Weeding once	Quncho	65.6^{fg}	141.6^{def}	90.6^{ef}	6.0^{abc}
	Weeding twice	Quncho	66.0^{efg}	146.0^{def}	102.3^{abcdef}	6.3^{abc}
	No weeding	Quncho	67.0^{defg}	133.6^{fg}	106.0^{abcd}	4.3^{cd}
Four passes	Weeding once	Quncho	65.6^{fg}	150.0^{cd}	97.0^{cdef}	6.3^{abc}
	Weeding twice	Quncho	67.3^{cdef}	172.3^{ab}	92.6^{def}	7.0^{a}
	No weeding	Quncho	68.6^{abcd}	145.6^{def}	97.0^{cdef}	4.3^{cd}
Six passes	Weeding once	Quncho	68.0^{abcd}	176.6^{a}	104.0^{abcde}	6.6^{ab}
	Weeding twice	Quncho	67.0^{defg}	182.6^{a}	100.6^{bcdef}	7.3^{a}
P value			***	*	*	**
CV (%)			1.6	5.2	8.1	23.3

Means followed by same letter(s) within a column are not significantly different at P > 0.05. ***, ** and * denote significant differences at P < 0.001, P < 0.01 and P < 0.05 probability levels, respectively.

minimum tillage combined with un-weeded plot for the local variety, while the lowest value (89.3 cm) was recorded for the same variety with one plow pass combined with weeding once at tillering stage (Table 5).
This may be due to fast vertical growth of the crop to successfully compete with weeds for light and space. The result of the present study was in agreement with the findings of Bekele et al. (2018) who reported that increased plant height with the weedy plot might be due to the effect of severe competition among plants which make them elongated in search of light.

Number of fertile tillers

The highest number of effective tillers (7.3) was recorded for six plows with two times weeding for the improved variety, followed by (7) four times plowing combined with two times weeding for the local variety, whereas the lowest value (2.6) was recorded for minimum tillage (one plow pass) with un-weeded treatments for the local teff type (Table 5). Number of fertile tillers increased with increasing tillage and weeding frequency, probably because of increased nutrient and moisture supply and more light to teff plants as a result of reduced inter-specific competition between the crop and weed species. The current result was in agreement with the findings of Gebreyesus (2014) who reported that number of effective tillers significantly increased as tillage frequency increased from minimum tillage up to four times plowing.

Thousand seed weight and harvest index

Thousand seed weight was significantly influenced only by the main effect of weeding frequency whereas harvest index insignificantly responded to main and interaction effects of the treatments (Table 6). Treatments in which weeds were removed resulted in higher and statistically similar values of thousand seed weight compared with control (un-weeded treatment). This might be attributed to better availability of growth resources for the crop in weeded treatment which results in better assimilate production and translocation to sink (seed).

Yield and yield components

Panicle length, above ground biomass and grain yield were significantly influenced by the interaction effects of

Table 6. Effect of ploughing and weeding frequencies on thousand seed weight and harvest index of teff.

Treatment	Thousand seed weight	Harvest index (%)
Ploughing frequency		
One pass	0.28	19.7
Four passes	0.32	18.6
Six passes	0.31	18.6
P-value	NS	NS
CV (%)	21.2	18
Weeding frequency		
No weeding	0.26[b]	20.0
Weeding once	0.32[a]	18.2
Weeding twice	0.31[a]	18.7
P-value	*	NS
CV (%)	20.5	17.7
Variety		
Local	0.29	19.5
Quncho	0.32	18.5
P-value	NS	NS
CV (%)	21.3	17.8

Means followed by same letter(s) within a column are not significantly different at P > 0.05. NS and * denote non-significant difference and significant difference at P < 0.05 probability levels, respectively.

ploughing frequency, weeding frequency and variety (Table 7).

Panicle length

The longest panicle (39.0 cm) due to four times ploughing and twice weeding in local variety whereas the shortest panicle (27.30 cm) was observed due to combined effect of one pass ploughing, un-weeded (control) treatment and local variety (Table 7). The increase in panicle length with repeated tillage and frequent weeding might be attributed to better availability of growth resources for the crop resulting from repeated tillage and weeding which is in agreement with the findings of Reicosky and Allmaras (2003) and the genetic nature of varieties.

