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College of Dry Land Agriculture and Natural Resources

CDANR

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Department of Dryland crops and Horticultural Sciences

Genotypic variation, N rates and Sowing method effects on Weed dynamics and Teff yield at Laelay Maychew district, Tigray, Ethiopia

By

Netsanet Kidane

A Thesis

Submitted in Partial Fulfillment of the Requirements for the

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In

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Co-advisor: Addis Abraha (PhD)

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DECLARATION

I, **Netsanet Kidane Teklehaymanot**, hereby present for consideration by the Department of Dryland Crops and Horticultural Sciences Department of the College of Dryland Agriculture and Natural Resources at Mekelle University, my Thesis entitled "**Genotypic variation, N rates and Sowing method on Weed dynamics and Teff at Laelay Maychew district, Tigray**" in partial fulfillment of the requirement for the Degree of Masters in Dryland Agronomy. I sincerely declare that this thesis is the product of my own efforts and no other person has published a similar study which I might have copied, and at no stage will this be published without my consent and that of the **Department of Dryland Crops and Horticultural Sciences**.

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DEDICATION

This thesis manuscript is dedicated to my whole family specially my mother (W/ro Letenchiel Kidane), and my husband (Alem Gebreslasie) who have committed to unreserved moral support, patient, encouragement and responsibility for the betterment and success of my life.

ABSTRACT

*Teff [Eragrostis tef (*Zucc,*)* Trotter*] is one of the major cereals that are cultivated on largest land than other cereals in Ethiopia. The need for its production as a stable food is increasing year after a year. Nevertheless, its productivity is low due to inappropriate use of agronomic practices and genetic factors. A field experiment was carried out during the 2020 main cropping season from July to November at Laelay Maychew district with the objectives of studying genotypic variation, N rates and sowing method effects on weed dynamics and teff yields. The treatments consisted of three improved varieties (Kora, Quncho and Boset), four nitrogen levels (0, 46, 69 and 92 kg N/ha) and two sowing methods (row planting and broadcast). The experiment was laid out in a split plot design with three replications. Sowing method was the main plot and combination of N rate and improved varieties as the subplot.*

Economic analysis showed row planting of Teff Kora variety with application 69 kg N/ha was the highest net benefit (121,014 ETB) and marginal rate of return (MRR) (454.86 %). Therefore, this variety Kora and 69 kg N/ha rate application could be economically feasible and recommended for the Hatsebo area. Results showed that sowing method, variety and N rates had significant effect ($p<0.05$) on most parameters evaluated. The factors had significant interaction effect on teff plant height and grain yield. Quncho variety had the tallest plant height (133.33 cm) which was planted in rows and applied with 92 kg N/ha, the highest grain yield (1887 Kg/ha) was recorded from Kora variety planted in rows and received 69 kg N/ha. Similarly, there were significant ($p<0.05$) differences of factors on weed dry weight. Boset variety resulted in higher (5.8 g/m^2) weed dry weight while the lowest weed dry weight was observed on variety Kora (3.94 g/m^2).

Key words: Grain yield, N Fertilizer, sowing method, teff variety and weed density.

BIOGRAPHICAL SKETCH

The author was born on 19 February 1993 in Adwa Woreda, Central Zone of Tigray, to her father Kidane Teklehaymanot and her mother Letenchiel Kidane Gebrihet. She completed her elementary, secondary and preparatory school education from 1999-2011 in Adi-Abeto Primary School, Tadelech-Hailu Secondary School and Ngste-Saba Preparatory School, respectively. After completing her Preparatory School education, she joined the Assosa University in 2012 and graduated with B.Sc. degree in Plant Science in 2014. Soon After graduation she served as soil fertility expert in office of Agriculture in Medebay-Zana Wereda, North Western Tigray from October 2014 to February 2017. Thereafter, she worked as junior researcher in TARI-AARC from March, 2017 until she joined the school of graduate studies at Mekelle University in October 2019 to pursue her MSc study leading to MSc. degree in Dryland Agronomy.

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TABLE OF CONTENTS

CONTENTS **PAGE**

ACRONOMY/ABBREVIATIONS

AARC	Alamata Agricultural Research Center
ANOVA	Analysis of Variance
AxARC	Axum Agricultural Research Center
CIMMYT	Center of International Maize and Wheat Improvement
CSA	Central Statistical Agency
DZARC	Debre Zeit Agricultural Research Center
EIAR	Ethiopian Institute of Agricultural Research Center
FAO	Food and Agricultural Organization of the United Nations
Kg/ha	Kilogram per Hectare
Masl	Meter above sea level
Mg/100g	Milligrams per 100 grams
MoA	Ministry of Agriculture
TARI	Tigray Agricultural Research Institute
TSP	Triple Super Phosphate

LIST OF TABLES

Table Page

LIST OF TABLES IN THE APPENDIXES

Table Page

LIST OF FIGURES

Figure Page

CHAPTER ONE: INTRODUCTION

1.1 Background

Teff *[Eragrostis tef (*Zucc,) Trotter] is endemic to Ethiopia where its major diversity is found. It is believed that teff is a very ancient crop in Ethiopia, where domestication took place before the birth of Christ (Vavilov, 1951 and Piccinin, 2010).

In Ethiopia, production of cereal crops covers about 82% of the total land used for agriculture and accounts about 88.7% of total production (CSA, 2022). Teff is an important stable crop in the county. It is first in area coverage but second and last in production and productivity among cereal crops following maize (CSA, 2022). Teff is the most important stable grain for 72% of the country's agricultural system and food security (Gebrekidan *et. al.* 2022). It has genetic traits useful for coping with eratic climatic conditions, generating income, fulfilling nutritional needs (Assefa *et al*. 2015). Teff is also considered as a healthy food since its grain is free of gluten (Spaenij-Dekking *et al*. 2005). Furthermore, it has relatively few disease and insect pest problems and it is very important in the overall national food security (Kebebew *et. al*. 2013).

In the 2020 cropping season, teff comprised 24% of cereal production in Ethiopia, yielding a total of 4.705 million tons. In Tigray region, with area coverage of 188,391.88 ha, produced 3,117,538.77 quintal of teff, with an average yield of 1655 kg/ha. Despite its economic significance and numerous benefits, the national average grain yield of teff remains relatively low at 1882 kg/ha (CSA, 2021). Research findings by Tareke *et al*. (2013) described a considerable difference in teff yields between research fields (4000 kg/ha) and farmers' fields (2500 kg/ha), indicating a gap in transforming research findings into practical farming practices.

The low national and regional teff productivity can be primarily attributed to a lack of improved agronomic practices and genetics. Historically, the broadcast sowing method has been the predominant practice, hindering optimal yield potential. To enhance productivity, the adoption of new agronomic practices is crucial. Row planting and transplanting month-old teff seedlings are promising techniques, as highlighted by Kebebew *et al*. (2011) that have the potential to significantly boost teff yields.

There are some serious problems with the way that crops are being grown in the Ethiopian highlands. One big problem is that farmers are not adding back enough organic matter to the soil (like manure or crop residue) and synthetic fertilizer. This means the soil is using nutrients, and becoming more eroded, which makes it harder to grow crops (Balesh *et al.* 2007).

Teff is very adoptable crop, but it also has some challenges. Because it can grow in a wide range of climates and soils, it is often exposed to diverse composition of weeds. Getting rid of weeds is one of the biggest challenges for farmers, as it is most expensive, time and energy consuming.

Studies show that weeds can reduce crop yields by 23-65%. The most common method to control weeds is by using hand-weeding, which is a laborious task (Rezene and Zerihun, 2001).

Teff production in Ethiopia is increasing year after year. However, the yield is lower than other cereal crops, the average yield is lower than other cereal crops, and the average yield is only 1.9 t/ha (CSA, 2022). This is mostly due to the poor agronomic practices, and the soil is often not fertile (Mihretie *et al.* 2021).

1.2 Statement of the problem

The area dedicated to teff cultivation in Ethiopia is expanding due to the high domestic market prices for both its grain and straw. Teff has also a high international market demand but exporting teff grain is legally banned in Ethiopia but processed teff injera is being exported to Europe and USA generating huge amount of foreign currency to the country. Teff resilience, with its adaptability to diverse agro-ecologies, tolerance to both drought and waterlogging and weed makes it a low-risk crop for farmers. This resilience positions teff as a valuable option for farmers facing climate change and fluctuating environmental conditions. However, main challenges limit teff productivity despite its potential.

Ethiopian farmers practice fine seedbed preparation for teff, typically employing up to three to four times oxen plowings, apply fertilizers, and hand weeding 2-3 times. This intensive seedbed preparation aims to create a weed-free environment and optimize conditions for successful crop germination. Despite these efforts, weed pressure remains a persistent challenge, limiting teff productivity. The weed infestation made a great yield loss from 35-65% (Kassahun & Tebkew 2013). This is due to weeds high competition with teff for essential resources like sunlight, water and nutrients this competition can stunt teff growth, reduce tillering, and lead to lower yields. Consequently, weed management is the most labor-intensive practice in teff production (Haftamu *et al*. 2019). Weed control in teff has largely depend on hand weeding, which is the most common method used by the majority of farmers, either alone or in combination with herbicides. While no single weed control method has proven consistently effective, current approaches often are relying on manual weeding or a combination of manual weeding and herbicides. This leads to persistent weed pressure year after year, increasing weed management costs, reducing yields, and ultimately diminishing the potential income from teff production. Exacerbate

Beyond weed management, suboptimal nitrogen fertilizer application and the prevalent use of local teff varieties further limits teff productivity. While nitrogen is crucial for boosting growth, tilleing, and overall yield, current practices often involve either insufficient or excessive application without the support of modern agricultural technologies. Furthermore, the application of blanket rates of urea only at sowing, as described by (Tarekegne, 2010; Bekele *et al*. 2000; Cheng *et al*. 2017), fails the crop from maximizing its potential and can even worsen weed growth.

Finally, broadcast sowing method also contributes to lower yields. While broadcast sowing is faster and cheaper, leads to uneven seed distribution, increased competition, poor tillering, reduced yield components, and makes weed control difficult. Incontrast, row sowing, although more labor-intensive and requiring specialized equipment, offers better resource utilization, improved weed control, and potentially higher yields.

National and regional research institutions have released numerous teff varieties adaptable to a wide range of environments. These varieties have early, intermediate, and late maturity periods, and are currently under production in Laelay Maychew district, Quncho, and Kora. However, these varieties have not been able to close the yield gap.

This study focused on an integrated weed management approach, aiming to significantly enhance teff productivity. The research involves identifying key weed species, exploring appropriate sowing methods, optimizing nitrogen application, and identifying teff varieties with strong competitive and suppressive abilities.

1.3 Objective

1.3.1 General objectives

To investigate the effect of N rate and sowing methods on yield traits of teff varieties and weed dynamics

1.3.2 Specific objectives

- To determine the optimum N fertilizer rate which enhance teff yield under weed competitiveness
- To evaluate teff varieties for their weed response under different planting methods
- To evaluate effect of teff varieties on weed dynamics
- To observe the synergetic effects of genotypic variation, N rates and sowing methods on weed dynamics and yield of teff.

1.4 Hypothesis

- There are differences between teff varieties for their weed competitiveness
- Variety competitiveness influence weeds under different planting methods
- Weeds respond to various N fertilizer rates differently

CHAPTER TWO: LITERATURE REVIEW

2.1 Morphology and Ecology of Teff

Ethiopia is the center of diversity for teff (*Eragrostis tef*), with a wide range of landraces, wild progenitors, and related species such as the closely related E. pilosa and the more distant E. heleromera and E. clianensis (Ingram and Doyle, 2003). In 2021, a research team of 6 Scientists analyzed grains discovered at archaeological sites in Mezber and Ona Adi, towns in the Tigray region of Northern Ethiopia. Their study of grains Aksumite and pre-Aksumite periods, revealed teff grains dating back to 1600 BC in Mezber. This discovery definitely confirms teff cultivation in Ethiopia for over 3000 years (Helina Weldekiros *et al*. 2022).

Teff is primarily cultivated in Ethiopia, with minor cultivation in Eritrea and recent introductions to the USA, Netherlands, and possibly Israel. Outside of these areas, it's mainly used as forage in countries such as South Africa, India, Pakistan, Uganda, Kenya, and Mozambique (Kebebew *et al*. 2007).

Teff is cultivated across a wide range of agro-ecologies in Ethiopia, primarily during the main rainy season, although some areas utilize the short rainy season. Optimal growing periods range from 90 to 130 days, though the total length can vary from 60 to 180 days depending on variety and altitude (Deckers *et al*. 2001).

Teff (*Eragrostis tef*) is a self-pollinating, annual C4 plant (Ketema, 1997; Alemayehu, 2001; Miller, 2008) with a fibrous root system and predominantly erect stems, though some cultivars exhibit bending. Its smooth, open leaf sheaths are shorter than the internodes; the ligule is short and ciliate, and the leaf blade is narrow and linear. Inflorescences are panicles ranging in density from loose to compact, with 2–12 florets per spikelet. Each floret comprises a lemma, palea, three stamens, an ovary, and usually two (occasionally three) feathery stigmas (Ketema, 1997; Alemayehu, 2001). It requires 60–140 days to mature (Assefa *et al*. 2001), exhibits C4 photosynthesis, utilizing malic or aspartic acid as the initial products. Optimal photosynthetic temperatures are high, and its CO_2 compensation point (6 ± 1 µl at 38°C) reflects its C4 nature. Teff also displays Kranz leaf anatomy with vascular bundles encircled by bundle sheath cells (Takele *et al*. 2001).

Teff (*Eragrostis tef*) is a fine-stemmed, tufted annual grass with a large crown, numerous shoots, and a shallow, extensive root system. Its inflorescence is a panicle, ranging from loose to compact, bearing hermaphroditic flowers (three anthers, two stigmas, and two lodicules per floret) (Ketema, 1997). The tiny seeds (1-1.5 mm long) are numerous (2,500-3,000 seeds/gram), germinate quickly, and tolerate diverse soil moisture conditions. Seed color varies (dark brown to yellowish-white), and the hundred-kernel weight is 0.18-0.38 mg. Teff is highly self-pollinating (less than 0.02% outcrossing), with flowering and maturation basipetal on the panicle and acropetal on the spikelet

(Kebebew *et al*. 2007). The plant's height varies considerably (20–155 cm), with the stem (culm, 11–72 cm) and seed head (panicle, 10–65 cm) comprising 47–65 % and 35–53% of the total height, respectively (Assefa *et al*. 2001).

Teff is well-suited at altitudes of 1800-2100 m, with annual rainfall of 750-850 mm and growing season rainfall of 450-550 mm, although it can tolerate as little as 300 mm, optimal temperatures range from 10-27°C. Teff is widely cultivated in both high-potential and marginal agricultural areas, including many Vertisols prone to waterlogging, and other soil types with low moisture stress (Ayalew *et al*. 2011; Piccinin, 2010).

2.1 Teff crop production

In 2019/2020 cropping season, teff had area coverage of 24.1% out of cereals with the production of more than 5.7 million tons. Moreover, in Tigray regional state, teff area coverage, total production and productivity were 188,391.88 ha, 311,753.87 tons and 1.65 t/ha, respectively. In the central zone of Tigray with area coverage, production and productivity was 71,391.19 ha, 117,396.67 tons and 1.64 t/ha, respectively (CSA 2020).

Teff outperforms other major crops in challenging conditions, particularly low moisture environments, and serves as a reliable alternative when crops like maize fail due to drought (Sintayehu *et al*. 2011). Its tolerance to waterlogged, anaerobic conditions surpasses that of cereals such as maize, wheat, and sorghum, making it a favored crop among farmers (Hailu and Seyfu, 2001).

Although Ethiopia produces over 90% of the world's teff (Esubalew and Tewabe, 2022), its market share remains limited. A 2006 ban on unprocessed teff exports (FAO, 2015), aimed at ensuring affordable domestic prices and food security, has been ineffective in controlling rising domestic prices due to increased demand from population growth, rising incomes, and urbanization (FAO, 2015; Abraham, 2015).

While teff cultivation is expanding globally in the production and marketing, including South Africa, Cameroon, Canada, Netherlands, British, India, USA, china and Uganda, comprehensive production and trade data remain scarce outside of Ethiopia. Although Ethiopia's teff production is dominant, the country isn't fully benefiting from its global market potential (Abraham, 2015; Araya *et al*. 2010).

Table 1: Area, Production and Yield of Crops for 2019/20 (2012 E.C)

Crop	Area in ha	Yield in ton/ha	Yield (ton/ha)
Ethiopia			
Cereal	10,478,218.03	29,672,647.694	
Teff	3,101,177.38	5,735,710.187	1.85
Maize	2,274,305.93	9,635,734.5	4.23
Sorghum	1,828,182.49	5,265,580.059	2.88
Wheat	1,789,372.23	5,315,270.328	2.97
Teff production in Tigray region			
Tigray	188,391.88	311,753.877	1.65
North -Western Tigray	44,678.49	78,937.769	1.76
Central Tigray	71,391.19	117,396.673	1.64
Eastern Tigray	7,933.13	12,604.459	1.59
Southern Tigray	32,805.98	51,949.986	1.58
Western Tigray	7,525.24	13,193.253	1.75
South-East Tigray	24,057.85	*	*

Source: CSA (Central Statistical agency), 2020.

2.2 The Teff variety

Teff (*Eragrostis teff (Zucc,) Trotter*) is an allotetraploid species with a base chromosome number of 10 (2n = 4x = 40) and belongs to the family poaceae, sub-family Eragrostidae and genus Eragrostis, coupled with disomic inheritance patterns (Berhe *et al*. 2001).

The presence of diverse genotypes in teff offer major potential for selecting superior traits; however, a thorough understanding of the existing genetic variation is crucial (Khan *et al*. 2010; Kotal *et al*. 2010). Plant breeding aims to develop improved teff cultivars that benefit both small-scale and commercial farmers, addressing challenges posed by population growth, land degradation, and climate change through increased yields, enhanced quality, and improved tolerance to drought, disease, and pests (Hussein and Mark, 2012). Since the discovery of teff flower opening time, allowing for controlled pollination, crossing efforts have resulted in the release of 37 improved varieties by the Ethiopian Agricultural Research System (MoANR, 2016).

Table 2: General description of some teff varieties released

Variety name	Common name	Year of release	Days to maturity	Seed color	Yield (t/ha)		Breeder/Maintainer:
					Research field	Farmers field	
DZ-01-196	Magna	1970	80-113	Very white	1.8-2.2	1.4-1.6	DZARC/EIAR
DZ-Cr-37	Tseday	1984	82-90	White	1.8-2.8	1.4-1.9	DZARC/EIAR
DZ-01-974	Dukem	1995	76-138	White	2.4-3.4	2.0-2.5	DZARC/EIAR
DZ-Cr-387 RIL355	Quncho	2006	80-113	Very white	2.2-2.8	2.0-2.2	DZARC/EIAR
Dz-01-3186	Etsub	2008	92-127	White	1.9-2.7	1.6-2.2	Adet ARC
D Z - Cr-385 RIL295	Simada	2009	72-88	White	2.8-2.8	1.6-2.4	DZARC/EIAR
DZ-Cr-409 Sel 50D	Boset	2012	75-86	Very white	1.9-2.8	1.8-2.2	DZARC/EIAR
DZ-Cr-438 RIL133B	Kora	2014	110-117	Very white	2.3-2.8	2.0-2.2	DZARC/EIAR
DZ-Cr-438 RIL91A	Dagem	2016	116-144	Very white	2.4-3.2	2.0-2.5	DZARC/EIAR
DZ-Cr-429 RIL7	Axumawit	2020	100-126	Pale white	1.7-2.2		Ax ARC

Source: MoA. 2021.

Table 3: Ranges of some important traits of teff

Trait	Minimum	Maximum
Days to panicle emergence	25	81
Days to mature	60	140
Grain filling period (days)	29	75
Plant height (centimeters)	20	156
Culm length (centimeters)	11	82
Panicle length (centimeters)	10	65
Number of tillers per plant (total)	4	22
Number of tillers per plant (fertile)	1	17
Grain yield (kilograms per hectare)	1058	4599
Harvest index (%)	5	39
Lodging index	20	100

Source: Modified from Assefa *et al.* (2001) and Chanyalew *et al.* (2013).

2.3 Importance of Teff (*Eragrostis Teff*)

In Ethiopia, teff is grown mostly for human consumption. Its straw is used for livestock feed and plastering component for construction purposes. Since teff grain fetches a high market price, it also serves as an important cash crop. Teff has recently begun to be exported, thus contributing to foreign exchange generation for the country (Kenea *et al*. 2001)

Teff, an Ethiopian native cereal, holds high value among farmers and consumers compared to other food crops due to its importance role in the national diet. Injera (thin, flat and pancake-like bread with evenly spread openings) is a staple diet of most Ethiopians is made of teff flour. Its resilience to various environmental stresses makes it a low-risk crop. Strong farmer preference and consistent urban demand have driven teff production to an average of 2 million hectares annually, establishing it as a leading crop in Ethiopia (Tefera and Ketema, 2001).

Teff offers several key advantages: it produces the highest quality injera, yields high returns in flour and injera production, exhibits excellent storability with minimal pest and disease damage, provides high-quality fodder from its straw, and commands premium market prices for both grain and straw, making it a valuable cash crop (Kebebew *et al*. 2007). The post-harvest straw is vital livestock feed, especially during dry seasons (Bekabil *et al*. 2011), and also finds use in construction (Alemu, 2013). Teff endemic nature contributes to its natural resistance to pests and diseases and its exceptional storage longevity.

Injera, a staple food in Ethiopia, is a thin pancake made from fermented teff flour and constitutes a primary food source in urban, northern and central regions. Teff flour is also used to produce alcoholic beverages (tella and katikalla), hot drinks (atmit), and unleavened bread (kitta) (Bultosa *et al*. 2002).

Teff is gaining international recognition as a health food due to several key attributes. Its gluten-free nature, confirmed by the absence of celiac-inducing proteins (Roseberg *et al*. 2005; Spaenij-Dekking *et al*. 2005), makes it suitable for those with celiac disease. Furthermore, its complex carbohydrates benefit diabetics. Teff also boasts a superior amino acid profile, particularly high in lysine, and significantly greater iron bioavailability compared to wheat, especially in bread form (Alaunyte *et al*. 2012). Its rich nutritional content (Abraham, 2015; Baye,2014; Cheng, 2017) including high energy (357 kcal/100g), protein, fiber, and phytochemicals – contributes to its potential in preventing anemia and managing conditions like celiac disease and diabetes (Cheng, 2017; Spaenij-Dekking et al. 2005; Gebru, 2020). This combination of factors, along with its established use within Ethiopian communities, fuels its expanding market in Western countries (Fufa B, 2013), driven by the increase in gluten-related disorders (Roseberg *et al*., 2005). It is also rich of iron, calcium, magnesium, and other essential nutrients contributes to several health benefits, including immune support, bone health, and a reduced risk of heart disease (Araya *et al*. 2018). The difference in mineral content between and within teff varieties is wide ranging. Red teff has a higher iron and calcium content than mixed or white teff (Abebe *et al*. 2007), while white teff has a higher copper content than red and mixed teff (Table 4).

Table 4: Mineral content of teff grain compared with other cereals (Mg/100g)

Minerals	White teff	Red teff	Mixed teff	Maize	Sorghum	Wheat	Rice
Iron	9.5–37.7	11.6– >150	11.5– >150	3.6–4.8	3.5–4.1	3.7	1.5
Zinc	2.4-6.8	2.3-6.7	3.8-3.9	2.6-4.6	1.4-1.7	1.7	2.2
Calcium	17-124	18-178	78.8-147	16	5.0-5.8	15.2-39.5	23
Copper	2.5-5.3	1.1-3.6	1.6	1.3	0.41	0.23	0.16

Source: Abebe *et al.* 2007

2.4 Soil fertility and Nitrogen

Ethiopia is among the 14 sub-Saharan African countries with the highest rates of soil nutrient depletion (Yu, 2006), a problem largely due to low fertilizer use, inadequate organic matter return, and significant nutrient losses from erosion and leaching. Limited access to fertilizers for smallholder farmers, due to high costs, poor credit, distribution challenges, and socioeconomic factors, leads to low and declining crop yields, threatening the long-term sustainability of agricultural practices (Balesh *et al*. 2005).

Additionally, Soil fertility reduction is one of the major challenges to crop production and productivity in Ethiopia (Amsal and Tanner, 2001). Rapid population growth is a key driver of the soil fertility reduction, soil erosion, over cultivation of farm land, insufficient fertilizer use, and the decreasing of traditional soil conservation methods (Hirpa *et al*. 2009). Most of the Ethiopian soils widely constrained low nutrient content due to erosion and absence of nutrient recycling. Additionally, most of the areas used for production of grains especially teff, wheat and barley fall under the low fertility soils (Tefera and Ketema, 2001).

Fertilizer application is critical for increasing food production to meet global demand, having historically led to substantial yield improvements (often over 100%) across various crops (Balesh *et al*. 2007). However, fertilizer use varies geographically, and optimal application depends on inherent soil nutrient levels. Nitrogen fertilization significantly boosts grain yields by influencing yield components, plant development (phenology), and leaf characteristics, impacting nutrient transport to developing grains during senescence (Mengel and Kirkby, 2012). For teff, fertilization is crucial for improving nutrient use efficiency (Girma *et al*. 2011), along with cultivar selection and management practices. Nitrogen and phosphorus are key nutrients affecting teff yield and quality, with nitrogen particularly important due to teff's susceptibility to lodging, although this is also partly related to its shallow root system (Zhang *et al*. 2006). However, excessive nitrogen application can be uneconomical, failing to increase yield or efficiency. Nitrogen's central role in vital plant compounds like amino acids, proteins, nucleic acids, and chlorophyll (Brady and Weil, 2000) explains its widespread use (approximately 80 million tons annually) in agriculture (Huber and Thompson, 2007), despite its abundant presence in the atmosphere, lithosphere, and hydrosphere. Its mobility within these systems highlights the need for optimized application to ensure efficient plant uptake.

Teff fertilizer recommendations are influenced by several factors, including waterlogging, planting time, cropping history, lodging, and weed growth (Kenea *et al*. 2001). Generally, the recommended rate of nitrogen (N) fertilizer for teff range from 25–40 kg ha^{-1} and phosphorus (P_2O_5) from 30–40 kg/ha on lighter soils (Nitosols, Luvisols, Cambisols); heavier soils (Vertisols) require higher rates: 50–60 kg N/ha and 30–35 kg P_2O_5/ha (Deckers *et al*. 1998).

Studies in Ethiopia show that teff responds well to nitrogen (N) fertilization but not consistently to phosphorus (P), particularly in Vertisol-dominant central highlands (Tekalign *et al*. 2001; Minale *et al*. 2004). Despite this, farmers often prefer DAP (containing both N and P) over urea (N only). Research on Vertisols indicates that P fertilization does not significantly increase teff yields. The timing of N application is crucial due to potential losses through denitrification in waterlogged soils and leaching in sandy soils. Furthermore, the type of preceding crop influences N fertilizer requirements; legume pre-crops may allow for reduced or omitted N application (Tekalign *et al*. 2001; Alemayehu *et al*. 2010).

Split nitrogen (N) fertilizer application, half at planting and half at tillering or booting, is recommended to optimize N use efficiency in teff, synchronizing N availability with peak crop demand (Tekalign *et al*. 2001; Teklu, 2003). Nitrogen is a highly mobile nutrient that can leads to losses through leaching, volatilization, and denitrification, influenced by application methods, soil type, and weather; optimal timing varies with soil moisture. Soil degradation and nutrient depletion severely threaten sustainable cereal production in Ethiopia, with nitrogen often being the most limiting nutrient, necessitating fertilizer application (Ryan, 2008). Balanced fertilization, tailored to soil type, climate, crop variety, and management practices, is basic to maximizing crop yields from existing farmland.

Furthermore, Refissa (2012) limited nitrogen and phosphorus availability has a major constraint to cereal production. The optimal amount of fertilizer needed depends on several factors: the soil's inherent nutrient supply capacity, the yield potential of the chosen crop variety, fertilizer cost and availability, and the climate during the growing season.

2.5 Teff response to nitrogen fertilizer

Most Ethiopian soils are deficient in nitrogen and phosphorus, but fertilizer application, particularly nitrogen, has significantly increased crop yields (Tekalign *et al*. 2001). Although nitrogen is a crucial plant nutrient, second only to carbon, oxygen, and hydrogen, it is frequently the most limiting nutrient in Ethiopian agriculture (Halvin *et al*. 2002).

Brhan (2012) found that crop response to nitrogen (N) is significantly reduced when phosphorus (P) is deficient. With adequate N and P, fertilizer N recovery was approximately 75%, compared to 40% with insufficient P. Optimal N and P fertilization maximizes yield, profitability, and N recovery while minimizing environmental impact. Sufficient nitrogen also enhances the uptake of other nutrients (FAO, 2000). Temesegen and Heluf (2001) showed that varying N fertilizer application rates significantly affected teff grain, straw, and biomass yields, plant height, and maturity, with the highest N rate (69 kg/ha) yielding 1950 kg/ha compared to 1620 kg/ha in the control. According to Debnath *et al*. (2011) indicated that increasing plant height teff increase with nitrogen and phosphorus at the rates of 64 kg N/ha and 69 kg P/ha on Nitosols.

Teff shows a strong positive response to nitrogen application, significantly improving yields and yield components (Lemlem *et al*. 2002). Legesse (2004) similarly observed that higher nitrogen application rates (69 kg N/ha) resulted in increased yield components. Increased nitrogen application led to greater grain uptake, reflected in increased plant height, overall yield, and components such as panicle length, panicle weight, grain yield, straw yield, and biomass yield.

Haftamu *et al*. (2009) reported that Nitrogen fertilizer rate caused significant effect in yield component attributes. Teff plants with higher plant height (92 cm) and panicle length (38 cm) were found by applying high amount of N fertilizer (92 kg N/ha). This is because high nitrogen usually favors vegetative growth of teff which results in taller teff plants having relatively greater panicle length.

2.6 Teff weed management

Rana and Rana (2016) define weeds as unwanted plants growing in cultivated fields. They are considered the most common crop pests, responsible for substantial yield reductions, comprising an estimated 30% of total pest-related crop losses. Their success is attributed to several factors (Dwight, 2017), are (1) produce abundant seeds, (2) rapid emergence and establishment, (3) better seed dormancy, longevity and viability, (4) ability to spread in wide areas, (5) rapid adaptability to new environments, (6) fast reproduction asexually by vegetative reproductive organs and sexually by seeds, and (7) ability to occupy human disturbed areas.

Weed management in teff production is extremely labor-intensive and time-consuming. Several researchers have documented the major teff weeds in Ethiopia, including Rezene and Zerihun (2001), Zewdie and Damte (2013), and Haftamu *et al*. (2019). Annual grasses present the most significant challenge due to their resemblance to teff and prolonged germination, making manual weeding ineffective. Teff is a poor weed competitor; uncontrolled infestations, especially early in the growing season, can reduce yields by at least 65% (Kassahun & Likyelesh, 2001).

Surveys in diverse Ethiopian teff-growing areas identified over 39 weed species from 18 families (Kassahun & Tebkew, 2013). These included broadleaf weeds, grasses, parasitic weeds, and sedges. The most prevalent species were *Argemone ochroleuca*, *Commelina benghalensis, Convolvulus arvensis*, *Echinochloa colona*, *Echinochloa crusgalli*, *Setaria pumila*, *Setaria verticillata*, *Oxalis corniculata*, *Parthenium hysterophorus*, *Plantago major, Polygonum nepalense, Raphanus raphanistrum*, and various *Cyperus species*.

Furthermore, In Tigray's major teff-growing areas, Haftamu *et al*. (2019) identified *Plantago lanceolata*, *Erucastrum abyssinicum, Setaria pumila, Cynodon dactylon, Cyperus esculentus, Cyperus rotundus, Avena abyssinica, Argemone mexicana, and Medicago polymorpha* as the most dominant and frequent weed species. Specifically, Axum sites showed dominance of *Plantago lanceolata, Cyperus esculentus, and Setaria pumila*, while Mekelle sites were dominated by *Avena abyssinica*, *Galinsoga parviflora, and Plantago lanceolata*.

According to Damte *et al*. (2019), teff weed communities are comprised mostly of annuals (70.5%) and a smaller proportion of perennials (29.5%). Both groups include broadleaf (dicotyledonous) and narrow-leaf (monocotyledonous) weeds. Understanding a weed's life cycle, growth habit, susceptible stages, and reproductive strategies is crucial for effective weed management.

Numerous grass and broad-leaved weed species affect teff productivity, especially during early crop establishment (Assefa, *et al*. 2008; Tesfahunegn, 2014). The report by Addisu, (2016) shows about 35% yield loss has been caused by weed competition. The weeds also harbor insect pests and make harvesting operations difficult (Zewde and Damte, 2013). Repeated hand weeding is necessary where both grass and broad-leaved weeds are present, making teff production expensive.

Numerous grass and broadleaf weeds negatively impact teff productivity, especially during the critical early growth stages (Assefa *et al*. 2008; Tesfahunegn, 2014). Weed competition alone can reduce yields about 35% (Addisu, 2016), while weeds also serve as pest reservoirs and complicate harvesting (Zewde & Damte, 2013). The need for repeated hand weeding, particularly where both grass and broadleaf weeds are prevalent, significantly increases the cost of teff production.