Biomass yield

The highest biomass yield (6759.2 kg/ha) was obtained from treatment combination of six times plowing with two times hand weeding at tillering and stem elongation stage for the improved teff variety, while the lowest value was 3888.8 kg/ha followed by 3981.4 kg/ha recorded for one-time plow and un-weeded plot for the improved variety (Quncho) indicating that 74% variation in above ground biomass due to treatment interaction (Table 7). The increase in biomass yield with increasing tillage and weeding frequency could be attributed to increased availability of nutrients and soil moisture for the crop as a result of reduced competition by weeds as reported by Alemu et al. (2016). On the other hand, the lowest biomass yield (3888.9 kg/ha) was recorded from combined effect of one plow and un-weeded plots in improved variety implying the sensitivity of modern varieties to poor agronomic practices.

Grain yield

The highest grain yield (1192.53 kg/ha) was recorded for six times (conventional) plowing combined with twice hand weeding for the improved variety (Quncho) followed by the value (1135.17 kg/ha) obtained from four times plowing with weeding twice at tillering and stem elongation stage for the local variety, which produced the lowest grain yield (775.93 kg/ha) when un-weeded and grown with one plow pass (Table 7). The increase in grain yield with frequent tillage and weeding might be due to enhanced uptake of essential nutrients by teff plants as a result of reduced competition of weeds as reported by Alemayehu et al. (2008). Variation in grain yield (54%) was recorded due to interaction effects of ploughing frequency, weeding frequency and varieties. The current result also evidenced by the findings of Gebreyesus (2014) and Alemayehu et al. (2008) who reported higher grain yield under frequent ploughing and weeding, respectively. Grain yield showed highly significant and positive linear relationship with total tiller number (r= 0.72**), effective number of tillers (r= 0.59**), panicle

Table 7. Interaction effects of treatments on yield and yield components of teff.

Ploughing frequency	Weeding frequency	Variety	Panicle length (cm)	Above ground biomass (kg/ha)	Grain yield (kg/ha)
One pass	No weeding	Local	27.3[f]	3981.4d[e]	775.93[i]
	Weeding once	Local	32.3[def]	5462.9[abcde]	964.77[fg]
	Weeding twice	Local	33.6[bcd]	5000.0[bcde]	1087.00[bcd]
Four passes	No weeding	Local	32.3[def]	4351.8[cde]	981.43[efg]
	Weeding once	Local	34.3[abcd]	5926.0[abc]	986.97[defg]
	Weeding twice	Local	39.0[a]	6388.8[ab]	1135.17[ab]
Six passes	No weeding	Local	34.3[abcd]	5185.2[abcde]	1012.63[def]
	Weeding once	Local	38.6[ab]	6203.7[ab]	1079.60[bcde]
	Weeding twice	Local	36.0[abcd]	6388.9[ab]	1118.50[abc]
One pass	No weeding	Quncho	27.6[ef]	3888.9[e]	799.97[hi]
	Weeding once	Quncho	32.6[de]	4074.0[de]	811.13[hi]
	Weeding twice	Quncho	36.3[abcd]	5740.7[abc]	1016.67[def]
Four passes	No weeding	Quncho	33.3[cd]	5555.6[abcd]	890.70[gh]
	Weeding once	Quncho	36.6[abcd]	5370.4[abcde]	1024.00cd[ef]
	Weeding twice	Quncho	37.0[abcd]	6203.6[ab]	1135.17[ab]
Six passes	No weeding	Quncho	36.6[abcd]	4999.9[bcde]	974.00[fg]
	Weeding once	Quncho	38.0[abc]	6296.3[ab]	1062.93[bcdef]
	Weeding twice	Quncho	35.0[abcd]	6759.2[a]	1192.53[a]
P-value			**	**	***
CV (%)			9.1	17.7	6.0

Values within a column followed by the same letter are not significantly different at P > 0.05. *** and ** denote significant differences at P < 0.001 and P < 0.01 probability levels, respectively.