Common cultural weed management practices in teff production (van der and Chauhan, 2017) include pre-planting tillage, hand weeding, and the application of pre- and post-emergence herbicides. Crop planting design, encompassing density, row spacing, and orientation, further enhances the crop's competitive ability against weeds. However, in Ethiopia's smallholder systems, weed competition significantly impacts yields (Haftamu *et al*. 2009). While tillage and hand weeding are common, the cost of herbicides presents a barrier for many farmers (Laizer *et al*. 2019; Teamti *et al*. 2016). The use of competitive teff varieties within an integrated, non-chemical approach is thus a promising, cost-effective, and sustainable solution (Haftamu *et al*. 2009).

Competitive cultivars present a cost-effective alternative to traditional cultural weed control methods, as they require no additional input costs. These cultivars can suppress weed seed production, leading to sustainable long-term weed management and reduced herbicide reliance (Lutman *et al*. 2013).

Effective weed management is essential for successful teff production (Kassahun & Rungsit, 2005), but current control methods are costly and time-consuming. These methods are constrained by limited technology, existing farming systems, environmental conditions (climate and soil), and the resources available to small-scale farmers. The lack of herbicide information and limited herbicide use means that hand weeding and other cultural practices remain the dominant weed control strategies.

2.6.1 Hand weeding

Hand weeding is removal of weeds either manually or by using tools like Hoe, when weeds grow up to some extent, effectively against annuals and biennials and controls only removes the aboveground portion of the perennial. To minimize the soil seed bank hand weeding should be done before weed flowering and seed setting stage. However, this method is labor intensive and is tiresome (Rana and Rana. 2016).

Weeding in teff is labor intensive, often requiring at least one hand-weeding even when herbicides are applied. Additionally, short periods of untimely rains during teff harvesting reduce the period of harvesting and negatively affect both on the quantity and quality (Friew & Lake, 2013).

Hand weeding 3- weeks after crop emergence was not effective because it is difficult to identify teff plants from grass weeds at this early stage (Alemayehu *et al*. 2008). The estimated time for hand weeding of teff on Vertisols ranges from 32 to 40 working days/ ha (Rezene, 2002). Weeding 3-6 weeks after crop emergence effectively controls broad leaved and grass weeds (DZARC, 2004).

Hand weeding three weeks after teff emergence proved ineffective due to the difficulty in distinguishing teff seedlings from grass weeds at early stage (Alemayehu *et al*., 2008). On Vertisols, hand weeding requires a substantial 32–40 working days/ ha (Rezene, 2002). More effective broadleaf and grass weed control is achieved by weeding at three and six weeks post-emergence effectively controlled both broadleaf and grass weeds (DZARC, 2004).

Rezene (2002) found that two hand weeding at three and six weeks after crop emergence (WACE) increased teff yields by 24% compared to a single application of 2,4-D herbicide (1 l/ha), 13% compared to a single weeding at 3 WACE, and 10% compared to a 2,4-D application plus a single weeding at 6 WACE. Early weeding (3 WACE) was ineffective due to difficulty distinguishing teff from grass weeds (Alemayehu *et al*. 2008). While two hand weeding (at tillering and stem elongation) were superior to a single weeding at either stage (Alemayehu *et al*. 2008), a single weeding at the tillering stage provided the highest monetary return. In teff intercropped with sesame or safflower, 2, 4-D application can damage the companion crop (Adamu & Kemelew, 2011).

Hand weeding teff is consistently reported as an expensive, time-consuming, and labor-intensive practice regardless of growing conditions (Rezene & Zerihun, 2001). The small size of teff seeds hinders both sowing and weeding, making mechanical weed control difficult and leaving farmers reliant on hand weeding or chemical herbicides (Ketema, 1997).

2.7 Sowing methods of Teff

The low national or regional teff productivity is mainly attributed by lack of improved agronomic practices; including mostly use of broadcast sowing. This practice reduces yields due to uneven seed distribution, higher competition for water, light and nutrients among plants, and difficult in weeding matured crops. However, new agronomic practices could increase the productivity of the crop. The studies by Fufa *et al.* (2011) and Kebebew *et al.* (2011) indicate that row planting and transplating one-month old seedlings teff are encouraging techniques.

Usually, farmers sow teff broadcasting the seeds by hand. However, experimental results have shown that row sowing has promise in increasing yields and simplifying weed control, harvesting, and fertilizer application. To facilitate widespread adoption by smallholder farmers, however, user-friendly, small-scale row-sowing implements are needed (Hundera *et al*. 2000).

It has been argued recently that low teff productivity is partly caused by the way farmers sow teff seed. Traditionally, farmers broadcast the seed using a rate of 25–50 kg per hectare (ATA 2013). This practice reduces yields because of the uneven distribution of the seeds, higher competition between plants for inputs (water, light and nutrients), and difficult weeding once the plants have matured (Fufa *et al*. 2011). Through row planting or transplanting, land management and especially weeding can be done more easily. The incidence of lodging is also found to be reduced, as the stem of row-planted teff is better able to support the weight of the filled head of grain (Berhe *et al*. 2011).

According to ATA 2013, labor requirement increased when adopting row planting, and there was a substantial drop in labor productivity for row-planting farmers compared with the traditional broadcast planting. These results suggest why most farmers exposed to row planting of teff continued row planting in the year afterward, but only on a small part of their teff lands. In addition, the sensitivity of the yield findings with regard to the effects of “learning by doing” (that is, experienced farmers) was analyzed as well as examining scenarios where mechanized row planters would reduce labor requirements. In such scenarios, adopting of row planting would become more beneficial for farmers.

Similarly, Vandercasteelen *et al*. (2016) reported the implementation of teff row planting requires 30% more labor than broadcasting. It also improves tillering, reduces crop lodging, decreases the competition among plants, and increases crop productivity (Hunt, 1999). According to Hundera *et al*. (2001), row sowing of teff with low seed rate reduces the problem of lodging on teff.

Studies have highlighted that traditional sowing methods hinders teff productivity (Berhe *et al.* 2011). Farmers commonly use broadcasting techniques, where they scatter teff seeds by hand at a high seed rate. However, alternative planting methods, such as row planting or transplanting seedlings, which involve lower seed rates and provide greater spacing between plants, are considered more effective than traditional broadcasting (Berhe *et al.* 2011, Fufa *et al.* 2011). Experiments have demonstrated that these alternative methods can lead to substantial improvements in teff yields (Berhe *et al.* 2011, Fufa *et al.* 2011).

CHAPTER THREE: MATERIALS AND METHODS

3.1 Description of the study area

The study was conducted in Central Zone of Tigray Regional state at Laelay Maichew district, Hatsebo research station, in 2020 main cropping season. Hatsebo is located at 14° 15' 40.2" N and 38° 34' 45" E (Figure 1) about 5 km east of Axum city. It is found at an elevation of 2148 m.a.s.l. with sub humid agro-ecology where most of the middle altitude crops such as teff, wheat, Faba bean are commonly grown. The mean minimum and maximum temperatures range from 8.7°C to 13.20°C and 24.40°C to 31.40°C , respectively. The area is characterized by mono modal rainfall pattern ranges from 700 to 800 mm/annum (AxARc). Soils of Hatsebo kebelle are dominant by black soil/Vertisols, which covers about 40% of the total area. Others are 21% red clay soil, 19% loam soil and the rest 20% course textured soil according to the classification made by FAO guideline for soil profile description (FAO, 2014).

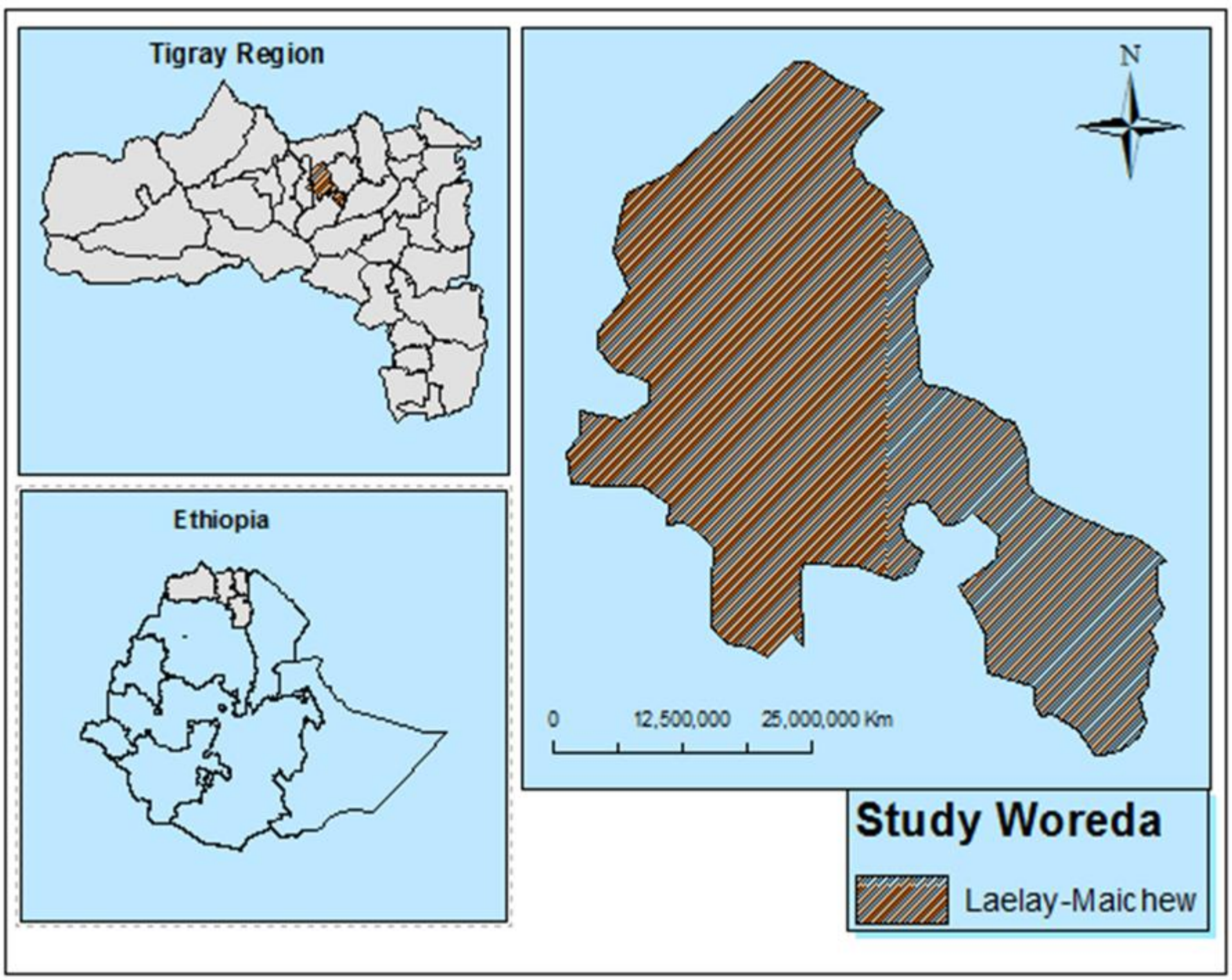

Figure 1: Location map of the study area

3.1 Experimental materials

3.1.1 Planting material

Improved teff Varieties: Kora, Boset and Quncho released by DZARC/EIAR were used as plant materials.

3.1.2 Fertilizer material

Urea (46 % N) and TSP (46 % P_2O_5) were used as a source of nitrogen and phosphorus nutrient elements respectively.

3.1.3 Treatments and Experimental Design

The treatments consisted of three levels of teff varieties (Kora, Quncho, Boset), four levels of nitrogen (0, 46, 69 and 92 kg N/ha), and two levels of sowing methods (row and broadcasting). Row was done at inter-row spacing of 20 cm and teff was sown by drilling at 3 cm.

The experiment was laid out in split plot design with three replications where the sowing method was main plots and the combination of teff varieties and N fertilizer rates were assigned as subplots. Both main and sub-plots were randomized independently.

The plot size was 2 m x 3 m and space of 1 m between main plots, 1 m between the subplots, and 1.5 m between blocks to control border effects (to avoid mixture of the seeds from the plots of the different teff varieties). The total area used for this study including the border area was 18 m * 47 m (846 m^2). The seed rate for row planting was 10 kg/ha and the seed rate for broadcasting was 15 kg/ha. Phosphorus was fertilized using TSP and applied at a rate of 100 Kg-TSP/ha (MOA).

3.2 Field Management

Land preparation was done according to farmers practice in the area (oxen-plough) and leveling was carried out by human power to ensure better seedbed for small seeds of teff. In accordance with the specifications of the design, a field layout was prepared and each treatment was assigned randomly to experimental plots within a block. Seeds were sown manually on July 16, 2020 at experimental site. TSP was applied equally to all plots at planting while ½ split of nitrogen fertilizer were applied at emergence, and the remaining ½ of nitrogen was top dressed before tillering. This was done to reduce loss of nutrients and to harmonize the supply with the crop demand. Hand weeding was done three times during the crop growth stage. First weeding August 12, second September 15, and third weeding was done on November 20, 2020. The weed samples were taken using 25 cm* 25 cm quadrant in each plot at all weeding activities. Weed Samples were dried in sun and weighed by sensitive balance.

Harvesting date was December 02, 2020. All other cultural and management practices were performed as per the recommendations for the teff crop.

3.3 Data collection

The data on days to 50% emergence, days to 50% heading, days to 90% maturity and grain yield were collected on plot basis. Data for plant height, panicle length, total number of tillers per plant, and number of productive tillers per plant were collected on the basis of randomly selected five plants from each plot.

And the weed species compositions were also collected from randomly placed quadrat which has an area of 25 cm × 25 cm (0.625 cm^2) per plot.

3.3.1 Soil Sampling and Analysis

The soil samples were taken from all identified layers for characterization of selected physical and chemical properties according to FAO guidelines (FAO, 2014). One disturbed composite soil sample was collected at 0-30 cm depth based on zigzag sampling method before planting to assess and describe soil characteristics of the experimental field. The collected sample were properly labeled, packed using polyethylene bags and transported to the Mekelle Soil Research Center laboratory for analysis. Then the soil sample was air dried. The soil samples were further crashed to pass through 0.5-mm sieve for further analysis of Total Nitrogen (TN) and Organic Carbon (OC) (FAO, 2008).

3.3.2 Crop phenology

Days to 50% emergence

It was determined by the number of days that elapsed from sowing up to the date when 50% of the seedling emerged in a plot.

Days to 50% heading

It was determined by counting the number of days from sowing to the time when 50% plants started heading.

Days to 90% maturity:

Days to physiological maturity was determined as the number of days from sowing to 90% of the plot stand attains physiological maturity as judged visually by the turning of the vegetative parts of the plants to very light yellow or straw color.

3.3.3 Yield and growth-related traits

The agronomic traits data were collected from the net plot area. Some of the traits were measured from randomly selected five plants while the rest were determined on plot basis.

Grain yield (GY)

Matured teff were harvested from the net plot area, sun dried and threshed separately by manual and then grain was weighed by using sensitive electronic balance (apply) in g/plot. For analysis g/plot was converted to kg/ha.

Plant height (PH)

Plant height was measured at physiological maturity from the ground level to the tip of the panicle of five randomly selected plants using tape meter (cm) in each plot.

Panicle length (PL)

It was determined by measuring the length of panicle from the node where the first panicle branch had emerged to the tip of the panicle utilizing the five plants selected for the measurement of panicle length.

Number of total tillers per plant (NTTPP)

It was determined by counting the number of tillers produced per plant assessed on five randomly selected plants from each plot.

Number of productive tillers per plant (NPT)

The number of productive tillers was determined by counting the tillers that produced panicles on randomly selected 5 plants per plot.

3.3.4 Data related to weed composition

Density, cover and biomass of weed: Plant density and dry weight (above ground biomass) were assessed three times before harvest in one randomly placed quadrat (25 cm × 25 cm) per plot. Weed cover was estimated visually (coverage) during weeding time (first, second, and third weeding). The biomass samples were dried to determine the weed dry weight.

Identification of dominant weed species: this was essential to determine the weed species importance, which might have aggressive competition with teff. The weeds in each quadrant were counted and identified to species level. The teff weed species were identified using Google.

3.4 Data analysis

Data collected were subjected to analysis of variance (ANOVA) using GenStat 18th edition. Means were separated using Fisher's LSD at 5%.

3.4.1 Weed community analysis and identification of weed species

Weed species composition was analyzed by frequency (F), abundance (A), dominance (D). (Assefa *et a*l., 2016; Esayas *et al*. 2013; Jaccard 1912; Taye & Yohanes 1998)

Frequency or prevalence: is the percentage of sampling plots on which a particular weed species is found. It explains how often a particular weed species occurs in the survey area. Frequency is calculated for all weed species as follows

$$F = X/N \times 100$$

Where, F = frequency, X = number of occurrences of a weed species, N = sample number.

Abundance: Population density of a weed species expressed as the number of individuals of weed plants per unit area

$$A = \Sigma W/N$$

Where, A = abundance, W = number of individuals of a weed species, N = sample number.

Density: measures the number of target species per given area.

D= number of individual target occurred/surface area of sampling unit

Dominance: Abundance of an individual weed species in relation to the total weed abundance (infestation level).

$$D = A/\Sigma A x100$$

Where, A= abundance of individual, D = dominance, ΣA = total abundance of all species.

3.4.2 Economic analysis

Economic analysis was performed to investigate the economic feasibility of the treatments followed the methodology described by CIMMYT (1998). The marginal rate of return (% MRR) was calculated based on the mean teff grain yield and the variable costs incurred in the 2020 cropping season. Variable costs considered in the analysis were the cost of seed, TSP, urea fertilizer, and the labor used for planting and for applying the different rates of fertilizer. Economic analysis was done using the prevailing local market price for inputs at planting/sowing season and for outputs at the time the crop was harvested. The cost of nitrogen and phosphorus fertilizers which were added in form of Urea (20 Birr/Kg) and TSP (30 Birr/Kg) respectively, and the cost of teff seed and grain was 80 and 85 Birr/Kg. Labor cost was estimated that the row method of sowing ranges 50-100 and 25-50 working days for broadcast sowing, for sowing and fertilizer application of TSP and for two split of urea applications. All costs and benefits were calculated on hectare basis in Ethiopian birr (Birr/ha). The average grain yield was adjusted by 10% down wards to reflect farmers yield CIMMYT (1998).

The Dominance analysis procedure as detailed in CIMMYT (1998) was used to select potentially profitable treatments from the range that were tested. The marginal rate of return (MRR) was calculated using equation 1 by considering a pair of non-dominated treatments listed in the order of increasing net benefit. MRR denotes a return per unit of investment in the change of field management practices tested herein.

- MRR (%) = (ΔNB/ ΔTVC) *100 ……… (1)

Where MRR is marginal rate of return, NB is net benefit/ha, TVC is the total variable cost/ha.

The results of marginal analysis were further checked by the residuals. Residuals were calculated by subtracting the rate of return that farmers required (i.e., the minimum of return multiplied by the total variable costs) from the corresponding net benefits. Since the combination of field management treatments tested in this study are new to the farmers, 100% is considered as the minimum acceptable rate return that farmers would require from their investment in order to change their practice (CIMMYT 1998). Following the analysis, treatments with the highest residuals were recommended to farmers.

- **Unadjusted grain yields (UGY)**; is the average yield in Kg/ha of each treatment.
- **The gross benefit per hectare**; is the product of the field price of teff and the mean yield of each treatment.
- **The total variable cost (TVC)**; is the sum of cost TSP and cost of Urea fertilizer application. The cost of land preparation, field management, harvest, weeding, transportation, and others was not included in the calculation because these activities were applied equally for all treatments.
- **The net benefit per hectare**; for each treatment is the difference between the gross benefit and the total variable costs.

CHAPTER FOUR: RESULT AND DISCUSSION

4.1 Soil characteristics of the study area

4.1.1 Soil physical properties

The results from the analysis of soil physical properties indicated that, clay particles dominated the soil and its textural class was categorized as clay, with a percentage of sand (16 %), silt (26 %) and clay (58 %) (Table 5)

Table 5: Selected physical and chemical properties of the experimental site

s/n	Parameter	Value	Rating	Source
1	Sand (%)	16		
2	Silt (%)	26		
3	Clay (%)	58		
4	Texture class	Clay		
5	pH(H2O)	6.8	Neutral	Tekalign (1991)
6	OC (%)	0.37	Low	Tekalign (1991)
7	TN (%)	0.073	Very Low	Tekalign (1991)
8	P_{av}(mg/kg)	4.92	Low	Olsen *et al*. (1954)
9	CEC cmol(+)kg^{-1}	42.4	Very high	Landon (1991)

According to FAO (2014), the soil is categorized as Vertisols. Berhanu (1985) reported that Vertisols in Ethiopia soils generally contain more than 40 % clay in their surface horizons.

4.1.2 Soil chemical properties

The pH of a soil is one of the most important properties influencing plant growth and production as it affects ion exchange capacity and nutrient availability.

According to Tekalign (1991), soil pH is classified as very strongly acidic (< 4.5), strongly acidic (4.5- 5.2), moderately acidic (5.3- 5.9), slightly acidic (6.0- 6.6), neutral (6.7- 7.3), moderately alkaline (7.4- 8.0) and strongly alkaline (> 8.0). The soil pH of the study area was neutral (pH= 6.82) since it was in the range of 6.7- 7.3.

Similarly, Eylachew (2000) also showed that Vertisols characterized in different parts of the country have shown pH ranges of 6.3 to 7.6 on the surface layer. Furthermore, according to Landon (1991) ratings, soils having pH value in the range 5.5 to 7.5 are considered suitable for most agricultural crops. Therefore, the soil pH of the study area lied in this range.

The Organic Carbon (OC) and Total Nitrogen (TN) in soil before sowing was 0.37 and 0.073% respectively (Table 6). According to the Tekalign (1991) rating, OC and TN of the study area were rated as low and very low respectively. Low TN content of the soil could also be attributed to the low soil OC content (Laekemariam *et al*. 2016).

The total nitrogen (TN %) described by Tekalign (1991), rated as very low (< 0.1 %), low (0.1 to 0.15 %), medium (0.15 to 0.25 %) and high (> 0.25 %). Depending on these scales, the composite soil of experimental area possessed very low total nitrogen (0.073 %) that indicates the soils of the study area are deficient in N and need to be supplemented with high application of nitrogen to satisfy the crop nutrient requirement for potential yield.

According to Tisdale *et al. (*2002), Olson extractable P below 3 mg/kg is considered as very low; between 4 and 7 mg/kg as low; between 8 and 11 mg/kg medium, and greater than 12 mg/kg as high. Thus, there was low available P content of the soil of the experimental sites before sowing (4.9 mg/kg) which was rated as low (Olsen *et al.,* 1954).

The cation exchange capacity of the soil before sowing was 42.4 cmol (+) kg^{-1} which is very high. Based on the rating of Landon (1991), the value of CEC was rated as moderate (15–25 cmol (+) kg^{-1}); high (25–40 cmol (+) kg^{-1}) and very high (>40 cmol (+) kg^{-1}). High CEC of the soil should be due to higher clay content of the soil as the soil OC content was found low for the study site.

4.2 Emergence, Heading and Maturity

Days to 50% emergence showed significant difference ($p<0.01$) among the varieties evaluated but not such difference was observed in the different sowing methods. However, the response of N rate was not observed since it was applied during emergence. The interaction of the factors did not result in significant ($p<0.05$) variation of the days to 50% emergence. The lack of significant effect of sowing method (Table 6) on days to 50% emergence may be due to genetic makeup of seeds plays a huge role in how quickly seeds germinate and emerge, and soil conditions (temperature, moisture, nutrient availability). Similarly, Abraham *et al.* (2018) suggested that sowing method and seed rate had little impact on emergence. They suggested that the primary factors influencing germination are the seed internal food reserves (endosperm) and external factors (moisture, temperature, and oxygen availability). Additionally, Jan *et al*. (2002) indicated that the embryo's growth is sustained by the stored food materials within the seed and does not rely on external nutrition. The response of variety was significant ($p<0.01$) to the emergence of teff. The early emerging variety was Boset with mean 6.9 days and Kora with 8.6 days which was late emerging variety (Table 6). Similarly, Haftamu *et al.* (2009) also found that the variety Boset was early emerging at 5.7 day and longest number of days to emergence was 16 for DZ-Cr-358.

There was not significant interaction effect of factors on days to 50% emergence ($p<0.05$) (Table 9). This may due to the genetic make of the varieties and environmental conditions. In line with the result of Abreham *et al.* (2018), the main as well as the interaction effects of sowing method and seed rate did not influence the number of days required for seedling emergence. Good land preparation and absence of excess water may have contributed to the smooth and uniform germination of seeds in each of the plots. Similarly, the interaction of sowing method and variety was not significant (Figure 2).

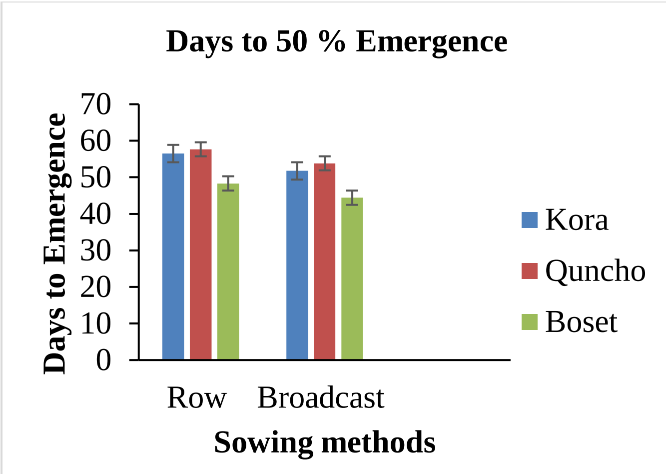

Figure 2: Effect of factors on emergence (Hatsebo, 2020)

Days to 50% heading was significantly ($p<0.01$) affected by sowing method, variety and N-rate (Table 6) but it was not influenced by their interaction. Teff flowers earlier (50 days) when broadcasted than when sown in rows (around 54 days). The earliness on broadcast sowing could be due to the higher plant population density, which might have caused strong competition among the plants (Mengie, 2021). When plants are crowded together, they compete for essential resources like sunlight, water and nutrients. This competition creates a stressful environment and inducing them to complete their life cycle. Moreover, Tamirat (2020) observed that dense spacing can lead to earlier flower on teff. This is likely due to reduced rates of photosynthesis caused by increased competition among plants for light, space, nutrients, and water. Similarly, Sisay *et al*. (2021) observed that teff grown with higher seed rates and narrow spacing tend to head earlier than those grown with lower seed rates and wider spacing. Variety Boset (46.3) was earlier in heading than Quncho (55.7). This may be due to genetic makeup of varieties. Additionally, Berhe *et al*. (2020) reported that from the three teff varieties, Boset and Asgori were early to flowering as compared to Kora. Teff grown at 0 kg N/ha had significantly earlier (49 days) to flower than those grown at 46 kg N/ha (51 days), 69 kg N/ha (53 days), and 92 kg N/ha (55 days). Commonly, as N rate increases the number of days to heading was also increased. This may be nitrogen is a key nutrient for plant growth, particularly for leaf and stem development. Higher N application promotes vigorous vegetative growth. A research by Getachew (2004) and Mekonen (2005) indicated that the highest nitrogen fertilizer application significantly delayed heading in wheat and barley, respectively. Similarly, Legesse (2004) revealed that nitrogen application resulted in a significant delay in the time it took for plants to reach heading.

There was not significant ($p<0.05$) interaction effect of factors on days to 50% heading (Table 9). This may be the genetic differences of teff varieties are robust than the effect of sowing methods or nitrogen rates, and an application can significantly influence the growth of teff.

The number of days to physiological maturity was significantly affected by the sowing method ($p<0.01$), variety ($p<0.001$), and N- fertilizer rate ($p<0.01$). The interaction of factors (sowing method*variety*nitrogen) did not result in significant ($p<0.05$) variation in the days to 90% maturity of teff (Table 9). However there was statistically significant interaction of sowing method and variety ($P<0.01$), and variety and nitrogen ($p<0.01$) on days to 90% maturity.

Teff matured earlier (94.6 days) when broadcasted than sown in rows (97.9 days) (Table 6). The earlier in physiological maturity may be due to the closer spacing with dense plant population might be the presence of intense intra-space competition which led to depletion of the available nutrient and as a result plants tended to mature earlier. However, in row sowing plants are widely spaced. This gives each teff more to grow and access nutrients, leading to less competition for resources and allows grow well. According to Mengie *et al.* (2021) teff planted at lower sowing rates experienced a delay in physiological maturity, which could be linked to their vigorous growth and development. This may result from a greater availability of growth factors, as there was a competition among the plants. Similarly, increasing the level of seed rate stimulated early physiological maturity in rice (Sewnet, 2005). Variety Boset (80.5) was earlier than Kora (112.5 days) in days took to 90% maturity (Table 6). This may be due to Boset variety had faster growing and reach maturity earlier, while others have a longer growth cycle (MoA, 2021). Similarly, Haftamu *et al*. (2009) found variations in the time for different teff varieties to mature. The early emerging Boset variety reached maturity around 90 days earlier than other varieties. Teff grown at 0 kg N/ha (control) had significantly earlier (91.6 days) to mature than those grown at 92 kg N/ha (101 days). Hence, it was postponed by around 10 days in response to receiving 92 kg N/ha than that of 0 kg N/ha (Table 12). The delayed maturity could be related to increased chlorophyll production, which enables the plant to photosynthesize for a longer duration. In line with the findings, Assefa *et al.* (2001) and Chanyalew *et al.* (2013) reported that days to maturity ranged from about 60 to 140 days.

Table 6: Teff phenology as affected by sowing method, genotypic variation and N-rate

Treatments	50% emergence	50% Heading	90% maturity

Sowing methods			
Row	7.97ns	54.2^{b}	97.89^{b}
Broadcast	7.91ns	50^{a}	94.67^{a}
LSD (<0.05)	1.45 ns	1.45**	1.35**
p value	0.885	0.006	0.009
Varieties			
Kora	8.5^{b}	54.22^{b}	112.79^{c}
Quncho	8.37^{b}	55.75^{c}	95.46^{b}
Boset	6.95^{a}	46.38^{a}	80.58^{a}
LSD (<0.05)	0.38**	0.7**	0.77***
p value	0.003	0.00	<0.001
Nitrogen rates			
0		49.1^{a}	91.67^{a}
46		51.1^{b}	94.11^{b}
69		53.1^{c}	98.33^{c}
92		55.1^{d}	101^{d}
LSD(<0.05)		0.8**	0.88**
p value		0.008	0.002
CV (%)	8.2	2.3	1.4

LSD (0.05) = least significant difference at 5% level; **, *** Significant at $p \leq 0.01$and $p<0.001$ probability level respectively, CV = coefficient of variation. Means in column and row of the same parameter followed by the same letters are not significantly differed at 95% significance level. Nitrogen did not have an effect on days to emergence because it was applied at emergence.

There was significant interaction effect of sowing method and variety on the number of days to reach 90% physiological maturity.

Table 7: Interaction effect of sowing method on days to 90% maturity of teff varieties

Sowing method	Variety	Mean (days)
Row	Kora	113.5^{f}
Row	Quncho	97.33^{d}
Row	Boset	81.83^{b}
Broadcasted	Kora	112.08^{e}
Broadcasted	Quncho	92.58^{c}
Broadcasted	Boset	79.33^{a}
LSD (<0.05)		1.1^{**}
p value		0.002
CV%		1.4

LSD (0.05) = least significant difference at 5% level; ** Significant at $p \leq 0.01$ probability level, CV = coefficient of variation. Means in column and row of the same parameter followed by the same letters are not significantly differed at 95% significance level.

The earliness was recorded when teff seeds were broadcasted with Boset variety (around 79 days) than when sown in rows Kora variety (113.5 days) in days to 90% maturity (Table 7).

In addition, the shortest number of days to 90% maturity was recorded from Boset variety with the control 0 kg N/ha (76.6) than Kora with 92 kg N/ha with a mean 115.6 days (Table 8). This implies that each variety responds differently to variable N rates.

Table 8: Interaction effect of variety and N- rate on teff days to 90% maturity

Variety	Nitrogen (kg N/ha)	Mean (days)
Kora	0	111^{i}
Kora	46	111^{i}
Kora	69	113.5^{j}
Kora	92	115.67^{k}
Quncho	0	87.33^{e}
Quncho	46	92.5^{f}
Quncho	69	98.17^{g}
Quncho	92	102.83^{h}
Boset	0	76.67^{a}
Boset	46	78.83^{b}
Boset	69	82.33^{c}
Boset	92	84.5^{d}
LSD(<0.05)		1.5^{**}
p value		0.003
CV%		1.4

LSD (0.05) = least significant difference at 5% level; ** Significant at $p \leq 0.01$ probability level, CV = coefficient of variation. Means in column and row of the same parameter followed by the same letters are not significantly differed at 95% significance level.