Table 8. Economic feasibility analysis of interaction of tillage and weeding frequency for teff production in 2019 cropping season.

Treatment	GY (kg/ha)	AGY (kg/ha)	GB (Birr/ha)	TVC (Birr/ha)	NB (Birr/ha)	MRR (%)
T1W0V1	775.93	698.3	21647.3	1100	20547.3	-
T1W0V2	799.97	720.0	23040	1175	21865	1757
T1W1V1	964.77	868.3	26917.3	1900	25017.3	435
T1W2V1	1087	978.3	30327.3	2700	27627.3	861
T4W1V1	986.97	888.3	27537.3	4300	23237.3	161
T4W1V2	1024.03	921.6	29491.2	4375	25116.2	2505
T4W2V1	1135.17	1021.2	31656.27	5100	26557.2	199
T4W2V2	1135.17	1021.2	32678.4	5175	27503.4	5800
T6W1V1	1079.6	971.6	30119.6	5900	24219.6	185
T6W1V2	1062.93	956.6	30611.2	5975	24636.2	555
T6W2V2	1192.53	1073.5	34352	6775	27577	4092

GY: Grain yield, AGY: adjusted grain yield, GB: gross benefit, TVC: total cost, NB: net benefit, MRR: marginal rate of return. Whereas T1, T4 and T6 were tillage frequencies of one plow, four plows and six plows, respectively; V1 and V2 were local and Quncho teff varieties, respectively; W0, W1 and W2 were weeding frequencies of un-weeding (as control), weeding once and weeding twice, respectively.

length (r= 0.57**), thousand seed weight (r= 0.36**), days to physiological maturity (r= 0.35**) and above ground biomass (r= 0.66**) implying that improvement in these parameters is also associated with better grain yield.

Economic analysis

The results of economic analysis indicated that the highest net benefit (Table 8) was obtained from the treatment of one plow pass combined with twice hand weeding at tillering and stem elongation stage on local variety due to its lower cost of production (about 48% lower) but its marginal rate of return (MRR) of 861% was lower than that of four-time plows combined with twice weeding for variety Quncho (5800%). According to the current result, plowing the soil more than once is important for teff production and productivity.

Conclusion

Four times tillage passes showed better yield and yield components as compared to the others. Similarly, twice hand weeding showed significantly higher yield of teff. improved variety (Quncho) resulted in a better yield compared to the local variety for most treatment combinations. In general, four times oxen plowing combined with twice hand weeding (at tillering and stem elongation stage) gave the highest MRR (5800%) and NB (ETB 27503.4 ha^{-1}) for variety Quncho as compared to other treatment combinations. Therefore, four ploughing, twice hand weeding (at tillering and stem elongation) and Quncho variety should be recommended for higher productivity and profitability of teff in Mirab Abaya, Southern Ethiopia.

Hence, this practice was found to be the best option that could be recommended for teff production by using improved variety (Quncho) in the study area and in areas with similar agro-ecology. However, it is advisable to undertake further research across different soil types, seasons and locations to draw a more comprehensive recommendation.

ACKNOWLEDGEMENTS

The authors would like to thank Arba Minch University for funding this research. They also thank Gamo Zone Environment Protection, Forest and Climate Change Controlling office for their help during study leave to the first author.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Aleligne K (1988). Diagnostic Survey Report of Adet Mixed Farming Zone. Research Report No.4:88. Ethiopian Institute of Agricultural Research, Addis Ababa,Ethiopia.

Alemayehu A, Minale L, Tilahun T, Belsti Y (2008). Effect of Tillage Frequency and Weed Control on Yield of Tef (*Eragrostis tef*) in Yielmana-Densa Area, Northwestern Ethiopia.

Alemu D, Kelemu K, Bezabih A, Zegeye F (2016). Transferring agri-cultural technologies: approaches, linkages and challenges. EIAR, Addis Ababa.

Bargali K, Vijyeta M, Kirtika P, Bargali SS, Upadhyay VP (2018). Effect of vegetation type and season on microbial biomass carbon in Central Himalayan forest soils, India. Catena 171(12):125-135.