There was no significant (p<0.05) interaction of factors on days to 50% heading and 90% maturity (sowing method*Nitrogen) (Figure 3).

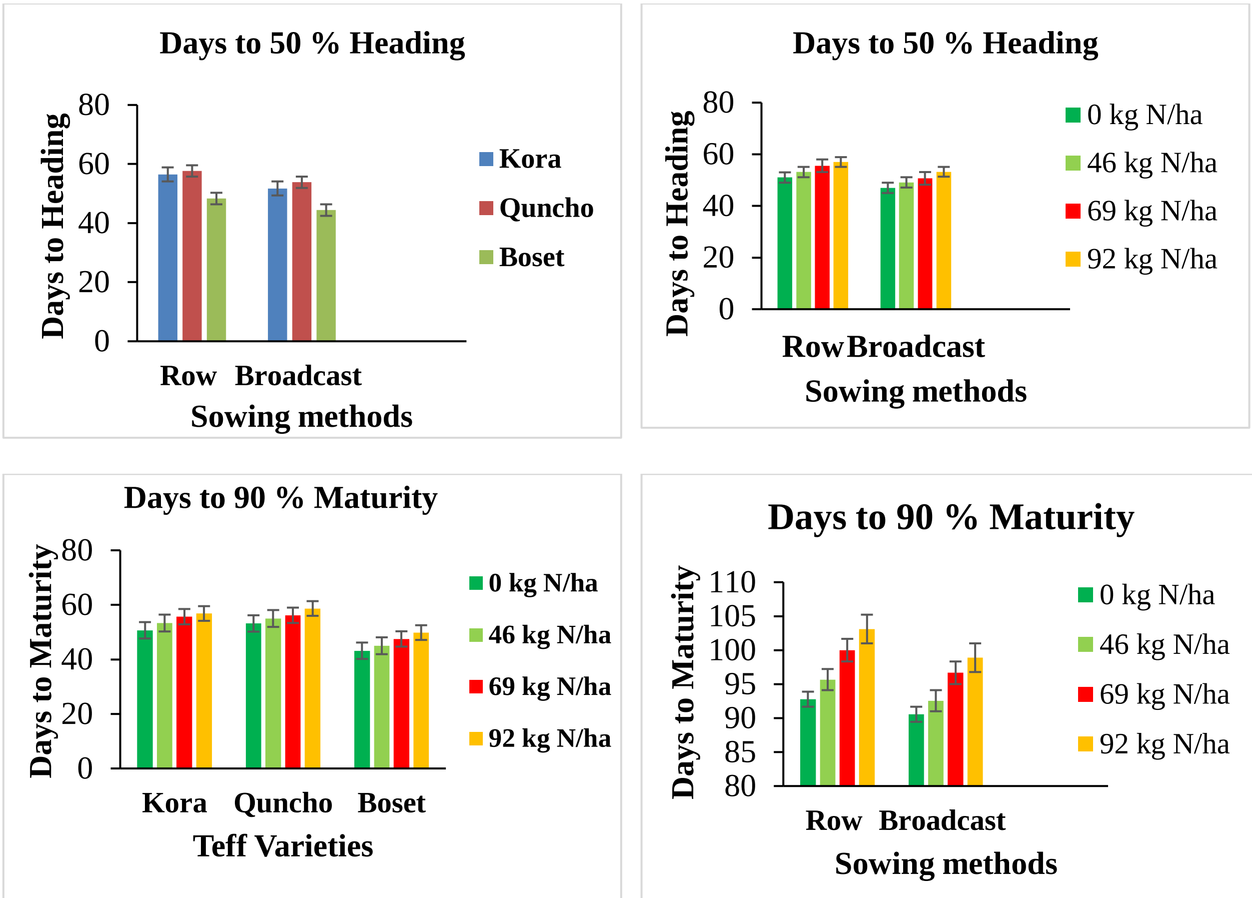

Figure 3: Effect of factors on teff phenology (Hatsebo, 2020)

Table 9: Mean performance of 24 treatments tested for teff phenology

Sowing method	Variety	Nitrogen (kg N/ha)	DH	DM
Row	Kora	0	53.33	111.33
Row	Kora	46	55.67	111
Row	Kora	69	58.67	114.67
Row	Kora	92	59	116.67
Row	Quncho	0	55	89
Row	Quncho	46	57	94.67
Row	Quncho	69	58.33	102
Row	Quncho	92	60.33	105.67
Row	Boset	0	45.33	77.67
Row	Boset	46	46.67	79.67
Row	Boset	69	49.67	83
Row	Boset	92	51.67	85.67
Broadcast	Quncho	92	57	99
Broadcast	Quncho	69	54	95.33
Broadcast	Kora	92	54.67	113.67
Broadcast	Kora	69	52.67	111.67
Broadcast	Kora	46	51	111
Broadcast	Quncho	0	51.33	86
Broadcast	Kora	0	48.67	110.33
Broadcast	Quncho	46	53	89.67
Broadcast	Boset	92	48	83.33
Broadcast	Boset	69	45.33	80.33
Broadcast	Boset	46	43	77.33
Broadcast	Boset	0	41	75.67
LSD (<0.05)			2	2.1
p value			0.958	0.079
CV (%)			2.3	1.4

Means in column and row of the same parameter followed by the same letters are not significantly differed at 95% significance level. DH= Days to Heading, DM= Days to Maturity

4.3 Teff growth parameters in response to sowing methods, variety and N rates

4.3.2 Plant height

Teff plant height was significantly affected by all factors tested (Table 10) i.e. sowing method ($p<0.05$), variety ($p<0.01$), nitrogen ($p<0.01$) and their interaction (Table 14). Plant height is an essential growth character directly linked with the productive potential of plants in terms of fodder and grain yield.

Teff varieties grown in rows were significantly taller than the broadcasted one. The taller teff plant was recorded a height 100.78 cm and the shorter was 91 cm. Similarly, teff grown at row sowing method was significantly greater than plants sown broadcast method (Abraham *et al*. 2018). In addition, Sate and Tafese (2016), observed that increasing teff plant height with row sowing and decreasing seed rate from 25 kg/ha to 10 kg/ha can be attributed to reduced competition among plants for essential resources like light, nutrients, and soil moisture. This reduced intra-specific competition allows for greater access to resources, leading to taller plants. There was also significant difference in heights of the varieties tested. Quncho was the taller (102.79 cm) and the variety Boset 84.79 cm was the shorter. Similarly, Haftamu *et al*. (2009) found that varieties Boset and DZ-01-1681 had the shortest plant height with an average value of 76 cm and taller plants were observed from the varieties DZ-Cr-387 and DZ-01-974, having an average value of 97 cm long. In addition, the tallest (110.94 cm) teff was recorded when received 92 kg N/ha and shortest (78.5 cm) PH was recorded 0 kg N/ha (no fertilizer). The plant height obtained from all treated plots (received N) was significantly taller plant height than the control plot. Nitrogen fertilizer is crucial for plant growth, especially in teff. This is because nitrogen primarily promotes vegetative growth, leading to taller teff plants. Plant height commonly increased with the increase in N rate. Our results align with Haftamu *et al*. (2009), who reported that teff plants with 92 kg N/ha showed significantly greater height (92 cm) compared to the control group (57.9 cm). Similarly, high nitrogen application resulted in significantly taller teff plants due to direct effect of N on vegetative growth of crop plants (Legesse, 2004).

There was significant ($p<0.05$) interaction effect of factors on plant height of teff (Table 20). Similarly, there were significant interactions of sowing method and variety ($p<0.01$), sowing method and nitrogen ($p<0.01$) and variety and nitrogen ($p<0.01$). The taller (108.5 cm) was recorded from row sowing with Quncho variety and the shortest (81.5 cm) plant height was recorded from broadcast sowing with Boset variety (Table 11). Similarly, the highest (118.5 cm) plant height was recorded row sowing with 92 kg N/ha and the lowest (77.5 cm) was recorded from broadcasted teff received no nitrogen (Table 12). Teff grown in rows from Quncho received 92 kg N/ha were significantly taller (122.6 cm) than when broadcasted Boset variety received no nitrogen (75.6 cm) (Table 13). From this interaction of factors plant height (PH) increased with increasing N rate.

4.3.3 Panicle length

Teff panicle length was significantly affected by all factors tested (p<0.01) and the interaction of factors sowing method*variety (p<0.05), sowing method*nitrogen (p<0.05), and variety*nitrogen (p<0.05) but it was not influenced by their interaction of these factors (Table 10).

Panicle length is one of the major yield attributes of teff that is positively correlated with grain yield. Teff grown in rows were significantly high panicle length than the broadcasted one. The taller teff was panicle length 27.5 cm and the shorter was 24 cm (Table 10). Row sowing, by providing more space for individual plants led to increased panicle length. This is because reduced competition for resources allowed plants to utilize more nutrients, water and sunlight. In contrast, broadcast sowing, with its higher plant density, resulted in greater competition for resources, leading to shorter panicle lengths. There were variations among varieties tested. Kora (around 29 cm) was the maximum panicle length and the variety Boset (21.3 cm) was the minimum (Table 10). This variation was due to the genetic difference among varieties. Our findings align with previous research by Abel (2005), who reported a range of panicle lengths from 17 to 42 cm. Similarly, Girma *et al*. (2019) observed a panicle length range of 22.7 to 39.5 cm in their study of teff genotypes. These results support the variation in panicle length observed in our study. Furthermore, Berhe *et al*. (2020) found a significant difference (p<0.01) in panicle length among teff varieties with Kora showed the longest panicles (56.07 cm), while Boset had the shortest (42.49 cm) panicle length. Also, the mean panicle length was in align with the report of Assefa *et al.* (2001) and Chanyalew *et al.* (2013) reported panicle length ranged from 10 to 65 cm.

Teff grown at 92 kg N/ha (32.2 cm) was higher panicle length than those grown at 0 kg N/ha (20 cm) (Table 10). Similarly, Tamirat (2021) found that significant impact of nitrogen application rate on teff panicle length. The highest panicle length (42.67 cm) was recorded with 90 kg N/ha, exceeding the control treatment by 11.57%, 30 kg N/ha by 7.73%, and 60 kg N/ha by 6.7%. Additionally, Haftamu *et al*. (2009) reported that high nitrogen application (92 kg N/ha) led to increased panicle length in teff, reaching an average of 38 cm. Also, Getahun *et al.* (2018) found that increasing nitrogen application from 0 to 69 kg N/ha led to a 26.3% increase in panicle length compared to the control treatment.

There was significant interaction effect of factors on panicle length of teff i.e. sowing method and variety (p<0.01), sowing method and nitrogen (p<0.05) and variety and nitrogen (p<0.05). The tallest panicle length was recorded when teff seeds were sown in rows with Kora variety (31.8 cm) than when broadcasted Boset variety (20.4 cm) (Table 11). The taller (35.1 cm) panicle length was when teff sown in rows received 92 kg N/ha than when broadcasted teff received no nitrogen (19.1 cm) (Table 12). Also, the tallest panicle length was recorded from Kora variety with 92 kg N/ha (37.3 cm) than Boset received no nitrogen 16.1 cm. This implies that each variety responds differently to variable N rates (Table 13).

There was no statistically significant interaction effect of factors (sowing method * variety * N rates) on panicle length of teff (Table 14). Similarly, Fenta (2018) found that panicle length in teff was not influenced by either fertilizer application rate, variety, or the interaction between them.

4.3.4 Total number of tillers per plant (TNTPP)

All the factors tested were significant effect on total number of tillers per plant (Table 10). The TNTPP was significantly affected by the sowing method ($p<0.05$), variety ($p<0.05$), nitrogen ($p<0.01$) and their interaction (Table 14).

Teff grown in rows were significantly high TNTPP than the broadcasted one. The higher tiller number per plant was 6.3 and the shorter was 5 (Table 10). Teff plants grown at row sowing was more numerous TNTPP than when broadcasted. The variation of row sowing over broadcast sowing might be due to the light population density in rows is important to the wise use of nutrients, moisture, and aeration. Similarly, Mengie, *et al*. (2021), reported that seed sown in row was produced 26% higher TNTPP than broadcasted teff. Also, Abraham, (2014); and Fekremariam *et al*. (2014), found that teff plants grown in rows produced significantly more tillers than plants grown using the broadcasting method. There were also variations among varieties tested. Kora (6.3) was the maximum TNTPP and the variety Boset (4.8) was the minimum (Table 10). Similarly, teff grown at 92 kg N/ha was higher (7.7) TNTPP than those grown at 0 kg N/ha (3.7). Unlike the findings of this study, Berhe *et al*. (2020) found no significant variation in the number of tillers of teff across different levels of nitrogen fertilizer.

There was significant interaction effect of factors on TNTPP. The maximum (7.4) TNTPP was recorded when teff grown in rows with Kora variety and the minimum (4.5) was recorded from broadcasted Boset variety (Table 11). The maximum (9.22) TNTPP was recorded when teff grown in rows with 92 kg N/ha and the minimum (3.67) was recorded when teff grown in broadcasted with no nitrogen (Table 12). In addition, the maximum (9.33) TNTPP was recorded from Kora variety received 92 kg N/ha and the minimum (3.5) was recorded from Boset received no nitrogen (Table 13). Also, the maximum (9.2) TNTPP was recorded when teff grown in rows with Kora variety received 92 kg N/ha and the minimum (3.6) was recorded from broadcasted teff received no nitrogen (Table 14). This implies that each variety responds differently to variable N rates. Similarly, The highest number of tillers per plant (6.8) was observed in the Kora variety at a lower seed rate, while the lowest number (4.4) was recorded for both Kora and Quncho varieties at a broadcasting rate of 15 kg/ha (Abera, & Gemechu, 2020).

4.3.5 Number of productive tillers per plant (NPT)

All the factors tested had significant effect on NPT. The number of productive tillers per plant was significantly affected by the sowing method, variety, and N ($p<0.05$) but not the interaction of all factors (Table 20).

Teff grown in rows were maximum number of productive tillers (NPT) than the broadcasted one. The maximum NPT was 3.8 recorded from row sowing and minimum NPT was 2.8 recorded from broadcast sowing (Table 10). In agreement to this study, Mengie, *et al.* (2021) and Abraham *et al.* (2018) seed sown in row was produced 32% higher number of fertile tillers per plant than broadcasted teff plants. This implies that dense planting resulted in stunted individual plant growth, leading to fewer productive tillers. There were variations among varieties tested. Kora (3.7) was higher NPT and the variety Boset (2.5) was the lower (Table 10). Also, teff grown at 92 kg N/ha (5.2) had significantly higher NPT than those grown at 0 kg N/ha (2) (Table 10). The maximum NPT was higher by 160%, 100% and 52.9% over the control (0 kg N/ha). Similarly, the highest number of productive tillers (13.79) in teff was achieved with the application of 97.5 kg N/ha. This enhanced tiller development is likely due to the increased nitrogen availability, which is crucial for cell division and growth (Abera, & Gemechu, 2020). Giday *et al*. (2014) also found that higher rates of nitrogen fertilizer led to a significant increase in the number of productive tillers in teff plants. Additionally, Chala (2021) found that increasing nitrogen fertilizer rates led to a significant increase in the number of effective tillers. The highest number of effective tillers was observed when 69 kg N/ha was applied. In contrast to the findings of this study, Berhe, *et al*. (2020) found no significant difference in the number of productive tillers across different levels of nitrogen fertilizer.

There was significant interaction effect of factors i.e. sowing method and N ($p<0.05$), and variety and N ($p<0.05$) on NPT per plant. The higher NPT was recorded when teff grow in rows with 92 kg N/ha (6.33) and the lower (1.78) was recorded from broadcasted teff received no nitrogen (Table 12). Similarly, the highest number NPT (6.5) was recorded from Kora variety recieved 92 kg N/ha and lowest NPT (2) were recorded from Kora variety received no nitrogen (Table 13).

The number of productive tillers per plant was not significantly ($p < 0.05$) affected interaction effect of the factors sowing method * variety * N rates (Table 14) and sowing method * variety (Figure 4).

4.3.6 Grain yield

Teff grain yield was significantly affected by all factors tested i.e. sowing method ($p<0.01$), variety ($p<0.001$), nitrogen ($p<0.001$) and their interaction (Table 14).