Bargali SS (1995). Efficiency of nutrient utilization in an age series of *Eucalyptus tereticornis* plantations in the tarai belt of Central Himalaya. Journal of Tropical Forest Science 7(3):383-390.

Bargali SS (1996). Weight loss and nitrogen release in decomposing wood litter in an age series of eucalypt plantation. Soil Biology and Biochemistry 28:699-702.

Bargali SS, Kirtika P, Kiran B (2019). Effects of tree fostering on soil health and microbial biomass under different land use systems in central Himalaya. Land Degradation and Development 30(16):1984-1998.

Bargali SS, Singh RP (1997). *Pinus patula* plantations in Kumaun Himalaya II. Nutrient dynamics. Journal of Tropical Forest Science 10(1):101-104.

Bargali SS, Singh RP, Mukesh J (1993a). Changes in soil characteristics in eucalypt plantations replacing natural broad-leaved forests. Journal of Vegetation Science 4:25-28.

Bargali SS, Singh SP, Singh RP (1993b). Pattern of weight loss and nutrient release in decomposing leaf litter in an age series of eucalypt plantations. Soil Biology and Biochemistry 25:1731-1738.

Bargali SS, Singh RP, Singh SP (1992). Structure and function of an age series of eucalypt plantations in Central Himalaya, II. Nutrient dynamics. Annals of Botany 69:413-421.

Bekele B, Dawit D, Zemach S (2018). Effect of Weed Management on Yield Components and Yield of Bread Wheat (*Triticum aestivum* L.) At Wolaita Sodo in Southern Ethiopia. International Journal of Research in Agriculture and Forestry 5(10):34-43.

CIMMYT (International Maize and Wheat Improvement center) (1988). An Economic Training Manual: from agronomic data recordation. CYMMT. Mexico. 79 pp.

Central Statistical Authority (CSA) (2010). Agricultural Sample Survey (2008/2009) vol. 1. Report on area and production for major crops (private peasant holding meher season) statistical Bulletin 417, Addis Ababa, Ethiopia.

Deckers JA, Nachtergaele FO, Spaargaren OC (1998). World Reference Base for Soil Resource: Introduction. Acco Leuven/ Amersfoort. Belgium pp.165.

Evert S, Staggenborg S, Olson LS (2008). Soil temperature and planting depth effects on tef emergence; Short communication. Journal of Agronomy and Crop Science, (ISSN 931:789)

Food and Agriculture Organization (FAO) (2006). Plant nutrition for food security: A guide for integrated nutrient management. FAO, Fertilizer and Plant Nutrition Bulletin 16, Rome.

Gebreyesus BT (2014). Response of Yield and Yield Components of Tef [*Eragrostis tef* (Zucc.) Trotter] to Tillage, Nutrient, and Weed Management Practices in Dura Area, Northern Ethiopia. International Scholarly Research Notes 1(1)

Habtegebrial K, Singh BR, Haile M (2007). Impact of tillage and nitrogen fertilization on yield, nitrogen use efficiency of tef (*Eragrostis tef* (Zucc.) Trotter) and soil properties. Soil and Tillage Research 94(1):55-63.

Haftamu G, Mitiku H, Yamoah CF (2009). Tillage Frequency, Soil Compaction and N-Fertilizer Rate Effects on Yield of Teff (*Eragrostis Tef* (Zucc) Trotter) in Central Zone of Tigray, Northern Ethiopia. Momona Ethiopian Journal of Science 1(1):82-94.

Hailu T, Peat WE (1996). Evaluation of selection methods for grain yield in the F2 and F3 generations of tef (Eragrostis tef). Ethiopian Journal of Agricultural Science 15(1-2):20-*32.*

Institute of Agricultural Research (IAR) (1998). Holleta Agricultural Research Center, progress report for the period April 1997 to March 1998. IAR, Addis Ababa, Ethiopia.

International Centre for Agricultural Research in the Dry Areas (ICARDA) (1984). Annual Report, 1983. Aleppo, Syria pp. 31-34.