Teff varieties grown in rows were significantly higher (1300.5 kg/ha) grain yield and lower (1159.3 kg/ha) in broadcasted one (Table 10). Row sowing resulted in a substantial yield increase, attributed to better individual plant growth due to reduced competition (light and nutrient) for growth factors. Similar with previous research reports, row planting showed to significantly increase teff grain yields compared to broadcasting. Mihretie *et al*. (2020) reported a 30% increase in yield with row planting, and Abraham (2014) found an 8% yield advantage for row-sown teff plants. Additionally, Getahun *et al*. (2018) observed a significant increase in yield from 973.8 to 1216.8 kg/ha when decreasing the seed rate in broadcast sowing from 25 to 10 kg/ha, suggesting that increased spacing between plants, similar to row planting, promotes tillering and higher yields. In contrast to this study, Lakew and Birhanu (2019) reported that a 15 kg/ha seed rate teff yielded higher grain yields than 10 kg/ha, and found no significant benefit of row spacing over broadcast sowing for grain yield. Similarly, Abraham *et al*. (2018) observed a general decrease in teff grain yield with lower seed rates, with the highest yield achieved at the highest seed rate (25 kg/ha). Correspondingly, there was significant variation in grain yields of the varieties tested. Kora was the high (1408.8 kg/ha) and the variety Boset (1014 kg/ha) was the lowest (Table 10). Kora showed a significant yield advantage of 11.2% and 38.9% over Quncho and Boset, respectively. Multiple studies have shown Kora to be a high-yielding teff cultivar. Haftamu *et al*. (2020), the average grain yields of DZ-Cr-358 (813.2 kg/ha) and DZ-01-354 (1001 kg/ha) were 40.4% and 26.6%, respectively, lower than the highest-yielding variety Kora having an average grain yield of 1364.1 kg/ha. Similarly, Bekele *et al*. (2019) found that Kora produced more grain yield than Boset during the optimal cropping season.

Additionally, the higher (1510 kg/ha) grain yield teff was recorded when received 69 kg N/ha and lower (793.8 kg/ha) grain yield was recorded when teff received no fertilizer (Table 10). N fertilization significantly boosted teff grain yield, with increases of 29.6%, 47.4%, and 46.7% at 46 kg N/ha, 69 kg N/ha, and 92 kg N/ha, respectively, compared to the control. This shows how much less yield was obtained without N fertilizer. In line with our result, Habtegebrial *et al.* (2007) found that grain yield increased with increase in N up to 90 kg N/ha, but grain yield showed a decreasing trend when the N fertilizer increased from 60 to 90 kg/ha. Similarly, Rockstrom *et al.* (2009) reported that lower grain yield of teff 510 kg/ha, below the national average from conventional tillage without fertilizer application. Similarly, Habtegebrial *et al.* (2007) observed a yield of 370 kg/ha yield of teff under zero nitrogen fertilizer application condition.

There was significant interaction effect of factors on grain yield of teff (Table 14). The high (1887 kg/ha) grain yield was recorded when teff grown in rows from Kora with 69 kg N/ha and low (736 kg/ha) was recorded when broadcasted Boset with 0 kg N/ha (no fertilizer).

Similarly, there was statistically significant interaction effect of variety and N fertilizer on teff grain yield. The higher (1782 kg/ha) grain yield was recorded from Kora variety received 69 kg N/ha and the lower (769 kg/ha) grain yield was recorded from Boset variety received no nitrogen (Table 13). Similarly, Fufa *et al*. (2001) suggested that integrating high-yielding varieties and improved management practices holds significant potential to increase teff productivity. As a result, Kora variety grown in rows with the application of 69 kg N/ha can contribute to higher grain yields.

Table 10: Teff growth as affected by sowing method, genotypic variation and N- rate

Treatments	PH	PL	TNTPP	NPT	GY (kg/ha)
Sowing methods					
Row	100.78^{a}	27.4^{a}	6.3^{a}	3.8^{a}	1300.5^{a}
Broadcast	91.03^{b}	24^{b}	5.0^{b}	2.8^{b}	1159.3^{b}
LSD (<0.05)	4.9*	2.2*	1.14*	0.6*	44.9**
p value	0.014	0.023	0.036	0.022	0.005
Varieties					
Kora	100.12^{b}	28.8^{a}	6.3^{a}	3.7^{a}	1408.8^{a}
Quncho	102.79^{a}	27^{b}	5.9^{a}	3.6^{a}	1266.7^{b}
Boset	84.79^{c}	21.3^{c}	4.7^{b}	2.5^{b}	1014.3^{c}
LSD (<0.05)	1.9***	1.2**	0.44*	0.3*	27.31***
p value	<0.001	0.002	0.015	0.033	<0.001
Nitrogen rates					
0	78.5^{d}	20^{d}	3.7^{d}	2.0^{d}	793.8^{c}
46	89.83^{c}	23.3^{c}	4.7^{c}	2.6^{c}	1127.6^{b}
69	104.33^{b}	27.3^{b}	6.5^{b}	3.3^{b}	1510^{a}
92	110.94^{a}	32.2^{a}	7.7^{a}	5.2^{a}	1488.3^{a}
LSD(<0.05)	2.2**	1.3**	0.5**	0.4*	31.5***
p value	0.002	0.003	0.002	0.03	<0.001
CV (%)	3.5	8.0	13.5	19.4	3.8

LSD (0.05) = least significant difference at 5% level; *, **, *** Significant at $p \leq 0.05$, $p \leq 0.01$, and $p \leq 0.001$ probability level respectively, CV = coefficient of variation. Means in column and row of the same parameter followed by the same letters are not significantly differed at 95% significance level. PL=panicle length, PH= Plant height TNTPP= number of total tillers per plant, NPT= number of productive tillers per plant, GY= grain yield

Table 11: Interaction effect of sowing method and variety on growth parameters of teff

Sowing method	Variety	PH	PL	TNTPP
Row	Kora	104.75^{b}	31.75^{a}	7.42^{a}
Row	Quncho	108.58^{a}	28.33^{b}	6.58^{b}
Row	Boset	88^{d}	22.33^{e}	5.08^{cd}
Broadcast	Kora	95.5^{c}	25.83^{c}	5.25^{c}
Broadcast	Quncho	96^{c}	25.75^{c}	5.25^{c}
Broadcast	Boset	81.58^{e}	20.42^{e}	4.5^{d}
LSD (<0.05)		3.7**	1.8**	0.86*
p value		0.002	0.003	0.042
CV%		3.5	8	13.5

LSD (0.05) = least significant difference at 5% level; *, **, Significant at $p \leq 0.05$ and $p \leq 0.01$ probability level respectively, CV = coefficient of variation. Means in column and row of the same parameter followed by the same letters are not significantly differed at 95% significance level. PH= Plant height, PL=panicle length, TNTPP= number of total tillers per plant.

Table 12: Interaction effect of sowing method and N- rate on growth parameters of teff

Sowing method	Nitrogen rate (kg N/ha)	PH	PL	TNTPP	NPT
Row	0	79.44^{f}	20.89^{de}	3.78^{fg}	2.33^{d}
Row	46	93.78^{d}	24.67^{c}	5.11^{de}	2.67^{c}
Row	69	111.33^{b}	29.22^{b}	7.33^{b}	4^{b}
Row	92	118.56^{a}	35.11^{a}	9.22^{a}	6.33^{a}
Broadcast	0	77.56^{f}	19.11^{e}	3.67^{g}	1.78^{d}
Broadcast	46	85.89^{e}	22.11^{d}	4.44^{ef}	2.56^{c}
Broadcast	69	97.33^{d}	25.44^{c}	5.67^{cd}	2.78^{c}
Broadcast	92	103.33^{c}	29.33^{b}	6.22^{c}	4.11^{b}
LSD (<0.05)		3.9**	2*	0.9*	0.6*
p value		0.003	0.032	0.038	0.029
CV%		3.5	8	8	19.4

LSD (0.05) = least significant difference at 5% level; *, **, Significant at $p \leq 0.05$ and $p \leq 0.01$ probability level respectively, CV = coefficient of variation. Means in column and row of the same parameter followed by the same letters are not significantly differed at 95% significance level. PL=panicle length, PH= Plant height TNTPP= number of total tillers per plant, NPT= number of productive tillers per plant, GY= grain yield.

Table 136: Interaction effect of variety and N rate on growth parameters of teff

Variety	Nitrogen (kg N/ha)	PH	PL	TNTPP	NPT	GY
Kora	0	80.83^{fg}	22.67^{fg}	3.8^{ef}	1.83^{g}	813^{g}
Kora	46	90.83^{e}	25.67^{e}	$4.67d^{e}$	2.67^{d-f}	1328^{d}
Kora	69	114^{c}	29.5^{c}	7.5^{b}	4.17^{b}	1782^{a}
Kora	92	118.33^{b}	37.33^{a}	9.33^{a}	6.5^{a}	1713^{b}
Quncho	0	79^{gh}	21.17^{gh}	3.83^{ef}	2.33^{e-g}	800^{g}
Quncho	46	95.5^{d}	25.33^{e}	5^{d}	2.83^{c-e}	1133^{e}
Quncho	69	114^{c}	28.5^{cd}	6.5^{c}	3.5^{bc}	1563^{c}
Quncho	92	122.67^{a}	33.17^{b}	8.33^{b}	5.83^{a}	1571^{c}
Boset	0	75.67^{h}	16.17^{i}	3.5^{f}	2^{fg}	769^{g}
Boset	46	83^{f}	19.17^{h}	4.67^{de}	2.33^{e-g}	922^{f}
Boset	69	88.67^{e}	24^{ef}	5.5^{d}	2.5^{e-g}	1186^{e}
Boset	92	91.83^{de}	26.17^{de}	5.5^{d}	3.33^{cd}	1181^{e}
LSD (<0.05)		3.9**	2.4*	0.8*	0.7*	54.6**
p value		0.003	0.038	0.04	0.022	0.038
CV%		3.5	8	13.5	19.4	3.8

LSD (0.05) = least significant difference at 5% level; *, **, Significant at $p \leq 0.05$ and $p \leq 0.01$ probability level respectively, CV = coefficient of variation. Means in column and row of the same parameter followed by the same letters are not significantly differed at 95% significance level. PH= Plant height, PL=panicle length, TNTPP= number of total tillers per plant, NPT= number of productive tillers per plant, GY= grain yield

There was no significant ($p<0.05$) interaction of factors (sowing method * variety) on the number of productive tillers per plant (NPT), and (sowing method * variety) and (sowing method *nitrogen) on grain yield of teff.

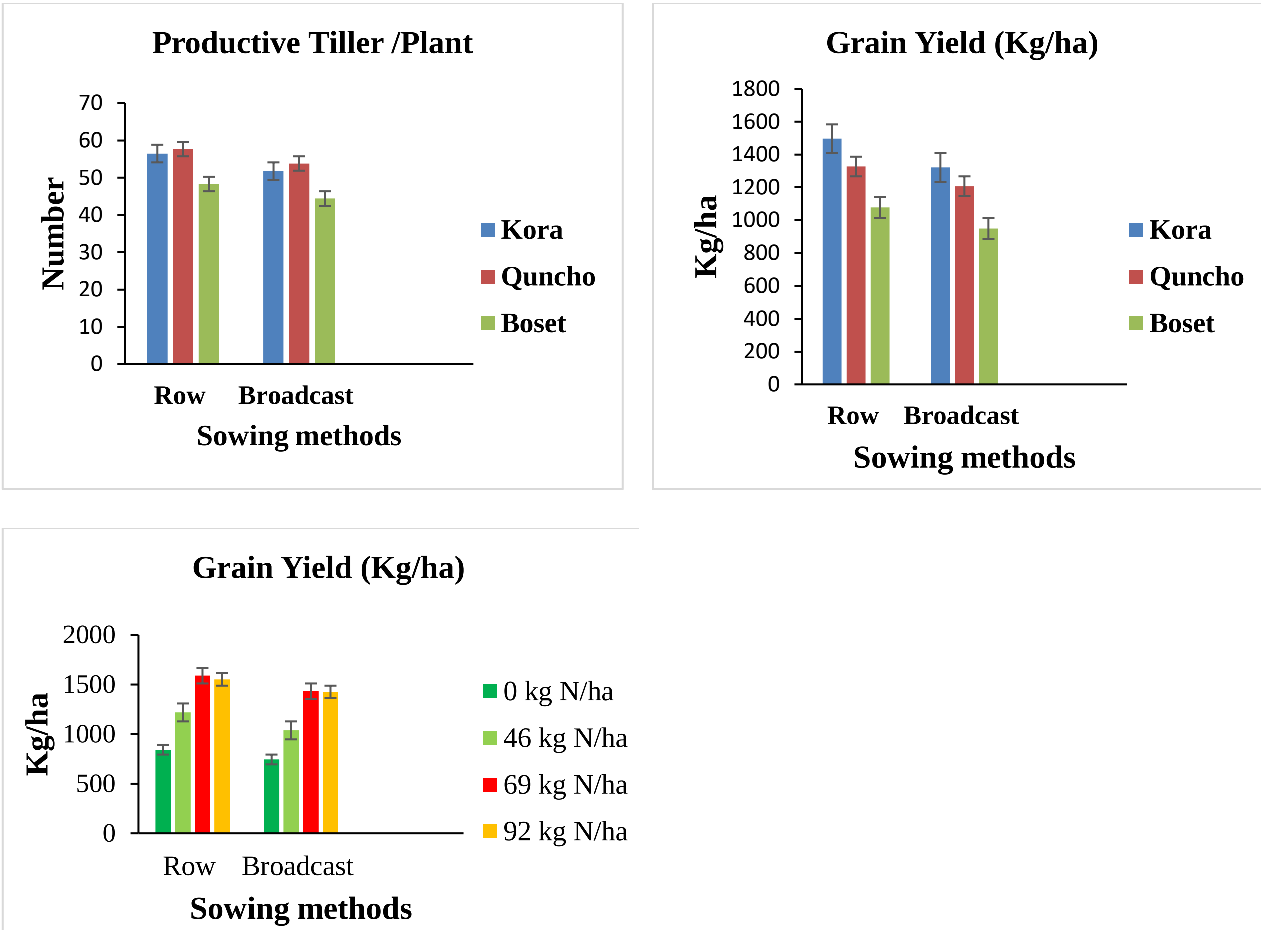

Figure 4: Effect of factors on NPT and GY (Hatsebo, 2020)

Table 14: Mean performance of 24 treatments tested for yield and growth parameters of teff

Sowing method	Variety	Nitrogen (kg N/ha)	PH	PL	TNTPP
Row	Kora	0	81.33^{j-l}	24.67	4^{i-k}
Row	Kora	46	93^{gh}	27.33	5^{f-h}
Row	Kora	69	118^{c}	32.33	9^{b}
Row	Kora	92	126.67^{b}	42.67	11.67^{a}
Row	Quncho	0	79^{k-m}	21.33	3.67^{jk}
Row	Quncho	46	102.67^{f}	25.67	5.33^{f-h}
Row	Quncho	69	123.33^{bc}	30.33	7.33^{c}
Row	Quncho	92	133.33^{a}	36	10^{b}
Row	Boset	0	78^{l-o}	16.67	3.67^{jk}
Row	Boset	46	85.67^{ij}	21	5.0^{f-i}
Row	Boset	69	92.67^{gh}	25	5.67^{e-g}
Row	Boset	92	95.67^{g}	26.67	6^{d-f}
Broadcast	Quncho	92	112^{d}	30.33	6.67^{c-e}
Broadcast	Quncho	69	104.67^{ef}	26.67	5.67^{e-g}
Broadcast	Kora	92	110^{de}	32	7^{cd}
Broadcast	Kora	69	102.67^{f}	26.67	6^{d-f}
Broadcast	Kora	46	89^{hi}	24	4.3^{h-k}
Broadcast	Quncho	0	79^{l-n}	21	4^{i-k}
Broadcast	Kora	0	80.33^{j-l}	20.67	3.67^{jk}
Broadcast	Quncho	46	88.33^{hi}	25	4.67^{g-k}
Broadcast	Boset	92	88^{hi}	25.67	5^{f-i}
Broadcast	Boset	69	84.67^{i-k}	23	5.33^{f-h}
Broadcast	Boset	46	80.33^{j-l}	17.33	4.3^{h-k}
Broadcast	Boset	0	73.33^{mo}	15.67	3.33^{k}
LSD (<0.05)			5.8*	3.4	1.3*
p value			0.02	0.133	0.04
CV (%)			3.5	8	13.5

LSD (0.05) = least significant difference at 5% level; * Significant at p ≤ 0.05 probability level, CV = coefficient of variation. Means in column and row of the same parameter followed by the same letters are not significantly differed at 95% significance level. PH= Plant height, PL=panicle length, TNTPP= number of total tillers per plant

Table 14: Continued….

Sowing method	Variety	Nitrogen (kg N/ha)	NPT	GY
Row	Kora	0	1.67	875^{j}
Row	Kora	46	2.67	1472^{d}
Row	Kora	69	4.67	1887^{a}
Row	Kora	92	8	1752^{b}
Row	Quncho	0	2.67	853^{j}
Row	Quncho	46	3.0	1171^{f-h}
Row	Quncho	69	4.33	1633^{c}
Row	Quncho	92	7	1650^{c}
Row	Boset	0	2.33	802^{jk}
Row	Boset	46	2.33	1012^{i}
Row	Boset	69	3	1248^{ef}
Row	Boset	92	4	1252^{e}
Broadcast	Quncho	92	4.67	1491^{d}
Broadcast	Quncho	69	2.67	1493^{d}
Broadcast	Kora	92	5	1674^{c}
Broadcast	Kora	69	3.67	1677^{bc}
Broadcast	Kora	46	2.67	1183^{e-g}
Broadcast	Quncho	0	2	747^{k}
Broadcast	Kora	0	1.67	750^{k}
Broadcast	Quncho	46	2.67	1096^{h}
Broadcast	Boset	92	2.67	1110^{gh}
Broadcast	Boset	69	2	1123^{gh}
Broadcast	Boset	46	2.33	832^{j}
Broadcast	Boset	0	1.67	736^{k}
p value			0.573	0.018
LSD (<0.05)			1.1	76.8*
CV (%)			19.4	3.8

LSD (0.05) = least significant difference at 5% level; * Significant at $p \leq 0.05$ probability level, CV = coefficient of variation. Means in column and row of the same parameter followed by the same letters are not significantly differed at 95% significance level. NPT= number of productive tillers per plant, GY= grain yield

4.4 The Composition of weed species

From the study area, 22 weed species representing 11 families were identified and documented (Table 15). Among 22 weed species, 16 (72.7 %) were monocot and 6 (27.3 %) were dicot. In addition, 15 (68.2 %) were with annual and 7 (31.8 %) with perennial life cycle. The families with highest number of weed species were *Poaceae* (8 species), *Asteraceae* (4 species), *Polygonanceae* (2 species), *Convolvulaceae*, *Brassicaceae*, *Plantagonaceae*, *Amaranthaceae*, *Papaveraceae*, *Apiaceae*, *Nyctaginaceae* and *Fabaceae* each consisting of one species.

Table 15: Importance of weed species of teff

Family	Scientific Name	Life cycle	Weed type
Convolvulaceae	*Convolvulus arvensis L.*	Perennial	Dicot
Poaceae	*Digitaria Sanguinalis (L) Scop*	Annual	Monocot
	Diqitaria ternata (A. Rich.) Stapf	Annual	Monocot
	Cynodon dactylon (L.) Pers.	Perennial	Monocot
	Avena abyssinica Hochst.	Annual	Monocot
	Setaria pumila (poir.)Roem.&Schilt	Annual	Monocot
	Cyperus rotundus L.	Perennial	Monocot
	pennisetum species	Annual	Monocot
	Cyrtococcum acrescens (Trin.) Stapf.	Perennial	Monocot
Brassicaceae	*Erucastrum abyssinicum (A.Rich.)*	Annual	Monocot
Plantaginaceae	*Plantago lanceolata L.*	Perennial	Monocot
Amaranthaceae	*Amaranthus spinosus L.*	Annual	Monocot
Papaveraceae	*Argemone mexicana L.*	Annual	Monocot
Asteraceae	*Galinsoga parviflora Cav.*	Annual	Monocot
	Xanthium spinosum L.	Annual	Monocot
	Sonchus arvensis	Perennial	Monocot
	Xanthium strumarium L.	Annual	Monocot
Apiaceae	*Agrocharis melanantha (Hochst.)*	Annual	Dicot
Polygonaceae	*Oxygonum sinuatum (Meisn) Dammer*	Annual	Dicot
	Salviia tiliifolia vahl	Perennial	Dicot
Nyctaginaceae	*Boerhavia coccinea Mill*	Annual	Dicot
Fabaceae	*Trifolium schimperi (Hochst.) A.Rich*	Annual	Dicot

According to Esayas *et al*. (2012) and Taye & Yohanes (1998), any family having greater than five weed species is considered as diverse. The poaceae families were most diverse because poaceae had more than five species.

Several weed species were absent during specific weed sampling periods. Pennis*etum species*, *Cyrtococcum acrescens (*Trin.*) Stapf*, and *Oxygonum sinuatum (*Meisn*)* were not found in the first weeding; *Argemone mexicana* L. and *Sonchus arvensis* were absent in the second; and *Erucastrum abyssinicum (*A. Rich.*), Amaranthus spinosus*, *Galinsoga parviflora*, *Argemone mexicana*, *Xanthium spinosum*, and *Agrocharis melanantha* were missing from the third sampling (Table 16).

Table 16: Identification of teff Weed species

S/n	First weeding	Second weeding	Third weeding
1	*Convolvulus arvensis* L.	*Convolvulus arvensis* L.	*Convolvulus arvensis* L.
2	*Digitaria Sanguinalis* (L) *Scop*	*Digitaria Sanguinalis* (L) *Scop*	*Digitaria Sanguinalis* (L) *Scop*
3	*Diqitaria ternata (*A. Rich.*) Stapf*	*Diqitaria ternata* (A. Rich.) *Stapf*	*Diqitaria ternata* (A. Rich.) *Stapf*
4	*Erucastrum abyssinicum (*A. Rich.)	*Erucastrum abyssinicum* (A. Rich.)	*Avena abyssinica Hochst.*
5	*Avena abyssinica Hochst.*	*Avena abyssinica Hochst.*	*Plantago lanceolata* L.
6	*Plantago lanceolata* L.	*Plantago lanceolata L.*	*Setaria pumila (poir.)Roem.&Schilt*
7	*Setaria pumila (poir.)Roem.&Schilt*	*Setaria pumila (poir.)Roem.&Schilt*	*Salviia tiliifolia vahl*
8	*Salviia tiliifolia vahl*	*Salviia tiliifolia vahl*	*Xanthium spinosum L.*
9	*Amaranthus spinosus* L.	*Amaranthus spinosus* L.	*Sonchus arvensis*
10	*Galinsoga parviflora Cav.*	*Galinsoga parviflora Cav.*	*Xanthium strumarium L.*
11	*Argemone mexicana* L.	*Xanthium spinosum* L.	*Cyperus rotundus L.*
12	*Xanthium spinosum* L.	*Xanthium strumarium* L.	*pennisetum species*
13	*Sonchus arvensis*	*Agrocharis melanantha* (Hochst.)	*Oxygonum sinuatum (Meisn)*
14	*Xanthium strumarium* L.	*Cyperus rotundus* L.	*Trifolium schimperi (Hochst.) A.Rich*
15	*Agrocharis melanantha* (Hochst.)	*pennisetum species*	*Cynodon dactylon* (L.) *Pers.*
16	*Cyperus rotundus* L.	*Cyrtococcum acrescens (Trin.) Stapf.*	
17	*Boerhavia coccinea Mill*	*Oxygonum sinuatum* (Meisn)	
18	*Trifolium schimperi (Hochst.) A.Rich*	*Boerhavia coccinea Mill*	
19	*Cynodon dactylon* (L.) *Pers.*	*Trifolium schimperi (Hochst.) A.Rich*	
20		*Cynodon dactylon (*L.) *Pers.*	

4.5 Weed frequency, abundance and dominance

Frequency, abundance and dominance of the identified weed species grown in association with teff, are presented in Table 17.

The most frequently observed weed species was *Agrocharis melanantha* (98.6%), *Xanthium strumarium* (98.6%) followed by *Trifolium schimperi* (97.2%), *Oxygonum sinuatum* (97.2%), Cyrtococcum acrescens (97.2%), *Galinsoga parviflora* (97.2), *Setaria pumila* (97.2%). The three most abundant and dominant weed species were *Digitaria ternata* (abundance 2.96, dominance

0.48), *Pennisetum sp*. (abundance 1.69, dominance 0.27), and *Convolvulus arvensis* (abundance 1.47, dominance 0.24) (Table 17).

Table 17: Frequency, abundance and dominance of weed species

S/n	Weed species	Density	Frequency	Abundance	Dominance
1	*Convolvulus arvensis* L.	105.6	61.1	1.47	0.24
2	*Digitaria Sanguinalis* (L) *Scop*	25.6	88.9	0.36	0.06
3	*Diqitaria ternata (*A. Rich.*) Stapf*	212.8	73.6	2.96	0.48
4	*Erucastrum abyssinicum (A. Rich.)*	6.4	94.4	0.09	0.01
5	*Avena abyssinica Hochst.*	76.8	58.3	1.07	0.17
6	*Plantago lanceolata* L.	8	93.1	0.11	0.02
7	*Setaria pumila (poir.)Roem.&Schilt*	3.2	97.2	0.04	0.01
8	*Salviia tiliifolia vahl*	20.8	84.7	0.29	0.05
9	*Amaranthus spinosus* L.	4.8	95.8	0.07	0.01
10	*Galinsoga parviflora Cav.*	3.2	97.2	0.04	0.01
11	*Xanthium spinosum* L.	4.8	95.8	0.07	0.01
12	*Xanthium strumarium* L.	1.6	98.6	0.02	0
13	*Agrocharis melanantha (Hochst.)*	1.6	98.6	0.02	0
14	*Cyperus rotundus L.*	4.8	97.2	0.07	0.01
15	*pennisetum species*	121.6	61.1	1.69	0.27
16	*Cyrtococcum acrescens (Trin.) Stapf.*	3.2	97.2	0.04	0.01
17	*Oxygonum sinuatum (Meisn)*	3.2	97.2	0.04	0.01
18	*Boerhavia coccinea Mill*	4.8	95.8	0.07	0.01
19	*Trifolium schimperi (Hochst.) A.Rich*	3.2	97.2	0.04	0.01
20	*Cynodon dactylon (*L.) *Pers.*	4.8	95.8	0.07	0.01

4.6 The effect of factors on weed dynamics

Weed density, Dry weight and Weed cover

The weed data analysis revealed that only the second weeding data showed significant ($p < 0.05$) differences in weed dry weight. In contrast, the first and third weeding data did not exhibit statistically significant ($p<0.05$) variation of factors in weed density, dry weight and weed cover.

Weed density did not show significant difference ($p<0.05$) among the factors (Table 18) and their interaction (Table 20).

Weed dry weight showed significant difference ($p<0.05$) on the varieties but not such difference was observed in the different sowing methods and N rates and their interaction except the interaction of sowing method and Nitrogen rate ($p<0.05$) (Table 18). The highest (5.8 g/m^2) dry weight was recorded from Boset and the lowest (3.94 g/m^2) weight was recorded from Kora variety. Contrary, Haftamu (2020) found weeds in weeded plots were shown a higher dry weight with varieties DZ-01-358 (262.27 g/m^2) and Kora (108.1 g/m^2).

Table 18: The influence of factors on weed density, dry weight and cover

Treatment	Weed density (no/m^2)	Weed dry weight (g/m^2)	Weed cover (%)
Sowing methods			
Row	5.91	4.58	10.03
Broadcast	6.44	4.8	11.67
LSD (<0.05)	6.7 ns	1.5 ns	5.8 ns
p value	0.192	0.061	0.353
Variety			
Kora	6	3.94^{b}	9.83
Quncho	5.93	4.34^{ab}	10.79
Boset	6.6	5.8^{a}	11.92
LSD (<0.05)	3.2 ns	1.4*	3.5 ns
p value	0.262	0.039	0.495
Nitrogen			
0	6.04	4.21	11.72
46	5.07	4.24	9.39
69	7.91	5.7	11.94
92	5.69	4.62	10.33
LSD (<0.05)	3.7 ns	1.7 ns	4 ns
p value	0.792	0.28	0.548
CV%	33.7	20.1	55.7

LSD (0.05) = least significant difference at 5% level; * Significant at $p \leq 0.05$ probability level and ns = non-significant, CV = coefficient of variation. Means in column and row of the same parameter followed by the same letters are not significantly differed at 95% significance level.

Correspondingly, the highest (6.18 g/m^2) weed dry weight was recorded when teff was broadcasted with 69 kg N/ha and lowest (3.226 g/m^2) weed dry weight was recorded when teff was broadcasted with 92 kg N/ha (Table 18).

Weed cover was not shown significant ($p<0.05$) in all factors and their interaction (Table 18).

There was not significant ($p<0.05$) interaction effect of factors on weed density, dry weight and weed cover (Figure 5 and 6) except the interaction of sowing method and Nitrogen on dry weight.

Table 19: Interaction effect of factors on weed dry weight

Sowing method	Nitrogen (kg N/ha)	Total dry weight (g/m^2)
Row	0	3.842^{bc}
Row	46	3.241^{c}
Row	69	5.215^{a-c}
Row	92	6.024^{ab}
Broadcast	0	4.576^{a-c}
Broadcast	46	5.233^{a-c}
Broadcast	69	6.18^{a}
Broadcast	92	3.226^{c}
LSD (<0.05)		2.2^{*}
p value		0.043
CV (%)		20.1

LSD (0.05) = least significant difference at 5% level; * Significant at p <0.05 probability level CV = coefficient of variation. Means in column and row of the same parameter followed by the same letters are not significantly differed at 95% significance level.

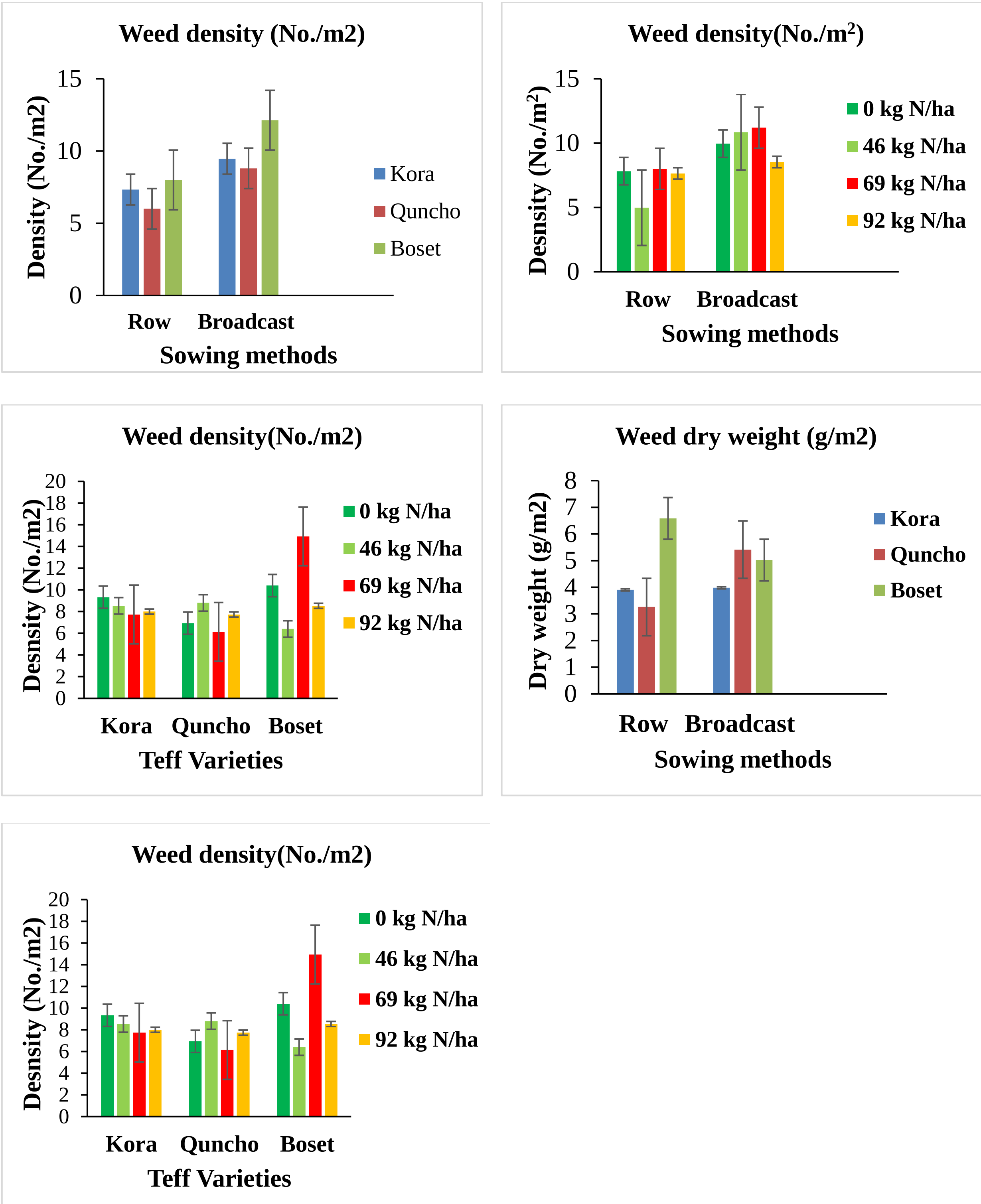

Figure 5: Effect of factors on weed density and dry weight (Hatsebo, 2020)