Kenea Y, Getachew A, Workneh N (2001). Farming Research on Teff: Small Holders Production Practices. In: Hailu T, Getachew B and M. Sorrels (Eds.), Narrowing the Rift: Teff Research and Development. Ethiopian Agricultural Research Organization (EARO), Addis Ababa, Ethiopia pp. 9-23.

Landon JR (1991). Booker Tropical Soil Manual: A hand book for soil survey and Agricultural Land Evaluation in the Tropics and

Subtropics. Longman Scientific and Technical, Essex, New York P 474. OR John Wiley & Sons Inc., New York.

Manral V, Kiran B, Bargali SS, Charu S (2020). Changes in soil biochemical properties following replacement of Banj oak forest with Chir pine in Central Himalaya, India. Ecological Processes 9:30

Melese T (2007). Conservation tillage systems and water productivity implication for smallholder farmers in semi-arid Ethiopia, Doctoral thesis, Delft University of Technology and of the Academic Board of the UNESCO-IHE, Institute for Water Education, Delft the Netherlands.

Mersie W, Parker C (1983). Response of teff (*Eragrostis tef* (Zucc.) Trotter) to 2, 4-D and MCPA at various growth stages. Weed Research 23(1):53-59.

Ministry of Agriculture (MoA) (2010). Ministry of Agriculture, Animal and Plant Health Regulatory Directorate. Crop Variety Register Issue No. 13, June 2010, Addis Ababa, Ethiopia.

Mulumba LN, Lal R (2008). Mulching effects on selected soil physical properties. Soil and Tillage Research 98(1):106-111.

Murphy HF (1968). A report on fertility status and other data on some soils of Ethiopia. College of Agriculture HSIU. Experimental Station Bulletin No. 44, Collage of Agriculture, p. 551.

Oicha T, Cornelis WM, Verplancke H, Nyssen J, Govaerts B, Behailu M, Haile M, Deckers J (2010). Short-term effects of conservation agriculture on Vertisols under Tef (*Eragrostis tef* (Zucc.) Trotter) in the northern Ethiopian highlands. Soil and Tillage Research 106(2):294-302.

Olsen SR, Cole CV, Watanabe FS, Dean LA **(**1954). Estimation of Available Phosphorus in Soils by Extraction with Sodium Bicarbonate. United States Department of Agriculture Circular 19, Washington DC, 939 p.

Padalia K, Bargali SS, Kiran B, Kapil K (2018). Microbial biomass carbon and nitrogen in relation to cropping systems in Central Himalaya, India. Current Science 115(9):1741-1750.

Rachman A, Anderson SH, Gantzer CJ, Thompson AL (2003). Influence of long-term cropping systems on soil physical properties related to soil erodibility. Soil Science Society of America Journal 67(2):637-644.

Rasmussen KJ (1999). Impact of ploughless soil tillage on yield and soil quality: A Scandinavian review. Soil and Tillage Research 53(1):3-14.

Reicosky DC, Allmaras RR (2003). Advances in Tillage Research in North American Cropping Systems. Journal of Crop Production 8(1-2):75-125.

SAS Institute (2004). SAS/STAT guide for personal computers, version 9.0 edition, SAS Institute Inc. Cary, NC.

Seyfu K (1993). Tef (*Eragrostis tef*): Breeding, Genetic Resources, Agronomy, Utilization and Role in Ethiopian Agriculture. Ethiopian Agricultural Research Organization (EARO), Addis Ababa, Ethiopia. P 102.

Sharma JJ, Adera S (2016). Response of Tef [*Eragrostis tef* (Zucc.) Trotter] to Different Blended Fertilizer Rates on Vertisols in Jama District, Northeastern Ethiopia (MSc Thesis, Haramaya University).

Tekalign T (1991). Soil, plant, water, fertilizer, animal manure and compost analysis. Working Document No. 13. International Livestock Research Center for Africa, Addis Ababa.

Tenaw W (2010). Effect of Plowing Frequency and Weeding Methods on Weeds and Grain Yield of Wheat at Arsi Negelle, Ethiopia East African Journal of Sciences 4(2):114-122.