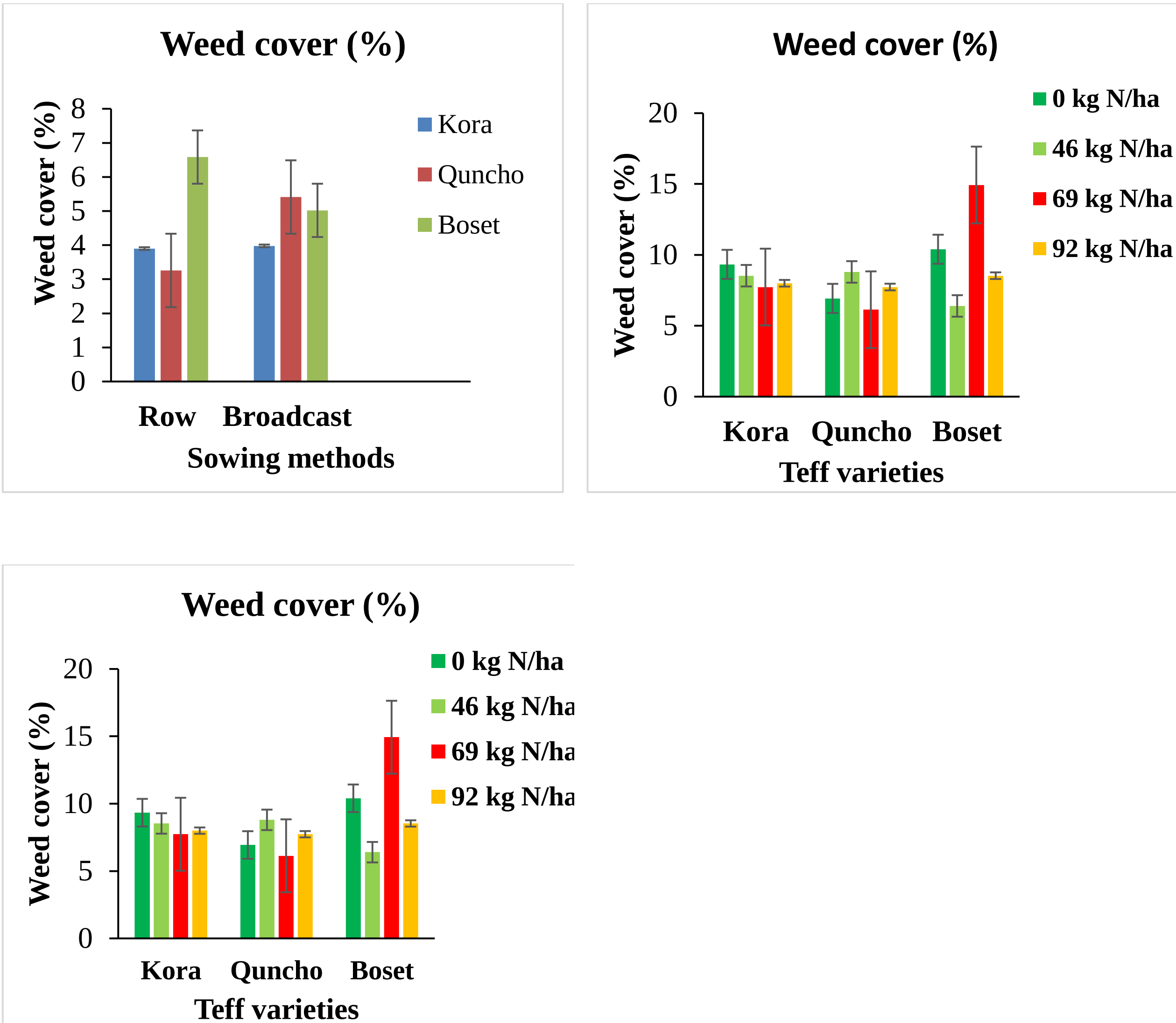

Figure 6: Effect of factors on weed cover (Hatsebo, 2020)

Table 207: Mean performance of 24 treatments tested for weed parameters

Sowing method	Variety	Nitrogen kg N/ha	Weed density (no/m^2)	Weed dry weight (g/m^2)	Weed cover (%)
Row	Kora	0	7.467	2.02	11.67
Row	Kora	46	6.4	3.105	9
Row	Kora	69	9.6	5.685	7.67
Row	Kora	92	5.867	4.789	7
Row	Quncho	0	9.067	4.061	11.67
Row	Quncho	46	4.267	3.344	7.33
Row	Quncho	69	3.733	2.634	8.33
Row	Quncho	92	6.933	2.993	8.33
Row	Boset	0	6.933	5.445	12.67
Row	Boset	46	4.267	3.275	10.67
Row	Boset	69	10.667	7.327	10
Row	Boset	92	10.133	10.290	16
Broadcast	Quncho	92	8.533	3.865	7.67
Broadcast	Quncho	69	8.533	7.629	17.67
Broadcast	Kora	92	10.133	3.991	10.67
Broadcast	Kora	69	5.867	3.07	13.33
Broadcast	Kora	46	6.4	5.243	9
Broadcast	Quncho	0	4.8	4.688	12.67
Broadcast	Kora	0	11.2	3.607	10.33
Broadcast	Quncho	46	13.333	5.468	12.67
Broadcast	Boset	92	6.933	1.822	12.33
Broadcast	Boset	69	19.2	7.841	14.67
Broadcast	Boset	46	8.533	4.988	7.67
Broadcast	Boset	0	13.867	5.431	11.33
LSD (<0.05)			9.4	4.1	9.9
p value			0.222	0.089	0.404
CV (%)			33.7	20.1	55.7

LSD (0.05) = least significant difference at 5% level, CV = coefficient of variation.

4.7 Partial budget Analysis

According to cost benefit analysis, the treatment of 69 Kg N/ha which was applied in row planted with Kora variety of teff resulted in the highest net benefit (121,014 Birr/ha) which was followed by the (108619 Birr/ha) broadcast sowing with application of 69 Kg N/ha in the same variety (Kora).

Table 8: Partial budget analysis of teff yield as influenced by factors

Sowing method	Variety	Nitrogen	AGY (kg ha^{-1})10%	TGB (birr/ha)	TVC (birr)	NB (birr/ha)	Dominance (D)
Broadcast	Boset	0	662.4	52992	7625	45367	
Broadcast	Kora	0	675	54000	7625	46375	
Broadcast	Quncho	0	672.3	53784	7625	46159	D
Row	Boset	0	721.8	57744	8850	48894	
Row	Kora	0	787.5	63000	8850	54150	
Row	Quncho	0	767.7	61416	8850	52566	D
Broadcast	Boset	46	748.8	59904	10325	49579	D
Broadcast	Kora	46	1064.7	85176	10325	74851	
Broadcast	Quncho	46	986.4	78912	10325	68587	D
Broadcast	Boset	69	1010.7	80856	12125	68731	D
Broadcast	Kora	69	1509.3	120744	12125	108619	
Broadcast	Quncho	69	1343.7	107496	12125	95371	D
Row	Boset	46	910.8	72864	12350	60514	D
Row	Kora	46	1324.8	105984	12350	93634	D
Row	Quncho	46	1053.9	84312	12350	71962	D
Broadcast	Boset	92	999	79920	14125	65795	D
Broadcast	Kora	92	1506.6	120528	14125	106403	D
Broadcast	Quncho	92	1341.9	107352	14125	93227	D
Row	Boset	69	1123.2	89856	14850	75006	D
Row	Kora	69	1698.3	135864	14850	121014	
Row	Quncho	69	1469.7	117576	14850	102726	D
Row	Boset	92	1126.8	90144	17850	72294	D
Row	Kora	92	1576.8	126144	17850	108294	D
Row	Quncho	92	1485	118800	17850	100950	D

N.B: cost of urea= 20 Birr/Kg, TSP cost= 30 Birr/Kg, labor cost= 100 Birr man/day's, sales of teff price grain = 20 birr/kg, sales of teff seed= 85 Birr/Kg, in Hatsebo market district. Where: AGY= Adjusted grain yield, TGB= Total gross benefit, TVC = Total variable cost, NB= Net benefit, MRR= Marginal rate of return, and D= Dominated treatment.

It was estimated that 50 persons were needed for the planting, variable rates nitrogen fertilizer and weeding under broadcasting and 100 persons were needed for the planting, variable nitrogen fertilizer and weeding under row sowing (100 ETB/days).

Whereas the lowest net benefit (45367 Birr/ha) was recorded from the control (no fertilizer application) in the Boset variety under broadcast sowing. The MRR (%) was computed for the non-dominated treatments which were listed in the order increasing net benefit. In comparison with the control of the corresponding factors, a MRR of 18.76 and 4.54 was gained for 46 kg N/ha in broadcast sowing with the Kora variety respectively. The results of un-dominated treatments indicated that for each one Birr invested in the purchase or production of treatments, it is possible to recover one birr plus an extra 14.03, 18.76, and 4.54 Ethiopian Birr by using broadcast sowing of Kora variety with 46 kg N/ha, broadcast sowing of Kora variety with 69 kg N/ha, and row sowing Kora variety with 69 kg N/ha respectively. Finally, the application of 69 kg N/ha in row sowing was compared with 69 kg N/ha at broadcast applied on the Kora variety, and a MRR of 454.86% was obtained from 69 kg N/ha with row sowing of Kora variety. Looking at the residuals (Table 22) the application of nitrogen fertilizer 69 kg/ha with row sowing followed by 69 kg N/ha with broadcast sowing applied in the Kora variety was the most profitable.

Table 9: Marginal rate of return and residual analysis for non- dominated treatments

Sowing methods	Variety	Nitrogen kg/ha	TGB (birr/ha)	TVC (birr)	NB (birr/ha)	MRR (%)	Residual	Rank
Broadcast	Boset	0	52992	7625	45367	0	37742	
Broadcast	Kora	0	54000	7625	46375	0	38750	
Row	Boset	0	57744	8850	48894	0	40044	
Row	Kora	0	63000	8850	54150	0	45300	
Broadcast	Kora	46	85176	10325	74851	1403.45	64526	3
Broadcast	Kora	69	120744	12125	108619	1876	96494	2
Row	Kora	69	135864	14850	121014	454.86	106164	1

5. CONCULUSION AND RECOMMENDATIONS

5.1 CONCULUSION

Teff (*Eragrostis tef*) is a crucial cereal crop in Ethiopia, thriving in diverse environments and out performing other cereals in challenging climatic and soil conditions. Despite its importance as an indigenous staple food and widespread cultivation, teff productivity remains low. This low productivity is attributed to insufficient adoption of improved agronomic practices, including the limited use of improved varieties, lack of optimal sowing methods, inadequate fertilizer application, and effective weed management.

The optimum N rate for enhancing teff yield was 69 kg N/ha. This rate produced the highest yield (1510 kg/ha) compared to other N rates.

While weed density and weed cover showed no significance difference among the factors and their interaction, weed dry weight was significantly affected by variety.

Kora showed the lowest weed dry weight indicating better weed competitive ability than other varieties. Boset showed the highest weed dry weight and highlighting its susceptibility to weed infestation.

Teff yield was significantly influenced by synergetic interactions between genotype, nitrogen rate, and sowing methods.

High-yielding genotype Kora benefited most from optimized nitrogen application and weed suppressing.

5.2 RECOMMENDATIONS

From the present study finding it was recommended that

Dominant weed species were *Digitaria ternata*, *Pennisetum species*, and *Convolvulus arvensis*. Weed management strategies to enhance teff production and productivity must focus on these weed species.

Row sowing of Kora variety with application of 69 kg N/ha was the best combination to achieve maximum grain yield for the study area site and other areas with similar agro-ecological conditions.

However, since the experiment was conducted for one season at one location, it is suggested that the experiment has to be repeated over seasons and locations using this and other improved varieties, planting methods, and fertilizer to make a conclusive recommendation.

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APPENDICES

Appendix Table 1: Treatment set up of the experiment

S/n	Treatments (Subplots)	Sowing method (Main plot)	S/n	Treatments (Subplots)	Sowing method (Main plot)
1	Kora x 0 kg N/ha	Row	13	Quncho x 92 kg N/ha	Broad Casting
2	Kora x 46 kg N/ha	”	14	Quncho x 69 kg N/ha	”
3	Kora x 69 kg N/ha	”	15	Kora x 92 kg N/ha	”
4	Kora x 92 kg N/ha	”	16	Kora x 69 kg N/ha	”
5	Quncho x 0 kg N/ha	”	17	Kora x 46 kg N/ha	”
6	Quncho x 46 kg N/ha	”	18	Quncho x 0 kg N/ha	”
7	Quncho x 69 kg N/ha	”	19	Kora x 0 kg N/ha	”
8	Quncho x 92 kg N/ha	”	20	Quncho x 46 kg N/ha	”
9	Boset x 0 kg N/ha	”	21	Boset x 92 kg N/ha	”
10	Boset x 46 kg N/ha	”	22	Boset x 69 kg N/ha	”
11	Boset x 69 kg N/ha	”	23	Boset x 46 kg N/ha	”
12	Boset x 92 kg N/ha	”	24	Boset x 0 kg N/ha	”

Appendix Table 2: Mean Square Values of ANOVA for Phenology and growth of Teff as influenced by factors

Source of variation	DF	DE	DH	DM	PH	PL
Replication	2	1.55	24.76	5.1	115.26	42.38
Sowing methods (SM)	1	0.05^{ns}	320.89^{**}	186.89^{**}	1711.12^{*}	217.01^{*}
Error	2	2.05	2.35	1.76	23.62	5.05
Variety (V)	2	17.59^{**}	606.5^{**}	6236.35^{***}	2264.89^{***}	360.72^{**}
Nitrogen (N)	3	0.66^{ns}	120^{**}	314.89^{**}	3822.13^{**}	498.19^{**}
SM * V	2	0.34^{ns}	2.18^{ns}	30.5^{**}	78.17^{**}	27.55^{**}
SM * N	3	0.05^{ns}	1.04^{ns}	3.04^{ns}	169.9^{**}	13.68^{*}
V * N	6	0.48^{ns}	1.4^{ns}	37.46^{**}	271.06^{**}	10.57^{*}
SM * V * N	6	0.12^{ns}	0.22^{ns}	3.55^{ns}	31.78^{*}	7.44^{ns}
Error	44	0.47	1.6	1.73	11.23	4.26
CV (%)		8.2	2.5	1.4	3.5	8.0

*, **, *** Significant at $p \leq 0.05$, $p<0.01$, $p<0.001$ probability level respectively, ns= non-significant, DF = degree of freedom, CV = coefficient of variation. DE= days to emergence, DM= days to maturity, PH= Plant height, PL=panicle length

Appendix Table 2: Continued….

Source of variation	DF	TNTPP	NPT	GY
Replication	2	2.51	1.43	1537
Sowing methods (SM)	1	33.34^{*}	19.01^{*}	358846.0^{**}
Error	2	1.26	0.43	1965
Variety (V)	2	15.26^{*}	11.06^{*}	957734^{***}
Nitrogen (N)	3	56.93^{**}	34.35^{*}	2075456^{***}
SM * V	2	3.76^{*}	0.39^{ns}	5398^{ns}
SM * N	3	7.23^{*}	3.79^{*}	5829^{ns}
V * N	6	4.96^{*}	3.56^{*}	97578^{**}
SM * V * N	6	1.43^{*}	0.33^{ns}	6238^{*}
Error	44	0.58	0.41	2203
CV (%)		13.5	19.4	3.8

*, **, *** Significant at $p \leq 0.05$, $p<0.01$, $p<0.001$ probability level respectively, ns= non-significant, DF = degree of freedom CV = coefficient of variation. TNTPP= number of total tillers per plant, NPT = number of productive tillers per plant, GY = grain yield

Appendix Table 3: Mean Square Values of ANOVA for weed parameters as influenced by factors

Source of variation	DF	Total Density (no/m^2)	Total dry weight (g/ m^2)	Weed cover (%)
Replication	2	24.04	5.904	15.60
Sowing methods (SM)	1	164.41^{ns}	0.895^{ns}	48.35^{ns}
Error	2	43.66	2.362	33.51
Variety (V)	2	43.56^{ns}	23.129*	26.1^{ns}
Nitrogen (N)	3	10.9^{ns}	8.738^{ns}	26.16^{ns}
SM * V	2	6.22^{ns}	20.831^{ns}	32.1^{ns}
SM * N	3	20.20^{ns}	19.594*	49.79^{ns}
V * N	6	39.53^{ns}	4.973^{ns}	18.41^{ns}
SM * V * N	6	45.33^{ns}	13.13^{ns}	8.93^{ns}
Error	44	31.52	6.6	36.56
CV (%)		33.7	20.1	55.7

* Significant at $p \leq 0.05$ probability level and ns = non-significant, CV = coefficient of variation.